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IEEE Recommended Practice for Electric Systems in Health Care Facilities

Sponsor

Power Systems Engineering Subcommittee
of the
Industrial and Commercial Power Systems Department
of the
IEEE Industry Applications Society

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Abstract: A recommended practice for the design and operation of electric systems in health care facilities is provided. The term *health care facility* as used here encompasses buildings or parts of buildings that contain hospitals, nursing homes, residential custodial care facilities, clinics, ambulatory health care centers, and medical and dental offices. Buildings or parts of buildings within an industrial or commercial complex, used as medical facilities, logically fall within the scope of this recommended practice.

Keywords: anesthetizing, clinical, critical branch, emergency system, equipment system, essential electrical system, examination, fire alarm, ground-fault circuit-interrupter, ground-fault protection, grounding, life safety branch, medical, nurse call, patient care, recovery, safety, standby generator, surgical, transfer switch, treatment, wet location

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Introduction

This introduction is not part of IEEE Std 602-2007, IEEE Recommended Practice for Electric Systems in Health Care Facilities.

IEEE Std 602, known as the *IEEE White Book*TM, was last published in 1996. This version of the *White Book* updates topics and categories to 2006.

IEEE Std 602 is written primarily for the practicing electrical design engineer, who may have limited experience with health care facilities, and for hospital operating personnel. It will also be useful for those who supply products and services for health care facilities. While the text deals with a broad range of topics relevant to the design and operation of health care facilities, it focuses on those aspects of facility design and operation that are unique to health care facilities. These include patient electrical safety, patient care issues, continuity of electric service, and a reliable source of power to sensitive computer-based clinical and biomedical equipment. The text also touches on communication and alarm systems that are unique to the health care facility.

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IEEE Recommended Practice for Electric Systems in Health Care Facilities

Chapter 1 Overview

1.1 Scope

IEEE Std 602, commonly known as the *IEEE White Book*[™], is published by the Institute of Electrical and Electronics Engineers (IEEE) to provide a recommended practice for the design and operation of electric systems in health care facilities. It has been prepared on a voluntary basis by design engineers and health care end users as well as electrical and medical manufacturers functioning as the White Book Working Group within the Power Systems Design Subcommittee of the Power Systems Engineering Subcommittee.

This recommended practice will probably be of greatest value to the power oriented engineer with limited health care experience. It can also be an aid to all engineers responsible for the electrical design of health care facilities. However, it is not intended as a replacement for the many excellent engineering texts and handbooks commonly in use, nor is it detailed enough to be a design manual. It should be considered a guide and a general reference on electrical design for health care facilities.

1.2 Health care facilities

The term *health care facility*, as used here, encompasses buildings or parts of buildings that contain hospitals, nursing homes, residential custodial care facilities, clinics, and medical and dental offices. Buildings or parts of buildings within an industrial or commercial complex, used as medical facilities, logically fall within the scope of this book. Thus the specific use of the building in question, rather than the nature of the overall development of which it is a part, determines its electric design category.

Today's health care facilities, because of their increasing size and complexity, have become more and more dependent upon safe, adequate, and reliable electrical systems. Every day new types of sophisticated diagnostic and treatment equipment, utilizing microprocessors or computers, come on the market. Many of these items are sensitive to

electrical disturbances and some require a very reliable power source. Invasive medical procedures such as cardiac catheterization make electrical safety extremely important. Moreover, new medical and surgical procedures are constantly being developed, and new technologies are being utilized. Modern facilities use robotics, telemedicine, picture archiving and communications systems (PACS), and the mixing of diagnostic and treatment modalities (i.e., surgical procedures combined with various types of medical imaging). In addition to the special safety and reliability requirements, health care facilities have unique life safety and communication requirements, because patients are generally unable to care for themselves or evacuate in the event of an emergency. For these reasons, perhaps no area of design or construction is changing as fast as health care facilities.

1.2.1 Industry Applications Society

The IEEE is divided into 42 societies that specialize in various technical areas of electrical engineering. Each group or society conducts meetings and publishes papers on developments within its specialized area. The Industry Applications Society (IAS) presently encompasses 18 technical committees covering electrical engineering in specific areas (petroleum and chemical industry, cement industry, glass industry, industrial and commercial power systems, and others). The Power Systems Engineering Subcommittee, which has responsibility for the White Book Working Group, is part of the Industrial and Commercial Power Systems Department of the IAS. Papers of interest to electrical engineers and designers involved in the field covered by the *IEEE White Book* are, for the most part, contained in the *IEEE Transactions on Industry Applications* of the IAS. The IAS also publishes the *IEEE Industry Applications Magazine*, which reports on the development and application of electrical systems, apparatus, devices, and controls to the processes and equipment of industry and commerce; the promotion of safe, reliable, and economic installations; the encouragement of energy conservation; and the creation of voluntary engineering standards and recommended practices.

1.2.2 Engineering in Medicine and Biology Society

Another IEEE group of interest to the electrical engineer involved in health care facility design is the Engineering in Medicine and Biology Society (EMBS). The *IEEE Transactions on Biomedical Engineering*¹ and the *IEEE Engineering in Medicine and Biology Magazine* include articles on the physiological effects of electrical shock and other subjects pertinent to electrical safety. Articles dealing with electrical equipment and instrumentation also appear in *IEEE Transactions on Biomedical Engineering*.

1.3 Professional registration

Most regulatory agencies require that design for public buildings be prepared by state-licensed professional architects or engineers. Information on such registration may be obtained from the appropriate state agency or from the National Council of Examiners for Engineering and Surveying (NCEES). The NCEES offers engineering registration, and

¹Information on references can be found in 1.12.

this registration helps in obtaining registration in the various states through reciprocity. All engineering graduates are encouraged to start on the path to full registration by taking the engineer-in-training examination as soon after graduation as possible. The final written examination in the field of specialization is usually conducted after 4 years of progressive professional experience.

Clinical engineering certification is available through an international commission. When possible, the hospital's clinical engineer should be involved in the electrical design process.

1.4 Codes and standards

1.4.1 National Electrical Code® and other NFPA standards

The electrical wiring and design requirements in the National Electrical Code® (NEC®) (NFPA 70) are vitally important guidelines for health care facility engineers. Article 517 of the NEC deals exclusively with installation criteria for health care facilities. The NEC is revised every 3 years, and care should be taken to use the edition that is current and adopted by the authority having jurisdiction (AHJ) for enforcement at the time of construction. The NEC is published and available from the National Fire Protection Association (NFPA). It does not represent a design specification, but only identifies minimum requirements for the safe installation and utilization of electricity on the premises. The introduction to the NEC, Article 90, covers purpose and scope, and describes the AHJ's role in interpreting and enforcing the code. The *National Electrical Code® Handbook*, published by the NFPA, contains the complete NEC text plus explanations. This book is edited to correspond with each edition of the NEC.

NFPA 99 addresses performance and testing criteria for electric systems in health care facilities as well as requirements for medical gas systems; heating, ventilation, and air conditioning systems; laboratories; emergency management; and other topics of interest to health care designers. Approximately two thirds of NEC Article 517 is extracted from NFPA 99. The *Health Care Facilities Handbook* [B2],² published by NFPA, contains the entire NFPA 99 text as well as comments and explanatory material. The book is published on a 3-year cycle to correspond with each edition of NFPA 99.

The NEC and other selected NFPA codes are generally adopted by local and state governments for enforcement by electrical and building inspectors and fire marshals.

1.4.2 Health care codes and standards

Additional electrical requirements for health care facilities are included in the *Accreditation Manual for Hospitals*, published by the Joint Commission, formerly the Joint Commission for the Accreditation of Healthcare Organizations (JCAHO). Hospitals seeking Joint Commission accreditation must undergo periodic inspection by their

²The numbers in brackets correspond to those of the bibliography in 1.13.

examiners. Accreditation depends on the hospital's conformance with the requirements included in the accreditation manual.

The Department of Health and Human Services formerly published a standard entitled Minimum Requirements for Construction and Equipment of Hospitals and Medical Facilities and enforced it on a national basis. The American Institute of Architects (AIA) obtained the copyright in 1987 and produced a revision called the Guidelines for Construction and Equipment of Hospitals and Medical Facilities. AIA revised the document in 1992–1993, 1996–1997, and again in 2001 as the Guidelines for Design and Construction of Hospital and Health Care Facilities; the 2006 update is called Guidelines for Design and Construction of Health Care Facilities. The Facilities Guidelines Institute (FGI), a non-profit corporation, was formed in 1998 for the purpose of continuing the publication of the Guidelines. FGI, which now owns the intellectual property, published the 2001 Edition with the cooperation of the AIA and the assistance of the U.S. Department of Health and Human Services. More than 40 states use some portion of this document as their model code for health care facilities.

Electrical designers working on projects for the Department of Veterans Affairs, Department of Defense, the General Services Administration, Public Buildings Service, and other government agencies must be aware that these agencies generally publish standards for electrical design. These standards or guidelines can be obtained from the appropriate agency.

1.4.3 Local, state, and federal codes and regulations

While most municipalities, counties, and states use the NEC without change, some have their own codes. In some instances the NEC is adopted by local ordinance as part of the building code, with deviations from the NEC listed as addenda. It is important to note that only the code adopted as of a certain date is official, and that governmental bodies may delay adopting the latest code. Federal rulings may require use of the latest NEC regardless of local rulings, so that reference to the enforcing agencies for interpretation on this point may be necessary.

Some city and state codes are almost as extensive as the NEC. It is generally accepted that in the case of conflict, the more stringent or severe interpretation applies. Generally the entity responsible for enforcing the code has the power to interpret it.

Failure to comply with NEC or local code requirements can affect the owner's ability to obtain a certificate of occupancy and may have a negative effect on insurance.

In most states, health care construction comes under the jurisdiction of a state health department. In some instances the state will have its own hospital or health care code with specific electrical requirements.

Both state and local authorities may adopt and enforce one of the model building codes written by a regional building officials group.

Legislation by the federal government has had the effect of giving standards, such as certain American National Standards Institute (ANSI) standards, the impact of law. The Occupational Safety and Health Act, administered by the U.S. Department of Labor, permits federal enforcement of codes and standards. The Occupational Safety and Health Administration (OSHA) has adopted the 1971 NEC for new electrical installations and also for major replacements, modifications, or repairs installed after 5 March 1972. A few articles and sections of the NEC have been deemed to apply retroactively by OSHA. The NFPA created the NFPA 70E Committee to prepare a consensus standard for possible use by OSHA in developing their standards. Major portions of NFPA 70E have been included in OSHA regulations.

The U.S. Department of Energy (DOE), by encouraging building energy performance standards, has advanced energy conservation standards. A number of states have enacted energy conservation regulations. These include legislation embodying various energy conservation standards such as ASHRAE/IESNA 90.1, which establishes energy or power budgets that materially affect architectural, mechanical, and electrical designs.

1.4.4 Standards and recommended practices

A number of organizations in addition to the NFPA publish documents that affect electrical design. Adherence to these documents can be written into design specifications.

ANSI approves the standards of many other organizations. ANSI coordinates the review of proposed standards among all interested affiliated societies and organizations to ensure a consensus approval. It is in effect a clearinghouse for technical standards of all types.

Underwriters Laboratories, Inc. (UL) is a non-profit organization, operating laboratories for investigation with respect to hazards affecting life and property, materials and products, and especially electrical appliances and equipment. In so doing, they develop test standards. Equipment that has been tested by UL or other nationally recognized testing organizations (NRLT) (e.g., OSHA), and found to conform to their standards, is known as *listed* or *labeled* equipment. UL lists, for example, nurse-call systems (UL 1069-2006 [B13]).

1.5 Manufacturers' data

The electrical industry, through its associations and individual manufacturers of electrical equipment, issues many technical bulletins, data books, and magazines. Manufacturer's catalogs and specification guides are a valuable source of equipment information. Some manufacturers' complete catalogs are quite extensive covering several volumes. However, these companies may issue condensed catalogs for general use. In recent years most manufacturers have begun to provide complete catalog and product information online.

Manufacturers of specialized hospital electrical equipment often publish design and installation recommendations and technical updates. This is particularly true of isolation panel, standby generator, and transfer switch manufacturers.

1.6 Safety

Safety of life and preservation of property are two of the most important factors in the design of the electrical system. This is especially true in health care facilities because of public occupancy, thoroughfare, high-occupancy density, and patients—some of them in serious or critical condition. In some small and rural health care facilities the operating staff may have limited technical knowledge and, perhaps, no specific electrical training.

Various codes provide rules and regulations as minimum safeguards of life and property. The electrical design engineer often needs to provide greater safeguards than outlined in the codes according to his best judgment, while also giving consideration to utilization and economics.

Electrical safety may be divided into the following five categories:

- a) Safety for maintenance and operating personnel
- b) Safety for staff, employees, and the general public
- c) Safety for general care patients
- d) Safety for critical care patients
- e) Safety for patients and staff in wet locations

Safety for maintenance and operating personnel is achieved through proper design and selection of equipment with regard to enclosures, key-interlocking, circuit breaker and fuse interrupting capacity, the use of high-speed fault-detection and circuit-opening devices, clearances from structural members, grounding methods, disconnecting means, and identification of equipment. Adequate lighting in electrical rooms and around electrical equipment is important to personnel safety.

Safety for the general public requires that all circuit making and breaking equipment as well as other electrical apparatus be isolated from casual contact. This is achieved by using locked rooms and enclosures, proper grounding, limiting of fault levels, installation of barriers and other isolation, proper clearances, adequate insulation, and other similar provisions outlined in this recommended practice. Only authorized personnel should have access to electrical equipment.

Safety for general patients requires all of the design features used for protecting the general public as well as special provisions to minimize potential differences between any two conducting surfaces likely to come in contact with the patient directly or indirectly. Green ground conductors, installed in metallic conduit with the power conductors, ensure that potential differences are below 20 mV when first installed. Potential differences in general patient care areas are required to be maintained below 500 mV under normal conditions. Potential differences in critical care areas must be kept below 40 mV under normal conditions. However, the designer must be aware that even with properly sized and installed ground conductors, higher potential differences can be generated during fault conditions. Other special protective systems such as ground-fault circuit-interrupter (GFCI) receptacles or isolation transformers are used in wet locations to protect patients

and staff and in critical care areas to protect catheterized patients from electric shock through an exposed catheter.

Although flammable anesthetics (like ether) are no longer used in the U.S., they are still popular in some foreign countries. Where flammable anesthesia is used, isolation transformers and a properly grounded conductive floor shall be provided. All wiring in the hazardous area must be installed as required for Class 1 Division 1 locations.

The National Electrical Safety Code® (NESC®) (Accredited Standards Committee C2-2007) [B1] is available from the IEEE. It covers outdoor distribution systems, supply and communications systems, overhead lines, high-voltage systems, and other items related to the supply of building power.

Circuit protection is a fundamental safety requirement of all electrical systems. Adequate interrupting capacities are required in services, feeders, and branch circuits. Selective, automatic isolation of faulted circuits represents good engineering. Tripping schemes for the emergency system must be selective, so that faults on adjacent branches or systems or faults on the emergency system itself do not disrupt service to unaffected emergency system circuits—especially if interruption of these circuits can jeopardize the lives or safety of patients. Physical protection of wiring by means of approved raceways under all probable conditions of exposure to electrical, chemical, and mechanical damage is necessary. In health care facilities the applicable codes require redundant grounding for circuits in patient care areas and special provisions for the physical protection of circuits on emergency systems.

Spare or oversized raceways, spare conductors, and pull wires should be considered for future use. The design engineer should locate equipment where suitable ambient temperatures exist and ventilation is available. The operation of fault-detection and circuit-interruption devices under conditions of abnormal voltage and frequency should be ensured.

1.7 Appliances and equipment

Improperly applied or inferior materials can cause electrical failures. The proper use of appliances and equipment listed by UL or other NLRT is recommended. The Association of Home Appliance Manufacturers (AHAM) and the Air-Conditioning and Refrigeration Institute (ARI) specify the manufacture, testing, and application of many common appliances and equipment.

Medium-voltage equipment should be specified to be manufactured in accordance with the National Electrical Manufacturers Association (NEMA), ANSI, and IEEE standards, and the engineer should make sure that the equipment specified conforms to these standards. Properly prepared specifications can prevent the purchase of inferior or unsuitable equipment. The lowest initial purchase price may not result in the lowest cost after taking into consideration operating, maintenance, and owning costs. Value engineering is an organized approach to identification of unnecessary costs; it utilizes such methods as life cycles, cost analyses, and related techniques.

1.8 Operational considerations

When the design engineer plans electrical equipment rooms and locates electrical devices, there may be areas accessible to unqualified persons due to limited space. Dead-front construction and ANSI/NEMA Category A type construction should be utilized whenever practical. Where dead-front construction is not available, all exposed electrical equipment should be placed behind locked doors or gates. This will result in a reduction in electrical failures caused by human error, as well as improved safety.

A serious cause of failure, which is attributable to human error, is unintentional grounding or phase-to-phase short-circuiting of equipment that is being worked upon. By careful design such as proper spacing, barriers, and padlocking, and by enforcement of published work-safety rules, the engineer can minimize unintentional grounding and phase-to-phase, and ground faults in the distribution equipment. High-quality workmanship is an important factor in the prevention of electrical failures. Therefore, the design should incorporate features that are conducive to good workmanship.

Selective coordination of overcurrent devices is important in health care facilities, especially for critical care areas. The system must be studied for both high- and low-level faults. It is therefore important to consider the different levels of available short-circuit current available from utility and standby sources. The selection and coordination of overcurrent protective devices (OCPDs) should take into consideration protection, selectivity, the nature of the circuits (critical or non-critical), and the project budget.

Ground-fault protection schemes on large service mains on wye-grounded 480 V systems will help to minimize damage from arcing ground faults. Arcing ground faults or *burn-downs* can cause total destruction of electrical equipment, jeopardizing patient safety by fire and loss of electrical service. By providing one or more additional steps of ground-fault protection downstream, designers can ensure that otherwise harmless ground faults (such as in the powerhouse or kitchen) will not cause an outage of the hospital main or patient care areas of the hospital. Ground-fault systems should be tested for selective tripping to ensure proper and safe operation per the NEC.

1.9 Maintenance

Maintenance is essential to proper operation. The installation should be so designed that building personnel can perform most of the maintenance with a minimum need for specialized services. Design details should provide proper space and accessibility so that equipment can be maintained without difficulty and excessive cost.

The engineer should consider the effects of a failure in the system supplying the building. Generally, the external systems are operated and maintained by the electrical utility, though at times they are a part of the health care facility distribution system.

In health care facilities where continuity of service is essential, suitable emergency and standby equipment should be provided. Such equipment is needed to maintain minimum lighting requirements for passageways, stairways, and to supply power to critical patient

care areas and essential loads. These systems are usually installed within the building, and they include automatic or manual equipment for transferring loads on loss of normal supply power or for putting battery- or generator-supplied equipment into service.

Although applicable codes determine the need for standby or emergency generating systems in health care facilities, they are generally required in any facility that keeps acutely ill patients overnight, performs invasive procedures, administers anesthesia, has critical patient care areas, or otherwise treats patients unable to care for themselves during an emergency. High-rise health care facilities, regardless of type, should have on-site emergency or standby generators. Periodic testing and exercising of standby generators is essential to system reliability.

Electrical engineers should consider the installation of bypass/isolation switches in conjunction with automatic transfer switches (ATSSs) to permit maintenance on a de-energized transfer switch without jeopardizing patient safety. The isolation/bypass switch permits removal of the transfer switch from the circuit while providing for manual transfer to the normal or emergency source.

Even with isolation/bypass switches, it is possible for a load-side circuit breaker to fail, causing loss of power to all or part of the critical branch. For this reason it is recommended to provide some normal circuits in critical patient care areas per the NEC.

1.10 Design considerations

Electrical equipment usually occupies a relatively small percentage of the total building space, and in design it may be easier to relocate electrical service areas than mechanical areas or structural elements. Allocation of space for electrical areas is often given secondary consideration by architectural and related specialties. In the competing search for space, the electrical engineer is responsible for fulfilling the requirements for a proper electrical installation while at the same time recognizing the flexibility of electrical systems in terms of layout and placement.

Today, architectural considerations and appearances are of paramount importance in the design of a health care facility. Aesthetic considerations may play an important role in the selection of equipment, especially lighting equipment. Provided that the dictates of good practice, code requirements, and environmental considerations are not violated, the electrical engineer may have to compromise the design to accommodate the needs of other members of the design team.

The electrical engineer should work closely with professional associates, such as the architect, the mechanical engineer, the structural engineer, and the civil engineer. There is also concern with the building owner or operator who, as clients, may take an active interest in the design. More often the electrical engineer will work directly with the coordinator of overall design activities, usually the architect. Cooperation with the safety engineer, fire protection engineer, the environmental engineer, and other concerned people, such as interior designers, all of whom have a say in the ultimate design, is essential.

The electrical designer should become familiar with local rules and know the AHJs over the design and construction. The designer should always contact the AHJs and all applicable utilities before beginning design. Local contractors are usually familiar with local ordinances and union work rules and can be of great help. Union work practices may, for reasons of safety or other considerations, discourage the use of certain materials and techniques.

In performing electrical design, it is essential, at the outset, to prepare a checklist of all the design stages that have to be considered. Major items include temporary power, access to the site, and review by others. It is important to note that certain electrical work may appear in nonelectrical sections of the specifications. For example, furnishing and connecting of electric motors and controls may be covered in the mechanical section of the specifications. Another notable example would be elevators, which are usually specified by the architect. The electrical engineer should insist that the proper starter, fireman's recall system, and emergency sequencing of elevators are specified.

Electrical engineers working on health care projects should have a working knowledge of medical gas systems because medical gas outlets often share consoles and headwalls that appear in the electrical specifications. The electrical engineer also should be familiar with medical gas alarm systems.

For administrative control purposes, the electrical work may be divided into a number of contracts, some of which may be under the control of a general contractor and some of which may be awarded to electrical contractors. Among items with which the electrical designer will be concerned are preliminary cost estimates, final cost estimates, plans or drawings, specifications (which are the written presentation of the work), materials, manuals, factory inspections, laboratory tests, and temporary lighting and power. The electrical engineer may well be involved in providing information on how electrical considerations affect financial justification of the project in terms of owning and operating costs, amortization, return on investment, and related items.

1.11 Other considerations

Those involved in the design of health care facilities should understand the process by which drawings are issued for bidding and construction. The designer should also have some knowledge of shop drawing review, estimating, and contract administration.

Design and construction of health care facilities are a team process involving engineers, architects, construction managers, general contractors, estimators, subcontractors and equipment vendors. In recent years the contractors and construction managers have become increasingly involved in the design process. In order to successfully complete a health care project, it is important to involve contractors who have a successful track record in health care construction. The larger and more complex the project the more important it is to have contractors who are skilled and experienced in the specialized construction techniques required for medical facilities.

1.12 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ASHRAE/IESNA 90.1, Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI).³

Guidelines for Design and Construction of Health Care Facilities.⁴

Joint Commission, *Accreditation Manual for Hospitals*.⁵

NFPA 20, Standard for the Installation of Stationary Pumps for Fire Protection.⁶

NFPA 53, Recommended Practice on Materials, Equipment, and Systems Used in Oxygen-Enriched Atmospheres.

NFPA 70, National Electrical Code® (NEC®).

NFPA 70B, Recommended Practice for Electrical Equipment Maintenance.

NFPA 70E, Electrical Safety in the Workplace.

NFPA 72, National Fire Alarm Code®.

NFPA 75, Standard for the Protection of Electronic Computer/Data Processing Equipment.

NFPA 77, Recommended Practice on Static Electricity.

NFPA 99, Standard for Health Care Facilities.

NFPA 101, Life Safety Code®.

NFPA 101, Life Safety Code® Handbook.

NFPA 110, Standard for Emergency and Standby Power Systems.

³ASHRAE publications are available from the Customer Service Department, American Society of Heating, Refrigerating and Air Conditioning Engineers, 1791 Tullie Circle, NE, Atlanta, GA 30329, USA (<http://www.ashrae.org/>).

⁴The current edition of the Guidelines is available from the American Institute of Architects Academy of Architecture for Health, 1735 New York Ave., N.W. Washington, DC 20006 (http://www.aia.org/aah_gd_hospcons).

⁵Joint Commission standards and manuals can be obtained from the Joint Commission, One Renaissance Blvd., Oakbrook Terrace, IL 60181 (<http://www.jcrinc.com/77/>).

⁶NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA (<http://www.nfpa.org/>).

NFPA 111, Standard on Stored Electrical Energy Emergency and Standby Power Systems.

NFPA 780, Standard for the Installation of Lightning Protection Systems.

NFPA Fire Protection Handbook™.

29 CFR 1910, Occupational Safety and Health Standards, Occupational Safety and Health Administration.⁷

1.12.1 Periodicals

IEEE Transactions on Biomedical Engineering.⁸

IEEE Engineering in Medicine and Biology Magazine.⁹

1.13 Bibliography

Additional information may be found in the following sources:

[B1] Accredited Standards Committee C2-2007, National Electrical Safety Code® (NESC®).¹⁰

[B2] *Health Care Facilities Handbook*, 2005 Edition.¹¹

[B3] IEEE Std 141™-1993, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (*IEEE Red Book*™).^{12, 13}

[B4] IEEE Std 142™-1992, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (*IEEE Green Book*™).

[B5] IEEE Std 241™-1990, IEEE Recommended Practice for Electric Power Systems in Commercial Buildings (*IEEE Gray Book*™).¹⁴

⁷CFR publications are available from the Superintendent of Documents, U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20013-7082, USA (<http://www.access.gpo.gov/>).

⁸*IEEE Transactions on Biomedical Engineering* is available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://www.embs.org/pubs.html>).

⁹*IEEE Engineering in Medicine and Biology Magazine* is available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://www.ieee.org/organizations/pubs/magazines/emb.htm>).

¹⁰The NESC is available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

¹¹See footnote 5.

¹²IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

¹³The IEEE standards or products referred to in this subclause are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

[B6] IEEE Std 242TM-2001, IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (*IEEE Buff BookTM*).

[B7] IEEE Std 399TM-1997, IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis (*IEEE Brown BookTM*).

[B8] IEEE Std 446TM-1995, IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (*IEEE Orange BookTM*).

[B9] IEEE Std 493TM-2007, IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (*IEEE Gold BookTM*).

[B10] IEEE Std 739TM-1995, IEEE Recommended Practice for Energy Management in Industrial and Commercial Facilities (*IEEE Bronze BookTM*).

[B11] IEEE Std 1100TM-2005, IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment (*IEEE Emerald BookTM*).

[B12] National Electrical Code[®] Handbook (NFPA 70), 2005 Edition.

[B13] UL 1069-2006, Hospital Signaling and Nurse Call Equipment.¹⁵

1.13.1 Periodicals

[B14] *ASHRAE Journal*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1791 Tullie Circle NE, Atlanta, GA 30329.

[B15] *Consulting-Specifying Engineer*, 2000 Clearwater Dr., Chicago, IL 60523.

[B16] *Electrical Construction and Maintenance*, 900 Metcalf Ave., Overland Park, KS 66212.

[B17] *Engineering Times*, National Society of Professional Engineers, 1420 King Street, Alexandria, VA 22314.

[B18] *Health Facilities Management*, Health Forum, Inc., One North Franklin St., 28th Floor, Chicago, IL 60606.

[B19] *Hospitals & Health Networks*, Health Forums Inc., One North Franklin, Chicago, IL 60606.

¹⁴The *IEEE Gray BookTM* will be of particular importance as a reference book to the hospital designer because of the many similarities between commercial buildings and health care facilities. Health care facilities typically have kitchens, dining areas, business offices, computer rooms, and central energy plants similar to commercial buildings. Moreover, medical outpatient facilities routinely exist in office buildings, shopping malls, and strip shopping centers.

¹⁵UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

[B20] *IAWI News*, International Association of Electrical Inspectors, 901 Waterfall Way, Suite 602, Richardson, TX 75080-7702.

[B21] *Journal of Clinical Engineering*, Ovid Technologies, 100 River Ridge Dr., Norwood, MA 02062.

[B22] *LD+A*, Illuminating Engineering Society of North America, 120 Wall St., 17th Floor, New York, NY 10005.

[B23] *Modern Healthcare*, 360 N. Michigan Ave., 5th Floor, Chicago, IL 60601-3806.

[B24] *Neta World*, published by the International Electrical Testing Association, P.O. Box 687, Morrison, CO 80465.

[B25] *NFPA Journal*, National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471.

[B26] *Plant Engineering*, 2000 Clearwater Dr., Oak Brook, IL 60523.

Chapter 2

Electrical loads

2.1 General discussion

Engineers should pay attention to health facility electrical loads for at least two reasons. First, engineers designing health care facilities should understand the nature of health care electrical system loads in order to coordinate the demand on the system with the relevant codes and standards to produce a system design that meets the needs of the project owner. Second, engineers designing and managing health care facilities should understand the costs that will be imposed on the owner of the electrical system as a result of the electrical system loads and the nature of the energy procurement process in order to select the optimal combination of systems and devices.

2.1.1 Overview

This chapter has two goals. First, the chapter will look at ways to understand and predict electrical loads for health care facilities. The goal for this subclause is to assist the engineer designing a hospital to size various system elements. Second, the chapter will summarize some of the options for procuring, generating/storing/distributing, and consuming electrical energy with the goal of assisting the engineer to optimize system design and operation to minimize energy consumption and costs.

2.1.2 Groups of loads

The cumulative effect of groups of individual loads is one of the determinants of distribution system design. Facility loads can be understood in a number of ways. First, the loads can be seen as calculated loads or as measured loads. They can be understood as load density (i.e., watts per square foot, W/ft^2) or in terms of circuits required. They can be viewed in terms of the one-time peak or in terms of the profile of the loads from hour to hour, from day to day, and from month to month. Each perspective has a different dynamic, and each perspective is important for a different reason. Each perspective will depend on many different factors, all of which are likely to change as the facility evolves. The best engineers who deal with health care facilities will attempt to understand the nature of the electrical loads under all of these kinds of circumstances and apply that knowledge to optimize the design and operation of the facility over its lifetime.

The figures that follow provide historical data summarizing health facility load data from a number of different sources. This data includes loads for different types of facilities, in different geographical areas, over different time frames. Taken together, these data can be used to generate some initial estimates of health facility loads. However, this data should be carefully applied, as it is data taken from one or another particular facility, with particular lines of services, patient census, weather conditions, etc. Engineers using this data should use common sense in applying it to another health care facility under a different set of circumstances.

2.1.3 Load evolution

Patterns of health care delivery have changed dramatically in recent years. No evidence suggests that this rate of change will abate. Some of the ongoing changes include the growing concentration of data systems in delivering health care services; the continuing evolution of health care technologies, often in ways that blur the lines between imaging and treatment for instance; the movement of more and more procedures to outpatient settings; the resultant acuity intensification for the patients in hospitals; and the nearly universal application of digital technologies in different kinds of loads.

Moreover, individual facilities constantly change and adapt to the particular demographics of the patient populations they serve, as well as changes in ownership and management structure and reimbursement policies. And, the nature of the facility itself will dictate the probable nature and rate of changes. For example, large teaching and research hospitals generally undergo a much more dramatic set of changes over the life of a building than will a small rural hospital, for instance. Outpatient facilities may undergo the most dramatic changes of all in future years as more and more procedures become simpler, more automated, and less invasive, and therefore more prevalent in outpatient settings.

Medical planners and building owners generally concur that the average projected life of a hospital being designed in the early part of the twenty-first century will be in the range of 50 years. Consider the changes that have taken place over the past 50 years, the increasing rate of change, and contemplate the kinds of changes that the hospitals we are designing now will undergo.

The upshot of the needs for change and the pace of change on electrical system loads is that the engineer who is designing electrical systems should design systems using historical data, but doing so in the context of the need for a system sufficiently robust to provide for the change that will likely come.

2.1.3.1 Ampacity vs. space

Obviously, engineers should design electrical systems with an eye towards sufficient ampacity or power ratings. Less obvious, but equally important, engineers should design electrical systems with space for additional distribution equipment. Recent history has taught that the need for additional breaker space in branch circuit panels usually determines when the panel is “out of capacity” far sooner than the need for additional ampacity. Sensitive electronic equipment with demands for dedicated circuits has been a primary driver of this need at the branch circuit level, and it may be that as technologies mature, the need for dedicated circuits may lessen. On the other hand, more and more devices are electrified and more and more devices are simple plug-in type, meaning that the need for outlets continues to grow.

So, while the rating of the equipment is important in the ability for an electrical system to support evolution over time, of equal importance is the space in the panels, the space within motor control centers, the space within switchboards, and the physical space within rooms dedicated to electrical equipment.

2.1.3.2 New technologies

As mentioned in the previous subclause, one of the drivers in the changes to clinical practice is the continued (and accelerating) advance in the development of medical technologies. As with other technological areas, in medical devices so too are we seeing more and more devices of more and more kinds, all demanding electrical power. Such advances are creating new procedures (robotic surgery), merging differing kinds of procedures (imaging and surgery), and putting constant demands on facility electrical systems for increased capacity, reliability, and power quality. On the other hand, as with all other technological areas, more and more medical devices are being designed to operate with lower and lower voltages, and even on batteries.

Complicating matters is the growing prevalence of digital equipment. Digital equipment often requires relatively clean electrical waveforms, while simultaneously injecting irregularities onto the incoming signal that are then transferred to other portions of the system. Many digital devices now include input filters that mitigate both the incoming signals as well as the disruption the device causes back onto the system.

Again, the evolution of these kinds of loads will impact the systems that are designed to serve them, and the engineer should design any new systems with the evolving nature of the loads to be served in mind.

2.1.3.3 Demand vs. connected loads

The word *demand* creates some confusion as it is commonly used to refer to two different things. One sense of the “demand” load for a system is the load that is actually on the system at any one time. This sense of the word is frequently used by utility companies, for example, who often bill for the peak demand for a facility. The National Electrical Code® (NEC®) (NFPA 70),¹ however, uses the word both in this sense [see, for example, 517-30(D) in the NEC] and in another sense. The NEC defines a *demand factor* as the “ratio of the maximum demand of a system, or part of a system, to the total connected load of a system or the part of the system under consideration.” Expressed this way, “demand” means essentially the same thing as expressed previously, but in practice, the NEC uses the phrase “demand factor” in a very different way. Various sections of the code list specific demand factors that may be used in calculating the loads for branch circuits, feeders, and other portions of the distribution system. This use of “demand factor” is therefore not the ratio of maximum demand of a system to the connected load; instead, it is the ratio of minimum permissible calculated load for equipment/feeder sizing compared to connected load. The code therefore uses “demand” in both senses. And again, the electrical engineer needs to understand both kinds of “demand,” for in sizing the electrical system, the engineer cannot violate the codes, but at the same time, the engineer should be mindful of the actual loads that the system will experience, in order to apply the appropriate diversity factors and be able to forecast the usage of the facility over time for budgeting purposes.

¹Information on references can be found in 2.6.

Generally speaking, the actual loads that any given portion of an electrical system will experience will be less than the sum of the connected loads on that portion of the electrical system, and less than the connected loads adjusted by the code's specifically enumerated demand factors. This difference results from the fact that the codes generally do not take into effect the notion of diversity. Diversity refers to the fact that, for any group of loads, not all will be on at any one time. And the more loads that are grouped together, the more that will likely be off at one time. IEEE Std 241™ (*IEEE Gray Book*™) points out this difference and defines diversity as the ratio of the sum of a group of demand loads to the total "maximum demand of the system" (see IEEE Std 241, 2.1).

In general then, the explicit code-specified demand factors will result in actual demands, especially at the service or the generator, that are considerably higher than the maximum demand that point in the system will experience. The *IEEE Gray Book* notes that the engineer may want to use a diversity of 100% in order to provide spare capacity, but in practice, using a diversity of 100% can create a system that is significantly larger than it will ever need to be. The engineer designing a health care facility needs to understand well the code-allowed demand factors, the loads that the system will actually be likely to experience, and the owner's needs for spare capacity. Only then can the engineer do a creditable job of specifying the right size for the various elements in the system.

Note, finally, that various authorities having jurisdiction (AHJs) over the design of health care facilities enforce and interpret various portions of the codes they enforce with varying levels of enthusiasm (one hospital engineer once complained that every person who walked in his door claimed that he was the AHJ.) However, various provisions of the NEC such as 220-21—which allow the engineer to reduce the sizes of feeders and services "where it is unlikely that two or more non-coincident loads will be used simultaneously"—can be used to allow more accurate sizing of electrical equipment or feeders if properly applied by the AHJ.

In designing electrical systems, therefore, engineers for health care facilities should be aware of the connected loads of their facilities, the relevant demand factors required and diversity factors allowed by their codes and their AHJs, and the likely actual maximum demand loads.

2.1.3.4 Occupancy type

Varying types of health care facilities have varying types of load profiles (see 2.5). The nature of health care facilities is such that occupancies are blurring. More and more outpatient procedures are being performed in outpatient facilities. More and more procedures are being moved to outpatient facilities and out of inpatient facilities. And more and more housing of patients is being transferred to the home, with resulting increase in the acuity of patients who remain in the hospital.

Different kinds of occupancies create different kinds of loads and different kinds of load profiles (see 2.5). Outpatient facilities may operate during business hours only. Ambulatory surgery facilities, offering 23.5 hour stays, may have profiles similar to those of acute care hospitals. Emergency departments and the associated diagnostic and treatment areas will have profiles differing from those of other areas of the hospitals.

Hospitals with full kitchens will have different profiles from hospitals with food prepared off-site and only served on-premises. Medical centers with laundries will have significantly different profiles than medical centers without. In general, facilities and portions of facilities dedicated to housing patients and their families will have relatively smaller load densities, while diagnostic and treatment areas will generally have higher load densities. Even these broad rules, however, should be used with caution, in view of the likely continuing evolution of patient care.

In general, the engineer analyzing or predicting or attempting to understand load profiles for medical centers should understand the occupancies within the medical center, their hours of operation, and their probable electrical load profiles. Moreover, the “shell and core” of a particular building may house many different occupancies over its lifetime. The nature of a modern health care facility is that it should respond to changes in ownership, in reimbursement policies, and in changes to its patient population. All of these external forces, together with technological changes in the practice of medicine, will create constant pressures for changing the mix of services within any particular facility.

2.1.3.5 Normal vs. emergency loads

Most health care buildings have loads on emergency distribution systems. Engineers should size components for these generation and distribution systems in addition to sizing the elements for those loads only on emergency power.

The relevant building codes set forth the loads that should be on the building emergency system. Loads on the emergency distribution system include loads for egress lighting, alarm and alerting systems, fans, pumps, and general lighting and receptacles. The considerations for sizing equipment serving these loads are similar to those for sizing normal equipment, except that the engineer should be aware of certain “tricks” available that can be applied to more closely size the generators to the actual loads.

In many instances, certain loads that run when the building is receiving utility power may, when transferred to emergency power, exhibit different running characteristics. For example, the engineer may put controls in place so that when the building is running on emergency power, only one elevator per bank may be used, rather than all of the elevators. Similarly, though the electrical code requires the generator to be sized for starting current for the fire pump, a particular sequence of operation may also require the fans to stop upon activation of the fire detection system. In this case, the fan load may be larger than the starting current of the fire pump, and the starting current of the fire pump can thus be ignored in sizing the emergency generator and its primary components. A third example is the recent addition to the NEC of language allowing an additional transfer switch(es) to serve loads that are not specifically named as having to be on emergency power. Here, the engineer need not size the generator based on these loads, as the control sequence may be designed to shed these loads upon generator overload.

Surveys of emergency power systems for various hospitals across the country show that the peak demand load for such systems is generally less than or equal to 3.5 W/f^2 , with the connected load two to three times more than this amount. Of this total, approximately half

is load on the equipment system, one-third is load on the critical branch of the emergency system, and the balance is load on the life safety branch of the life safety system.

2.1.4 Sustainable/green buildings

In the early 1970s, the Arab oil embargo left the U.S. reeling, and together with the flourishing environmental movement, created the first interest in energy efficient buildings. Health care facilities generally implemented energy savings measures largely in order to contain operating costs and were generally reluctant to implement energy solutions that did not offer a “payback” of only a few years.

However, energy prices remained relatively stable for many years, thus lessening the interest of health care facilities in investing in new energy saving technologies (see Mann [B24]).²

In the closing years of the twentieth century, however, new forces have emerged that are rekindling the interest of health care facilities in reducing their energy usage and in implementing *green* technologies. First, the U.S. energy supply infrastructure and reserve capacity have changed as markets have changed, with the result that both infrastructure and reserve capacity limits are being tested. This results in various kinds of energy price and supply volatility in the face of sudden or unexpected changes to the underlying assumptions as to supply or demand (see Joskow [B21]).

Second, the deregulation efforts for the electricity markets have been “incomplete, balkanized, and suffer from serious market design and regulatory imperfections.” These unsuccessful attempts to deregulate some of the country’s electricity producers have exacerbated the problems caused by relatively limited infrastructure and reserve capacity. While little of the country’s electricity is currently produced from petroleum supply (see Joskow [B21]), the pervasive impact of petroleum shortages tends to magnify public perceptions of “energy crisis” in the event of disruptions (or threatened disruptions) to oil supply].³ Coupled with the U.S.’ growing dependence on foreign oil supplies (see Joskow [B21]), this problem is likely to persist for many years. Finally, the link between energy consumption and the health of the environment are becoming daily more and more obvious (see Mann [B24]).

The result of these forces, together with a propensity to change our national energy policy only in response to crises, tends to breed an air of uncertainty in the energy field.

Another development is the rise of the *green buildings* movement. Many organizations have promoted the ideas of green or sustainable building for many years.⁴ But the U.S. Green Building Council’s recent publication of its LEED rating system [Leadership in Energy and Environmental Design (LEED) Green Building Rating System™] has greatly accelerated the interest in energy technologies that create less harm to the environment.

²The numbers in brackets correspond to those of the bibliography in 2.7.

³ For example, one frequently cited fear of a U.S.-led attack on Iraq in 2002 was the fear of oil shocks.

⁴ For example, the Rocky Mountain Institute has promoted the use of green technologies in building for many years.

Indeed, the *healthy buildings* movement⁵ has combined with the green movement to create a force for developing energy strategies that are both environmentally benign, as well as promoting health for the occupants of staff and for patients.⁶

All of these factors combine with continuing pressures to reduce costs in the face of often declining revenues faced by health care facilities to create a continued pressure to manage the energy costs of the health care facility in a way that supports the overall mission of the organization (see American Society for Healthcare Engineering [B3]). Indeed, a recent survey by the U.S. Department of Energy (DOE) show that 99% of inpatient health care buildings are owner occupied. Owners of buildings have a fiduciary interest in their economical operation, unlike say, a landlord who passes energy costs on to tenants, or tenants who may or may not benefit from energy saving investments. The combination of financial pressures together with the healing mission of the organizations who own and operate health care facilities combine to drive better and better decisions regarding the *greenness* of health care facilities.

2.2 Obtaining load data

Engineers may obtain load data from a number of different sources, depending upon the precise nature of the need. Obviously, equipment manufacturers publish data on the energy consumption of their equipment. Often, these manufacturers express their data in the form of “minimum circuit ampacity,” which does not accurately reflect the actual energy demand of the equipment supplied. In these cases, a quick phone call to the manufacturer will usually yield more accurate information. This kind of detailed information is usually required in the final design stages of a project.

Engineers can obtain estimates of calculated demand loads from other projects performed in the same jurisdiction or in a jurisdiction following similar interpretations of the codes. At least one engineering firm has compiled a database, by department, of the watts per square foot and circuits per square foot for the normal system and each emergency branch and system in a hospital. This kind of data can be used to quickly and accurately estimate the loads for a facility early in the design process, allowing for accurate layouts of distribution equipment early in the process. Table 2-1 and Table 2-2 show some typical data for two different medical office buildings (MOBs) in California.

⁵ Propounded, for example, by the Healthy Buildings Network; see www.healthybuilding.net.

⁶ Kaiser Permanente’s National Facilities Services has adopted the following statement of green goals: “Kaiser Permanente’s mission is to improve the health of the communities we serve. In recognition of the critical linkages between environmental health and public health, it is KP’s desire to limit adverse impacts upon the environment resulting from the siting, design, construction and operation of our health care facilities. We will address the life cycle impacts of facilities through design and construction standards, selection of materials and equipment, and maintenance practices. Additionally, KP will require architects, engineers, and contractors to specify commercially available, cost-competitive materials, products, technologies and processes, where appropriate, that have a positive impact, or limit any negative impact on environmental quality and human health.” See similar goals from the UT Hospital at <http://www.swarthmore.edu/NatSci/sciproject/GreenGoals.html>.

Table 2-1—Sample MOB load/circuit data^a

MOB	ft ²	480 V poles	480 V spares	480 V spaces	480 V poles/ ft ²	208 V poles	208 V spares	208 V spaces	208 V poles/ ft ²
1	54 000	258	91	66	0.004778	848	161	98	0.015704
2	32 430	54	9	12	0.001665	394	72	27	0.012149
ave	43 215	156	50	39	0.003221	621	116.5	62.5	0.013926

^aReprinted with permission from Kaiser Foundation Health Plan Inc.**Table 2-2—Sample MOB load/circuit data, continued^a**

MOB	ft ²	Ltg (VA)	Ltg (VA/ ft ²)	Receps (VA)	Receps (VA/ ft ²)	Equip (VA)	Equip (VA/ ft ²)	HVAC (VA)	HVAC (VA/ ft ²)
1	54 000	144 725	2.68	429 371	7.9513	283 600	5.2519	197 670	3.6606
2	32 430	33 010	1.02	117 800	3.6324	159 010	4.9032	89 560	2.7616
ave	43 215	88 867	1.85	273 586	5.7919	221 305	5.0775	143 615	3.2111

^aReprinted with permission from Kaiser Foundation Health Plan Inc.

With respect to the actual demand loads, this kind of data can only come from experience. The state of California requires that an engineer adding load to an existing system measure the loads for the system for a minimum of three days to verify that the system has adequate capacity for adding more load (see OSHPD Policy Intent Notice 3-220). These kinds of measurements dramatically show the differences between connected loads, calculated demand loads, and actual demand loads.

Recording existing loads is not always as straightforward as it might appear. For example, most recording ammeters will record motor starting surges. Using the motor starting surge as the “peak load” for a particular point in a system is highly inaccurate, as overcurrent devices are designed to ride through a certain amount of surge without tripping. Indeed, the rating of most overcurrent devices reflects the load that the device can tolerate for a long time, not the load that the device will trip on in an instantaneous surge situation (see Nash [B25]).

2.3 Using load data to design health care facilities

2.3.1 General considerations

As previously mentioned, when a circuit or feeder serves a single load, that load can generally be either on or off. So, the engineer should size that circuit or feeder to carry 100% of the connected load for that device. (In the case of a continuous load, as defined by the NEC, the engineer should size the circuit or feeder to carry 125% of the connected load in order to protect against excessive heat buildup over time.) However, as more and more loads are concentrated onto a single feeder, the engineer should use more and more demand and diversity factors in order to ensure that the feeders are not oversized relative to the loads they will actually have to carry.

The data in Annex 2B show the daily consumption of electricity during a typical summer day for a typical hospital, as well as showing a breakdown of electricity demands for different portions of the hospital distribution system. This hospital was constructed in 1995 and uses centrifugal electric chillers in a central plant for cooling. The portions of the system studied were as follows.

2.3.2 Internal building loads and distribution system

2.3.2.1 Lighting loads

Lighting for the health care facilities is presented in Chapter 6. Loads imposed by the lighting systems will be a function of several variables, including the following:

- a) Tasks to be performed
- b) Quality and quantity of illumination required
- c) Choice of lighting sources

Lighting design for some areas will be similar to that for other commercial buildings. Other spaces will require the application of specialized lighting techniques. Among the latter are patient rooms, intensive care units, nurseries, and surgical and obstetrical suites.

In all cases, task lighting techniques should be applied, in the interest of energy management and of optimum distribution system capacity.

2.3.2.1.1 Lighting loads by function

For initial calculations, lighting connected loads are estimated by relying on the designer's previous experience, or they may be estimated using the Illuminating Engineering Society of North America (IESNA) lighting power budget technique. Refer to 2.6, 2.7, and Chapter 6 for more on this subject.

2.3.2.1.2 Lighting demand

As with other types of loads, demand factors may be applied to lighting connected load when determining distribution system component capacity. The appropriate factor will depend upon some or all of the following:

- a) Function performed in the area served
- b) Means of lighting control, i.e., switching, dimming
- c) Hours of operation for the area served
- d) Local code authority requirements

As an upper limit, the continuous load supplied by a lighting branch circuit should not exceed 80% of the branch circuit rating. For good design practice, the continuous load supplied should not exceed 70% of the branch circuit rating and in some cases should be even lower.

The NEC permits the use of lighting demand factors in calculating lighting load on feeders. Refer to Table 220-11 of the NEC. However, designers should develop their own factors based on the characteristics of a specific project, consistent with restraints imposed by code authorities.

The factors shown in Table 2-3 may be used in sizing the distribution system components shown and should result in a conservative design.

As a general rule, the life safety branch in a hospital, consisting primarily of exit signs and egress lighting, will show little diversity. So a demand factor of 100% is appropriate for these lighting loads. Similarly, areas where the entire lighting is likely to be used at one time should also be sized at 100%.

Table 2-3—Factors used in sizing distribution system components

Distribution system component	Lighting demand factor
Lighting panel bus and main overcurrent device	1.0
Lighting panel feeder and feeder overcurrent device	1.0
Distribution panel bus and main overcurrent device	0.5 0.4
First 50 000 W or less	
All load over 50 000 W	
Remaining components	0.4

2.3.2.2 Power loads

Power loads may be divided into the following broad categories:

- a) Building equipment
- b) Heating, ventilating, air conditioning, and refrigeration (HVAC&R)
- c) Transportation (elevators, trolleys)
- d) Auxiliary pumps (fire, sump, clinical air and vacuum, pneumatic tube)
- e) Functional equipment
- f) Kitchen
- g) Dialysis
- h) Communication systems
- i) Business machines
- j) Laundry
- k) Medical equipment
- l) X-ray and imaging systems
- m) Radiation therapy
- n) Laboratory
- o) Surgery
- p) Intensive care, recovery, emergency
- q) Physical and occupational therapy
- r) Inhalation therapy
- s) Pharmacy
- t) Materials management
- u) Medical records

NOTE—Major loads occur in categories a) and b), and these loads are similar to those in other types of commercial buildings. Category c) is unique to health care facilities.⁷

2.3.2.3 Building equipment

The types of HVAC&R equipment chosen for a specific building will have the greatest single effect on the electrical load. First, the choice of fuel will be critical. If natural gas, fuel oil, or coal is chosen, electrical loads will be lower than would be the case if electricity were chosen. Second, the choice of refrigeration cycle will have considerable impact. If absorption chillers are chosen, electrical loads will be lower than those imposed by electric centrifugal or reciprocating chillers. Early discussions between mechanical and electrical designers will be advantageous in planning the electrical distribution system.

For initial estimates, before actual loads are known, the factors shown in Table 2-4 may be used to establish the major elements of the electrical system serving HVAC&R systems.

⁷Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

Table 2-4—Factors used to establish major elements of the electrical system serving HVAC&R systems

Item	Unit
Refrigeration machines	kVA/ton of chiller capacity
Absorption	0.10
Centrifugal/reciprocating	1.0
Auxiliary pumps and fans	
Chilled water pumps	0.08
Condenser water pumps	
Absorption	0.15
Centrifugal/reciprocating	0.07
Cooling tower fans	
Absorption	0.10
Centrifugal/reciprocating	0.07
Boilers	kVA/boiler hp
Natural gas/fuel oil	0.07
Boiler auxiliary pumps	kVA/boiler hp 0.10
Deaerator	
Auxiliary equipment	kVA/bed
Clinical vacuum pumps	0.18
Clinical air compressors	0.10

Where it is unlikely that two dissimilar loads will be in use simultaneously, it is permissible to omit the smaller of the two loads in computing the total load for a feeder. For example, if the heating hot water pumps and the air conditioning chilled water pumps are connected to the same feeder and are not used at the same time, only the larger of the two loads is considered. Likewise, if a pump or air compressor has two motors that operate on an alternating basis, only one of the motors need be included in the calculation.

Similarly, where feeders serve motors that duty cycle, operate intermittently, or where all motors will not operate at the same time, the AHJ often grants permission for feeder conductors to have an ampacity of less than that required for the total connected load (NEC 430-26). While this option will be exercised rarely for feeders with only a few motors, it should be used more aggressively for feeders supplying large groups of motors (i.e., the equipment system). Diversity factors are appropriate for hospitals that have a great number of motors of different types (air compressors, pumps, etc.) that operate intermittently.

Another potential reason for applying diversity factors for feeders to motor loads has to do with sizing round off and safety factors used by the mechanical engineer in sizing the equipment. If the actual fan load is 42 hp, the mechanical engineer will specify a 50 hp motor simply because a 50 hp motor is the next standard size. Likewise, if the calculation calls for 48 hp, the mechanical engineer will specify a 60 hp motor as a safety factor. Moreover, inlet vanes and variable frequency drives (VFDs) will modulate airflow according to demand. So since induction motors produce load in proportion to the torque on the shaft, regardless of the motor nameplate rating, the actual motor load will be less than the calculated load most of the time. Therefore, it is reasonable to use a diversity factor of something less than 100% for portions of the electrical system serving a large number of air handling units.

Elevators are usually large loads, but since only a few are required in most health care facilities, elevators do not represent a large portion of total load. For preliminary design of the distribution system in buildings of up to 12 stories, assuming vertical speeds up to 450 ft/min, 4500 lb capacity, the following estimates may be use:

Electric traction elevators, each: 40 hp to 75 hp

Hydraulic elevators, each: 35 hp to 50 hp

Hydraulic elevators ordinarily will not be used in buildings higher than seven stories and speeds usually will be limited to 150 ft/min. However, capacities may be higher than 4500 lb. Actual loads should be obtained from the elevator vendor once vertical transportation requirements have been defined sufficiently to permit calculation.

The NEC contains demand factors that may be assigned to feeders serving groups of elevator loads, and the engineer should be certain to take advantage of them. Similarly, some, but not all, of the elevators may be required to be on the emergency generator. Codes usually required one elevator per bank to be on generators. Hospital engineers should verify the requirements of their local AHJ, as well as the needs of the owner, and size the emergency system components appropriately.

Escalators are not installed frequently in health care facilities, but may be employed in a few buildings. For initial estimates, escalator load will be approximately 25 hp for each landing served above the lowest landing served.

Horizontal and vertical transportation systems for food, supplies, and materials using automated trolleys or carts are found in a few large health care facilities. Pneumatic tube systems are more common and may be used as the sole means of transport of small supplies and paper records or as one component in a materials handling system. Automated trolleys or carts impose relatively small loads (less than 10 hp) at numerous locations but will usually be combined with dedicated elevators whose loads will be similar to a service elevator. Pneumatic tube systems are powered by vacuum pumps or exhausters located in a few central locations. Motor drives will vary depending on the extent of the system but are under 10 hp (many are less than 3 hp).

2.3.2.4 Functional equipment

Equipment of this type usual consists of numerous small loads except that used in the kitchen and some office copiers. The effect on the electrical system is to require panel space and multiple branch circuits but low load density.

The type of kitchen (full kitchen or cook-chill) and the fuel in the kitchen is the major determinant of loads for the kitchen. If natural gas is the primary fuel, electrical loads will be lower on a watts per square foot basis than where electricity is the primary fuel. Preliminary planning should address this question early. For estimating purposes, the following factors may be used in calculating kitchen floor area include cooking and preparation, dishwashing, storage, walk-in refrigerator/freezer, food serving lines, tray assembly, and offices.

Primary fuel	W/ft ²
Natural gas	25
Electricity	125

Data processing equipment is now used in most areas of the hospital. Generally, centralized equipment for these systems will occupy one or more rooms with satellite rooms distributed throughout the building. The centralized room will often have an equipment load of between 50 W/ft² and 100 W/ft², while the satellite telecom rooms will have loads of between 1 kW and 2 kW. However, the engineer should work closely with the information technology (IT) and telephony staff to determine power requirements for these spaces. Often they will need uninterruptible power supply (UPS) backup in addition to the emergency power system available from the generators. The facility may want to have a single UPS located in or near the central room with feeders to the satellite telecom rooms, or they may have small UPSs scattered through all of the spaces. Again, the engineer needs to work closely with the IT and telephony staff for the hospital to determine the optimal mix of UPS distribution.

For individual workstations, the nameplate data for the equipment can be 1 kW to 2 kW per workstation. In practice, however, the stations rarely draw that kind of load, especially on a consistent basis. Printers, however, can reach their stated connected load, and circuits to feeders should be sized for the connected loads. Again, however, as more and more of these devices are grouped together, a higher and higher diversity factor will apply, as all of these devices have various kinds of internal power saving devices, and not all will ever be operating at full capacity at one time.

2.3.2.5 Medical equipment

Types of medical equipment used in the various departments of health care facilities are discussed in Chapter 8.

Power distribution systems serving multiple x-ray machines require special attention. Designers should always be guided by the specific data furnished by vendors supplying equipment for the specific facility. However, an excellent planning guide is available as a

National Electrical Manufacturers Association (NEMA) standard (NEMA XR 9) and should be consulted.

Quality of voltage supplied is important to x-ray installations. Again, service as direct as possible from the source is desirable. Minimum transient disturbance and voltage drop are essential.

Note that most x-ray machines have two load ratings: continuous and momentary. The continuous load is usually small and poses little problem for either source—utility or standby generator. The momentary demand, however, can be a problem for a standby generator, especially a large x-ray machine served by a small generator. Since x-ray machines have a high power factor, a real power load is imposed on the generator. The effect of this should be evaluated in sizing the generator set.

While momentary demand of x-ray installations will figure prominently in feeder and distribution equipment sizing, it need not be considered in calculating overall power demand imposed on the utility source, provided it is a part of a moderate size system. If the system requires 750 kVA or more, the momentary nature of x-ray operation will not add measurably to the overall demand. For small systems and for additions to existing facilities where service equipment is near capacity, some provision for x-ray demand may be advisable.

Clinical laboratories in hospitals require numerous branch circuits to serve the multitude of electrical devices, but load density is usually low and individual equipment loads are low, most under 1 kVA. A few pieces of equipment in laboratories today perform multiple specialized tests. The loads for these will range between 3 kVA and 8 kVA each. These same items often are sensitive to transient conditions on the power system and may require locally applied surge arrestors.

2.3.3 Building service

As discussed many times within this chapter, the more loads that are on a feeder, the more diversity in loads that feeder will benefit from. Since the building service is the feeder in the building that combines all of the loads together, it is the feeder that will have the greatest difference between its connected load, its calculated demand load, and its actual demand load. Again, however, the engineer designing a hospital should not necessarily design the service to the minimum size to meet the probable maximum demand. Rather, the engineer should apply restrictions of the AHJ, of the serving utility, and should consider needs for future expansion and/or spare capacity in sizing the service.

Table 2-5 presents the actual peak service entrance demand per gross square foot for a group of health care facilities operated by the VA. The tables in Annex 2A show similar, related data for more hospitals.

**Table 2-5—Service entrance peak demand
(Hospital Corporation of America)**

Hospital and location	Floor area (ft ²)	Beds ^a	Degree days ^b		Principal ^c fuel	W/ft ² ^d
			Cooling	Heating		Maximum
#1 East	273 000	458	1353	3939	NG/FO	6.8
#2 Southeast	278 000	250	2294	2240	NG/FO	6.3
#3 Central	123 000	157	—	—	NG/FO	7.5
#4 Central	36 365	62	2029	3227 ^e	E	13.7
#5 Central	318 000	300	1107	4306	NG/FO	4.6
#6 Southeast	182 000	225	3786	299 ^e	NG/FO	5.3
#7 East	283 523	320	1030	4307	NG/FO	6.8
#8 Southwest	135 396	150	2250	2621 ^e	NG/FO	6.6
#9 West	190 000	97	927	5983	NG/FO	2.8
#10 Southeast	161 000	170	3226	733 ^e	NG/FO	6.3
#11 Southeast	157 639	214	2078	2146	NG/FO	7.3
#12 Southeast	162 187	222	2143	2378 ^e	NG/FO	4.3
#13 East	109 617	146	1030	4307 ^e	NG/FO	5.7
#14 East	76 000	153	1030	4307 ^e	E	8.8
#15 Southeast	135 150	190	1995	2547 ^e	NG/FO	5.9
#16 Southwest	75 769	131	2587	2382 ^e	NG/FO	7.4
#17 Central	75 769	128	1636	3505 ^e	NG/FO	6.3
#18 Northwest	129 000	150	714	5833 ^e	NG/FO	4.4
#19 Central	54 938	108	1694	3696 ^e	E	13.3
#20 West	144 000	160	2814	1752	NG/FO	4.5
#21 Southeast	149 000	123	2078	2146 ^e	NG/FO	4.5
#22 Central	89 000	128	2029	3227 ^e	E	8.4
#23 Central	128 500	150	1197	4729 ^e	NG/FO	6.2
#24 West	135 169	170	927	5983 ^e	NG/FO	4.7
#25 Southeast	80 000	124	1722	2975 ^e	NG/FO	6.2
#26 Southeast	83 117	126	3226	733 ^e	NG/FO	8.5

**Table 2-5—Service entrance peak demand
(Hospital Corporation of America) (continued)**

Hospital and location	Floor area (ft ²)	Beds ^a	Degree days ^b		Principal fuel ^c	W/ft ² ^d
			Cooling	Heating		Maximum
#27 Central	51 000	97	1569	3478	NG/FO	8.8
#28 Southeast	66 528	120	2929	902 ^e	E	9.7
#29 East	112 000	140	1394	3514	E	4.3
#30 Central	202 000	223	1636	3505	NG/FO	4.8
#31 Southeast	56 000	51	3786	299 ^e	NG/FO	7.4
#32 West	47 434	50	927	5983 ^e	NG/FO	7.0
#33 Central	23 835	32	1694	3696 ^e	E	10.8
#34 Southeast	105 000	95	2706	1465 ^e	NG/FO	8.3
#35 West	48 575	60	3042	108 ^e	NG/FO	7.7
#36 Southwest	130 000	185	2587	2382 ^e	NG/FO	6.3
#37 Central	42 879	66	1694	3696 ^e	E	15.7

^aTotal beds shown. Beds actually occupied could affect values shown for watts per square foot.

^bDegree days: Normals, base 65 °F, based on 1941–1970 period. From *Local Climatological Data Series*, 1974, NOAA.

^cNG/FO = Natural gas/fuel oil. Principal fuel is defined as that used for heating. In all cases, electricity was the fuel used for refrigeration.

^dWatts per square foot (W/ft²) based on measured values at service entrance during metering periods ranging from 9 days to 17 days, during cooling season in all instances, 1981.

^eData shown for nearest recorded location.
(Each facility was self-contained in that refrigeration and air-conditioning equipment loads are included in the power demands shown.)

Table 2-5 shows the type of facility, the gross floor area and number of beds for each, the geographic location, and the major fuel type employed for HVAC&R systems in that facility. The derived factors may be used to estimate the anticipated demand for other facilities similar in size, location, and type of fuel. They also may be used to make initial estimates of service entrance capacity, switchgear size, and space required for service entrance equipment. It is important to recognize, however, that they will be useful principally in the schematic design phase. As design proceeds through the preliminary and working drawing phases, these initial estimates should be modified by the actual conditions prevalent in the project.

Table 2-6, Table 2-7, and Table 2-8 present operating load data for large general medical and surgical hospitals. This data is useful for visualizing changes in demand over time for a typical operating hospital.

Table 2-6—Kaiser service entrance peak demand table (1998–2001)^a

Location in California	Gross ft ²	Peak demand, 1998–2001	
		kW	W/ft ²
Vallejo	217 839	1935	8.88
Richmond	95 100	762	8.01
South San Francisco	114 436	1295	11.32
Santa Clara	385 790	1632	4.23
San Jose	226 041	1352	5.98
South Sacramento	214 253	1896	8.85
Sacramento	309 499	2380	7.69
Roseville	282 016	2350	8.33
Walnut Creek	345 420	3109	9.00

^aReprinted with permission from Kaiser Foundation Health Plan Inc.

Table 2-7—John Muir Medical Center load monthly electricity and natural gas load profiles (1999–2002)^a

Electrical date	Total usage (kWh)	Billing demand (kW)	Kitchen therms	Therms (gas Phase 1, 2)	Therms (gas Phase 3)	Gas date
09/22/1999	1 002 310	2230	674	n/a	n/a	09/23/1999
10/22/1999	1 022 602	2036	641	n/a	n/a	10/22/1999
11/22/1999	889 308	1964	655	n/a	n/a	11/22/1999
12/23/1999	818 478	1706	695	n/a	n/a	12/23/1999
01/25/2000	852 457	1652	722	n/a	n/a	01/25/2000
02/24/2000	768 893	1636	650	n/a	n/a	02/24/2000
03/24/2000	778 081	1922	631	n/a	n/a	03/24/2000
04/24/2000	879 066	1958	653	n/a	n/a	04/24/2000
05/24/2000	909 490	2282	630	n/a	n/a	05/24/2000
06/23/2000	985 176	2066	634	n/a	n/a	06/23/2000
07/25/2000	1 001 813	2006	660	n/a	n/a	07/25/2000

Table 2-7—John Muir Medical Center load monthly electricity and natural gas load profiles (1999–2002)^a (continued)

Electrical date	Total usage (kWh)	Billing demand (kW)	Kitchen therms	Therms (gas Phase 1, 2)	Therms (gas Phase 3)	Gas date
08/23/2000	1 011 026	2090	613	n/a	n/a	08/23/2000
09/22/2000	990 350	2220	620	n/a	n/a	09/22/2000
10/23/2000	912 312	2034	603	n/a	n/a	10/23/2000
11/21/2000	742 564	1818	542	n/a	n/a	11/20/2000
12/21/2000	738 274	1592	596	n/a	n/a	12/21/2000
01/31/2001	203 271	1324	653	n/a	n/a	01/23/2001
02/22/2001	479 597	1594	621	n/a	n/a	02/22/2001
03/23/2001	725 136	1862	563	n/a	n/a	03/23/2001
04/23/2001	790 280	1886	616	n/a	n/a	04/23/2001
05/01/2001	219 157	1870		n/a	n/a	
05/31/2001	967 004	2176	620	n/a	n/a	05/24/2001
06/30/2001	989 319	2174	641	n/a	n/a	06/25/2001
07/31/2001	988 818	2214	606	n/a	n/a	07/25/2001
08/31/2001	967 829	2118	575	51 094	80 709	08/22/2001
09/30/2001	909 671	1930	594	16 075	17 983	09/21/2001
10/31/2001	908 626	1966	645	16 208	21 253	10/23/2001
11/30/2001	800 611	1692	587	16 244	20 260	11/20/2001
12/31/2001	791 935	1540	615	12 693	37 663	12/21/2001
01/31/2002	758 936	1434	635	16 060	40 462	01/23/2002
02/28/2002	717 829	1696	606	14 549	34 653	02/22/2002
03/31/2002	841 221	1666	669	15 433	36 779	03/26/2002
04/30/2002	791 240	1910	643	32 856	8 289	04/25/2002
05/31/2002	909 730	2064	619	72 562		05/23/2002
06/30/2002	980 269	2040	704		2 850	06/24/2002
07/31/2002	1 066 598	2046	666	66 221	20	07/24/2002
08/31/2002	1 086 967	2046	603	33 718		08/22/2002

^aReprinted with permission from John Muir Medical Center.

2.3.4 Campus distribution system

The various feeders on a campus may serve one or more buildings. The engineer designing a campus type system will be operating more like a utility engineer than a building engineer. In this case, the engineer needs to understand the actual peak loads of the various buildings being served, as well as the load profiles of each type of building. The engineer should consider all of the load profiles, together with the system topology and needs for redundancy and expansion, to size components for the system. Table 2-8 gives some typical peak load data for several kinds of buildings on a typical hospital campus, which, combined with the load profiles given in the other tables, can provide a good starting point for such an analysis.

Annex 2A describes loads recorded at an urban hospital in California. The campus consists of a large hospital, an MOB, a cancer center with two linear accelerators, and a central plant. The central plant W/ft^2 loads given in the annex uses the square foot for the total of the three buildings. The profiles given show how loads are divided between different kinds of buildings, as well as how the loads are divided between the central plant and the other loads within a hospital.

Table 2-8—Emergency generator peak loading

Facility	Gross ft^2	Emergency capacity (kW)	EP dem (kW)	EP capac (W/ft^2)	EP dem (W/ft^2)	Norm dem (kW)	Norm dem (W/ft^2)
#1 SF Bay Area	156 000	550	499	3.53	3.20		
#2 LA Basin	150 000	500	83	3.33	0.55		
#3 Orange County CA	407 000	1250	850	3.07	2.09		
#4 Arkansas	173 000	900	390	5.20	2.25	1120	6.47
#5 San Louis Obispo County CA	646 000	1800	1300	2.79	2.01		
#6 Kern County CA	390 000	3600	600	9.23	1.54		
#7 LA Basin	43 500	250	94	5.75	2.16		
#8 LA Basin	29 600	250	36	8.45	1.22		
#9 LA Basin	14 529	145	36	9.98	2.48		
#10 Tulare County	50 000	350	60	7.00	1.20		
#11 Butte County	120 000	400	100	3.33	0.83		

Table 2-8—Emergency generator peak loading (*continued*)

Facility	Gross ft ²	Emer- gency capacity (kW)	EP dem (kW)	EP capac (W/ ft ²)	EP dem (W/ft ²)	Norm dem (kW)	Norm dem (W/ft ²)
#12 SF Bay Area	210 000	1100	435	5.24	2.07	1,638	7.80
#13 Northern CA	254 000	1700	1650	6.69	6.50		
#14 Florida	130 000	600	324	4.62	2.49	790	6.08
#15 Central CA	117 380	670	287	5.71	2.45		
#16 SF Bay Area	114 000	600	320	5.26	2.81		
#17 Santa Cruz County	240 000	1500	932	6.25	3.88		
#18 Florida	265 000	800	490	3.02	1.85	1644	6.20
#19 Central CA	500 000	3500	100%	7.00	n/a	2800	5.60
#20 Humboldt County	90 000	500	360	5.56	4.00		
#21 LA Basin	900 000	1730	1040	1.92	1.16		
#22 Central CA	42 699	135	36	3.16	0.84		
#23 SF Bay Area	400 000	2210	1400	5.53	3.50	2340	5.85
#24 San Diego County	849 722	1800	420	2.12	0.49	1850	2.18
#25 LA Basin	200 000	420	186	2.10	0.93	960	4.80
#26 LA Basin	118 000	600	240	5.08	2.03		
#27 San Diego County	99 000	425	120	4.29	1.21	592	5.98
#28 SF Bay Area	112 000	350	200	3.13	1.79	692	6.18
#29 Orange County CA	550 000	2400	2000	4.36	3.64		
#30 LA Basin	212 000	800	675	3.77	3.18	1660	7.83
#31 Central CA	422 097	2900	1000	6.87	2.37		
#32 SF Bay Area	344 251	2650	815	7.70	2.37		

Table 2-8—Emergency generator peak loading (*continued*)

Facility	Gross ft ²	Emer- gency capacity (kW)	EP dem (kW)	EP capac (W/ ft ²)	EP dem (W/ft ²)	Norm dem (kW)	Norm dem (W/ft ²)
#33 SF Bay Area	303 872	850	600	2.80	1.97	1856	6.11
#34 SF Bay Area	387 000	1000	482	2.58	1.25	1632	4.22
#35 Sonoma County CA	165 000	1200	350	7.27	2.12	540	3.27
#36 SF Bay Area	227 913	1050	512	4.61	2.25	1352	5.93
#37 Central CA	385 200	2000	400	5.19	1.04	1270	3.30
#38 Kern County	45 867	250	166	5.45	3.62		
#39 Humboldt County	70 000	230	67	3.29	0.96		
#40 Orange County	240 000	830	316	3.46	1.32		
#41 Central CA	415 000	1200	400	2.89	0.96		
#42 Central CA	50 000	300	240	6.00	4.80		
#43 LA Basin	1 200 000	2175	1056	1.81	0.88		
#44 SF Bay Area	102 200	300	120	2.94	1.17	507	4.96
#45 SF Bay Area	325 000	810	460	2.49	1.42	991	3.05
#46 LA Basin	500 000	1500	500	3.00	1.00		
#47 LA Basin	22 326	115	72	5.15	3.22		
#48 SF Bay Area	48 000	315	75	6.56	1.56		
#49 Stanislaus County	38 000	229	87	6.03	2.29		
#50 Butte County	175 000	350	249	2.00	1.42		
#51 Napa County	299 000	1300	700	4.35	2.34		
#52 LA Basin	281 000	800	332	2.85	1.18	1400	4.98

Table 2-8—Emergency generator peak loading (continued)

Facility	Gross ft ²	Emer- gency capacity (kW)	EP dem (kW)	EP capac (W/ ft ²)	EP dem (W/ft ²)	Norm dem (kW)	Norm dem (W/ft ²)
#53 San Bernar- dino County	110 000	500	281	4.55	2.55		
#54	340 000	2657	1727	7.81	5.08		
#55 SF Bay Area	617 400	4000	1200	6.48	1.94		
#56 Riverside County	74 000	575	154	7.77	2.08		
#57 Central CA	133 289	700	241	5.25	1.81		
#58 Sonoma County	261 797	1500	1014	5.73	3.87	1651	6.31
#59 Fresno County	64 500	150	42	2.33	0.65		
#60 San Diego County	232 282	2050	800	8.83	3.44	1350	5.81
#61 San Diego County	205 250	1200	360	5.85	1.75	1000	4.87
#62 San Diego County	794 394	3000	1450	3.78	1.83	3030	3.81
#63 Riverside County	66 296	1225	333	18.48	5.02	583	8.79
#64 Siskiyou County	41 000	250	72	6.10	1.76		
#65 Humboldt County	130 000	450	113	3.46	0.87		
#66 Santa Cruz County	38 600	175	86	4.53	2.23		
#67 Florida	900 000	3000	2573	3.33	2.86	4594	5.10
#68 LA Basin	50 000	330	81	6.60	1.62		
#69 LA Basin	275 000	225	153	0.82	0.56		
#70 Central CA	185 000	625	335	3.38	1.81		
#71 Central CA	500 000	1800	600	3.60	1.20		
#72 Tulare County	70 000	90	36	1.29	0.51		

Table 2-8—Emergency generator peak loading (continued)

Facility	Gross ft ²	Emer- gency capacity (kW)	EP dem (kW)	EP capac (W/ ft ²)	EP dem (W/ft ²)	Norm dem (kW)	Norm dem (W/ft ²)
#73 SF Bay Area	250 000	1500	665	6.00	2.66		
#74 Monterey County	169 000	1050	332	6.21	1.96		
Minimum	14 529	90	36	0.82	0.49	507	2.18
Average	258 621	1098	504	4.92	2.11	1514	5.42
Maximum	1 200 000	4000	2573	18.48	6.50	4594	8.79

2.3.5 Standby power source(s)

Sizing for standby power system elements is more like sizing for building services than for sizing of components of the internal distribution system. Most of the feeder sizing rules given in the NEC are written so as to minimize damage to cables due to overheating of insulation, and these considerations have nothing to do with sizing emergency generators. Indeed, the most recent versions of both the NEC and NFPA 99 have included provisions within them noting that hospital emergency generators should be sized based on prudent historical demand factors, and should not be sized based on the feeder sizing procedures (see Nash [B25]).

In fact, it is extremely important to size the generators accurately, and not to the sizes dictated by the feeder calculation procedures. Because these explicit demand factors do not take into account the system diversity, slavish application of them will usually result in generators that are sized significantly larger than the actual loads the generators are intended to serve. In many cases, generators so sized are capable of carrying more than the entire maximum peak demand for the hospital. See Table 2-10 for benchmark data regarding appropriate sizing of hospital emergency generators.

Table 2-9—Energy consumption comparison—Natural gas consumption

Year	Facility	Location	Remarks	ft ²	Natural gas				
					Total \$	\$/ft ²	Therms	Therms/ ft ²	\$/ therm
2002	Kaiser Average	Nationwide	Includes MOBs and hospitals and others	51 764 071	15 953 734	0.31	26 703 083	0.52	0.65
2001	Sutter General Hospital & MOB	Sacramento, CA		600 642		0.00		0.00	
2001	Sutter General Radiation Oncology	Sacramento, CA		22 000		0.00		0.00	
2002	Sutter General Radiation Oncology	Sacramento, CA		22 000		0.00			
2002	Sutter General Hospital & MOB	Sacramento, CA		600 642		0.00			
2002	John Muir Medical Center	Walnut Creek, CA	Includes kitchen gas	368 000		0.00	540 417	1.47	0.00
2001	John Muir Medical Center	Walnut Creek, CA	Includes kitchen gas	368 000		0.00		0.00	
2001	John Muir Medical Center	Walnut Creek, CA	Includes kitchen gas	368 000		0.00		0.00	

Table 2-9—Energy consumption comparison—Natural gas consumption (continued)

Year	Facility	Location	Remarks	ft ²	Natural gas				
					Total \$	\$/ft ²	Therms	Therms/ ft ²	\$/ therm
2001	John Muir Medical Center	Walnut Creek, CA	Includes kitchen gas	368 000		0.00		0.00	
2000	Mt. Diablo Medical Center	Concord, CA	Includes kitchen gas	403 000	58 243	0.14	467 835	1.16	0.12
2001	Mt. Diablo Medical Center	Concord, CA	Includes kitchen gas	403 000	280 093	0.70	644 295	1.60	0.43
2000	MDMC Behavioral Health	Concord, CA		40 000	20 037	0.50	26 688	0.67	0.75
2001	MDMC Behavioral Health	Concord, CA		40 000	20 914	0.52	18 092	0.45	1.16
1994	St. Luke's Medical Center	Phoenix, AZ		497 049		0.00		0.00	
1995	St. Luke's Medical Center	Phoenix, AZ		497 049		0.00		0.00	
1996	St. Luke's Medical Center	Phoenix, AZ		497 049		0.00		0.00	
1997	St. Luke's Medical Center	Phoenix, AZ		497 049		0.00		0.00	
1998	St. Luke's Medical Center	Phoenix, AZ		497 049		0.00		0.00	
1999	Jordan Valley Hospital	Salt Lake City, UT		109 000		0.00		0.00	
1998	Jordan Valley Hospital	Salt Lake City, UT		109 000		0.00		0.00	

2.4 Using load data to manage energy costs

One of the two fundamental purposes for understanding electrical load data is to allow the hospital engineer to better manage costs. Engineers have two opportunities for managing these costs: first, during the design of the facility, and second, in managing that plant over time. Since the 1970s, Americans have paid increasing attention to energy costs and demand (see Joskow [B21]). Voluminous literature now lines the shelves about energy technology alternatives (see Association of Energy Engineers [B4]). IEEE Std 739TM (*IEEE Bronze Book*TM) also includes recommendations for energy management and conservation.

This portion of this chapter will not attempt to recreate this mass of data. Instead, it lays out a framework for approaching the problem of crafting an energy strategy, noting significant areas for possible study in crafting that strategy, as well as unique challenges and opportunities posed by health care facilities. This approach to energy strategy applies equally to the engineer designing a new facility and to the engineer trying to maintain and/or improve upon an existing set of systems.

2.4.1 Introduction to energy strategy

The approach to an energy strategy for any building or facility is comprised of three elements. First, the engineer should look at strategies for obtaining energy supplies. Here, the engineer should consider the mix of fuels to be selected, the methods for purchasing the fuels, the degree to which systems should be designed based on a particular selection of fuels and fuel prices, and the degree to which to design into the strategy the ability to switch between fuels, or to shift the consumption of a fuel during peak pricing periods. See Figure 2-1 and Figure 2-2.

Once a fuel acquisition strategy has been determined, the engineer needs to focus on the central utility plant (here, the term central utility plant is being used to encompass both a conventional central plant as well as the set of primary energy generation/conversion/transformation/distribution elements within a building). In addition, engineers should consider various demand reduction strategies available. The process of selecting between strategies at the generation/conversion level as opposed to the demand reduction level should be somewhat iterative, as decisions in one arena may affect decisions in the other. In general, gains made in demand reductions tend to be more “profitable” over the long run than gains made in the generation/conversion realm—that is, not consuming a watt is more cost effective than more efficient, cost-effective production of the energy to fuel a watt.

2.4.2 Energy codes and standards

Energy codes and regulations increasingly impact health care systems. A uniform standard for energy utilization in various types of facilities does not exist. Unless and until one does, engineers should consult and adhere to legally adopted codes in the jurisdiction where the facility will be constructed. Most health care operators will also want a facility with the lowest possible energy consumption or at least the lowest possible energy cost consistent with that owner’s life-cycle-cost goals.

For years, California's Title 24 Energy Regulations have exempted hospitals, but the pressure continues to grow for that state to expand its coverage to include hospitals. Currently, California Title 24 does not apply to UBC Groups I and U (hospitals, nursing homes, etc.). It does apply to UBC Groups A, B, E, F, H, M, R (limited), and S. This means that some clinics and doctors offices may be subject to Title 24 requirements. The new nonresidential standards went into effect on June 1, 2001.

The DOE has recently ruled that every state must meet or exceed the ASHRAE/IESNA 90.1 regulations, and these regulations do apply to hospitals. The applicable edition of ASHRAE/IESNA 90.1 varies depending upon state or local requirements.⁸ Any local requirements should also be verified prior to starting design.

ASHRAE/IESNA 90.1 gives minimum energy efficiency requirements for commercial building design. There are requirements for lighting densities (allowable watts per square foot) for the different occupancy types, for interior vs. exterior lighting, the number and/or types of controls required, HVAC controls, building envelope, etc. Lighting power densities (LPD) are given for various buildings and space types. For example, in the 1999 edition, the LPD for a hospital is 1.6 W/ft².

NOTE—Emergency lighting is excluded and there are some additions allowed for some uses of accent lighting in some occupancies. IESNA's Web site has models and a downloadable user's guide for working with various building/space types and the LPD per the requirements of ASHRAE/IESNA 90.1.

Another federal standard that impacts electrical designs, especially through its impact on products, is the Energy Policy Act of 1992 or EPAct. EPAct covers the various aspects of energy, from energy efficiency of buildings and products to utilities to fuel sources and more. A pertinent section is Title I—Energy Efficiency. Subtitle A covers building energy efficiency. Subtitle C covers appliance and equipment energy efficiency standards [lamps, high-intensity discharge (HID) lamps, transformers, motors, office equip, etc.]. Subtitle F focuses on federal agency energy management. While federal building energy efficiency standards may not apply to all buildings, they do apply to Veteran's Administration hospitals, as well as other military hospitals. Moreover, they influence other private hospitals, through the impacts of market transformation resulting from the products specified, particularly lamps and motors.

Federal facilities are also bound by requirements in the Code of Federal Regulations: Title 10—Energy, CFR Part 436—Federal Energy Management and Planning [B33]. Executive Order 13123 requires Federal agencies to reduce energy use in Federal buildings by 35% from 1985 levels by 2010.

In addition to federal and national energy codes like ASHRAE, the various building codes may have their own energy code. The new IBC (International Building Code) has an associated energy code, the IECC 2000 (International Energy Conservation Code). The IECC was the old Model Energy Code (MEC).

⁸ The following Web site provides a location where the status of the energy codes for each state can be checked: http://www.energycodes.gov/implement/state_codes/index.stm.

Along with codes that bear directly on construction, more and more agencies exercise indirect control over the energy decisions a health care facility should make regarding its energy strategy. Air Quality Management Districts exercise increasing control over the emissions from boilers and diesel generators. Neighbor groups, unhappy at emissions or noise, can bring political pressure to bear on nearby health care facilities. Regulations regarding the installation and operation of different kinds of equipment can drive energy system decisions (see e.g., California Title 8, section 781, requiring a full time operator for a boiler of more than 10 hp). The prudent designer will familiarize himself with the applicable energy codes, be they local, federal or state as well as other associated requirements before starting design.

2.4.3 Energy procurement considerations and strategies

2.4.3.1 Deregulation and energy market volatility⁹

Electric deregulation began in California in the spring of 1998. Since that time, California and the nation have experienced significant price volatility for both electricity and natural gas. These two energy markets differ substantially. Natural gas as a national benchmark price, though there can be substantial variations by region, depending on the geographic source of the gas and transmission constraints. Natural gas wholesale markets are more effectively regulated at the federal level, which gives a more standardized character for the gas business nationally. In contrast, electricity markets are more decidedly regional in nature. Federal regulation has so far been less effective in creating a standard set of rules for the various power pools and independent system operators (ISOs) that govern wholesale markets, and retail deregulation has been almost entirely a matter of state purview, ranging from aggressively pro-competition to no change whatsoever in the traditional cost-of-service regulatory scheme. Federal Energy Regulatory Commission (FERC) has published draft rules for a Standard Market Design (SMD), but there has been much resistance at the state level.

Despite their differences, both markets have been prone to price volatility. Gas prices on the national NYMEX exchange for next-month contracts have ranged from under \$2.00 to over \$10.00 per MMBtu. Daily spot markets have been even wilder, spiking at times over \$50.00 per MMBtu. While the worst period was winter 2000–2001, the market has continued to experience significant volatility. The National Gas Institute (NGI) reports that monthly settlement prices ranged from \$2.94 to \$9.28 in 2003.

⁹ See, generally, DOE [B34].

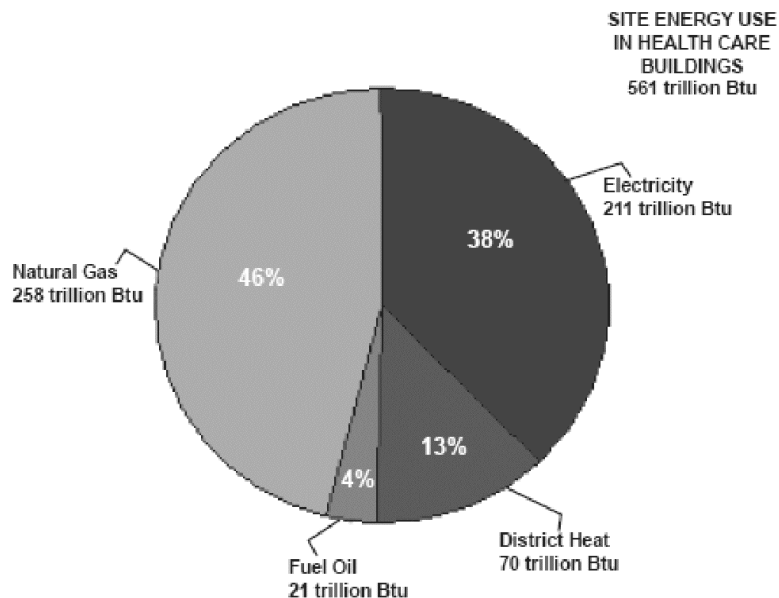


Figure 2-1—DOE Energy Information Administration, fuels consumed by health care buildings (1995)

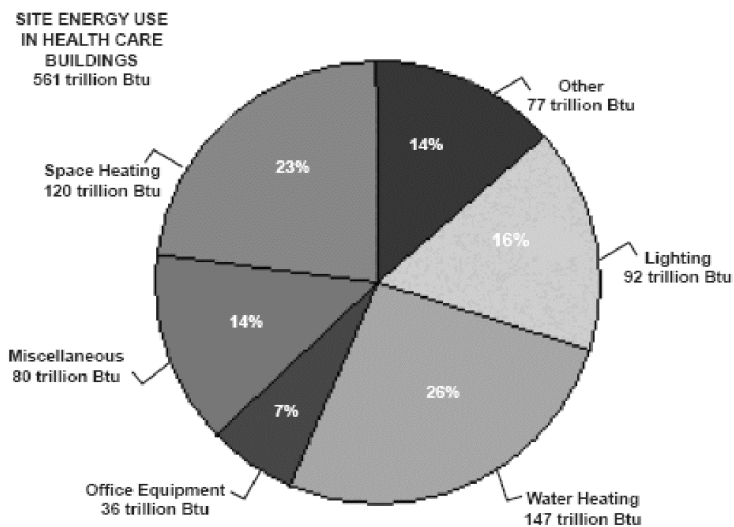


Figure 2-2—DOE Energy Information Administration, site energy use in health care buildings (consumption) (1995)

NOTE—Figure 2-2 is a national average, including all types of health care buildings and all sizes of buildings. Also, it is expressed in Btu, so some of the numbers appear to be wrong.

Electricity price volatility has been much worse and would have been especially extreme in California if a pricing mechanism could have truly balanced supply and demand there. Starting in January 2001, California experienced *rolling blackouts* because there was no effective way to match market prices to costs to consumers. Had a market-clearing price mechanism been in place, prices would have likely exceeded \$10 000 per mWh, or \$10 per kWh. Even with the blackouts, prices often exceeded \$1000 per mWh, and the State of California had to resort to extreme measures just to keep the lights on (and Californians, and California health care facilities, will be paying the bills for many years to come). See Figure 2-3 and Figure 2-4.

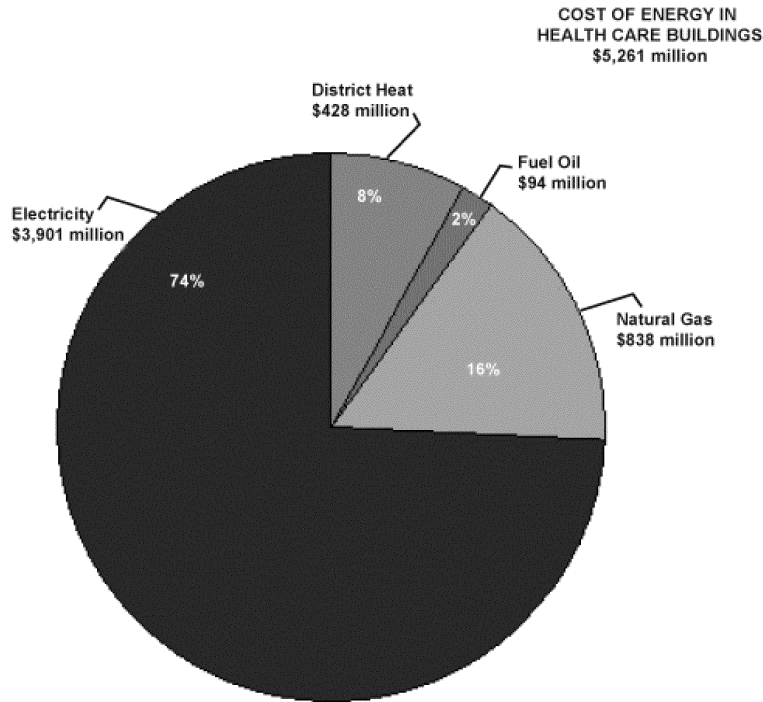


Figure 2-3—DOE Energy Information Administration, cost of energy in health care buildings table (1995)

NOTE—Figure 2-3 expresses how dollars are spent on energy streams nationally.

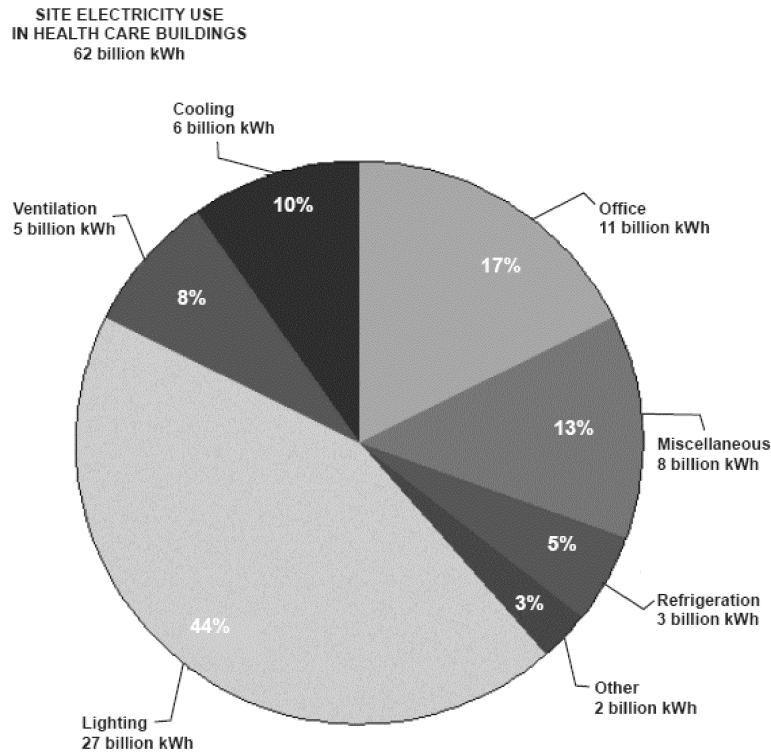


**Figure 2-4—DOE Energy Information Administration,
site electricity use in health care buildings (1995)**

NOTE—Figure 2-4 looks at how the electrical portion of the overall energy pie is consumed within the large pool of health care facilities.

Both short-term and long-term energy market dynamics pose potential troubles to health care facilities. The most immediate crisis is expected to be with regard to natural gas. Although the 2002-2003 heating season started with an adequate amount of gas storage, withdrawals were heavy because of unusually cold weather in Midwestern and Northeastern states, and because the threat of war in Iraq kept oil prices artificially high. These higher oil prices, and the potential threat to supply, kept many large dual-fuel users burning gas. See Figure 2-5 and Figure 2-6.

As a result, 2003 gas storage was at a record low. This low storage situation came at a time when North American natural gas production was low and declining. Although drilling activities have picked up, the number of active rigs in 2003 is only about 75% of the peak in 2001, and analysts predict an overall 2003 production decline of 1% to 4% relative to 2002 (which had dropped about 5% from 2001). The storage situation makes gas supply and prices extremely vulnerable to weather as well as to any disruption in the oil market.

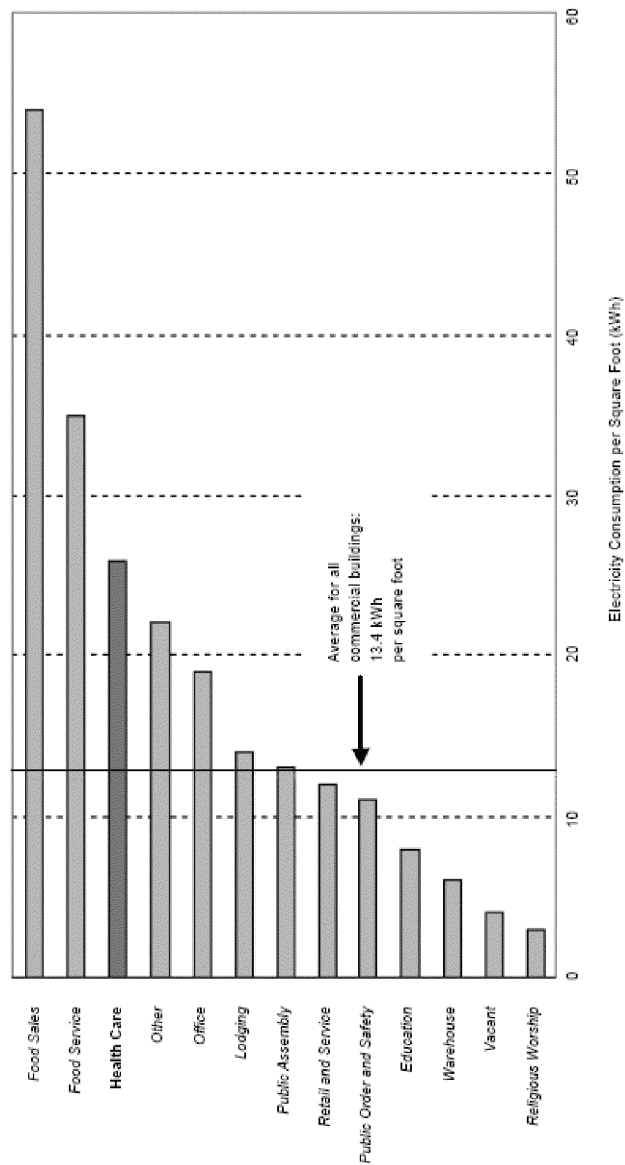


Figure 2-5—DOE Energy Information Administration, electricity intensity comparison table (1995)

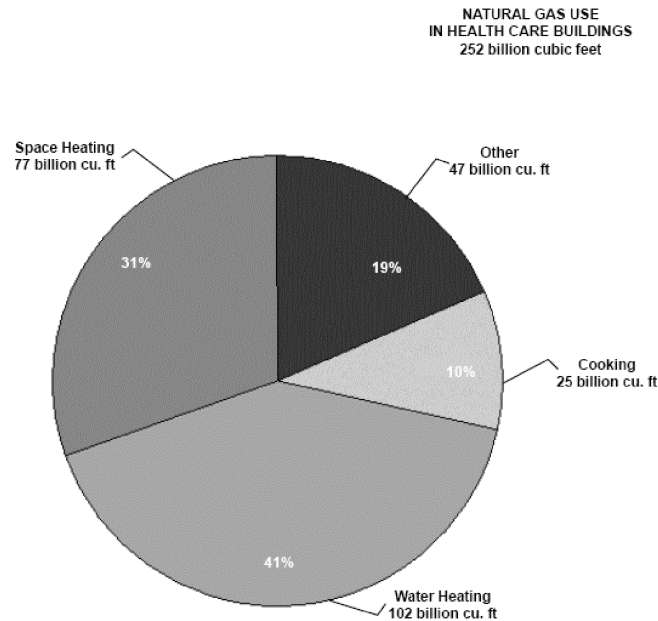


**Figure 2-6—DOE Energy Information Administration,
natural gas use in health care buildings (1995)**

Longer term, overall gas demand is expected to rise as new gas-fired power generation dominates the projected decline in industrial demand. Indeed, there had been projections of the need for an overall 20% increase in interstate pipeline capacity nationally to accommodate new power generation projects. However, due to the dismal financial condition of independent power companies, many expected power plants have been cancelled or delayed throughout the country. Nonetheless, production and transmission of gas may both grow into major concerns. To some extent, these concerns can be ameliorated by a greater role of imported liquefied natural gas (LNG), but then the gas markets will become more vulnerable to geopolitical influences, similar to oil markets.

The power plant slowdown has eased pipeline expansion needs, but poses another serious risk: lack of adequate power generating capacity. Most markets have no short-term electric capacity constraints. The California Energy Commission (CEC) projects adequate capacity for California for the early part of the decade, but it also projected a dangerously low 1% to 2% electric reserve margin by 2007.

The high degree of interrelationship between electric and gas markets could become especially problematic. New efforts at integrated electric and gas planning being conducted for the CEC have hinted at truly catastrophic scenarios in California; for example, if very low precipitation periods are linked with high electric and gas demand periods. Low precipitation means less available hydropower, which in California would be replaced by gas-fired generation. High demand for gas and power, during either a

heating or cooling system could then lead to gas supply interruptions for power generators, who stand lower in priority than residential and other gas consumers. The effects of these kinds of disruptions will be felt by consumers across the country.

One final factor that will influence energy events in the future is the state of the electrical distribution grid. The grid is aging and capacity constrained (see *The Business Week Fifty* [B32]). This limitation may limit the availability of sufficient power to various areas; may require investments into transmission infrastructure that will result in further price hikes; and/or may create more incentives for distributed power generation to ease congestion on the constricted grid.

Given the many varied and complicating factors driving the energy markets, hospital engineers need to have as many tools at their disposal as possible to be able to keep their overall energy costs under control.

2.4.3.2 Utility rate structures and billing

An engineer should understand the options for purchasing energy commodities and should both design his facility to take best advantage of current rate structures and to provide sufficient flexibility to react to changes in those rate structures. Health care facilities consume electricity, natural gas, some district heat, some diesel (see Figure 2-1 and Figure 2-3). While electrical engineers mostly need to understand the pricing of the electrical energy to be consumed by the facility, an electrical system is still only part of an overall energy consumption and delivery machine. Thus, the electrical engineer should understand, in at least a basic way, the energy options available to the hospital, the relative pricing structures of the various fuels, and the likely trends in pricing and supply in the future in order to design a system that makes most economical use of the available energy supplies. See Table 2-10.

Each state has a public utilities commission that regulates the investor-owned utilities in the state. Other, municipally owned utilities are not regulated by the states, but by the federal government, through the FERC.

The electrical engineer should contact the electric utility supplying service early in the design. Late utility negotiations may result in increased costs and delays in service. A complete discussion of service, metering, and billing is always in order, no matter how preliminary. These negotiations should provide sufficient time for the consideration of various proposals and the selection of the one best suited to a given application.

Electrical rate structures come in many different forms. Rate structures generally distinguish between customers of different sizes, giving lower rates to larger customers. Some hospitals have been known to artificially increase their peak demand once per year in order to obtain a better pricing structure for the local utility. Rate schedules often vary based on the voltage supplied to the customer. Larger facilities, such as medical center campuses, then may elect to take a higher supply voltage and to own their transformer rather than shifting ownership of it to the utility, in exchange for better rates. Engineering staff for health care institutions tends to be more expert than the engineering staffs for other kinds of buildings, making it more feasible for them to employ such strategies.

Table 2-10—DOE projected electricity price increases to 2020

Year	Projected electricity prices, cents/kWh			Projected NG prices, \$/1000 ft ³		
	Low growth	Ref. case	High growth	Low growth	Ref. case	High growth
2004	6.9	7.0	7.0	6.12	6.20	6.28
2005	6.8	6.9	7.0	6.10	6.16	6.27
2006	6.6	6.7	6.9	6.04	6.12	6.25
2007	6.5	6.6	6.9	6.09	6.19	6.31
2008	6.5	6.6	6.9	6.19	6.31	6.51
2009	6.6	6.7	7.0	6.31	6.42	6.68
2010	6.5	6.7	7.1	6.43	6.56	6.88
2011	6.5	6.8	7.1	6.46	6.62	6.97
2012	6.5	6.8	7.1	6.49	6.69	7.03
2013	6.6	6.8	7.2	6.53	6.73	7.07
2014	6.6	6.9	7.2	6.53	6.79	7.08
2015	6.6	6.9	7.2	6.50	6.83	7.01
2016	6.7	7.0	7.2	6.56	6.87	7.04
2017	6.7	7.0	7.3	6.61	6.86	7.13
2018	6.7	7.1	7.3	6.63	6.83	7.01
2019	6.8	7.1	7.3	6.68	6.84	6.84
2020	6.9	7.2	7.3	6.82	6.94	6.88
2021	6.9	7.1	7.4	6.98	6.92	7.00
2022	7.0	7.2	7.5	7.11	6.97	7.16
2023	7.0	7.2	7.5	7.25	7.05	7.26
2024	7.1	7.3	7.7	7.26	7.15	7.48
2025	7.0	7.3	7.8	7.18	7.22	7.79

Many rate structures separate demand (maximum kilowatts over a period of time) and usage (total kilowatthours consumed over the period of time). That is, the demand charges measures the greatest rate at which the facility consumes energy while the energy charge measures the total energy consumed. In such instances, strategies to control the peak may be beneficial. Finally, many utilities have time of use rate structure, in which the cost of the electricity varies with the season and with the time of day. Hospital engineers in these situations will want to look for ways to lower their peaks during the more expensive times of day and times of the year; something that will probably require fuel switching or thermal- or other time-shifting strategies, since the usage of hospitals and other health care buildings closely approximates that of other commercial users, such that the peak consumption comes at the peak pricing periods and the minimum consumption occurs during the minimum pricing period. (See Annex 2A for typical load profiles for typical hospitals both over the course of a year, and Annex 2B, for over the course of a day).

Each electric utility has a series of rate schedules for supplying power to customers under various conditions. Engineers should compare the various options available to arrive at the most economic choice for obtaining power. The following factors form the basis for establishing and evaluating most rate structures:

- a) Maximum demand in kilowatts or kilovoltamperes
- b) Energy consumption in kilowatthours
- c) Adjustment for low power factor
- d) Voltages available
- e) Transformer or substation ownership
- f) Utility fuel cost adjustments
- g) Demand interval
- h) Minimum bill stipulations, including ratchet clauses
- i) Multiple-metering provisions
- j) Auxiliary or standby service charges
- k) Seasonal and time-of-day service rates
- l) Prompt payment savings
- m) Provisions for off-peak loads and interruptible loads
- n) Load factor

Since the oil embargo of 1973, and as a direct result of the National Energy Act of 1978, electric utilities have introduced *rate reform*. Essentially, rate reform usually incorporates various forms of the following:

- 1) Inverted rates
- 2) Flat rates
- 3) Lifeline rates
- 4) Marginal cost pricing
- 5) Long-run incremental costing
- 6) Construction work in progress

- 7) Interruptible rates
- 8) Time-of-day pricing
- 9) Reduction in the number of declining blocks
- 10) Modifications of utility fuel cost adjustments
- 11) Deletion of electric discounts

One option often desired by hospitals is obtaining two feeds from the utility company, to increase the reliability of service. Increasingly, utilities are reluctant to provide these dual feeds without considerable payment, usually in the form of “special facilities charges,” whose amounts make the second feeder unattractive

2.4.3.2.1 Metering

Some common metering arrangements are as follows:

- a) *Metering by type of premises:* Availability of a particular kind of metering and billing often depends upon the type of building and load. The utility will usually meter a single-occupancy building, such as a hospital, with a watthour demand meter. Should multiple services be required, and should they be permitted by the electric utility, owners may totalize watthour demand meter readings to take advantage of lower rates. Some medical centers may benefit from separately metering portions of the buildings, such as physicians’ offices, separately owned pharmacies, or other concessionaires lease space within the project. Be sure to coordinate such installations with the respective utility company.
- b) *Metering by service-voltage characteristics:* Metering of the incoming service may be located on the high-voltage or the low-voltage side of the transformer, depending on the terms of the contract with the electric utility. When the meter is on the primary side, the transformer losses will be charged to the customer. In some cases, the customer is given a discount to offset this loss. When metering is on the secondary side of the transformer, utilities may add 1% to 2% to the bill for transformer losses or may install a device to increase the meter indication to account for transformer losses.
- c) *Meter location:* Subject to agreement with the utility, the meter may be installed indoors at the customer’s secondary distribution point, in a suitable meter room, or in a separate control building that may also house primary switchgear and associated controls. Outdoor installations include pole, exterior wall, and pad mounting. In general, utilities will require accessibility for meter readings and maintenance, and suitable meter protection.
- d) *Types of metering:* Tabulated as follows are types of metering. Utility requirements govern the types available for any given project.
 - 1) Master metering
 - 2) Multiple metering
 - 3) Primary metering
 - 4) Secondary metering
 - 5) Totalized metering

- 6) Impulse metering
- 7) Compensated metering
- 8) Submetering
- 9) Subtractive metering
- 10) Coincident demand
- 11) Telemetering
- 12) Power factor metering
- 13) Kilovoltampere metering

2.4.3.2.2 Billing

For hospitals, the primary metering and attendant billing forms are the following:

- a) *Conjunctional billing*: Large institutional customers within the territory served by a given utility should explore the availability of conjunctional billing. This method consists of adding the readings of two or more meters for purposes of a single billing. Due to the usual practice of decreasing rates for larger consumption, conjunctional billing may result in a lower energy usage bill than individual meters would produce. Conjunctional billing will generally result in a higher demand charge than a master or totalizing meter because the maximum demand readings on the individual meters are added. Since maximum demands seldom occur simultaneously, the arithmetic sum will be greater than the simultaneous sum, unless a provision is made for coincident demand measurement.
- b) *Power factor billing*: If the load to be served will result in a low power factor, an evaluation should be made to determine if power factor improvements can be justified to avoid penalties.
- c) *Flat billing*: Some applications involved service to loads of a fixed characteristic. For such loads, the utility may offer no-meter or flat-rate service. Billing is based upon time and load characteristics. Examples include area lighting and remote pumping stations.
- d) *Off-peak billing*: This is reduced rate billing for service used during off-peak periods such as water-heating loads. The utility monitors, and may control, off-peak usage through control equipment or special metering.
- e) *Standby service billing*: Also known as *breakdown* or *auxiliary* service, this service is applicable to utility customers whose electric requirements are not supplied entirely by the utility. In such cases, billing demand is determined either as a fixed percentage of the connected load or by meter, whichever is higher. This applies to loads that are electrically connected to some other source of supply, but for which breakdown or auxiliary service is required.
- f) *Backup service billing*: This service is provided through more than one utility circuit, solely for a customer's convenience. The customer often bears the cost of establishing the additional circuit and associated facilities. Usually, each backup service is metered and billed separately.
- g) *Demand billing*: Usually this represents a significant part of electric service billing, and a good understanding of kilowatt demand metering and billing is

important. An electric demand meter measures the rate of use of electric energy over a given period of time, usually 15 min, 30 min, or 1 h billing intervals. The demand register is manually reset periodically when read for billing purposes.

- h) *Minimum billing demand:* A utility customer may be subject to minimum demand billing, generally consisting of a fixed amount or a fixed percentage of the maximum demand established over a prior billing period. This type of charge may apply to customers with high instantaneous demands, customers whose operations are seasonal, or those who have contracted for a specific service capacity. Equipment and service requirements should be reviewed carefully to reduce or avoid minimum billing demand charges.
- i) *Ratchet clause:* Utility contracts may also include ratchet clauses that establish minimum demand charges based on maximum demand experienced in the previous contract period (e.g., one year's peak demand establishes next year's minimum demand). Designers should advise their clients to control peak demand for several reasons, but especially where the utility contract includes a ratchet clause. Clients should be aware that a major decrease in demand may not be reflected in savings for up to 12 months, unless a modification to the ratchet clause is negotiated.
- j) *Load factor billing:* The ratio of average kilowatt demand to peak kilowatt demand during a given time period is referred to as the *load factor*. Many utilities offer a billing allowance or credit for high load factor usage, a qualification usually determined by evaluating how many hours during the billing period the metered peak demand was used. As an example of such credit, the utility may provide a reduced rate for the number of kilowatthours that are in excess of the peak demand multiplied by a given number of hours (after 360 h for a 720 h month or a 50% load factor).
- k) *Interruptible service:* A form of peak load shaving used by the utilities is interruptible service. Primarily available for large facilities with well-defined loads that can be readily disconnected, the utility offers the customer a billing credit for being able to require a reduction of demand to a specified contract level during a curtailment period. If the customer fails to reduce actual demand during any curtailment period, at least to the contract demand, the utility assesses severe financial penalties on the owner.

In short, both the design engineer and the operating engineer should understand the market in which they will operate in order to select the most cost-effective energy transformation and delivery systems, and in order to operate those on site most effectively.

2.4.3.3 Fuel source coordination

Having said all that, health care facilities, because of the vital nature of their mission, should take a proactive role in anticipating and being able to deal with various kinds of energy shocks. In general, the best strategy for health care facilities appears to be to create a set of systems that can withstand pricing and/or supply shocks in one fuel by shifting to other less costly, more readily available replacement fuels. Health care facilities, then, would be well served to implement strategies that include a fair amount of generation

redundancy, allowing the facility to operate on electricity, natural gas, or diesel fuel for extended periods of time.

Even if supply or price shocks do not occur, with this kind of system, the facility can much more easily fuel shift to take advantage of pricing differentials between alternative fuels as conditions change in today's dynamic energy markets. Such systems have another crucial benefit to health care facilities, which is the availability of redundant systems to increase the reliability of the energy streams on which the lives of the patients often depend. Various kinds of control systems exist that track changes in spot markets of energy supplies and start and stop equipment and shift loads in order to achieve lowest overall cost of operation to achieve the facility's mission.

Finally, the health care facility should always be looking for ways to share energy opportunities with other types of users. As mentioned in 2.4.4.1, most hospitals have decanted their laundry and cooking functions off-site, with the result that the base heat load is too low to make large-scale cogeneration feasible. However, at least one hospital still has an on-site laundry and is able to generate all of its own electricity using natural gas turbines and using the heat to produce steam for its laundry. In fact, the laundry for this site is of sufficient size that it does laundry for other hospitals in the area that have outsourced their laundry function. This hospital gets to keep its energy cake and eat it, too!

2.4.3.4 Procurement options

Most health care facilities will buy electricity from their local service provider, either an investor-owned utility or else a municipal utility district. In some places, health care facilities have options to purchase from other sources, in which case they will contract separately for supply and transmission services.

One option worth considering is to partner with an energy provider who will simply supply energy streams to the hospital for a contract amount. One good example of such a system is a partnership between for-profit organizations that can install photovoltaic systems or cogeneration systems, take advantage of accelerated depreciation, and sell the electricity generated to a non-profit health care facility, usually for a discount off of the utility rate. This kind of strategy allows the health care facility to purchase green electricity, reduce local emissions, and lock in the pricing for a small portion of its overall electricity bill.

On a larger scale, the health care facility can contract with a third party who will develop the energy plant and sell energy streams to the hospital. This kind of arrangement reduces many of the worries (fewer staff, no managing of energy purchase contracts) of the health care facility, but also robs it of considerable flexibility over time. In addition, it does not significantly protect the health care institution from price fluctuations, as contracts for these arrangements can contain provisions for indexing pricing against utility cost changes.

2.4.3.5 Aggregation

Aggregation is the practice of putting together all of the various buildings that a facility has and purchasing energy supplies for them as an aggregate. Pursuing this strategy can create a demand with sufficient heft that the buyer is able to obtain more favorable rates that it would be able to achieve through purchasing separately. Health care organizations are ideal candidates for this kind of purchasing arrangement, for most hospitals are surrounded by many clinics, imaging facilities, doctors' offices, etc. Many older hospitals contain addition after addition, each with its own meter. Simply consolidating these meters can often yield surprising benefits.

2.4.4 Generation and transformation options

Once hospitals obtain their energy commodities, they may transform them in various ways so as to reduce their overall costs. Some examples of supply side management strategies are cogeneration, peak shaving, thermal energy storage, and alternative fuel/energy sources.

2.4.4.1 Cogeneration

Cogeneration involves the use of a single piece of equipment to generate both heat and electricity. Generally, this involves using some type of natural gas generator with heat recovery. This kind of design was at one time very applicable to hospitals because hospitals had both a high power load and a high heat load. Much of this heat, during the warmer parts of the year, however, was consumed by laundries and kitchens. In recent years, most health care institutions have found it more economical to outsource these services, relying on small cook-chill kitchens and delivered linens and food. Such facilities offer much more limited opportunities for cogeneration. In these cases, one option that is still available is to create a heat load by adding a small absorption chiller to consume the heat. In this case, the generator can operate to generate electricity year-round, heat in the winter, and cooling in the winter. It can thus have two ways to reduce the peak electrical demand and usage, creating significant savings over the use of electricity. And as discussed, it gives the hospital much more flexibility in fuel switching and in redundancy of equipment to ensure reliable energy supplies to its staff and patients.

2.4.4.2 Peak demand shaving

Since the largest cost of an electrical utility is its investment in plant and transmission capacity, electrical utilities frequently construct their rates based on the peak demand that a facility is likely to produce, particularly if that peak occurs at the same time that other peaks are likely to occur. For health care facilities, electricity consumption tends to rise during the summer, as needs for air conditioning grow (see Annex 2A). Similarly, energy use during a day tends to reach its peak during the latter part of the afternoon, when the demand for air conditioning is at its peak (see Annex 2B). Some rate structures contain ratchet provisions, charging repeatedly over time for achieving a certain peak. The higher peak electrical rates, together with the higher peak time electrical usage, combine to create a multiplier effect, with often very high summer time demand charges.

Facing this prospect, many hospital engineers seek to lower their peaks in order to flatten out their electrical use profile and to lower their cost. Many strategies are available to engineers seeking such a solution.

One obvious strategy for reducing the electrical peak is for a health care owner to run its diesel generators during the time when the peak demand occurs. This strategy certainly does lower the peak, and in some sense, may well be financially attractive. However, operating diesel generators in limited bursts on relatively frequent occasions may ultimately reduce the life and/or reliability of the generator.

Worse, diesel exhaust is extremely toxic. The California Air Resources board has now labeled diesel generator exhaust as a toxic air contaminant. Diesel exhaust contributes more than 70% of all cancer risk from air toxics in the U.S. The health risk from diesel exhaust is about 10 times greater than the risk from all other toxic air pollutants combined. Diesel exhaust creates numerous acute and chronic non-cancer effects on human body. Now, in-place diesel generators are only a small part of engines emitting diesel exhaust, and hospital generators are only a small part of the overall inventory of permanently installed diesel engines, but hospital generators tend to produce a higher percentage of harmful exhaust than comes from other sources. This higher degree of harm results from the fact that hospitals are often located in densely populated areas so that their diesel exhaust is more directly able to affect the public health than for other diesels (see Ryan, Larsen, and Black [B27]). Similarly, because hospitals are required to test their generators on a frequent, periodic basis, and then, to give them a cold start and run them, often relatively unloaded for only a short time, hospitals operate them more often and in a mode that creates more harmful toxics than other owners of diesels are likely to do. Finally, given the health and air quality issues surrounding the use of diesel generators, more and more air quality regulating jurisdictions are imposing additional restrictions on the use of such generators, restricting their use to only emergency and testing occurrences. This trend is not likely to reverse in the foreseeable future.

One option that may make diesel generators more acceptable as an alternative fuel source would be to buy and use bio-based fuels to operate the diesel generators. Burning these fuels produces significantly less toxins than does burning normal diesel fuel, and so may offer a good alternative for those hospitals looking to make the most use of their diesel generators while simultaneously trying to comply with local air quality regulations.

In general, while peak shaving might be a tempting energy cost reduction strategy, hospital engineers would do well to look elsewhere for peak shaving opportunities.

Other opportunities for electricity peak shaving include natural gas fired generators, natural gas fired absorption chillers (either direct-fired or steam powered), or fuel cells.

2.4.4.3 Thermal energy storage

Thermal energy storage is a form of peak shaving that seeks to flatten the consumption curve for electricity by shifting the purchase of electricity from one time period to another in order to take advantage of lower rates. This strategy generally involves the use of chillers at night to produce either chilled water or ice, when the electrical rates are lower.

Then during the day, as the rates ratchet up, the chillers may run lower than they would need to run to meet the demand, because they are able to use the “coldness” that they stored the night before.

Thermal energy storage typically requires a significant amount of space for the storage medium used to store the cold. Ice storage takes less space because it stores more energy per cubic measure of water than does chilled water, but ice storage takes considerably more energy to create its stored energy than does cooling water. Cooled water, though, requires significantly more space for storage to achieve a similar stored capacity of energy.

Both strategies (chilled water or ice) ultimately consume more energy than simply generating the cooling at the time it is required because of the double conversion from one form to another. This strategy relies totally on the rate differential between peak demand and off peak demand periods to create a financially feasible approach. This rate dependence leaves the owner with this strategy vulnerable to changes in the energy supply markets.

2.4.4.4 Alternative fuel sources

Hospitals purchase their energy supplies in a number of different forms (see, for example, Annex 2A and Annex 2B to this chapter). Hospital designers typically select systems based on fuels that appear to provide the lowest overall cost to the facility. However, decisions about energy purchase and production may be weighted heavily towards first cost in the initial design, resulting in a less than optimal plant configuration. Market conditions will certainly change over the life of a particular building. Finally, relying only on one source of fuel for different energy needs can create vulnerabilities for a facility in the event of various kinds of emergencies.

For each of these reasons, hospital engineers should carefully consider the mix of fuels they rely on for their energy needs, and strive for the ability to switch between different fuels in different circumstances. One obvious example of this kind of strategy is the common practice of having a supply of diesel fuel on site for the purpose of generating electricity in the event of a power outage. Other examples include having some chillers that run on electricity and some that run on natural gas, or having both natural gas and diesel fuel available to run boilers. In general, where a plant can be provided with more flexibility in selecting between fuel sources, it will have added tools for controlling its costs and for weathering various kinds of supply disruptions.

One interesting emerging alternative is the use of bio-based diesel fuels. Many hospitals contain dual-fuel boilers that can run on either natural gas or diesel fuel. Normally, these facilities operate on natural gas because of the bad characteristics of the diesel fuel when it comes to products of combustion. However, bio-based fuels burn much cleaner than petroleum-based diesel fuels (see “Biodiesel: A Cleaner Fuel for the 21st Century” [B5]).

2.4.4.5 Centralized systems vs. distributed systems

Today's medical centers consist of many buildings located close to each other. In every such situation, a tension develops between the cost of having a central utility plant to serve all of the buildings or stand-alone systems for each building. Generally speaking, having centralized systems offers significant savings advantages in energy terms as contrasted with stand-alone systems. Opportunities for part-loading equipment more efficiently, fuel switching, and simply buying better, more efficient equipment are much greater with a central plant. Often, however, the option of having small, decentralized systems has a first cost advantage, due at least partly to the ability to do away with long piping runs.

2.4.5 Demand side management

Demand side management looks at those items on the load side of the electrical system. These items are things like motors, lights, and controls. Demand side management deals with how energy use can be reduced, by the user. It does not change the unit energy cost (i.e., dollars per kilowatthour) nor does it care from what source or how the energy is obtained. Demand side management strategies are often easier and less expensive to implement than supply side strategies, particularly in retrofit applications.

Note, again, that libraries full of books have been written on various energy demand reduction strategies and techniques. The intention here is not to repeat the information in these other excellent references, but to highlight areas of special interest, opportunity, and challenge to health care facilities and to their engineers.

2.4.5.1 Lighting technologies

"Lighting accounts for 20% to 25% of all electricity consumed in the U.S. Commercial establishments consume 20% to 30% of their total energy just for lighting" (see Consumer Energy Information [B9]). (See also Annex 2A and Annex 2B). Because lighting consumes so much of facilities' energy and energy budget, it is a natural first target for energy use reduction strategies. The main methods to reduce lighting energy consumption are the use of energy efficient technologies, using natural daylighting, and aggressive use of lighting controls. Because much of the energy consumed by most lighting sources produces heat rather than light, reducing the energy used to produce artificial light load also reduces energy needed to cool the building.

EPAct eliminated many previously used lamps and mandated minimum efficiency standards for others. EPAct also required packaging and product literature to carry labeling indicating lumen output, efficiency, and lamp life. Health care electrical engineers should refer to lamp manufacturers' catalogs or other published data to compare the energy characteristics of various lamp choices. In selecting light fixtures, however, the engineer should also consider the visual tasks that are necessary for the health and safety of the patients and staff (see Chapter 6 for more recommendations regarding lighting systems for health care).

Several common techniques for conserving energy in the use of fixtures include:

- a) Using T-8 or T-5 lamps with electronic ballasts. T-5 lamps are smaller in diameter and are typically used more in indirect lighting fixtures.
- b) Using task lighting in conjunction with lower overall footcandle levels in applicable rooms.
- c) Limiting the use of incandescent fixtures to those applications that cannot use either compact fluorescent or metal halide lamps.
- d) Using LED or electroluminescent exit signs in lieu of fluorescent or incandescent.
- e) Using single ballasts per fixture where multiple level switching is not needed.

In existing facilities, retrofitting older, inefficient lighting systems will save both energy and money, with paybacks of only a very few years.

New technologies are constantly emerging, and the health care electrical engineer should keep abreast of such developments and incorporate them into the facility designs when and where appropriate.

In any area, regular maintenance of luminaires, lamps, and ballasts is essential to energy efficiency regardless of types employed. “Light levels decrease over time because of aging lamps and dirt on fixtures, lamps and room surfaces. Together, these factors can reduce total illumination by 50% or more, while lights continue drawing full power” (see Consumer Energy Information [B9]).

2.4.5.2 Daylighting

“Daylighting is the use of direct, diffuse, or reflected sunlight to provide full or supplemental lighting for building interiors” (see Consumer Energy Information [B10]). “Modern buildings designed for daylighting typically use 40% to 60% less electricity for lighting than do conventional buildings” (see Consumer Energy Information [B9]). To effectively save energy, daylighting systems should include sensors and dimming ballasts to decrease artificial light when sufficient daylight is present. The interior design of the space is crucial to effective daylight harvesting (i.e., light finishes, ability to disperse/distribute the sunlight in the space, etc.).

Extensive daylight harvesting in health care facilities can be difficult because of the building profile, with relatively fewer outer spaces and relatively more interior spaces. Similarly, health care facilities require privacy for its occupants, with the result that these facilities contain many small, partitioned spaces when compared to offices or schools. Finally, building codes require that patient rooms occupy the perimeters in order to assure outside views for all patient rooms, thus further blocking the infusion of daylighting into the interior spaces.

Health care facility designers have a number of strategies available to them to increase the amounts of daylighting into the facility, however. To begin with, some hospital planners have begun experimenting with longer, thinner buildings, which have relatively moiré exterior spaces so that it becomes easier to introduce daylight into interior spaces.

Daylight harvesting can also be increased by simply increasing the amount of glazing. The amount of glazing can be increased at the top or sides of a building through the use of windows, skylights, clerestory windows or monitors and atrium spaces. Large amounts of glazing do not necessarily provide good daylighting, as it can cause glare in the space or heat gain to the space that must then be cooled. Much better than such direct infusions of light are reflected daylighting strategies that redirect sunlight into the building. This is typically accomplished through the use of light shelves at the base of the window. These shelves reflect light onto the ceiling and then back into the space. The shelves should slope to prevent their being used as actual shelves for storage.

Three kinds of mechanical devices can focus and direct daylight into a building: heliostat, light pipes, and Fresnel lens devices. A heliostat is a mirrored device that tracks the sun and focuses it onto a secondary mirror, which then directs the light into light pipes or down through a skylight. Light pipes are tubes with reflective surfaces that direct daylight down into building interiors. Fresnel lens devices track and focus light, directing it to secondary lens, which then directs the light into building. These devices can also direct or concentrate the light to fiber optic cables. Fiber optic cables can be used to distribute light to diffuser panels, lenses, or other fixtures.

Daylighting has a number of drawbacks, including unpredictability; some areas are not ideal candidates for heavy use of daylighting. If improperly designed, daylighting schemes can add heat gain in summer and heat loss in winter. Direct daylighting can cause glare and fade interior furnishings and finishes. Glare can pose visual problems especially with computer screens. Mechanical daylighting systems can have problems with dust/debris collecting on the mirror or lens. These systems also use energy in the motors that provide the tracking ability.

Other barriers to the use of daylighting are cost, maintenance, and lack of familiarity with the concept. To be cost effective, the energy savings (lights, HVAC reductions) must offset the increased costs of system installation. Maintenance personnel may not be familiar with the controls and systems; it is more complex than re-lamping. Unfamiliarity with daylighting may also be a problem as the designer or the user may not want to try something new.

2.4.5.3 Lighting controls

Lighting controls also bear directly on energy utilization. Lights that are left on when the spaces they serve are unused or vacant waste electricity. Health care facilities have been slow to adopt much in the way of lighting controls, and we are constantly amazed to go into soiled utility rooms that are empty of people, but lit up like a used car lot. Small investments into lighting controls will yield tremendous investments to most health care facilities.

Lighting controls range from simple on/off switches to complex programmable controls. Lighting controls can be divided into three categories, as follows:

- a) Manual switches
- b) Automatic switches
- c) Programmable controls

Manual switches can be a standard toggle switch, a keyed switch, or a timer. Manual switches are the cheapest initially, but except for the timer, depend upon people to turn the lights off. A manual switch can control all of the lights in one area, or the area can be subdivided with multiple switches. Fixtures can also be multi-level switched. Multiple switching allows some lights to be turned off when the space is occupied.

Automatic switches are controls that react to an input (i.e., movement or light levels) and then turn the lights off when that input is no longer there. Occupancy sensors and photocells are examples of automatic switches. They are appropriate for spaces like storage rooms, janitor's closets, public restrooms, offices, etc. Occupancy sensors can be used in conjunction with a manual override switch, they can be combined with "regular" switches (i.e., the sensor turns the lights on and off, but a regular switch allows for switching part of the lights off), and they can be combined with space HVAC controls. Occupancy sensors are easy to install into existing buildings, but care should be taken to make sure they do not leave people in the dark.

Programmable controls contain elements of both manual and automatic controls in that some input is required by a user initially and then the predetermined program controls the lights without further action by the occupants. Programmable controls can be as simple as a time clock for exterior lights (on at sunset, off at sunrise), to a small controller programmed for specific "scenes" (preset levels and combinations of fixtures), to auto control of corridor lights based upon time of day to more complex systems that control all of the lights and digital lighting controls systems. Programmable controls can also be used in conjunction with manual override, and some systems allow a user to telephone in and extend the "on" time. The building automation system (BAS) can also be used to control the lights. While a scheduled system allows for greater control of the lights, there are some drawbacks to such a system: it may not be appropriate for small rooms, the schedule may not fit all occupants/uses, a large number of zones increases circuit costs. These kinds of systems are rarely appropriate for hospitals, but may provide great benefits within MOB's.

2.4.5.4 Motors

Selection of motors for efficient use of energy is essential. Motors should be chosen to operate at three-quarters load or more, as part-loaded motors tend to operate with low efficiencies. However, since motor size is typically not selected by the electrical designer, and since the sizes are based upon things like pump curves, loading, static pressure, etc., there is not much that can be done with regard to size to reduce energy consumption. There are a couple of other options for energy reduction with motors, including using energy efficient motors, using VFDs to control certain motors and voltage.

Energy efficient motors have been mandated by EPCa. Existing motors can either be replaced when they fail or they can be retrofitted (while still functional) with energy efficient motors. Which option is used depends upon the motor horsepower, hours of use, and cost of electricity. For a smaller motor with low run time, it may be more economically feasible to wait until the motor needs replacement before upgrading to an energy efficient motor. New motors should be specified as being "energy efficient." When shopping for energy efficient motors, the descriptions may be confusing. Manufacturers may call their motors "super efficient," "premium," "high efficiency," etc. Check the

nominal and minimum efficiencies listed for the motor. NEMA MG 10 has a table that gives the nominal efficiencies for energy efficient motors.

Another specification tool is the NEMA premium efficiency program [B26], which started in 2001. NEMA MG 10 now contains two tables, 12-12 and 12-13, which give the nominal efficiencies for motors to be labeled *NEMA premium*. The efficiencies for these motors are higher than from regular energy efficient motors. This program also covers motors that are not covered by EPart, such as 200 hp to 500 hp and medium-voltage motors.

Another area for reducing energy consumption is to control them better. VFDs reduce the motor speed when the motor does not need to run at 100%. Ventilation and pumping systems are typically good candidates for VFDs. These motors tend to be sized for the maximum demand that rarely occurs. When spaces are unused, the systems can be ramped back, saving energy.

Another option is to look at the voltages used. For large installations and motors, consider using a higher voltage (i.e., 4160 V in lieu of 480 V) to serve the motor. A 1200 T to 1500 T chiller is a usually a good candidate for service at 5 kV. The higher voltage means that the motor amperes are lower. Lower ampacity yields lower I²R losses. The engineer should weigh potential savings from using a higher voltage against the increased cost of motors and starters. Also, if the maintenance staff is not qualified to take care of higher voltage equipment, this may not be a feasible option.

A more in-depth discussion of energy efficient motors and their use in energy management can be found in IEEE Std 739 (*IEEE Bronze Book*), Chapter 5. A more in-depth discussion of motor and motor controllers can be found in IEEE Std 241 (*IEEE Grey Book*), Chapter 6.

2.4.5.5 Transformers

Energy efficient transformers have lower losses than standard transformers at a particular loading level. The governing standards are NEMA TP 1 and NEMA TP 3. NEMA TP 1 gives a basis for determining energy efficiency performance while NEMA TP 3 defines the labeling for transformers that comply with TP 1. For a transformer complying with NEMA TP 1, the “losses are approximately 30% lower than a standard transformer at 35% loading and approximately 15% less at full load” (see Square D Bulletin [B30]). Since transformer efficiency is a function of load, “loss evaluations” of transformers should be conducted before purchase. The cheapest first-cost transformer may actually cost more in the long run. Loss evaluations should include conductor losses (windings) as well as the core losses. Load and duty cycle should also be evaluated. This should be done for interior transformers as well as building transformers (or distribution). Transformers have a long life (approximately 20 years or more), so lower losses can yield significant savings over the life of the equipment.

2.4.5.6 Energy management systems

Use of an energy management system (EMS) is an accepted and frequently recommended way to lower energy and demand costs and to conserve energy. Energy management is a technique for automatically controlling the demand and energy consumption of a facility to a lower and more economical level by implementing operating strategies that optimize system performance to meet building needs more efficiently. Most facilities achieve this through the use of an automated building management system (BMS). Coordination among owner, architect, and engineers during schematic design may allow one BMS to control the lighting, the HVAC systems, and to perform fire and security functions as well. These systems can also monitor critical energy streams, giving the hospital engineer the diagnostic tools needed to ensure optimal plant operation over time.

Computerized systems can replace much of the lost time expended by maintenance crews to verify operating status of boilers, fans, and other equipment. It can enable control of HVAC functions and lighting from a central unit, performing operations such as start/stop, load shedding, and controlling air mixtures. These functions can be accomplished using mid-range energy controllers.

State-of-the-art EMSs use direct digital controls (DDC). These systems have minicomputers and microprocessors spread throughout the system, including field controllers. The main computer is free to perform sophisticated energy management tasks, while simpler tasks are delegated to the field controller. Each controller can be a stand-alone management center reporting to the central system, and if the main CPU or a transmission link fails, the balance of the system continues to perform its respective function.

2.4.5.7 Power factor correction

An electrical system consumes both real power (kW), reactive power (kvar) and apparent power (kVA). Prediction of system power factor is difficult during design but more readily determinable in an operating system. A large portion of a building's loads is comprised of motors, transformers, and lighting ballasts, which are all primarily inductive loads. Motor power factor varies with load and is the worst with a lightly loaded motor. A customer can be penalized by the serving utility company for having a poor power factor. This penalty can appear as a direct charge in the utility bill or as a charge for the vars used.

In order to minimize a poor power factor, consideration should be given to application of capacitors at three-phase, constant-speed induction motors. In addition, application of power factor correction capacitors or synchronous condensers to the system should be evaluated during design, and provisions should be made to install them without major renovations of switchgear. Where nonlinear loads are present, care should be taken when adding capacitors to avoid resonance. In addition to avoiding utility fees, the hospital can gain other benefits from power factor correction, including release of system capacity upstream, allowing additional loads to be served, and reduction in losses due to reduction in currents.

See also IEEE Std 241 (*IEEE Grey Book*) Chapter 6 for a discussion on power factor and power factor correction.

2.4.5.8 Use of energy-efficient equipment

Various kinds of equipment consumes almost one third of the energy used by a health care facility. Few manufacturers of medical equipment appear to worry much about the energy consumption of their equipment. However, more and more makers of office and food service equipment are working to reduce the energy consumption of their equipment. While the hospital engineer rarely specifies the medical equipment for a health care facility, he should still be aware of the implications of various equipment options available on the overall electrical loads of the facility.

Energy Star is a voluntary program sponsored by the Environmental Protection Agency (EPA).¹⁰ The Energy Star Program looks at the whole building. It has a five-stage approach: green lights, building tune-up (adjustments to existing equipment), load reductions, fan systems upgrades, and heating and cooling systems upgrades. An owner can get recognition as an energy star participant/partner. Currently 3037 organizations participate in the Energy Star and Green Lights programs. Specifying equipment that bears the Energy Star label means that the equipment installed is more energy efficient than standard equipment.

2.4.5.9 Alternate cooling methods

Hospitals often have an interest in gas-fired cooling equipment for at least two reasons. First, they believe that these systems, coupled with heat recovery, can produce cost-effective energy streams. Second, such systems provide additional levels of redundancy of equipment in the event of a power failure, as noted in the preceding procurement strategy discussion.

Desiccant systems directly remove moisture from the air without cooling it. The benefits of a desiccant dehumidifier are the downsizing of chillers and ducts, lowering humidity levels in occupied spaces, and allowing for utility load shifting (desiccant dehumidifiers may be supplied by natural gas, propane, steam, hot water, or waste heat).

Absorption chillers use a cycle of condensation and evaporation to produce cooling. These chillers are driven by heat, not a mechanical compressor. Absorption systems may be directly fired by gas, or indirectly by hot water, steam, or recovered heat. The benefits of an absorption system are reduced electricity consumption and demand, few moving parts and so lower maintenance, lower operating costs, the ability to fuel switch from electricity to gas, no CFCs, and high reliability.

Natural gas engine-driven chillers use a natural gas engine in lieu of an electric motor to drive the compressor. The engine and exhaust heat can be recovered for other uses. Some

¹⁰See Energy Star at www.energystar.gov for additional information about the programs, some online evaluation tools, and links to other governmental energy pages.

of the benefits are reduced electricity consumption and demand, efficient part-load performance, and providing a hedge against the uncertainties of electric deregulation.

Hybrid chillers/chiller plants combine dissimilar equipment into a single plant operation. They can either combine gas-fired and electric equipment or two gas technologies. These systems are especially good if the facility is subject to real time pricing (RTP) billing or time of use billing. The nonelectric chiller would be used in times of high electricity cost, while the electric chiller would be used in off-peak hours. The lowest cost per hour is used to determine when and which chiller should be run and at what percentage loading. Not only do hybrid systems lower kilowatthour costs, but they can also avoid some peak rates and associated charges (ratchet charge avoidance). Hybrid systems can use equally sized equipment, or the nonelectric machine can be sized for the whole load with the electric machine only sized for off-design conditions.

Chillers combined with VSDs are another way to reduce the HVAC energy usage in a building. “Chillers typically spend less than 1% of their time operating at design conditions” (see Western Energy Services [B38]). In off-design conditions, the cooling load can be less than design or the entering and leaving water temperatures can be different than the design. A VSD will decrease the chiller’s power draw in response to off-design loads and water temperatures. “In certain part load conditions, the VSD control can low chiller energy consumption by up to 50% compared to fixed-spnd, high-efficiency chillers” (see Case Studies [B8]). VSDs can only be used with centrifugal chillers.

Some chiller manufacturers have software available to do energy analysis/operating cost analysis of chiller usage, type, energy source, options, kW/ton, system comparisons, etc. There are many options for optimizing a chiller, or chiller plant; see 2.7 for articles that cover these topics in greater depth.

2.4.5.10 Heat recovery

Some health care facilities have considered moving towards all outside air systems for health benefits. However, such systems can be very costly in terms of energy loss as compared to systems that recirculate previously heated or cooled air. One approach to minimizing this disadvantage is through the use of heat recovery.

Heat recovery recovers energy from exhausted air and transfers it to the incoming air for a building. This transfer reduces the amount of energy needed to lower or raise the temperature of the incoming air. There are three types of heat recovery systems: heat wheels, heat pipes, and runaround loops. All three work in a similar fashion in that the incoming air is tempered by the outgoing exhaust. Heat recovery wheels and heat pipes both require that the incoming and outgoing air streams are adjacent. Humidity control can also be added through the addition of a desiccant or an additional pipe. Loops are used when the incoming and outgoing air streams are not adjacent. This is a more costly system as it involves a piped, and pumped, water or glycol system and transfer coils.

2.4.5.11 Building siting

Building siting and orientation has an impact on the HVAC loading. Reducing the HVAC load in turn reduces electricity consumption. Ideally you want minimum exposure in the summer and some heat gain in the winter. Reducing the leakage of the building envelope, increasing the R-value (insulation) and replacing clear, single-pane windows with tinted, double-pane insulating glass all reduce building heating and cooling requirements, and therefore, energy costs. Weather-stripping and regular building maintenance help to reduce outside air infiltration and its resultant heating/cooling costs. Since windows should admit daylight and block solar energy (heat), window film can also be applied to guard against glare and heat loss.

Computer simulations are available that take into account location, orientation, etc., and can provide the payback time for various energy saving opportunities. Solar panels can also be incorporated as a part of building envelope/exterior. A building's interior can also impact energy usage. A building with dark, matte finishes will need more lighting as there will be little reflectance off of the interior surfaces. Light finishes should be used in interiors because they reflect light and reduce the amount of light needed. Such finishes also help with daylighting and light reflection into interior spaces. Finally, landscaping, trees for shading, and "green" screens (wires for vines/greenery to climb up) can reduce the cooling load of a building.

2.5 Load management funding mechanisms

Engineers have a number of opportunities for funding energy saving schemes. Typically, energy use consumes about 1% to 2% of a facility's total operating budget, so hospitals are often reluctant to part with much needed capital to fund energy saving schemes.

Generally, hospital engineers will have to justify their proposed investments into energy saving technologies with a financial analysis that shows the impact of the decision over time. Often engineers rely on a simply payback approach, though a net present value analysis will be both more accurate and more likely to resonate with financially minded hospital CEOs.

Many states now offer incentives for implementing energy saving strategies. Occasionally the federal government or others offer grant opportunities for funding such projects. No-cost options like allowing a third party to install photovoltaic panels on the roof and then purchasing power from them are also options.

One problem with the recent relatively low energy prices is that newer, more energy efficient technologies have been slow to become cost effective. However, the cost per kilowatt continues to drop for most of these systems, and even if the facility cannot now afford such systems, they should always be aware of making decisions that will allow them to pursue them in the future. To take one simple example, one health care facility signed an energy purchase agreement that effectively forbade it from generating any of its own power for a substantial number of years. Avoid such agreements, and design spaces and systems so as to enable future additions of new technologies.

2.6 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ASHRAE/IESNA 90.1, Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI).¹¹

BOCA National Energy Conservation Code.¹²

Energy Policy Act of 1992 (EPAct).¹³

IEEE Std 739, IEEE Recommended Practice for Energy Management in Industrial and Commercial Facilities (*IEEE Bronze Book*).^{14, 15}

IEEE Std 241, IEEE Recommended Practice for Electric Power Systems in Commercial Buildings (*IEEE Grey Book*).

IES LEM-3-3, Design Considerations for Effective Building Lighting Energy Utilization.¹⁶

Leadership in Energy and Environmental Design (LEED), U.S. Green Building Council (USGBC).¹⁷

NEMA MG 10, Energy Management Guide for Selection and Use of Fixed Frequency Medium AC Squirrel-cage Polyphase Induction Motors.¹⁸

NEMA TP 1, Guide for Determining Energy Efficiency for Distribution Transformers.

NEMA TP 3, Standard for the Labeling of Distribution Transformer Efficiency.

¹¹ASHRAE publications are available from the Customer Service Department., American Society of Heating, Refrigerating and Air Conditioning Engineers, 1791 Tullie Circle, NE, Atlanta, GA 30329, USA (<http://www.ashrae.org/>).

¹²BOCA publications are available from the Building Officials and Code Administrators (BOCA) International, Inc., 4051 West Flossmoor Rd., Country Club Hills, IL 60478-5795 and from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

¹³This publication is available from https://energy.navy.mil/publications/law_US/92epact/hr776toc.htm.

¹⁴IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

¹⁵The IEEE standards or products referred to in this clause are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

¹⁶IES publications are available from the Illuminating Engineering Society of North America, 120 Wall Street, FI 17, New York, NY 10005-4001.

¹⁷USGBC publications are available from the U.S. Green Building Council, 1015 18th Street, NW, Suite 508, Washington, DC 20036 (<http://www.usgbc.org>).

¹⁸NEMA publications are available from the National Electrical Manufacturers Association, 1300 N. 17th St., Suite 1847, Rosslyn, VA 22209 (<http://www.nema.org/stds/>).

NEMA XR 9, Power Supply Guidelines for X-Ray Machines.

NFPA 70, National Electrical Code® (NEC®).¹⁹

NFPA 99, Standard for Health Care Facilities.

Nonresidential Manual For Compliance with California's Energy Efficiency Standards, Publication: P400-01-005.²⁰

OSHPD Policy Intent Notice 3-220, California Office of Statewide Health Planning and Development.²¹

2.7 Bibliography

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[B4] Association of Energy Engineers, 700 Indian Trail, Lilburn, GA 30047, various publications.

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[B9] Consumer Energy Information: EREC Fact Sheets Energy Efficient Lighting; available at http://www.eere.energy.gov/buildings/info/documents/pdfs/ee_lightingvolII.pdf.

¹⁹NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA (<http://www.nfpa.org/>).

²⁰This publication is available at <http://www.energy.ca.gov/title24/>.

²¹OSHPD publications are available from OSHPD, 1600 9th St., Sacramento, California 95814 (<http://www.oshpd.ca.gov/>).

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Annex 2A

(informative)

Sutter general loads**Table 2A-1—Hospital^a**

Dates	Peak kW	Total kWh	W/ft ²	kWh/ ft ²
12/21/2002–1/20/2003	1424	975 000	3.62	2.48
11/21/2002–12/20/2002	1419	904 800	3.60	2.30
10/21/2002–11/20/2002	1482	878 400	3.76	2.23
09/21/2002–10/20/2002	1495	969 000	3.80	2.46
08/21/2002–09/20/2002	1502	952 800	3.81	2.42
07/21/2002–08/20/2002	1512	900 600	3.84	2.29
06/21/2002–07/20/2002	1462	950 400	3.71	2.41
05/21/2002–06/20/2002	1439	930 600	3.65	2.36
04/21/2002–05/20/2002	1514	909 000	3.84	2.31
03/21/2002–04/20/2002	1504	904 200	3.82	2.30
02/21/2002–03/20/2002	1491	883 400	3.79	2.24
01/21/2002–02/21/2002	1497	975 000	3.80	2.48
12/21/2001–01/20/2002	1461	1 020 000	3.71	2.59
11/21/2001–12/20/2001	1465	928 200	3.72	2.36
10/23/2001–11/20/2001	1444	867 600	3.67	2.20
09/22/2001–10/22/2001	1149	889 800	2.92	2.26
08/23/2001–09/21/2001	1377	860 400	3.50	2.18
07/25/2001–08/22/2001	1374	836 400	3.49	2.12
06/23/2001–07/24/2001	1402	938 400	3.56	2.38
05/24/2001–06/22/2001	1389	876 600	3.53	2.23
04/25/2001–05/23/2001	1392	858 000	3.53	2.18
03/27/2001–04/24/2001	1466	867 000	3.72	2.20

Table 2A-1—Hospital^a (continued)

Dates	Peak kW	Total kWh	W/ft ²	kWh/ ft ²
02/24/2001–03/26/2001	1466	906 600	3.72	2.30
01/25/2001–02/23/2001	1451	894 600	3.68	2.27
12/22/2000–01/24/2001	1462	988 800	3.71	2.51
11/21/2000–12/21/2000	1426	894 600	3.62	2.27
10/21/2000–11/20/2000	1448	898 200	3.67	2.28
09/21/2000–10/20/2000	1393	862 200	3.54	2.19

^aReprinted with permission from Sutter Medical Center.

Table 2A-2—Central plant (serves hospital, MOB, and cancer center)^a

Dates	Peak kW	Total kWh	W/ft ²	kWh/ft ²
12/21/2002–1/20/2003	521	191 600	0.84	0.31
11/21/2002–12/20/2002	847	234 800	1.36	0.38
10/21/2002–11/20/2002	957	260 000	1.54	0.42
09/21/2002–10/20/2002	1257	454 400	2.02	0.73
08/21/2002–09/20/2002	1303	518 800	2.09	0.83
07/21/2002–08/20/2002	1311	494 400	2.11	0.79
06/21/2002–07/20/2002	1353	578 400	2.17	0.93
05/21/2002–06/20/2002	1308	503 600	2.10	0.81
04/21/2002–05/20/2002	836	320 000	1.34	0.51
03/21/2002–04/20/2002	822	312 400	1.32	0.50
02/21/2002–03/20/2002	814	206 800	1.31	0.33
01/21/2002–02/21/2002	529	158 800	0.85	0.26
12/21/2001–01/20/2002	681	156 400	1.09	0.25
11/21/2001–12/20/2001	811	215 600	1.3	0.35
10/23/2001–11/20/2001	828	361 200	1.33	0.58
09/22/2001–10/22/2001	1367	476 800	2.20	0.77

Table 2A-2—Central plant (serves hospital, MOB, and cancer center)^a
(continued)

Dates	Peak kW	Total kWh	W/ft ²	kWh/ft ²
08/23/2001–09/21/2001	1305	558 000	2.10	0.90
07/25/2001–08/22/2001	1307	527 200	2.10	0.85
06/23/2001–07/24/2001	1341	586 800	2.15	0.94
05/24/2001–06/22/2001	1375	508 000	2.21	0.82
04/25/2001–05/23/2001	1374	469 600	2.21	0.75
03/27/2001–04/24/2001	1294	217 600	2.08	0.34
02/24/2001–03/26/2001	943	204 400	1.51	0.33
01/25/2001–02/23/2001	890	75 200	1.43	0.12
12/22/2000–01/24/2001	836	88 400	1.34	0.14
11/21/2000–12/21/2000	850	124 000	1.37	0.19
10/21/2000–11/20/2000	909	232 400	1.46	0.37
09/21/2000–10/20/2000	1314	380 800	2.11	0.61

^aReprinted with permission from Sutter Medical Center.**Table 2A-3—Medical office building**
(8 stories, heating hot water and chilled water from plant)^a

Dates	Peak kW	Total kWh	W/ft ²	kWh/ft ²
12/21/2002–1/20/2003	400	219 200	2.12	1.16
11/21/2002–12/20/2002	406	201 600	2.16	1.07
10/21/2002–11/20/2002	411	193 200	2.18	1.03
09/21/2002–10/20/2002	426	204 800	2.26	1.09
08/21/2002–09/20/2002	434	210 400	2.31	1.12
07/21/2002–08/20/2002	425	212 400	2.26	1.13
06/21/2002–07/20/2002	427	231 600	2.27	1.23
05/21/2002–06/20/2002	432	223 600	2.29	1.19
04/21/2002–05/20/2002	430	216 400	2.28	1.15

**Table 2A-3—Medical office building
(8 stories, heating hot water and chilled water from plant)^a (continued)**

Dates	Peak kW	Total kWh	W/ft ²	kWh/ ft ²
03/21/2002–04/20/2002	447	218 400	2.37	1.16
02/21/2002–03/20/2002	490	237 600	2.60	1.26
01/21/2002–02/21/2002	540	302 400	2.87	1.61
12/21/2001–01/20/2002	546	341 200	2.90	1.81
11/21/2001–12/20/2001	575	326 800	3.05	1.74
10/23/2001–11/20/2001	688	370 000	3.65	1.97
09/22/2001–10/22/2001	692	424 000	3.68	2.25
08/23/2001–09/21/2001	705	422 000	3.74	2.24
07/25/2001–08/22/2001	697	396 800	3.70	2.11
06/23/2001–07/24/2001	687	425 600	3.65	2.26
05/24/2001–06/22/2001	670	397 600	3.56	2.11
04/25/2001–05/23/2001	680	396 800	3.61	2.11
03/27/2001–04/24/2001	698	396 400	3.71	2.11
02/24/2001–03/26/2001	678	398 000	3.60	2.11
01/25/2001–02/23/2001	676	390 000	3.59	2.07
12/22/2000–01/24/2001	678	441 600	3.60	2.35
11/21/2000–12/21/2000	670	408 000	3.56	2.17
10/21/2000–11/20/2000	673	407 600	3.57	2.16
09/21/2000–10/20/2000	675	393 600	3.59	2.09

^aReprinted with permission from Sutter Medical Center.

Table 2A-4—Cancer center (underground, linear accelerators)^a

Dates	Peak kW	Total kWh	W/ft ²	kWh/ft ²
12/21/2002–1/20/2003	116	48 000	5.27	2.18
11/21/2002–12/20/2002	113	43 440	5.14	1.97
10/21/2002–11/20/2002	111	43 440	5.05	1.97
09/21/2002–10/20/2002	112	47 680	5.09	2.17
08/21/2002–09/20/2002	108	39 440	4.91	1.79
07/21/2002–08/20/2002	101	38 240	4.59	1.74
06/21/2002–07/20/2002	109	43 360	4.95	1.97
05/21/2002–06/20/2002	127	46 720	5.77	2.12
04/21/2002–05/20/2002	118	43 760	5.36	1.99
03/21/2002–04/20/2002	123	47 920	5.59	2.18
02/21/2002–03/20/2002	123	46 480	5.59	2.11
01/21/2002–02/21/2002	112	45 920	5.09	2.08
12/21/2001–01/20/2002	113	46 640	5.14	2.12
11/21/2001–12/20/2001	108	43 200	4.91	1.96
10/23/2001–11/20/2001	111	41 360	5.05	1.88
09/22/2001–10/22/2001	113	45 680	5.14	2.07
08/23/2001–09/21/2001	109	44 960	4.95	2.04
07/25/2001–08/22/2001	107	42 160	4.86	1.92
06/23/2001–07/24/2001	104	44 240	4.73	2.01
05/24/2001–06/22/2001	109	42 000	4.95	1.91
04/25/2001–05/23/2001	108	40 000	4.91	1.82
03/27/2001–04/24/2001	113	41 120	5.14	1.87
02/24/2001–03/26/2001	110	43 120	5.00	1.96
01/25/2001–02/23/2001	109	43 440	4.95	1.97
12/22/2000–01/24/2001	114	47 040	5.18	2.14
11/21/2000–12/21/2000	114	44 720	5.18	2.03
10/21/2000–11/20/2000	105	42 400	4.77	1.93
09/21/2000–10/20/2000	106	42 000	4.63	1.91

^aReprinted with permission from Sutter Medical Center.

Annex 2B

(informative)

Kaiser Roseville Medical Center continuous electrical demand profile (summer 2001) ²⁵

<u>Load</u>	<u>Description</u>
Substation A	Normal power, central plant and ATSS
Substation B	Normal power, hospital
Substation C	Normal power, hospital
Transfer switch TSCA	Critical branch
Transfer switch TSEA	Equipment system (hospital loads)
Transfer switch TSEB	Equipment system (in central plant)
Transfer switch TSEC	Non-essential load in central plant (chiller)
Transfer switch TSLA	Life safety branch

²⁵Reprinted with permission from Kaiser Foundation Health Plan Inc.

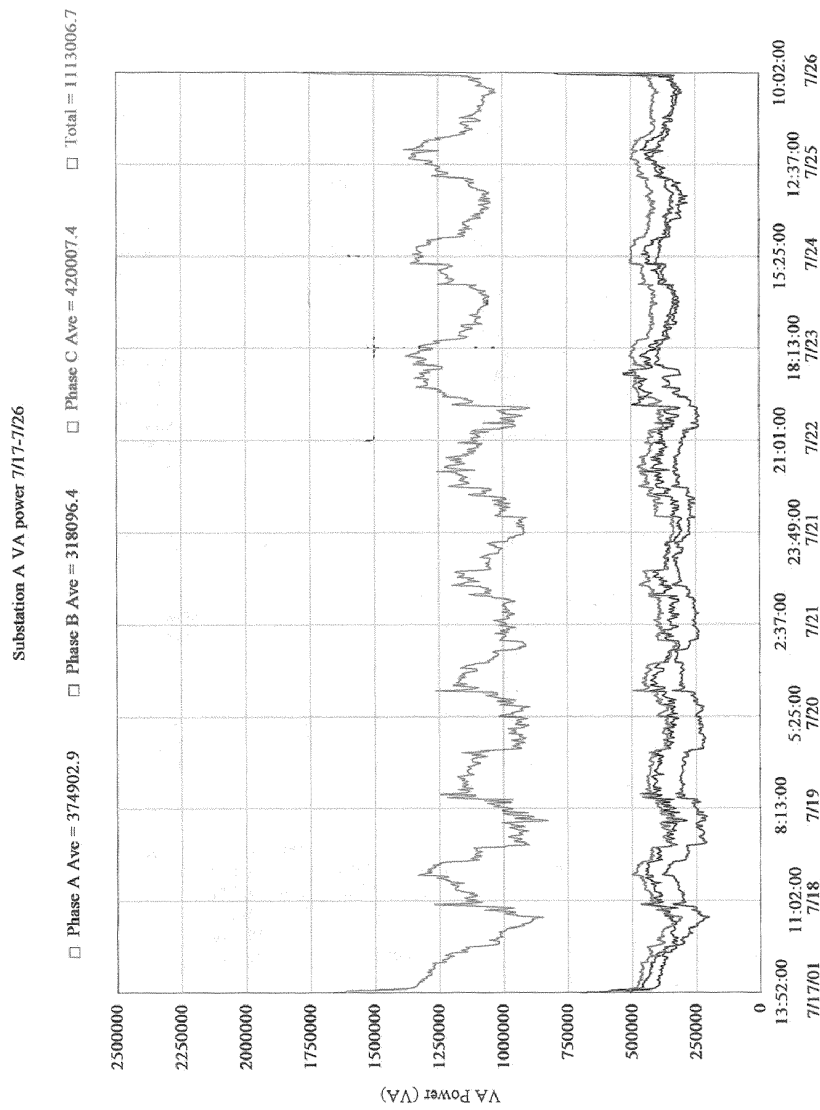


Figure 2B-1—Substation A VA power 7/17 to 7/26

Figure 2B-1 through Figure 2B-16 reprinted with permission from Kaiser Foundation Health Plan, Inc.

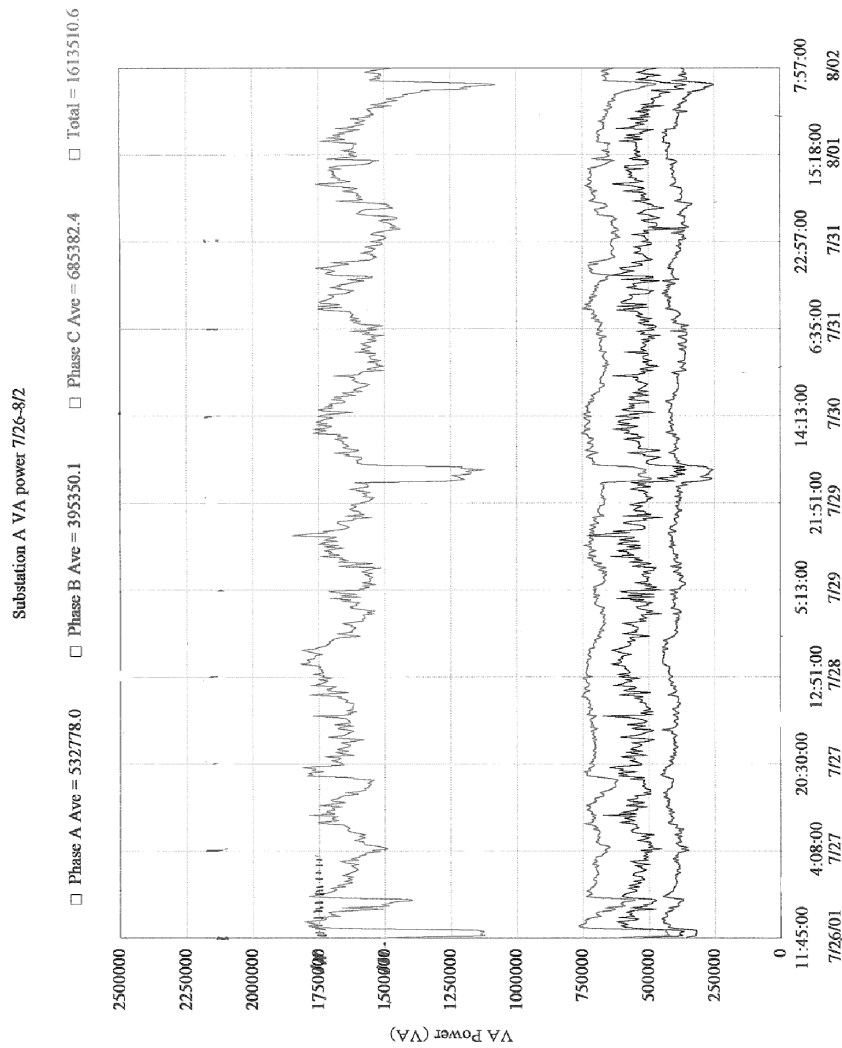


Figure 2B-2—Substation A VA power 7/26 to 8/2

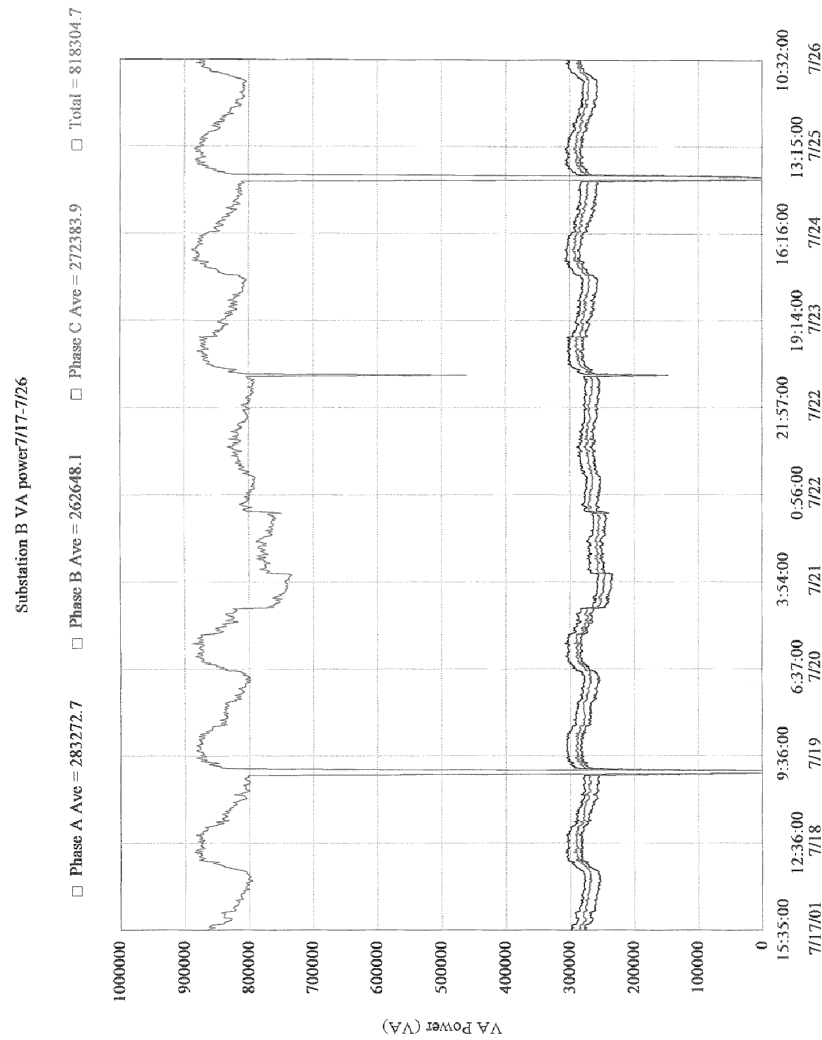


Figure 2B-3—Substation B VA power 7/17 to 7/26

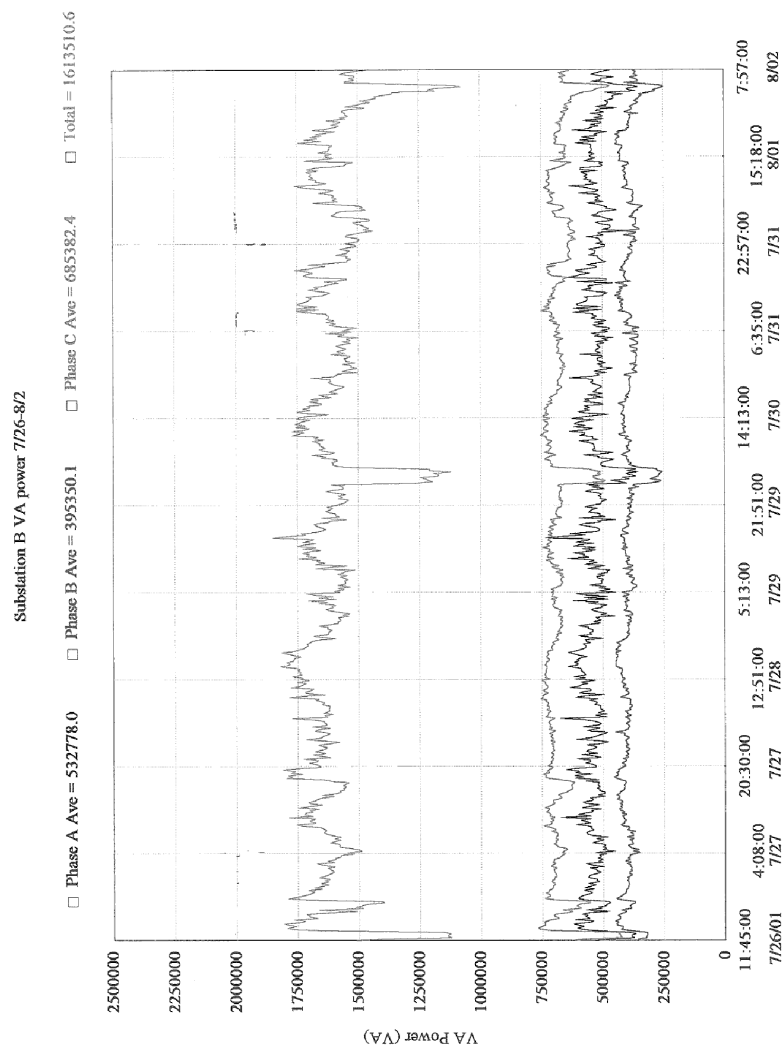


Figure 2B-4—Substation B VA power 7/26 to 8/2

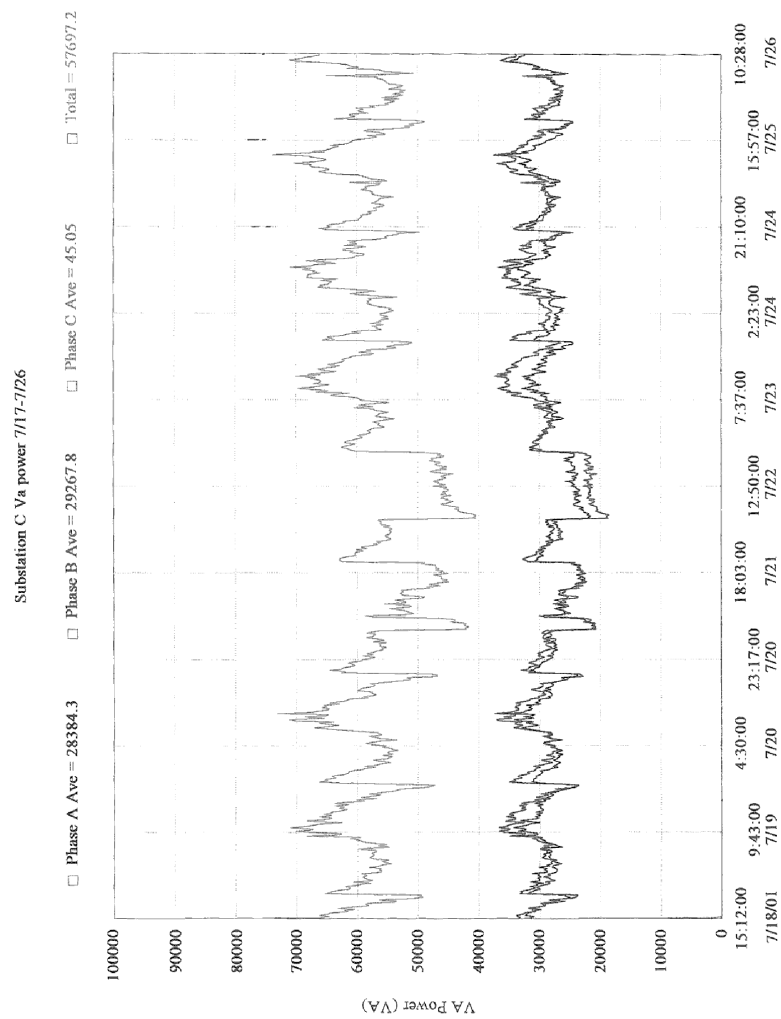


Figure 2B-5—Substation C VA power 7/17 to 7/26

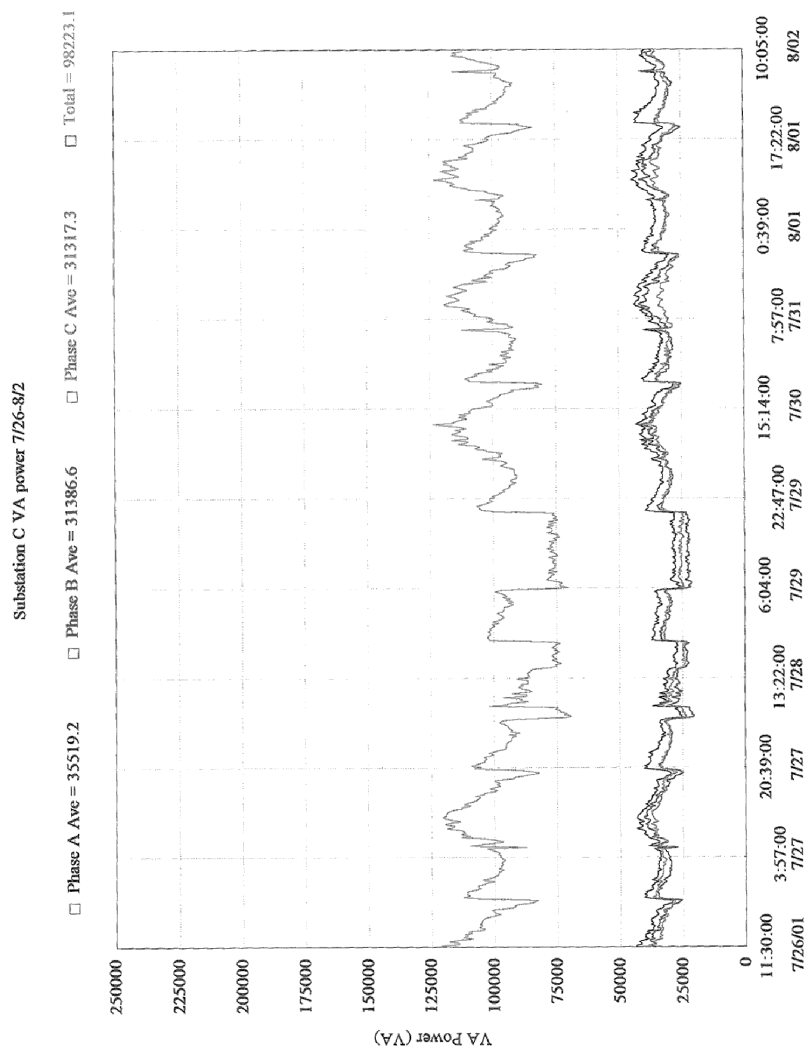


Figure 2B-6—Substation C VA power 7/26 to 8/2

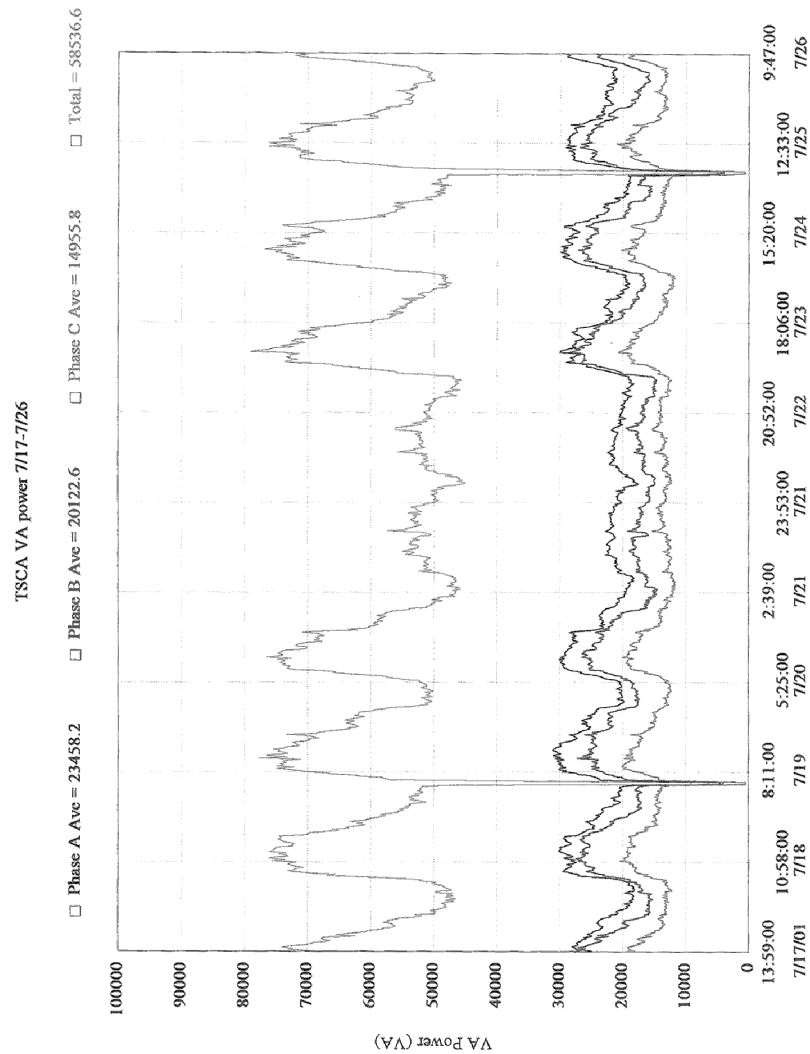


Figure 2B-7—TSCA VA power 7/17 to 7/26

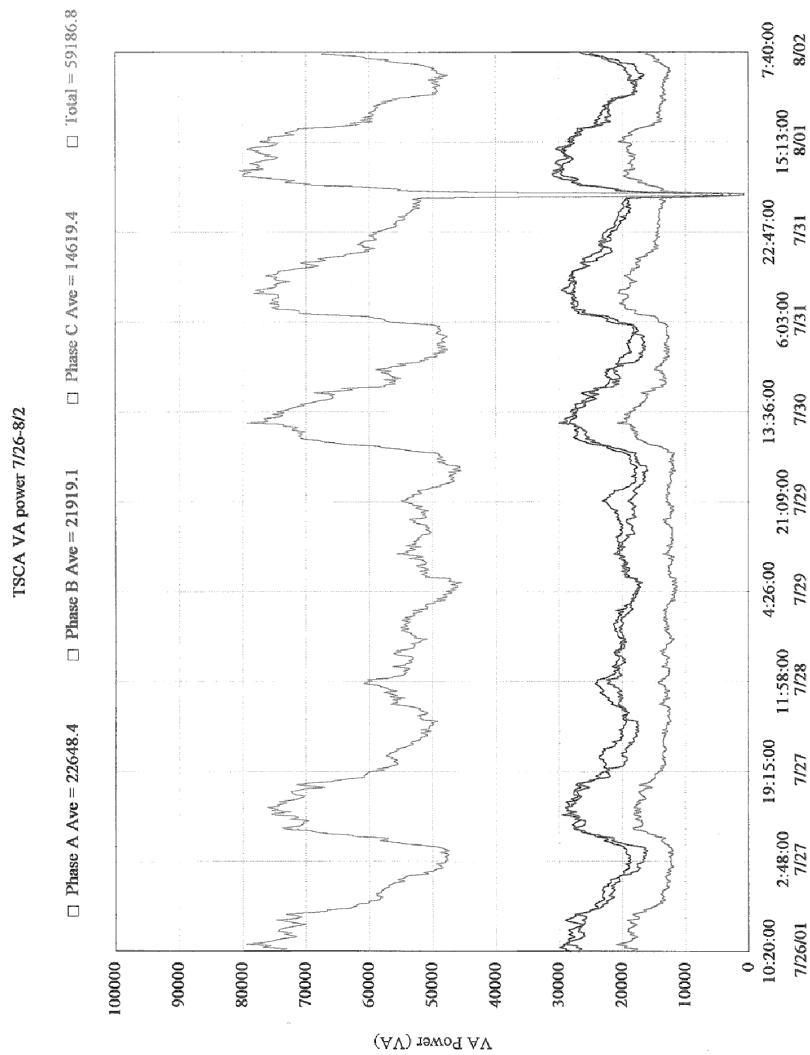


Figure 2B-8—TSCA VA power 7/26 to 8/2

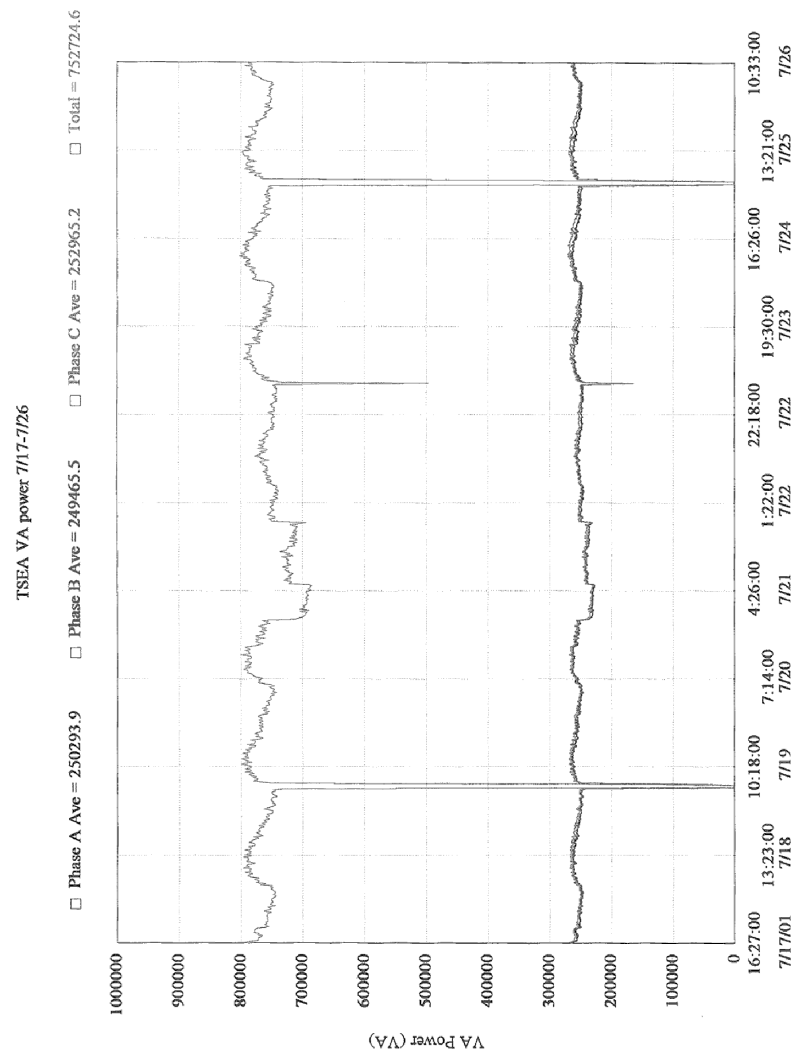


Figure 2B-9—TSEA VA power 7/17 to 7/26

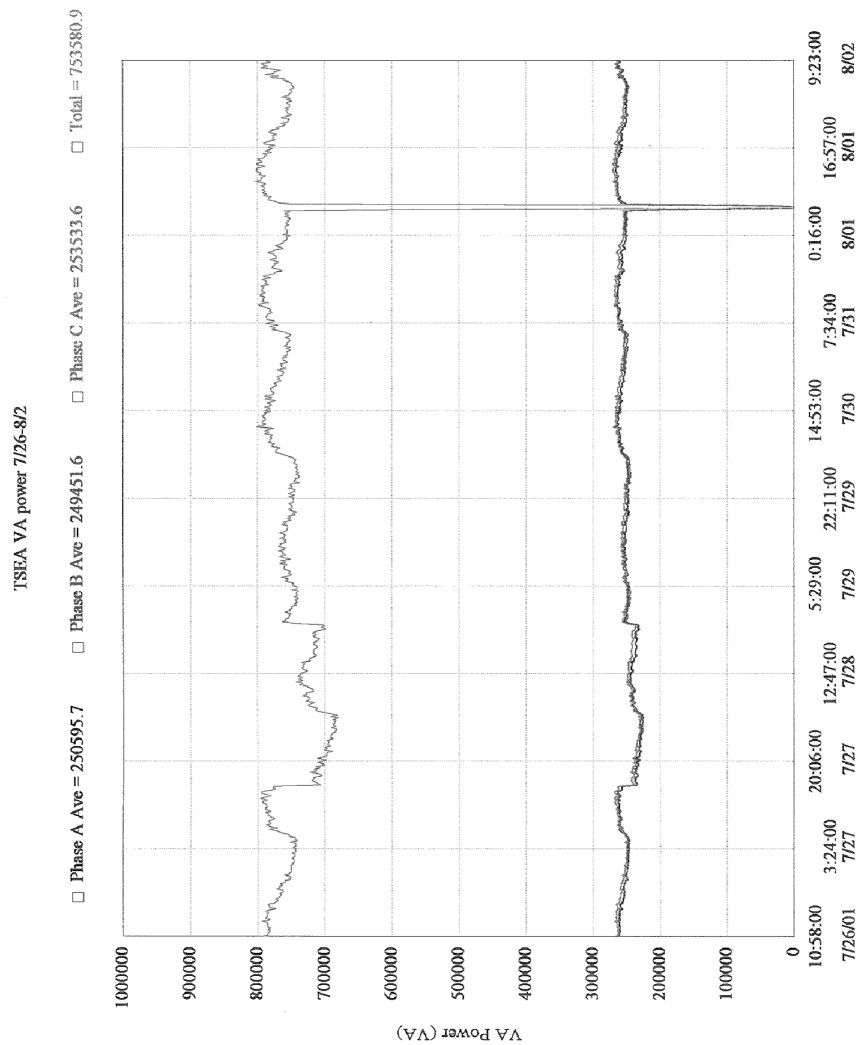


Figure 2B-10—TSEA VA power 7/26 to 8/2

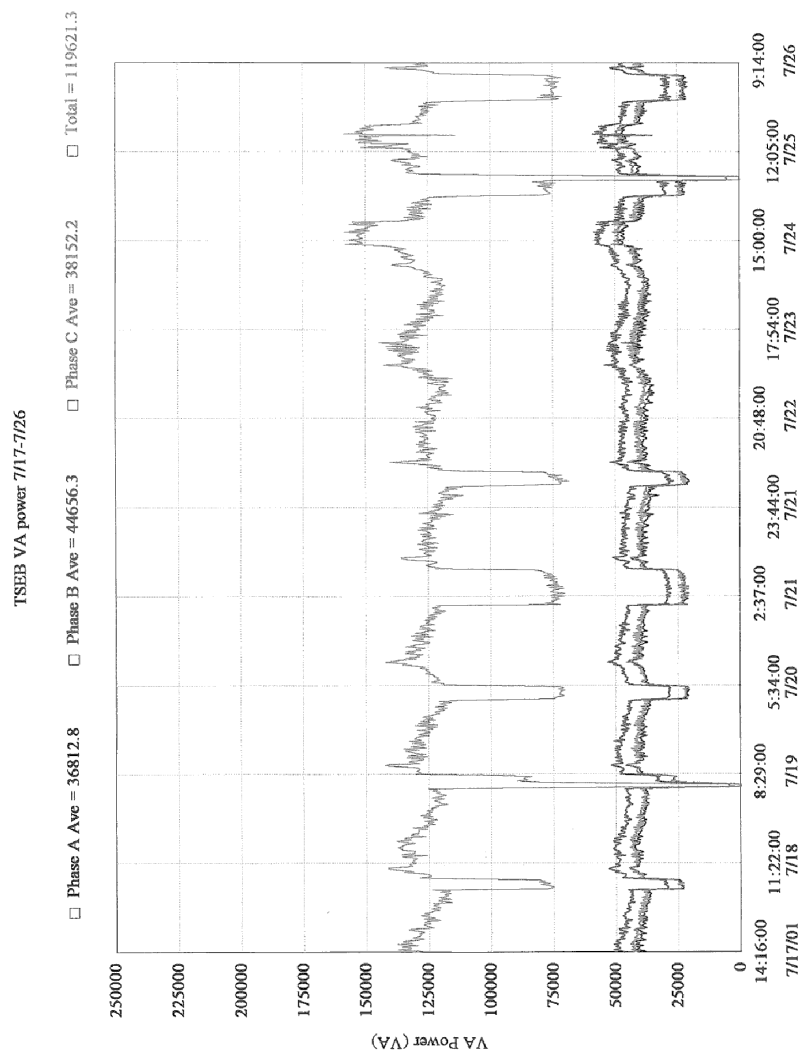


Figure 2B-11—TSEB VA power 7/17 to 7/26

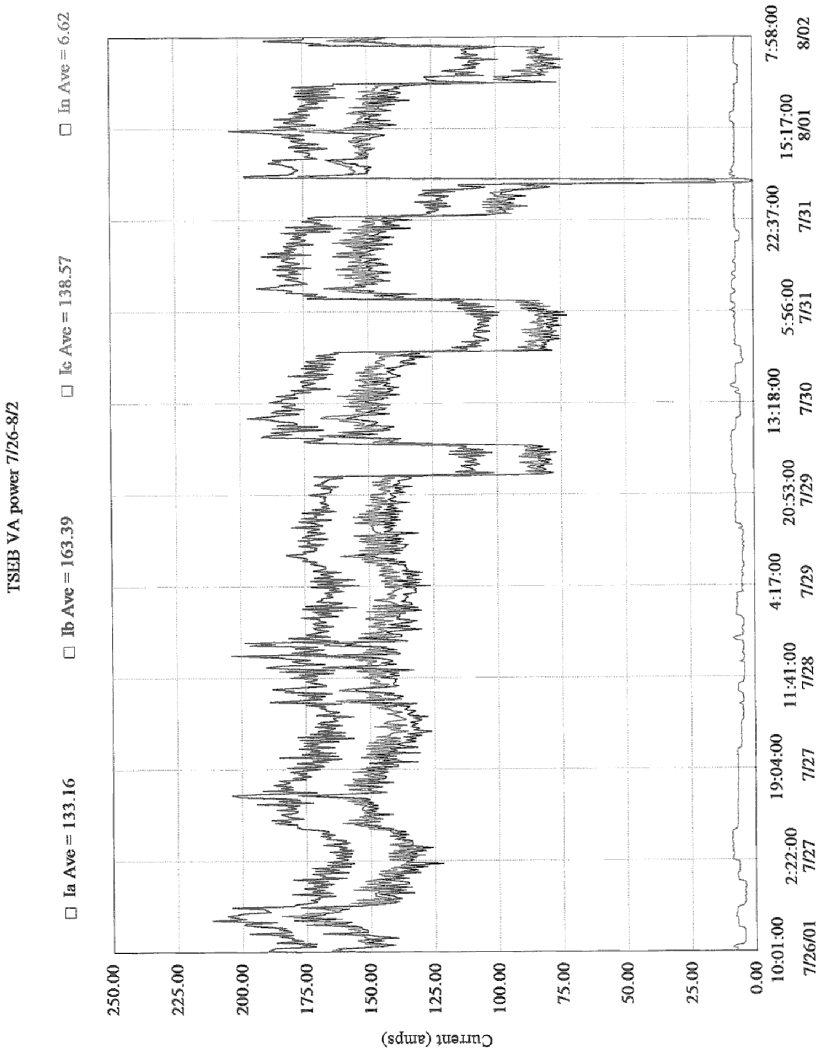


Figure 2B-12—TSEB VA power 7/26 to 8/2

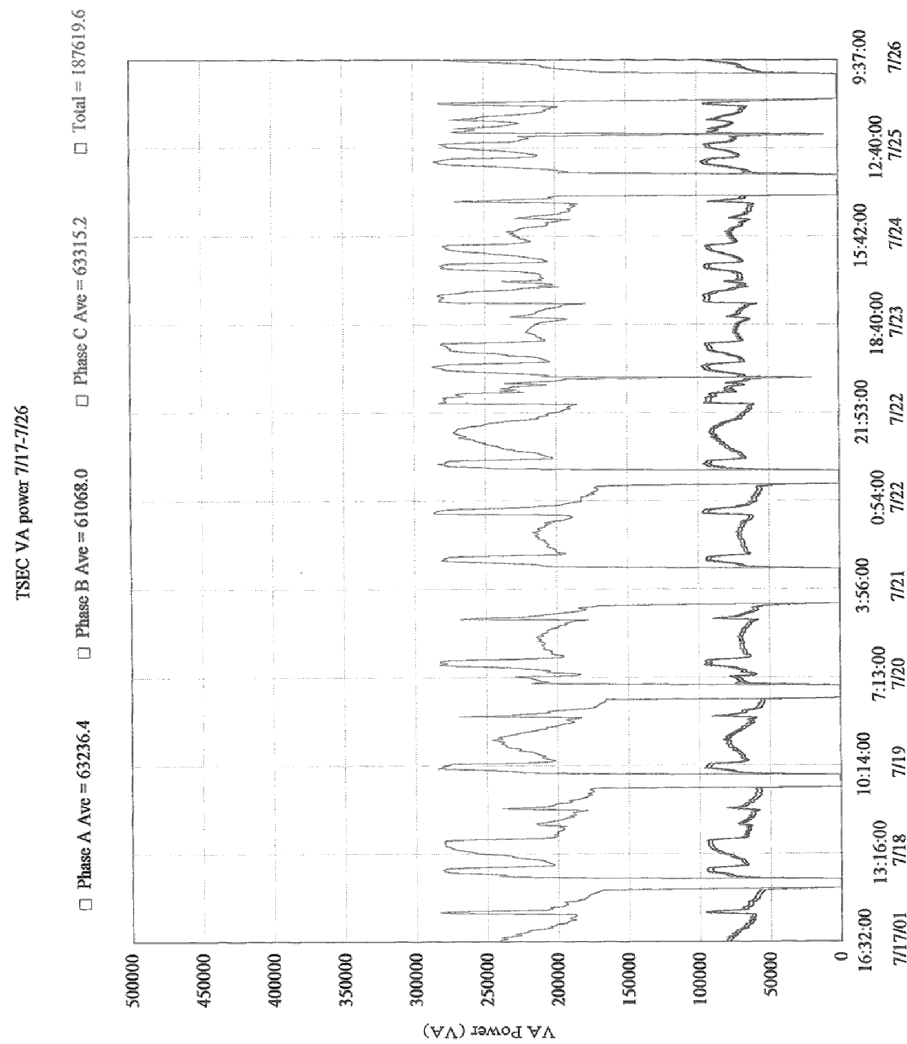


Figure 2B-13—TSEC VA power 7/17 to 7/26

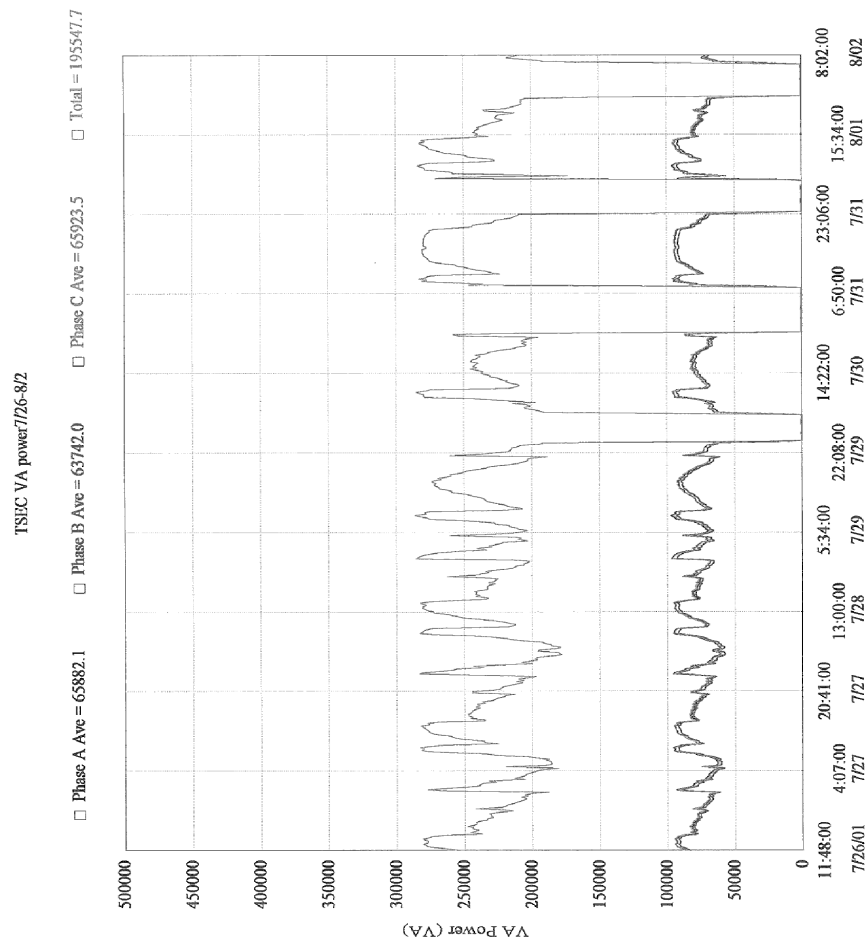


Figure 2B-14—TSEC VA power 7/26 to 8/2

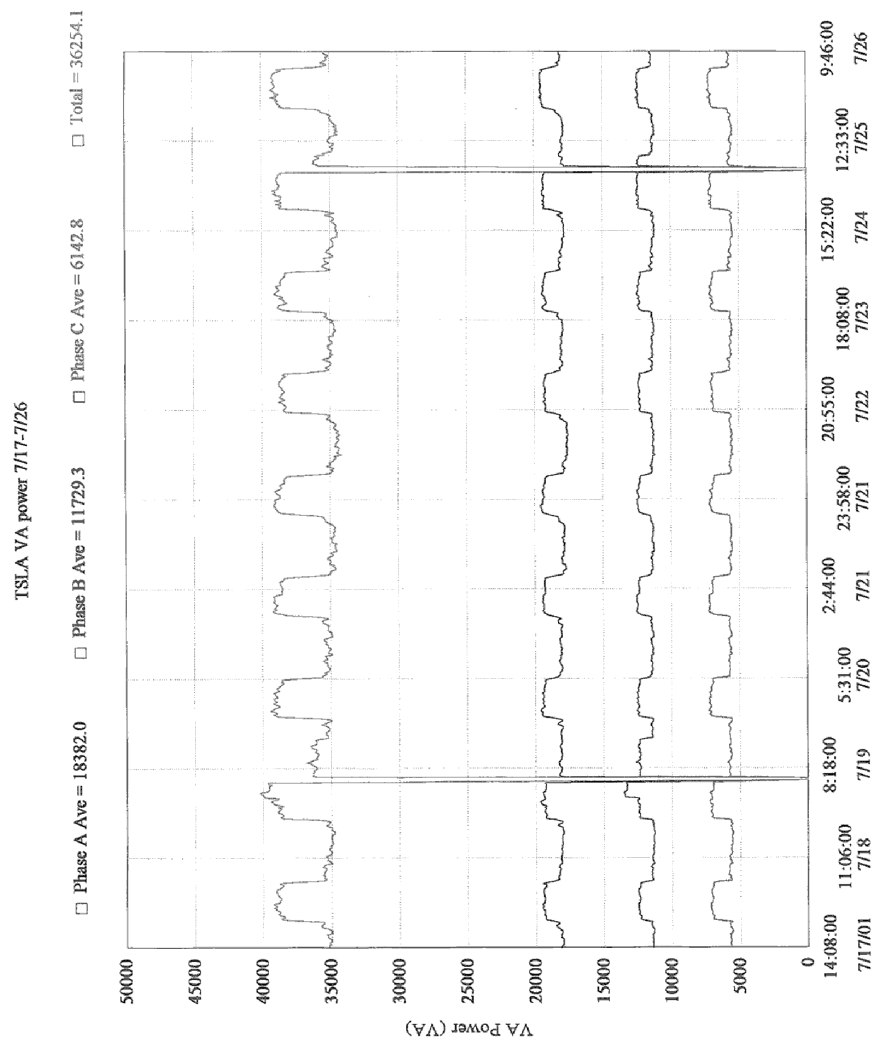


Figure 2B-15—TSLA VA power 7/17 to 7/26

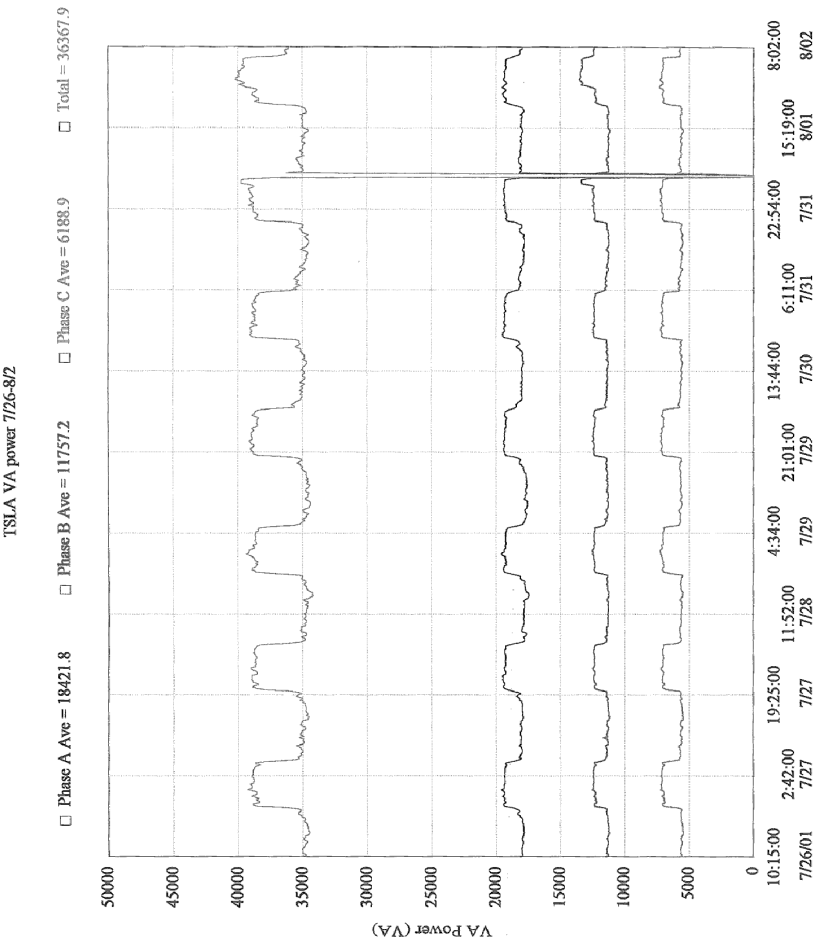


Figure 2B-16—TSLA VA power 7/26 to 8/2

Chapter 3

Electrical power distribution systems

3.1 General discussion

As the medical profession is increasingly more dependent upon complex electrical equipment and instrumentation for patient care and facility operation, the proper design of electrical power distribution systems in health care facilities is most important. The proper selection of the system components, and their arrangement, is critical to providing the health care facility with reliable, safe, and economical electric power.

Total or partial loss of electric power in a health care facility can cause acute operational problems (i.e., power loss to the lighting systems makes it impossible to perform vital medical tasks such as dispensing medicine, performing surgical procedures, or performing precise medical laboratory work). The loss of power to tissue, bone, or blood bank refrigerators can leave the health care facility without these vital resources. Power loss to electrical life support equipment such as heart pumps, medical vacuum pumps, dialysis machines, and ventilators can be fatal. Clearly, continuity of high-quality electric power should be the most important factor in the design of the electrical distribution systems for health care facilities.

Safety is another particularly important design criteria for health care facilities because

- a) Medical personnel frequently come into contact with electrical apparatus in their daily routines.
- b) Patients often are very vulnerable to electrical shock hazard because of their weakened condition, because of drugs or anesthesia administered, and/or because of their unconscious state. Electrical shocks that would not severely affect a healthy person could be fatal to a patient.
- c) It is necessary for maintenance personnel in health care facilities to come in daily or weekly contact with electrical distribution equipment for routine maintenance or minor system additions and renovations.

Maintainability, expandability, and flexibility are also very important design criteria. Hospitals are under increasing financial pressures, and the ability to spend capital dollars wisely is crucial to their overall health. Investments in electrical infrastructure that support maintainability, expandability, and flexibility can significantly contribute to the financial viability of the health care organization. Electrical systems should allow needed preventive and failure maintenance to be done with little disruption to the operations of the hospital. New technologies are always being presented to the medical profession. These new technologies may require additional power, additional support systems, and often, new building areas. The ability to expand, and the flexibility to change, the distribution system to meet these new technologies are also very important design criteria.

This chapter will develop these basic design criteria as they relate to system planning, electrical power systems, voltage considerations, current considerations, grounding,

overcurrent protection and coordination, electrical equipment, and installation and system arrangements.

3.2 Systems planning

Basic overall systems planning is the first and probably one of the most important phases in the overall design of an electrical power distribution system for a health care facility. During this phase, preliminary design data is gathered from administrators and staff of the health care facility, the local utility, and authorities having jurisdiction (AHJs) over electrical construction. All relevant national, state, and local codes, and facility design guidelines, should be reviewed. Two national codes having a major affect on health care power distribution design are:

- National Electrical Code® (NEC®) (NFPA 70)¹
- NFPA 99, Standard for Health Care Facilities

In addition, electrical engineers should examine the architectural plans and existing site conditions from an electrical system perspective to determine potential problems and needs. The following subclauses will discuss some of the issues that should be addressed during the system planning phase of the design.

3.2.1 Consult with the project architect

A vital step in systems planning is early and ongoing coordination with the project architect. A first step is giving input to, and providing review of, the preliminary floor plan and schematics from an electrical design perspective. The electrical engineer should be sure to provide informed input to the planners and architects to ensure that the spaces provided will support the needs of the electrical systems. Examples of early coordination input include the following:

- a) Provide adequate electrical and communication equipment room sizes
- b) Orient the spaces to minimize electrical costs and to support future maintenance and expansion of the system
- c) Provide adequate space in other certain areas having significant electrical equipment such as radiology suites or computer rooms
- d) Ensure electrical rooms have adequate accessibility to the electrical equipment and devices so as to prevent restrictions on equipment removal and installation after initial construction is complete
- e) Avoid locating “wet areas” near or above electrical or communication rooms
- f) Telephone/communications/data room size and location requirements need to provide needed working or maintenance clearances
- g) Provide adequate ventilation, cooling, and/or exhaust needs of electrical/communication rooms
- h) Provide space for routing of needed raceways, busways, and cable trays

¹Information on references can be found in 3.10.

- i) Plan space for any temporary installation and use of large electrical testing apparatus such as load banks that may be needed in the future

Electrical designers should locate electrical equipment in rooms dedicated to such equipment. Codes then prohibit piping, ductwork, or any architectural appurtenances not serving that room or space (and only those rooms) from passing over or within working clearances of the equipment. Accordingly, the designer needs to work closely with the architect and mechanical engineer to ensure proper placement and utilization of electrical spaces. A common problem to beware of is the location of toilet rooms or mechanical equipment rooms directly over electrical spaces. Planning these rooms in this way will result in the installation of “forbidden” piping or equipment over the electrical gear.

3.2.2 Consult with the health care facility staff

Engineers designing electrical distribution systems should also consult with various representatives of the facility early in the process.

- a) *Facility users.* The designer must know the specific functions to be performed in the facility. This information is needed in order to apply the proper codes and to weigh the importance of reliability, quality of electrical power, safety, and economy. For example, the reliability designed into a distribution system serving a hospital that specializes in open-heart surgery would not be justified in an outpatient clinic with no surgical functions. In addition, a facility that extensively utilizes computerized diagnostic, patient records, and accounting systems would require a higher quality of electric power.

The facility will usually have some plans for the future. These plans could be in the form of preliminary ideas or may be well documented. It is essential that these plans be analyzed and well incorporated into the electrical system design. Depending on budget constraints, additional capacity should at least “set up” the distribution system for future expansion(s).

- b) *Financial and budget representatives; information.* The designer must know the financial expectations of the administrators. The administrators will start a project with a budget that will need to be held to in order to allow the business to operate successfully once the project is complete. This budget must be considered in all phases of design in order to assure satisfaction. Such economic constraints, however, do not allow critical needs to be ignored. If the budget is unrealistic, the designer shall call this to the attention of the hospital administrator as soon as possible.

Health care administrators are concerned with both the one-time capital costs of the projects and the yearly operating costs of the installed systems. Designers should therefore provide information on both the initial capital requirements and the relative operating expenses of different possible design options. The administration may decide it is better to increase the capital outlay to reduce the facility’s ongoing expenses.

- c) *Facility operations staff.* The maintenance/operational staff often have preferences on the types of systems or equipment to be installed in their building(s). The reasons for these preferences are many and varied, and include

availability of replacement parts, prevalence of one vendor over another in an existing building, pricing, and levels of support locally available. Whatever the reason, the designer should keep these preferences in mind throughout the system design. If the designer feels that these preferences are unjustified, he or she should review them with the staff during the design process; and if necessary, with the administrators as to the cost, safety, and/or code implications of the staff's preference.

The skill, number (relative to facility size), and 24-hour availability of the facility's maintenance and operations personnel are an important design consideration. For example, if the maintenance personnel for a particular facility does not include skilled electricians, the designer may consider specifying a system that requires minimum maintenance, is relatively simple to operate, or is automated and supervised from a competently staffed remote location (in real time), compared to a system that requires much more maintenance and/or more ongoing operator involvement. Where the skill level of the maintenance staff may compromise the necessary design of the electrical systems to meet the other goals, then electrical designers should consider designs that are simpler and require less operator intervention.

- d) *Future expansion of the facility.*

3.2.3 Determine the basic loads and demand data

The designer should begin to tabulate preliminary load data. The preliminary architectural floor plans can be used effectively by superimposing load data on them. The floor plans should show major equipment loads, block loads based on square footage, and any future loads or buildings that the power system should be designed to accommodate. Always allow for load growth even beyond the defined plans for future expansions. See Chapter 2 of this recommended practice for guidance on determining these loads.

In the initial stages of planning, exact load data will seldom be known. However, the designer can estimate probable loads based on existing, similar, health care facilities. Helpful data is listed in Chapter 2 of this recommended practice and in IEEE Std 241™ (*IEEE Gray Book™*) (Chapters 2 and 16). Also refer to the electrical load data in the handbooks of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). The sum of the electrical ratings of each piece of equipment will provide a total "connected load." Since most equipment will operate at less than full load, and some intermittently, the "connected demand" on the power source is always less than the "connected load." Standard definitions for these load combinations have been devised and defined in Chapter 2 of this recommended practice, IEEE Std 141™ (*IEEE Red Book™*), and the NEC. The projected electrical system's heat loads should always be reviewed with the mechanical engineer to ensure that the air-conditioning system is sized properly for that load.

3.2.4 Consult with the local electric power company

Electrical designers should discuss the proposed health care facility with the relevant power provider to determine their specific requirements and limitations. The power

company will be interested in the size of the load demand, the projected power factor, the load factor, and the need for backup service. They will also be interested in the plans for on-site generation, the size of the largest motors and the method of starting (for voltage drop reasons), and any unusual demands or service requirements.

The designer should clearly determine the following:

- a) Are there any limitations on the size of load the utility can service?
- b) Will there be any “up-front” charges for supplying power to the facility?
- c) What type of service does the utility plan to provide? What are their requirements? What is the service history?
 - 1) Single phase (two or three wire) or three phase (three or four wire)
 - 2) Voltage level
 - 3) One circuit or two circuits
 - 4) Overhead or underground services
 - 5) Termination details for their cables and/or overhead lines (phase rotation, circuit labeling, etc.)
 - 6) Space requirements for their equipment (including landscaping, set backs, roadways, etc.)
 - 7) Metering requirements, details, and space requirements. Also are there any loads needing separate meters, etc.?
 - 8) Outage histories of proposed services to evaluate reliability (also confirm “outage” definitions as used in those histories)
- d) What components of the electrical service will the owner be required to furnish?
 - 1) Primary conduit(s)
 - 2) Primary trenching, backfill, and “markers”
 - 3) Primary cables
 - 4) Transformer(s)
 - 5) Transformer vault(s)
 - 6) Concrete pad(s)
 - 7) Metering and metering conduit
 - 8) Surge arresters and transient voltage surge suppression
 - 9) Environmental protection (noise abatement from transformers, oil spill systems, fire protection, etc.)
 - 10) What is the physical “break line” between utility-supplied and owner-supplied equipment (e.g., property line, last pole, underground vault)?
- e) What are the utility’s billing rates and rate structure? Following are some general considerations (see Chapter 2 for more details).
- f) How reliable will the power source be? (Obtain a copy of the utility outage record for the past several years.)

- g) What will be the maximum and minimum voltage to be expected at their power supply point? (Will voltage regulating equipment be required?) If possible, get a copy of the voltage meter chart.
- h) May internal generation, if it will exist in the proposed system, be allowed to operate in parallel with the utility? If yes, what are their requirements on relaying, control, metering, and communications?
- i) What is the maximum short-circuit current available? Ask them to supply three-phase and single-phase-to-ground duties (with the respective X/R ratios) for today's system, and as expected 5 years into the future.
- j) What are their protective device coordination requirements?

Please note that the utility is not required to follow the NEC in providing an electrical service. The utility does normally, however, follow the National Electrical Safety Code™ (NESC™) (Accredited Standards Committee C2). The designer in any case should stress the utility's responsibility to work with the designer in order to provide the health care facility with safe, reliable service.

3.2.5 Reliability issues

Life support and high-value continuity uses may merit the redundancy offered by secondary-selective systems, radial systems with secondary voltage transfer switches, and other similar systems. The system designer should plan to perform the increased engineering analysis that accompanies these higher reliability systems, and compare the value of improved continuity of service, reduction in false outages, and the improved level of equipment protection—all balanced against cost and simplicity of operation. IEEE Std 493™ (*IEEE Gold Book*™) describes the reliability of radial systems and other systems.

3.2.6 Consult with the local authorities having jurisdiction over new electrical construction

The designer should also meet with the local AHJs over electrical construction and discuss their special requirements and interpretations of the relevant codes. The designer should incorporate the effects of these interpretations during the system planning stage. The local authorities can also provide input on any local natural phenomena that may affect the electrical design, such as the presence of frequent violent electrical storms, seismic conditions, or a corrosive environment. These authorities include the electrical inspector, fire marshal (chief), Department of Health (city, state, and/or federal), Occupational Safety and Health Administration (OSHA), insurance underwriters, etc.

3.3 Electrical power systems basics

Power systems for health care facilities require a high degree of safety, operability, maintainability, expandability, flexibility, and reliability. Some areas of health care facilities require electrical design similar to that documented in IEEE Std 241 (*IEEE Gray Book*) (Chapter 2 and Chapter 16). However, most areas will require additional considerations as dictated by the following:

- a) The numerous governing codes and standards
- b) The use of complex and electrically sensitive medical equipment
- c) Most importantly, the fact that patients and medical personnel must be guarded against electrical hazards

3.3.1 Power sources

Generally, the electric utility provides power to the facility. Codes require the owner to also supply an alternate power source, such as an on-site generator set, uninterruptible power supply (UPS), or battery/inverter system. However, when the normal source consists of an on-site power generator(s), the alternate power source required can be another power generator unit or the electric utility. A battery/inverter system can be applied as the principal alternate power source for nursing homes, residential custodial care facilities, and other health care facilities provided they meet the conditions outlined in the NEC, Article 517, and NFPA 99. Many facilities will require a UPS for computing centers, communication systems, or other critical, sensitive loads.

Additional data pertaining to generator units and batteries can be found in Chapter 5 of this recommended practice, as well as the NEC (Articles 517 and 700), NFPA 99, NFPA 110, NFPA 111, and IEEE Std 446TM (*IEEE Orange Book*TM).

3.3.2 Distribution circuits

Distribution systems for health care facilities are basically divide into two categories—the normal (“non-essential”) electrical system and the essential electrical system. The normal source supplies both systems, but the essential electrical system can transfer to the alternate power supply whenever the normal power source experiences a power failure.

- a) *Non-essential electrical system.* The non-essential electrical system consists of distribution equipment and circuits that supply electrical power from the normal power supply to loads that are not deemed essential to life safety, or the effective and essential operation of the health care facility.
- b) *Essential electrical system.* The essential electrical system consists of the transfer equipment, distribution equipment, and circuits required to assure continuity of electrical service to those loads deemed as essential to life safety, critical patient care, and the effective operation of the health care facility. NFPA 99 and the NEC cover these topics in great detail and should be carefully reviewed. The information given here summarizes much of that data.

Codes require that hospital essential electrical systems be subdivided into two systems—the *emergency system* and the *equipment system*. The emergency system consists of two branches defined as the life safety branch and the critical branch. These branches include distribution equipment and circuitry, including automatic transfer devices required to enable emergency loads to be transferred from normal to emergency power sources automatically. To increase the reliability of the system, circuits from each of these two branches are required to be installed separately from each other and from all other types of circuits. NFPA 99 and the NEC require that the hospital’s emergency system automatically restore electrical power within 10 seconds of power interruption. The NEC

also defines the types of electrical loads to be served by the life safety branch and the critical branch. The NEC allows the designer to install “other equipment and devices necessary for the effective operation of the hospital” on the critical branch of the emergency system. This gives some flexibility in tailoring the design to the specific needs of the health care facility. The designer should use his/her experience, hospital staff input, and good engineering judgment in applying this article to the design.

The equipment system consists primarily of three-phase distribution equipment and circuits, including automatic, delayed-automatic, or manual transfer devices to serve equipment loads essential to the effective operation of the facility as defined by NFPA 99 and NEC Article 517. In addition, the Joint Commission, formerly the Joint Commission on Accreditation of Healthcare Organizations (JCAHO), requires that if a hospital has a fire pump it must be connected to the equipment system via an automatic transfer switch (ATS).

For nursing homes and residential custodial care facilities, which provide care requiring electromechanical sustenance and/or surgical or invasive treatment requiring general anesthesia, the essential electrical system also consists of two systems, but these two systems are the *emergency system* and the *critical system*. The emergency system in these cases is limited to those loads defined for the life safety branch for hospitals, plus sufficient illumination to exit ways in dining and recreation areas. These emergency system circuits are required to be installed separately and independent of nonemergency circuits and equipment. The NFPA standards require that this emergency system branch be designed to permit automatic restoration of electrical power within 10 seconds of power interruption. The critical system is limited to critical receptacles, task illumination, and equipment necessary for the effective operation of the facility.

For other health care facilities (excluding hospitals, nursing homes, and residential custodial care facilities where the facility administers inhalation anesthetics or requires electromechanical life support devices), the essential electrical system consists of one system supplying a limited amount of lighting and power considered essential for life safety and orderly cessation of procedure whenever normal electrical service is interrupted for any reason. The type of system selected should be appropriate for the medical procedures performed in the facility.

NFPA 99 requires the emergency power source, typically standby generators, to meet the requirements defined for Type I, Type II, and Type III installations as noted in NFPA 99. These “type” designations define maximum start times, maximum run times, etc.

3.4 Voltage considerations

The proper selection, regulation, and quality of utilization voltages are extremely important because of the extensive use of sensitive medical equipment. The health care facility cannot fulfill its mission of providing patient care without this equipment, and misapplied or poorly regulated voltages or voltages with high harmonic content can cause the equipment to fail to operate. Engineers should recognize the dynamic characteristics of the overall system, and the proper principles of voltage control should be applied so that

satisfactory voltage will be supplied to all utilization equipment under all conditions of operation (i.e., including large motor starting). Refer to IEEE Std 141 (*IEEE Red Book*) and IEEE Std 241 (*IEEE Gray Book*) for a detailed discussion of voltage.

3.4.1 Select system voltages

The best voltage levels for a particular system will depend on the utility voltage available, the size of the health care facility, the loads served, expansion requirements, the building layout, voltage regulation requirements, and cost.

Typically, a large health care facility will be supplied power at a medium voltage level from the utility, and it will be stepped-down to either 480Y/277 V or 208Y/120 V for utilization. Either 480 V or 208 V can be used to supply mechanical equipment (chillers, fans, pumps, etc.), medical equipment (radiology, medical air pumps, etc.), and other support equipment such as laboratory equipment and kitchen equipment. If 480 V is present, however, it offers a number of advantages for certain applications, particularly for larger loads. In general, 480 V systems can serve the same amount load using much smaller conductors, frequently requiring fewer circuits and smaller feeders.

The use of 277 V lighting in lieu of 120 V in large health care facilities is common. The application of 277 V lighting in hospitals, however, differs from other commercial facilities because of the requirement for the four divisions of the electrical system (normal, critical branch, life safety branch, and the equipment system). Depending on other equipment requirements, applying 277 V lighting may increase the number of 480Y/277 V panels on each floor and/or in each electrical room. There is no general rule on when to apply 277 V lighting. Each individual application should be analyzed to determine its feasibility. Typical benefits of 277 V lighting include reduced system losses, reduced number of branch circuits for lighting, reduced sizes of power conductors, reduced heat gains on the air conditioning system due to power losses, and segregation of the harmonics of the electronic ballasts in luminaires from the medical equipment operating at 208Y/120 V. Once the designer has chosen the preferred operating voltage for the lighting systems, it should be used consistently throughout the facility. It is dangerous to operating personnel to mix voltages on similar type lighting systems.

3.4.2 Nominal voltage

Once engineers select the nominal utilization voltages for the system, they should carefully check all medical equipment to assure proper application. If the equipment will be new, it should be ordered to one of the planned utilization voltages. If this is not possible, then a “buck/boost,” autotransformer or standard two-winding transformers will be needed to supply rated voltage to the equipment. A common misapplication includes the use of nominally rated 230 V motors installed on a 208 V system.

Carefully consider the design of the distribution system to supply equipment obtained from international sources. These are often designed for use on 415Y/240 V, 400Y/230 V, or 380Y/220 V, and/or 50 Hz systems. International voltages are harmonized to 400Y/230 V ($\pm 10\%$). While the voltage in a particular country could be 415Y/240 V,

400Y/230V, or 380Y/230 V, they should be recognized as 400Y/230 V systems and are acceptable tolerances.

Imaging equipment is available in a variety of single-phase and three-phase voltages. Make sure to know the exact voltage requirements and tolerances of the equipment from the manufacturer's data to properly plan for its installation. Because of their operating characteristics (low load factor, low power factor, and/or high surges), power distribution systems dedicated to these pieces of equipment may be appropriate.

In general be aware that transformer regulation may result in a voltage drop of 2.5% to 5%. Therefore, to maintain acceptable voltage at the utilization equipment, the voltage drop in the wiring should be limited to less than 2.5%.

3.4.3 Voltage variation and disturbances

Variations in the sinusoidal voltage waveform can be caused by many different types of power system disturbances. Transient overvoltages are caused by lightning, capacitor switching, fault switching, welding, arcing grounds, brush-type motors, or switching of inductive loads, such as motors, radiology equipment, etc. Nonlinear loads such as switch-mode power supplies, ballasts, and adjustable speed drives are generators of harmonics that can cause serious neutral overloading, transformer overloading, and interference problems. See IEEE Std 1100TM (*IEEE Emerald Book*TM). Momentary total loss of voltage can be the result of utility switching, fault clearing operations, some transient voltage arrester operations, or equipment failure. Transient voltage suppression is dealt with in IEEE Std 141TM (*IEEE Red Book*TM), IEEE Std 142TM (*IEEE Green Book*TM), and IEEE Std 241TM (*IEEE Gray Book*TM), and the IEEE Surge Protection Standards Collection (C62) [B8].² See also the requirements of NFPA 780.

Many kinds of voltage protection, regulating, and conditioning equipment is available on the market. Surge arresters, voltage regulators, transient voltage surge suppressors, shielded isolation transformers, voltage regulators, power conditioners, UPSs, or combinations of this equipment can be applied to solve voltage variation problems. The choice of which equipment to apply depends on the nature of the voltage variations and the characteristics of the equipment to be protected.

- a) Surge arresters, voltage regulators, and transient voltage surge suppressors are designed to remove temporary overvoltages from the power system for protection of distribution and utilization equipment.
- b) Shielded isolation transformers are effective in rejecting certain types of transients. They will, however, not provide a clean, noise-free ground. IEEE Std 142 (*IEEE Green Book*) and IEEE Std 1100 (*IEEE Emerald Book*) are excellent references on transformer and sensitive load grounding.
- c) Voltage regulators or constant voltage transformers are designed to tightly control output voltage (for many cycles) regardless of variations of input voltage. The range of input voltage for which the output voltage will remain regulated is generally -10% to +20%, or -15% to +15% of nominal. In addition to input

²The numbers in brackets correspond to those of the bibliography in 3.11.

voltage range, other considerations in applying a voltage regulator are regulator load sensitivity, load compatibility, power factor, energy efficiency, and electrical isolation.

- d) Power conditioners generally combine regulation, isolation, and/or transient suppression into one package.
- e) Static (electronic) UPSs provide a constant voltage with standby battery capacity for power failures and short outages. Static UPSs may, however, be a source of electrical noise/harmonics themselves and may not always deliver a clean sinusoidal waveform unless they are specified carefully.

Rotary (mechanical/electrical) UPSs are available to provide a pure sinusoidal waveform. Further, there is a rotary UPS configuration that is always online and that relies on a diesel engine for backup. This type of UPS does not require large battery banks.

Harmonic currents can be controlled or suppressed through the use of delta-connected transformers, harmonic filters, isolation transformers, etc. IEEE Std 141 (*IEEE Red Book*) deals with this subject in great detail.

The first step toward properly solving a voltage variation problem is to properly diagnose the problem. Only when the problem is properly defined is it possible to select the proper voltage regulating, protection, or conditioning equipment. Unless the exact problem is known, an engineer may specify equipment that amplifies the problem, rather than reduces or eliminates the problem.

3.4.4 Voltage problem diagnosis

In an existing facility, engineers can use a high-accuracy power analyzer to diagnose voltage problems. These tools can observe a portion of the electrical system over a period of time with voltage variations and quality recorded including magnitude, duration of the variation, the per-unit harmonic content, and the time of occurrence. This data can then be matched with medical equipment operational logs, problem logs, and/or maintenance trouble reports to determine any possible correlations.

In new facilities, the distribution equipment can be designed to include solid-state metering to provide continuous monitoring. These monitors can provide detailed power quality information in addition to load data.

Users will commonly notice variations in the voltage in a health care facility in the operation or output of computerized equipment. The designer should calculate voltage variations from motor starting, etc., on all of the various available circuits. Select the arrangement that best provides stable voltages within acceptable limits, at the lowest cost. High electrical energy losses may result if equipment operates with voltages that are unbalanced or high in harmonic content. If the load being served is on the essential electrical system, analyze both normal and emergency power sources.

3.4.5 High transient loads

Radiology and some other machines draw very high momentary currents during an exposure. These machines therefore require a low-impedance source to assure that the voltage drop is within acceptable limits, usually 3% to 5%. An x-ray tube will experience loss of life and equipment malfunction if it does not have the proper voltage regulation. Note, however, that standard voltage regulators applied on radiology equipment feeders may not improve regulation because the pulse width of the equipment may be less than the response time of the regulator.

Voltage fluctuations and dips caused by motor starting within the hospital should be maintained within the limits dictated by the utility and by industry standards for computerized equipment. Normally, systems can accomplish this goal if the motors have reduced voltage starters or *soft starters* on large motors, or if separate transformers supply the large motors. The designer should carefully study the application of these starters, or separate transformers, to minimize system voltage drops at reasonable costs.

3.5 Current considerations

The load equipment in a health care facility will determine the full-load current requirements in a health care power system. However, the power sources, together with contributions from rotating equipment such as motors will determine the short-circuit current requirements of the system.

The impedance of the circuits and equipment from the source to the point of fault and the X/R ratio of the system will limit the short-circuit current that may flow during a fault to the point of the fault. The fault current will not necessarily be directly related to the power demand of the system.

In most health care facilities, the fault-current contribution will differ in magnitude and decay rate between the normal and the alternate power sources. This can occur when

- a) The normal power source is from a utility having a high-fault current capability, and the service entrance point is removed by several transformations and transmission circuits, from the utility generation sources.
- b) The alternate power supply consists of a relatively low kilovoltampere on-site generator, or generators, and relatively short-distribution circuits between the alternate power supply and essential electrical power circuitry.

Thus for a fault occurring within the essential electrical power system, the fault-current magnitude from the normal power source would be relatively large and have a slow decay rate. A fault under the same fault conditions when served by the alternate power source would be relatively small and have a fast decay rate. These factors should be taken into account when selecting and setting protective devices since the essential electrical system can be supplied power from either source.

Short-circuit calculations must be understood to correctly apply protective equipment, choose adequately rated equipment, choose protective devices settings, determine degree

of coordination achieved, and calculate the voltage dips of impact loads such as motor starting, etc. Refer to IEEE Std 141 (*IEEE Red Book*), IEEE Std 241 (*IEEE Gray Book*), IEEE Std 242 (*IEEE Buff Book*), and IEEE Std 393™ to obtain information on these fundamentals.

3.6 Grounding

The word *grounding* is commonly used in electrical power work to cover both “equipment grounding” and “system grounding.” These and other terms used when discussing this topic are defined in the NEC and IEEE Std 142 (*IEEE Green Book*). These definitions should be quite familiar to obtain a better understanding of grounding principles.

In health care facilities, both the system and equipment are grounded. In addition, codes require special grounding requirements for those subsystems and equipment involved in patient care areas, operating rooms (ORs), anesthetizing locations, and special environments as presented in Chapter 4 of this recommended practice, the NEC, and NFPA 99.

3.6.1 Equipment grounding

Equipment grounding is the interconnection and bonding (grounding) of nonelectrical conducting material that either encloses, or is adjacent to, electrical power conducting components. Its purpose is to reduce electrical shock hazards; to provide freedom from fire hazards; and to minimize damage to equipment from component overheating caused by overcurrents, arcs, or bolted faults. To achieve these safety goals, engineers need to design and ensure the proper installation of a sufficiently low-impedance path to ground-fault currents. For ac systems, the (return) ground current will flow through the lowest impedance path, not the lowest resistance path as in dc systems. The lowest ground-impedance path will be a path close to the power conductors, such as a ground conductor installed with the power conductors and/or the metal raceway enclosing the power conductors (i.e., the conduit, housing of busway).

Furthermore, to maintain the lowest ground-current impedance, junctions and terminations must be properly installed. Metal joints should make good contact to avoid sparking during fault conditions. Adequate connections between equipment ground buses and/or housings and metal raceways should be provided. In addition, size the ground return circuit components (conductors, terminations, etc.) to carry the available ground-fault current for all types of fault conditions and durations “permitted” by the overcurrent protection system (i.e., the ground-fault current may be 12 000 A or more).

3.6.2 System grounding

System grounding relates to the type of grounding applied to the electrical system. The basic reasons for system grounding are the following:

- To limit the differences of electrical potential between all noninsulated conducting objects in a local area.
- To provide for isolation of faulty equipment and circuits where a fault occurs.

- To limit overvoltages appearing on the system under various fault conditions.

WARNING

Note that in an ungrounded system, a fault condition can, in certain instances, lead to system resonance that causes an extreme overvoltage to be imposed on the system. This overvoltage can be sufficient in magnitude to create severe shock hazard as well as cause electrical equipment failure due to insulation breakdown. For these and other reasons, codes require system grounding for all health care facilities.

Several methods for achieving system grounding are as follows. The preferred method for health care facilities is solid neutral grounding, since the system neutral is generally readily available. This will avoid the special system operating precautions required when employing other grounding methods. See also IEEE Std 142 (*IEEE Green Book*).

- a) *Selection of system grounding points.* The NEC requires the engineer to solidly ground the system at each voltage level to achieve the advantages of neutral grounding in all parts of the system. Each voltage level may be grounded at the neutral lead of a generator; power transformer bank; or in rare instances, neutral deriving grounding transformer.

When two or more sources serve a given point, each source should have a grounded neutral point since the bus-tie circuit may be open. Refer to IEEE Std 242 (*IEEE Buff Book*) and to NEMA PB 2.2 for special techniques of system neutral grounding of double-ended substations.
- b) *Neutral circuit arrangements.* After selecting the grounding method, the engineer will need to consider how many source generator(s) or transformer neutral(s), or both, will be used for grounding, and whether to use
 - 1) An independent ground for each neutral, or
 - 2) A neutral bus with single ground connection.
- c) *Medium-voltage source neutral(s).* The medium-voltage portion of the power system most often consists of a three-phase, three-wire system where the neutral is not used as a circuit conductor. IEEE Std 141 (*IEEE Red Book*) extensively covers the advantages and disadvantages of various medium-voltage grounding methods as well as design conditions for each method.
- d) *Low-voltage source neutral(s).* Health care facilities usually have three-phase, four-wire system using the neutral conductor as a circuit conductor for their low voltage system. Thus, the source's neutral should be solidly grounded to permit neutral loading as well as meet the requirements of the NEC.

Where the power supply consists of services that are dual fed in a common enclosure or grouped together in separate enclosures and employ a nonswitched (solid) secondary tie, the common neutral conductor can be effectively grounded at one point. Where the power supply for the health care facility consists of a normal and an alternate power supply, at least one of the power supplies, usually normal, is considered the service and its neutral(s) will need to be effectively grounded. If the normal and alternate power supply is not

electrically connected, then both power supply neutrals will have to be effectively grounded.

3.6.3 System and load characteristics

The type of grounding system and the arrangement of system and equipment grounding conductors will affect the service continuity. Engineers should design grounding conductors and connections so that objectionable stray neutral currents will not exist and ground-fault currents will flow in low-impedance, predictable paths to protect people from electrical shock and to assure proper operation of the circuit protective equipment.

Where systems serve phase-to-neutral loads, codes require them to be solidly grounded. However, 600 V and 480 V systems supplying only phase-to-phase loads may be solidly grounded, high-resistance grounded, or ungrounded. High-resistance grounded systems may provide a higher degree of service continuity than solidly grounded systems and might be useful in serving phase-to-phase loads requiring very high reliability. Any such system, however, needs to be carefully monitored to detect phase-to-ground faults early enough so that the fault(s) can be isolated and repaired promptly. Do not use ungrounded systems since they may experience overvoltages due to resonance conditions, or “neutral” shifts occurring during a ground-fault condition. For safety reasons, provide only solidly grounded systems below 600 V.

When the alternate power supply [generator(s) or separate utility service] and its wiring system electrically interconnect with the normal power supply by the neutral or phase conductors, then the NEC does not consider the alternate power supply to be a separately derived system. Thus, its neutral is cannot be grounded. In this case, only the normal power supply neutral can be grounded as shown in Figure 3-1. This requirement will prevent objectionable neutral load currents from flowing in the system ground conductors. Note that the equipment grounding conductor defined as EGC in Figure 3-1 is still required; thus the generator neutral must be insulated from the machine frame.

When the alternate power supply [generator(s) or separate utility service] and its wiring system are not electrically interconnected with the normal power supply wiring system either by the neutral or phase conductors, or both, then the NEC considers the alternate power supply to be a separately derived system. In this case, the alternate power supply neutral must be grounded [in addition to the neutral(s) of the normal power supply]. Figure 3-2 depicts a system where the neutral and phase conductors between the alternate and normal power supply wiring systems are not electrically interconnected by the use of a four-pole transfer device. Since the neutral conductors are isolated between the two power systems, grounding of the generator neutral will not provide an alternate path (to ground) for load currents on the normal power source.

Engineers should carefully consider whether or not to switch the neutral. See IEEE Std 446 (*IEEE Orange Book*) and IEEE Std 242 (*IEEE Buff Book*) for more details on these issues.

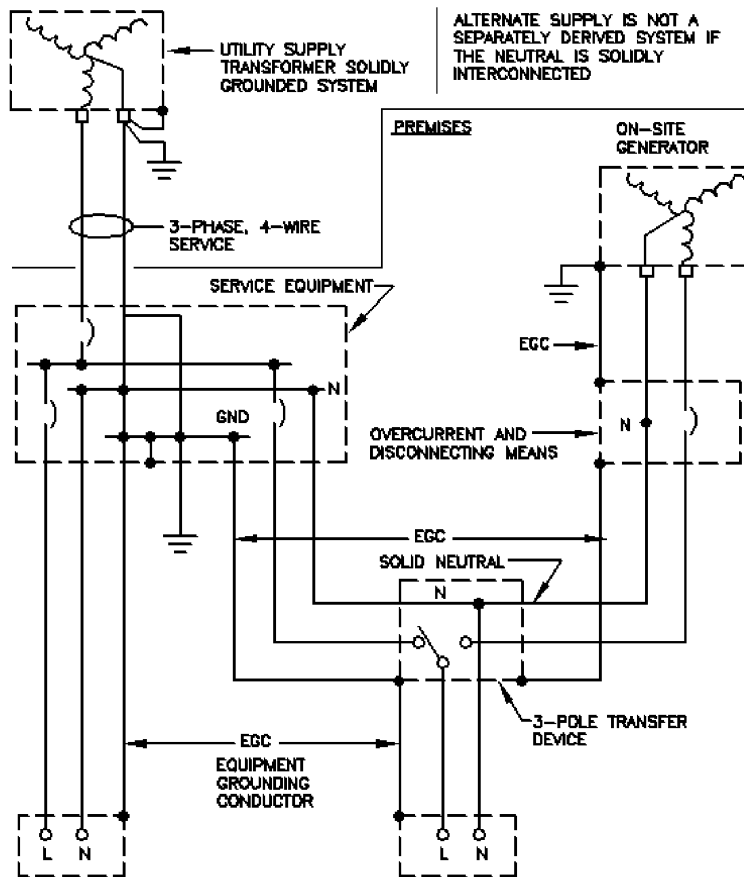


Figure 3-1—Solidly interconnected neutral conductor

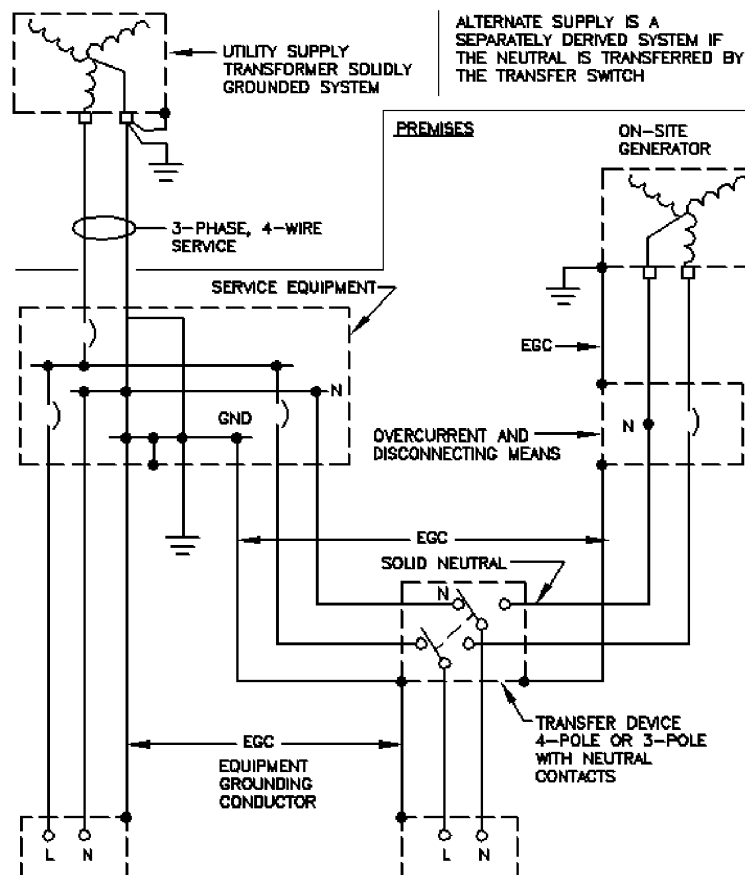


Figure 3-2—Transferred neutral conductor grounded at service equipment and at sources of an alternate power supply

3.7 System protection and coordination

The system and equipment protective devices guard the health care facility power system from the ever present threat of damage caused by overcurrents that can result in equipment loss, system failure, and hazards to patients and other people. All protective devices should be applied within their ratings of voltage, frequency, current interrupting rating, and current withstand rating. In addition, the site where they will serve needs to be taken into account (i.e., if it is at a higher altitude, if seismic activity is common, if temperatures are extreme, if humidity is high, etc.). Many references and standards provide guidelines as to the various device descriptions, their ratings and application limits, and rating factors if required. These requirements are best documented in IEEE Std 141 (*IEEE Red Book*), IEEE Std 241 (*IEEE Gray Book*), and the other ANSI, NEMA, and IEEE standards listed in 3.10. The reader should refer to these for details. The following summarizes some of the information in those references.

3.7.1 Protection system basics

Protection, in an electric system, is designed to minimize hazards due to the high energy released during short-circuit conditions. Other hazards may include overvoltage, undervoltage, or under-frequency. The protective features built into a system are on standby until called upon to clear a fault or some other unplanned or unintentional disturbance. They are designed to reduce the extent and duration of the power interruptions and the hazards of property damage and personnel injury.

It is not possible to build a practical, fault-proof power system. Consequently, modern systems provide reasonable insulation, physical and electrical clearances, etc., to minimize the possibility of faults. However, even with the best designs, materials will deteriorate and the likelihood of faults will increase with age. Every system is subject to short circuits and ground faults. Engineers should develop a knowledge of the effects of those faults on system voltages and currents in order to better design suitable protection.

3.7.1.1 Protection requirements

The design of a protective system involves the following two separate, interrelated, steps:

- a) Selecting the proper device to protect the intended system or device.
- b) Selecting the correct ampere rating and setting for each device so that each device will operate selectively with other devices (i.e., to disconnect only that portion of the system that is in trouble, or faulted, and with as little effect on the remainder of the system as possible).

Select protective devices to ignore normal operating conditions such as full-load current, permissible overload current, and starting (or inrush) currents. Choose them to detect abnormal currents and to operate quickly. Many such devices operate in an inverse-time manner on sustained overloads or short circuits (i.e., the higher the fault current level, the shorter the operating time to open the circuit).

Protective devices should be “coordinated” so that the protective device closest to the fault opens before “line-side” devices open. This arrangement can help to limit outages to affected equipment. Coordination can also be improved by system topography. That is, systems designed with many devices, distribution panels, lighting panels, etc., serving each other in series prove more complicated and difficult to coordinate. A flatter topography distribution with fewer pieces of equipment in series improves the ability to coordinate the system.

Determining the ratings and settings for protective devices requires familiarity with the NEC requirements for the protection of cables and motors, and with IEEE Std C57.12.59TM and IEEE Std C57.12.00TM for transformer magnetizing inrush current and transformer thermal and magnetic stress damage limits. Determining the size or setting for the overcurrent protective device (OCPD) in a power system can be a formidable task that is often said to require as much art as technical skill. Continuity of health care facility electrical service requires that interrupting equipment operates selectively as stated in

NFPA 99 and the NEC. NEMA PB 2.2 provides information on the overcurrent tolerances of various classes of equipment.

As selectivity and maximum safety to personnel are critical, engineers should always perform a total short-circuit, coordination, and component protection study for a project. This study first determines the available short-circuit currents at each major component throughout the system. Then it will include time vs. current coordination curves to be drawn and to coordinate time intervals to determine if the overcurrent devices are selectively coordinated at the various available fault currents. Then the study will examine the component withstand ratings to ensure that the device can actually protect the components at the fault current levels that may be present during a fault. This method of analysis is useful when designing the protection for a new power system, when analyzing protection and coordination conditions in an existing system, or as a valuable maintenance reference when checking the calibration of protective devices. The coordination curves provide a permanent record of the time-current operating relationship of the entire protection system.

3.7.1.2 Current-sensing protectors

The current-sensing (overcurrent and short-circuit) detectors in the circuit protectors (circuit breakers, fuses, etc.) need to detect all types of faults that may be present in the distribution system. The current magnitude of those faults depend upon the system's overall impedance (from the utility) and upon the method of system grounding.

3.7.1.3 Types of faults

For the bolted or arcing fault, the solution involves a two-step approach.

First, minimize the probability of fault initiation by

- a) Selecting equipment that is isolated by compartments within grounded metal enclosures.
- b) Selecting equipment with drawout, rack-out, or stab-in features where available to reduce the necessity of working on energized components. Such equipment should have "shutters" that automatically cover the energized bus when the device is withdrawn.
- c) Providing isolated bus.
- d) Providing insulated bus to prevent the occurrence of ground faults, especially on the line side of mains where the utility does not provide ground-fault protection.
- e) Providing proper installation practices and supervision including arc flash protective requirements for personnel.
- f) Protecting equipment from unusual operating or environmental conditions.
- g) Insisting on a thorough cleanup and survey of tools and instruments immediately before initial energization of equipment.
- h) Executing regular and thorough maintenance procedures.
- i) Maintaining daily good housekeeping practices.

Second, sense and remove the defective circuit quickly so that damage will be minimized.

- 1) Pay careful attention to system design, monitoring equipment, and to the settings of protective devices.
- 2) Pay careful attention to component withstand ratings and fault clearing capabilities.

3.7.1.4 Ground-fault protection

The load requirements will normally determine the phase overcurrent devices settings. Engineers should set these devices to be insensitive to full-load and inrush currents and to provide selectivity between load-side and line-side devices. Accordingly, the phase overcurrent device cannot distinguish between normal load currents and low-magnitude, ground-fault short-circuit currents of the same magnitude. Therefore, ground-fault detection is added to supplement the phase overcurrent devices to provide arcing ground-fault protection.

The application of ground-fault protection requires additional careful attention (i.e., the fault currents from the generator normally are much lower than from the utility).

3.7.1.4.1 Equipment selection

When choosing ground-fault protective devices, engineers must consider the system ground currents and system wiring configuration.

3.7.1.4.2 Types of ground currents

Several types of ground currents can exist in any power system, including:

- a) Insulation leakage current from appliances, portable cleaning equipment and/or tools, etc. Normally, the magnitude of this current is very low (in the order of micro-amperes in small systems to several amperes in extensive systems). Line-isolating power supplies, or ground-fault circuit-interrupters (GFCIs) (serving patient or staff functions) will be appropriate for these lower current values.
- b) Bolted-fault ground current commonly caused by improper connections or metallic objects wedged between phase and ground. For this type of fault, the current magnitude may even be greater than the three-phase fault current.
- c) Arcing fault ground current commonly caused by broken phase conductors touching earth, insulation failure, loose connections, construction accidents, rodents, dirt, debris, etc. The current magnitude may be very low in relation to the three-phase fault current. The expected level is 35% to 40% of the single-phase-to-ground fault current, but may be only one half of this magnitude.
- d) Lightning discharge through a surge arrester to ground. The magnitude of current could be quite large depending on the energy in the lightning stroke; however, the duration is extremely short, measured in microseconds. Protective overcurrent devices within a building's distribution system are not ordinarily affected by direct lightning strokes.

- e) Static discharge.
- f) Capacitive charging current.

3.7.1.5 Cost vs. equipment safety

System designers should balance economics against cost of equipment damage to arrive at a practical ground-fault protection system, keeping in mind that the extent of equipment damage can increase the extent of power service loss, thus increasing risk to patients. Consider the following:

- a) *Power system selection.* The type of ground-fault detection scheme applied is a function of voltage level and system arrangement. Most health care distribution systems are low voltage with a radial arrangement. These systems are the easiest to analyze and protect. The problem becomes more difficult with secondary-selective and spot-network circuit arrangements.
- b) *Neutral circuit*
 - 1) A three-phase, three-wire or three-phase, four-wire power system with radial feeders (and associated neutrals) presents few problems.
 - 2) Power systems with neutrals used as load conductors and where those neutrals are looped, or continuous, between alternate power sources require extreme care in applying ground-fault protection.
- c) *Ground return path.* Design the ground return path to present a low-impedance path and to provide adequate ground-fault current-carrying capability to hold the voltage gradients along its path to less than shock hazard threshold values. This kind of design will also permit sensitive detection of ground-fault currents. IEEE Std 142 (*IEEE Green Book*) provides details on the design of low-impedance, higher current grounding systems.

3.7.2 Ground-fault detection schemes

The following are two basic methods of applying ground-fault sensing devices to detect ground faults:

- a) *Ground return method.* The ground-fault sensing device is placed to detect the total ground current flowing in the grounding electrical conductor and the main bonding jumper. This method can only be used at the main disconnect point of services or for separately derived systems.
- b) *Outgoing current method.* The ground-fault sensing device is placed to detect the vectorial summation of the phase and neutral (if present) currents. The sensing device is located load side (downstream) from the point at which the distribution system is grounded. This is the only method that can be used for feeders. It can also be used for the incoming main disconnect, for multiple mains, and for ties.

The ground-fault relay pickup level is adjustable and may be equipped with an adjustable time-delay feature. Operation of the relay releases the stored energy (spring) holding mechanism on the interrupting device. Selectivity in substations can be achieved either through a time delay, and/or current setting or blocking function/ zone selectivity. The “blocking function” or “zone selective

interlocking” are systems that restrain main breaker tripping when the same fault is also seen on a feeder breaker. In these cases the main breaker should only trip if the feeder breaker failed to trip properly.

Take care to selectively coordinate load-side levels at ground-fault protection with line-side levels and also to coordinate ground-fault protection with both line-side and load-side phase overcurrent devices. (It is easy and dangerous to design a system with ground-fault devices that coordinate with one another, but do not coordinate with the phase overcurrent devices.) A carefully designed and coordinated ground-fault detection system is an important component of a reliable, safe, and economic power distribution system.

Electronic ground-fault trip devices may have a “memory circuit.” Consult with the manufacturer of the device to determine if adjustments must be made to avoid memory-circuit, nuisance trips for cycle loads, pulsating loads, loads generating nonsinusoidal waveshapes, or other “unusual” loads.

3.7.3 Medium-voltage systems

As previously discussed, medium-voltage systems for health care facilities are generally three-phase, three-wire systems with the neutrals solidly grounded or resistance grounded.

If a system has a solidly grounded neutral, the resulting ground-fault current magnitude will be relatively high, requiring a residual connected ground-fault relay. This relay, shown in Figure 3-3, monitors the outgoing ground-fault current.

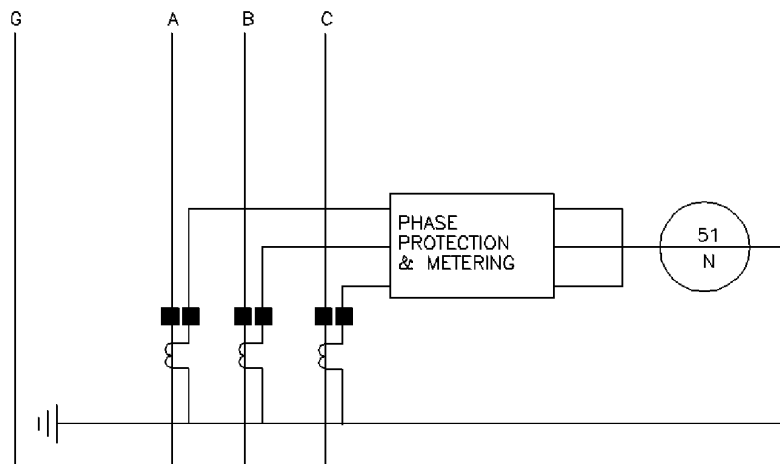


Figure 3-3—Residually connected ground-fault relay

If the system has a resistance grounded neutral, the ground-fault current magnitude will be relatively low, 1200 A or less. To detect these currents, use a ground sensor with a secondary connected ground-fault relay as shown in Figure 3-4.

The ground sensor relay shown in Figure 3-5 monitors the returning ground-fault current.

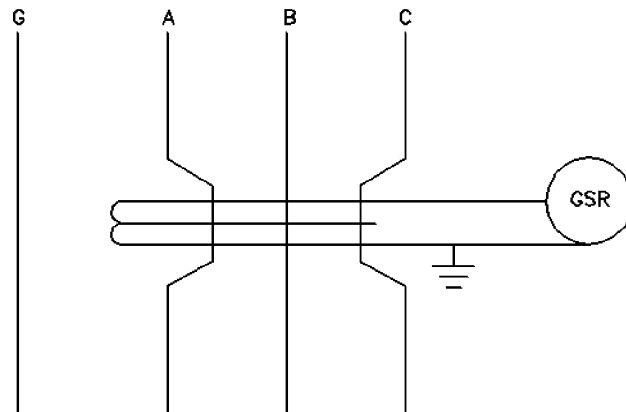


Figure 3-4—Ground-fault sensor and ground-fault relay

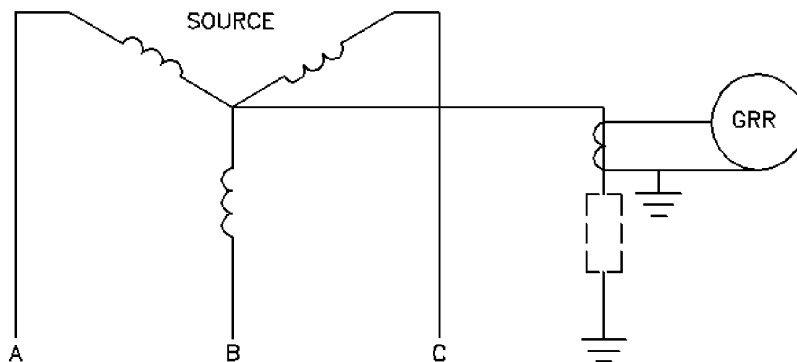


Figure 3-5—Ground sensor monitoring returning ground-fault current

3.7.4 Low-voltage systems

As previously discussed, low-voltage systems for health care facilities are generally three-phase, four-wire systems. These systems usually contain effectively grounded normal power source neutrals. Here the alternate power source neutral may, or may not be, effectively grounded at the alternate source. The ground-fault schemes applicable will depend on how the alternate power supply is grounded.

For feeder circuits having no neutral conductor requirements (three-phase, three-wire loads), or for three-phase, four-wire loads where the neutral conductors are not electrically interconnected between power source on the load side of the feeder breaker, residually connected, ground-fault relay, or integral ground-fault relays (see Figure 3-6, Figure 3-7, and Figure 3-8) may be applicable for the feeder overcurrent device.

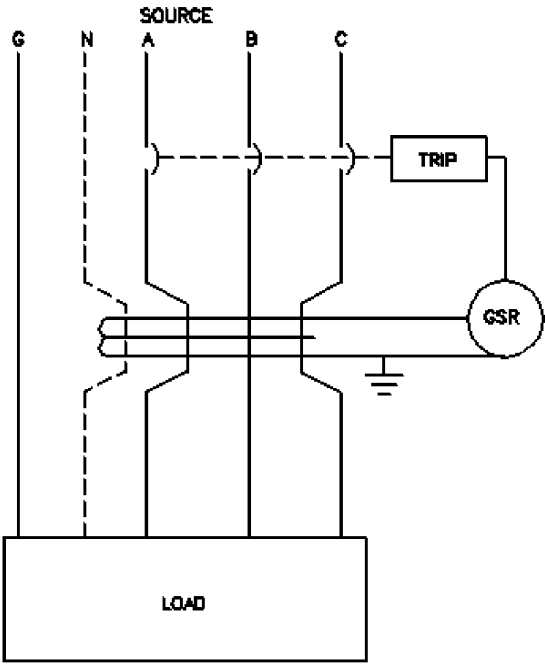


Figure 3-7—Ground sensor fault relay

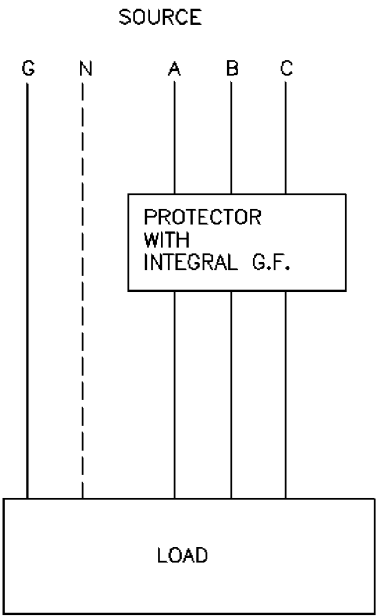


Figure 3-8—Integral ground-fault relay

For feeder circuits with neutral conductor requirements where the neutral conductors are electrically interconnected between power sources on the load side of the overcurrent device, “outgoing current method” schemes will be applicable. Figure 3-9 is an example of such a circuit.

Typical ground-fault relaying systems are shown (see Figure 3-10 and Figure 3-11) for a health care facility power system that consists of normal and alternate power supplies. The power systems shown in Figure 3-10 have an electrical power conductor interconnection between power supplies. Note the vectorial summation of ground-fault currents (outgoing current method) in the relaying scheme required for the power system shown in Figure 3-10. In both Figure 3-10 and Figure 3-11, ground-fault relay R2 is optional.

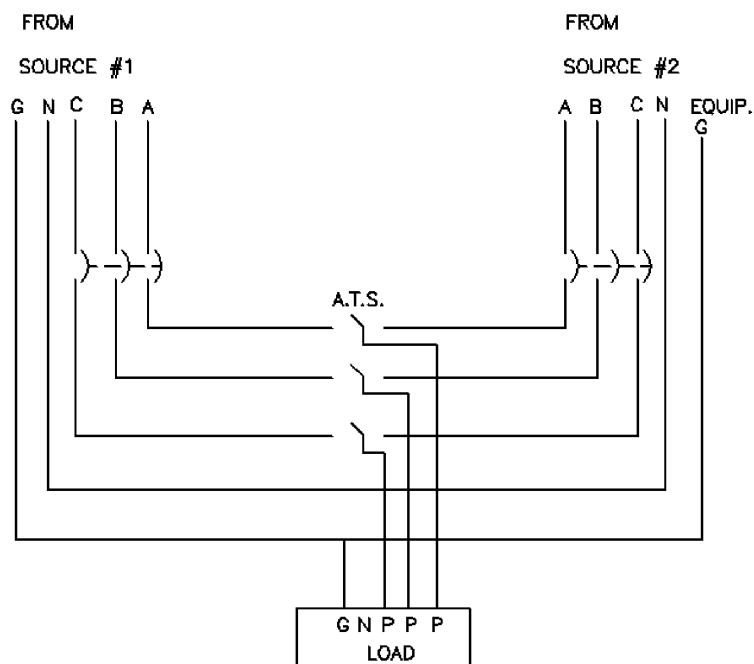


Figure 3-9—Dual source electrically interconnected

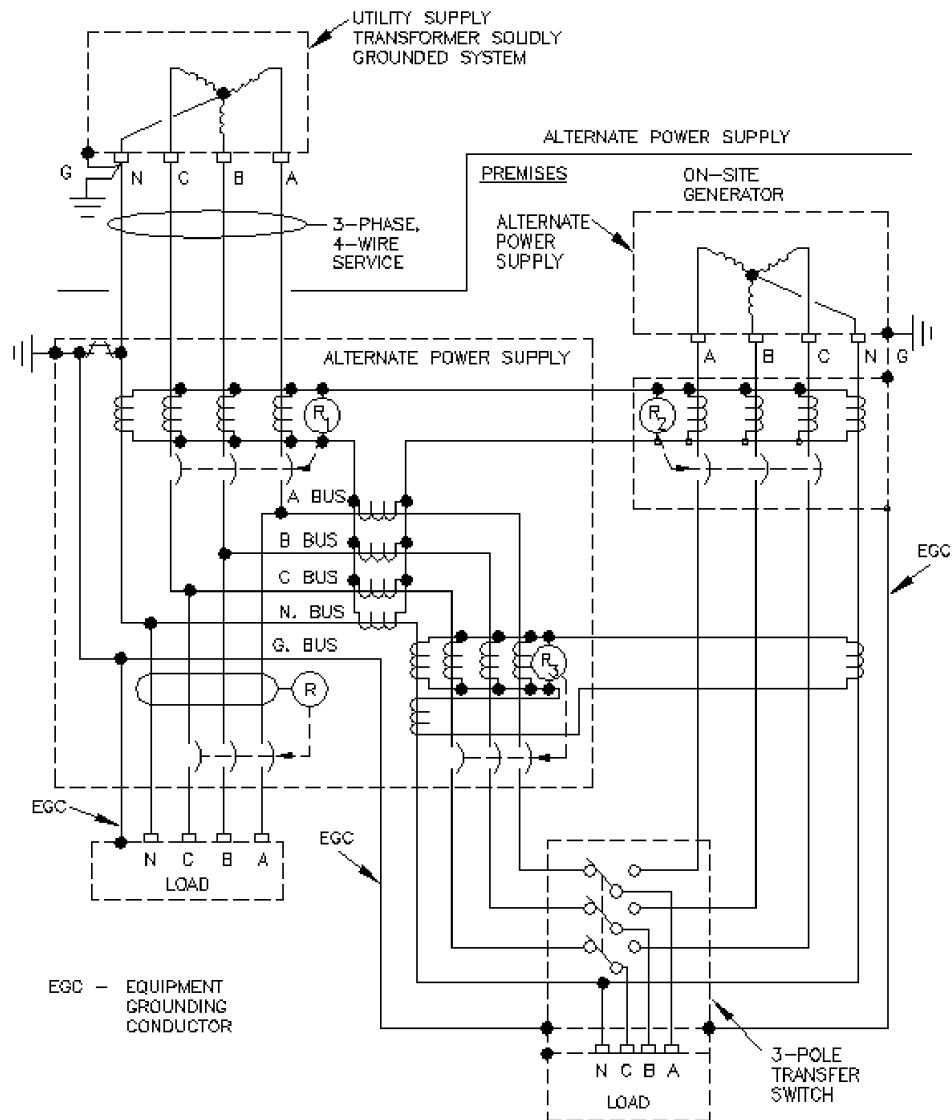


Figure 3-10—Ground-fault scheme for a normal and alternate power supply having an electrical power conductor (neutral) interconnection between supplies

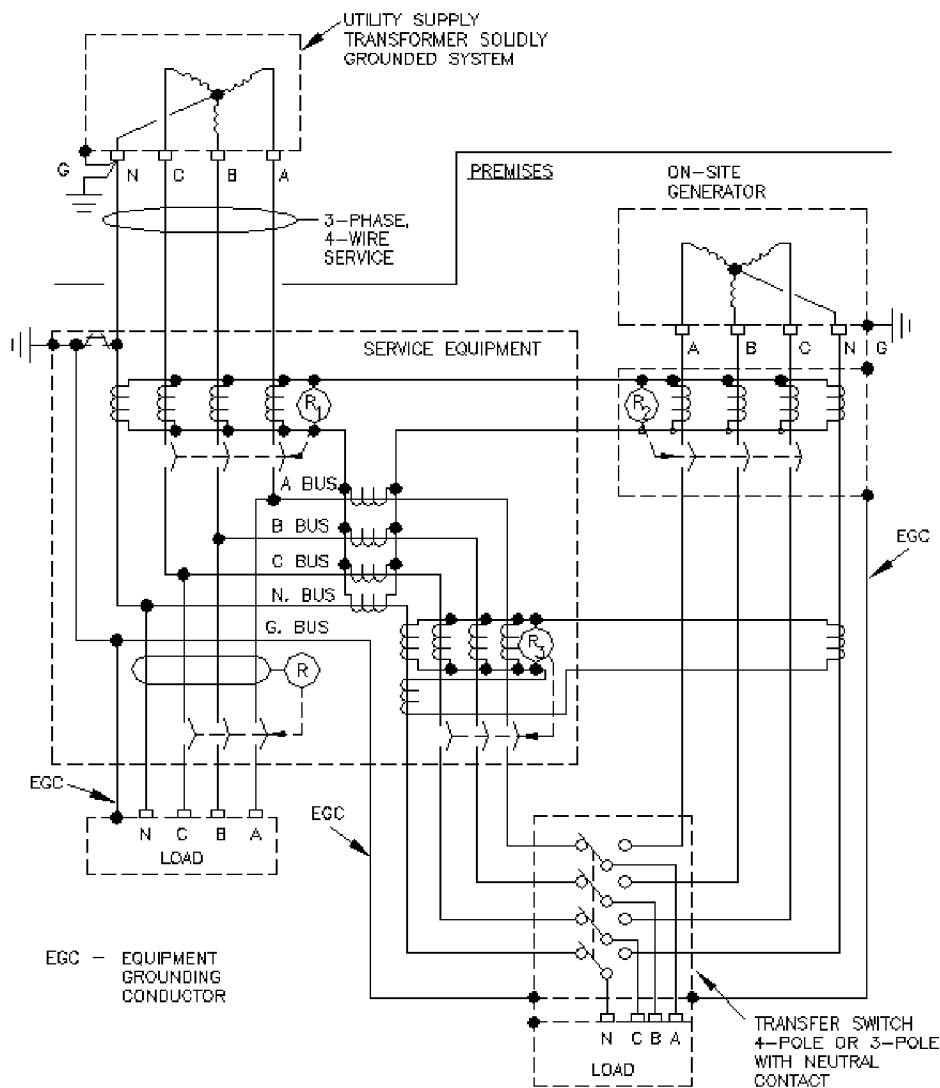


Figure 3-11—Ground-fault scheme for a normal and alternate power supply with no electrical power conductor interconnection between supplies

3.8 Electrical equipment selection, installation, and testing

3.8.1 Equipment selection

IEEE Std 141 (*IEEE Red Book*) and IEEE Std 241 (*IEEE Gray Book*) describe electrical power distribution equipment in detail. However, engineers must consider more criteria when using this equipment in health care facilities, including the following:

- a) Reliability, protection, and coordination requirements
- b) How rapidly vital service can be replaced following an outage
- c) Initial cost including installation and cost of space
- d) Maintenance facilities, maintenance cost, availability
- e) Listing and labeling of equipment according to recognized standards by a nationally recognized testing laboratory (NRTL)

Remember that not just revenues or production will be lost should the system fail, but possibly human lives. The system should therefore provide the most reliable power possible (within economic feasibility) to patients and procedures that require electrical power. All the components used in the electrical system for health care facilities should provide a reliable and safe distribution system. Carefully consider the location of the electrical components during the design to minimize exposure to hazards such as lightning, storm, floods, earthquakes, fires, or toxic and/or environmental hazards created by adjoining structures or activities.

3.8.2 Working space

Provide ample working space around electrical components to allow and permit all tasks, installation, maintenance, testing, operating, etc., to be performed in a safe manner. See the NEC, NFPA 70B, and NFPA 70E.

3.8.3 Labeling

Ensure that installers properly label all distribution system components. Equipment such as switchgear, switchboards, motor control centers, panelboards, ATs, etc., should all have engraved plastic nameplates (that designate source, purpose, and loads served) applied on incoming sections, tie sections, and feeder sections. All cables, busways, and buses should also be identified as to phase, to assist in maintaining proper phase sequence. Maintenance staff will be able to more effectively service the equipment if it follows a consistent method of labeling. Finally, the NEC requires arc flash labeling for equipment requiring maintenance or adjustment while energized.

3.8.4 Acceptance testing

Once an installer has completed an installation but not yet energized a system, they should thoroughly clean all the components. They should first visually inspect the devices to assure that all components are installed properly and protective devices are set properly. After completing these steps, an organization specializing in acceptance testing of

electrical components can begin acceptance testing for the system. This testing should include all components including protective devices and circuitry, control circuitry, etc., to assure proper operation. Refer to NFPA 70B and the NETA Acceptance Testing Specifications (ATS).

3.8.5 Segregation of services

In selecting and installing the electrical distribution components for the essential electrical system, give high priority to achieving maximum continuity of the electrical supply to the load. To achieve this high reliability, the components (distribution circuitry, electrical equipment, etc.) for the essential electrical system should be installed so that they are physically separated from the non-essential power system components. Furthermore, as in NFPA 99, each branch of the emergency system should be installed physically separate and independent of the others and of all other wiring. The only exception to this rule would be when an electrical component such as a transfer switch requires two separate services.

3.8.6 Equipment selection

The following subclauses discuss the equipment commonly applied in health care facilities. Considerations mentioned here are those of specific concern in a health care facility. The in-depth considerations as outlined in IEEE Std 141 (*IEEE Red Book*) and IEEE Std 241 (*IEEE Gray Book*) should be understood to assist in choosing proper equipment.

3.8.7 Transformers

While transformer operating cost is an important factor when selecting a transformer, engineers should consider initial cost, operating costs of no-load and load losses, reliability, sound level, thermal life, overload capability, ability to supply nonlinear loads, installation costs, size, weight, availability of application, and servicing resources. Ideally, the no-load losses and load losses should be at a minimum at the normal loading point of the transformer [i.e., a transformer whose load losses are four times as large as the no-load losses would be most efficient at approximately 50% of its nameplate (base) rating].

3.8.8 Switchgear, switchboards, and motor control centers

Locate electrical switchgear as close as possible to their loads to shorten cable runs, reduce losses in the cables, and minimize voltage drops. Do not locate these pieces of equipment near electronic monitoring equipment that is sensitive to electromagnetic interference (EMI). If this is unavoidable, consider shielding the electronic equipment or specifying the electronic equipment to be compatible with the EMI that may be present. Plan for adequate clearances and ventilation for present equipment and possible future expansions.

Consider incorporating adequate metering equipment in the switchgear, switchboard, or motor control center to permit proper monitoring of the (quantity and quality) current and voltage, electrical demand, and consumption conditions of the power system. Refer to

IEEE Std 739TM (*IEEE Bronze Book*TM) and to ANSI C57.12.10 for additional recommendations regarding metering.

3.8.9 Protective devices

Carefully coordinate OCPDs to provide complete coordination of the system. The following four different kinds of circuit interrupting devices have two basic elements that provide a detecting function and a switching function.

- a) Circuit breakers equipped with protective relays or direct acting trips
- b) Contactors equipped with overload relays
- c) Transfer switches equipped with voltage and frequency sensing relays
- d) Switches equipped with fuses

When applied within their ratings, the switching devices are generally capable of performing the following:

- 1) *Contactors and transfer switches.* Repetitively closing, carrying and interrupting normal load currents; interrupting overload currents; withstanding but not interrupting any abnormal currents resulting from short circuits (unless circuit breakers or fuses are built-in).
- 2) *Switches.* Closing; carrying and interrupting load current; and when properly coordinated with a fuse, withstanding but not interrupting any abnormal current resulting from overloads and short circuits. The fuse provides detection and interruption feature for overloads and short circuits within its design characteristics.

NOTE—When switches include “shunt trip coils” they can be electrically tripped by ground-fault relaying equipment, or other controls.³

- 3) Closing; carrying and interrupting load current; withstanding and interrupting overload, short circuit, and ground-fault currents.

Of these devices, only circuit breakers and fused switches can be OCPDs that interrupt overload, short-circuit currents, and arcing ground-fault currents. Transfer switches transfer loads from one source of power to another by monitoring power source voltage. Contactors are applied as load powering devices such as motor starters, lighting, etc.

Protective devices use three types of detectors—fuses, relays, and direct acting trips.

- Low-voltage fuses detect and interrupt the abnormal current in one nonadjustable element. They are thermal-type devices and are sensitive to ambient temperature and the current flowing through them. The continuous current ratings typically are based in open air, and when applied inside equipment, may need to be derated to account for increased ambient temperature. Normally, an 80% derating factor is applied. Fuses are single-phase devices and must be installed in each phase of a three-phase circuit fusible switch. The application of fuses as OCPDs is similar to applying circuit breakers.

³Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the recommended practice.

High-voltage fuses operate in a similar manner except that they are more often practical for interrupting short circuits. Also, their fuse size (e.g., 25E) does not directly relate to the current at which they operate.

- Protective relays respond to electrical quantities that change during normal and abnormal conditions. The basic quantities that may change are the magnitude and/or direction of current, voltage, power, phase angle, and frequency. Protective relays are responsive to one or more of these quantities instantaneously or at a time rate dependent on magnitude. Figure 3-12 shows a typical relay response curve. Generally, these relays are field adjustable, have a wide operating ambient temperature range, and have a drawout construction. They may include special features such as sensitivity to directional quantities only, etc. Relays, although not limited to, are normally applied in conjunction with high- and medium-voltage circuit breakers. Upon pickup, at the selected current setting, and after any time delay selected, the relay trip contacts close to energize the trip circuit of the circuit breaker, which releases the stored energy (spring) holding mechanism that then opens all circuit breaker poles. Electronic (solid-state) and microprocessor based tripping units for low-voltage circuit breakers operate similarly to other protective relays except the circuit breaker tripping devices are often integral with the removable circuit breaker element. Figure 3-13 shows several typical, lower voltage response curves.
- Direct acting trips respond to current either instantaneously or at a time rate dependent on the current magnitude. They are mounted inside low-voltage circuit breakers in series with the breaker trip mechanism, which opens all circuit breaker poles. They are of a thermal-magnetic, magnetic, or electronic design. As for fuses, the thermal type requires a derating factor consideration. Some units are ambient compensated. The electromagnetic, electromechanical, or electronic (static) types are generally field adjustable.

Trip units generally do not respond to load or circuit conditions that generate minor harmonic distortions. Where a trip unit will experience high harmonic content, or where the loads are pulsating, the engineer should work with the manufacturer of the device to ensure proper operation of the device. Nuisance trip signals from electronic trip units may result when the trip unit has a memory circuit. (See 3.7.2 for more information on memory circuits.)

Medium-voltage systems generally accomplish ground-fault detection by electromagnetic overcurrent relays and toroidal or bar-type current transformers (CTs). In low-voltage systems, microprocessor relays and matching current sensors, whether integral or external to the protective device, provide the ground-fault protection.

Note that ground-fault detection requires additional attention as outlined in 3.7.1.4 if nuisance power outage is to be avoided.

For further protective device description and application, refer to IEEE Std 141 (*IEEE Red Book*), IEEE Std 241 (*IEEE Gray Book*), NEMA PB 2.2, NEMA AB 3, and manufacturers' publications.

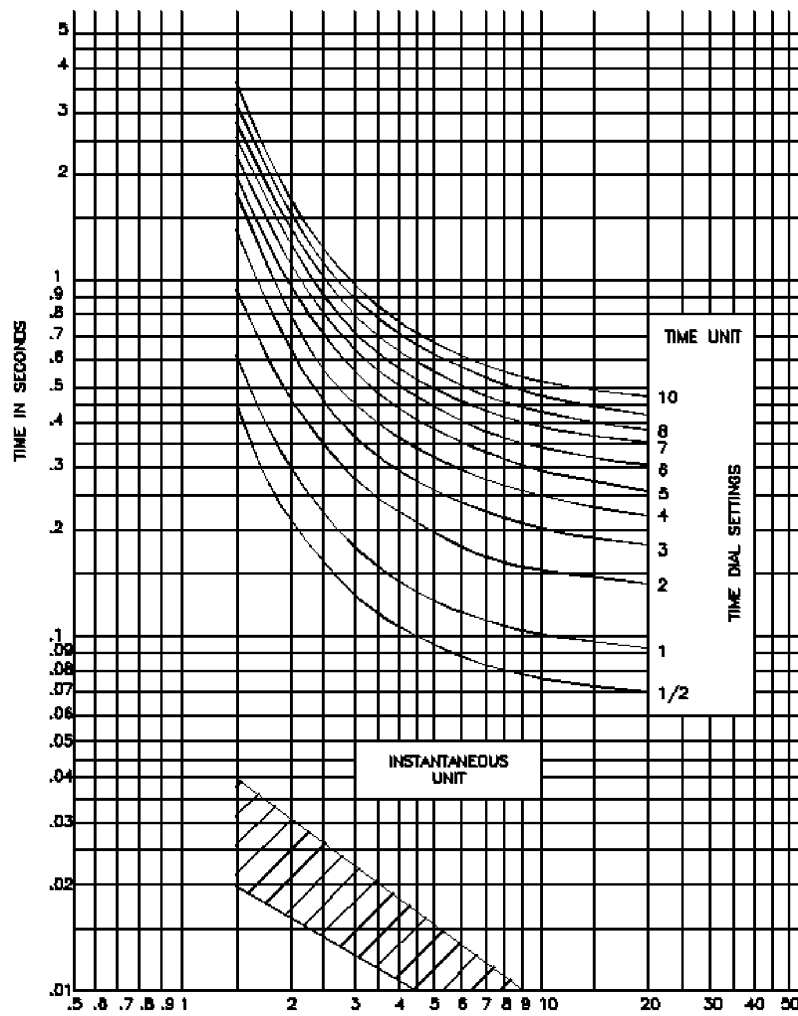


Figure 3-12—Time-current characteristics of a typical inverse-time overcurrent relay

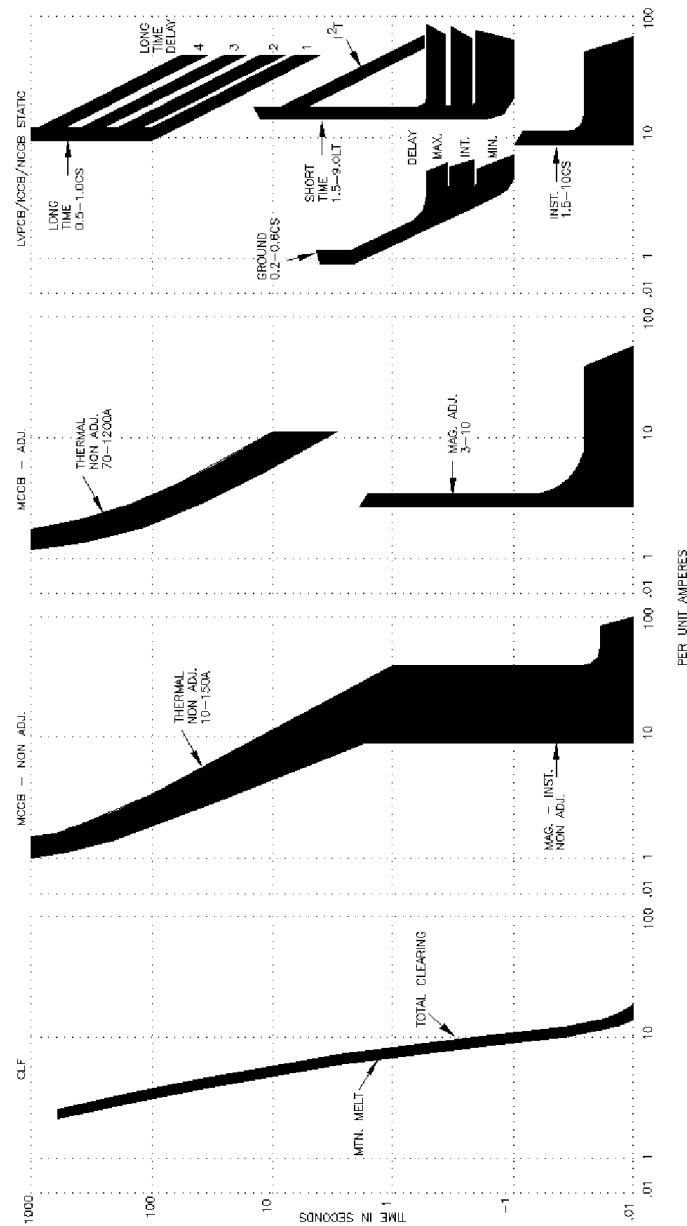


Figure 3-13—Typical time-current characteristics for low-voltage protection

3.8.10 Transfer switches—Automatic and manual

Transfer switches transfer from one power source to another to maintain service to the essential power system and designated equipment. Due to their important function in the health care facility power system, they must be listed for emergency electrical service and have adequate capacity for the loads being served. In addition, locate them to provide reliable service to downstream loads. Generally, the switches should be located as close to the loads to be served as possible (thus implying more, smaller switches, rather than fewer, larger switches). Furthermore, they must have adequate withstand ratings to prevent contact welding due to load, overload, or short-circuit currents.

Automatic transfer switches (ATSs) operate electrically and latch mechanically to prevent change of state, open or closed, whenever control power is unavailable.

An ATS permits the transfer and retransfer of the load automatically when required. Manual or nonautomatic transfer switches also have a mechanical latching feature. For related requirements such as switch position indication, interlocking, voltage sensing, time delay, etc., refer to NFPA 99, the NEC, NFPA 110, and NFPA 111.

To permit ease of maintenance, consider incorporating bypass/isolation features into these switches. This feature will allow normal preventive maintenance and breakdown maintenance to be performed when required with minimal, or no, disruption to patient services.

3.8.11 Generators

See Chapter 5.

3.8.12 Special wire, cable, and busway

In addition to meeting the general code requirements as noted in the NEC (Chapter 1 through Chapter 4), certain hospital/health care occupancies require special attention (i.e., wire and cable installed in areas classified as hazardous must meet certain installation requirements of Class 1, Division 1). One such hazardous area would include any remaining areas where staff will use flammable anesthetizing agents. These areas must have wire and cable installed in approved rigid metal raceways utilizing threaded connections that are properly sealed. All boxes, fittings, and joints must be suitable for hazardous locations.

Wiring downstream of the isolation transformers cannot have voltages higher than 600 V between conductors. The conductors shall have a dielectric constant of 3.5 or less and be color coded as in the NEC (Article 517). Installers of these conductors must do it carefully so as to not increase the conductors' dielectric constant.

3.8.13 Panelboards

Locate electrical panelboards as close to the load as possible. Lighting and receptacle panelboards should be located to minimize circuit length to approximately 22.9 m (75 ft)

between the panelboard and load. This close placement reduces voltage drops on the circuits. Locating panels in electrical equipment rooms will allow future maintenance and revisions to these to be done much more safely than if they are located in corridor walls. Including bus bars and spare circuits will allow for much more economical future additions of new circuits.

Good design and code requirements include a low-resistance ground path from all panelboard ground buses back to the source of power. This ground path will limit shock hazards and provide a low-impedance path for ground-fault currents in a grounded system.

3.8.14 Isolated power supplies

Isolated power supplies consist of an isolating transformer, motor-generator sets or batteries, a line isolation monitor (LIM), and the ungrounded circuit conductors and overcurrent protectors. Refer to Chapter 4 for more on this topic.

3.9 System arrangements

In designing the electrical power system, carefully consider how to select the proper electrical system arrangement to provide a reliable power system. A power service consisting of two or more separate dedicated utility service feeders, fed from separate substations or from separate distribution buses, provide a much higher degree of reliability than one utility service feeder, but often require additional initial and ongoing fees from the utility company. Furthermore, the reliability is enhanced even more if each service feeder is installed separately (i.e., on separate pole lines) so that a fault in one feeder circuit will not affect the other feeder.

Distribution system arrangements should be designed and installed to minimize interruptions to the electrical systems due to internal failures. Among the factors to be considered as outlined in NFPA 99 are

- a) Abnormal current-sensing devices, both phase current and ground current, should be selected and set to quickly disconnect any portion of the system that is overloaded or faulted.
- b) Abnormal voltage conditions such as single-phasing of three-phase utilization equipment, switching and/or lightning surges, voltage reductions, etc., should be anticipated.
- c) Capability to quickly restore any given circuit after clearing a fault or overload.
- d) Ability of system to be modified for accepting increasing loads in the facility and/or changes in supply capacity.
- e) Stability and power capability of the alternate power systems' prime mover during and after abnormal conditions.
- f) Sequence reconnecting of loads to avoid large transient currents that could trip overcurrent devices or overload the emergency generator(s).

- g) Feeder and branch circuits should be adequately rated to power their electrical loads and sufficient in number to allow load distribution that will minimize the effect of a feeder or branch circuit outage.
- h) Separate nonlinear loads or high harmonic current loads [such as UPSs and adjustable frequency drives (AFDs)] from loads requiring higher quality power.

Large motors have high inrush current characteristics. When supplied from the same power source that supplies voltage-sensitive equipment, engineers should take precautions to prevent these inrush currents from adversely affecting the voltage-sensitive equipment. In facilities with one utility service, one method is to provide a separate feeder for supplying the voltage-sensitive equipment. Another method is to design systems with motor feeders separated from the general lighting and power feeders on double-ended switchgear or switchboards, to reduce the effects of motor starting on other electrical loads.

The motors in a health care facility that might cause voltage dip problems include elevators, air compressors, vacuum pumps, and large chiller motors. Due to their infrequent starting (once or twice a day), chiller motors seldom present a severe problem if their starts are carefully scheduled and/or sequenced. The voltage drop problems of all of these loads can be minimized by electronic (soft start motor starters/controllers) or reduced voltage starters (such as autotransformer starters with closed transitions).

3.9.1 Radial system arrangement

3.9.1.1 Smaller facilities

For small facilities, small nursing homes and residential custodial care facilities, a single service-entrance switchboard, and a small generator can be the major components of the electrical system (see Figure 3-14). These facilities usually have several normal power panelboards fed from the normal power system. If motor loads are to be energized by the generator, their restoration under emergency conditions can be delayed by using a time-delay relay in the ATS (see Chapter 5) or by adding a time-delay relay in the motor starter, which is energized by auxiliary contacts within the transfer switch as shown in Figure 3-15.

Where there will be significant emergency power requirements, several transfer switches may be used to increase reliability. The transfer switches used for the equipment system can be adjusted to transfer sequentially, thus minimizing generator inrush requirements. However, the transfer switch(es) serving the emergency system, which includes the critical system and the life safety system, shall transfer within 10 s.

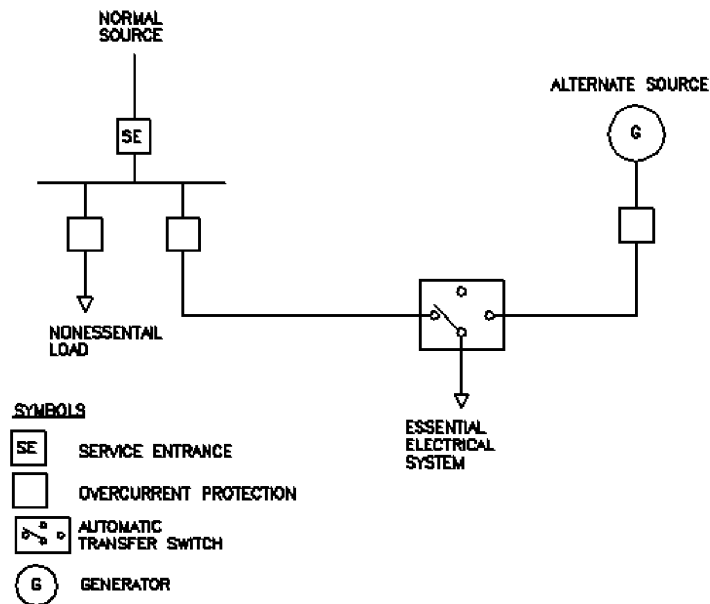


Figure 3-14—Major components of the electrical system

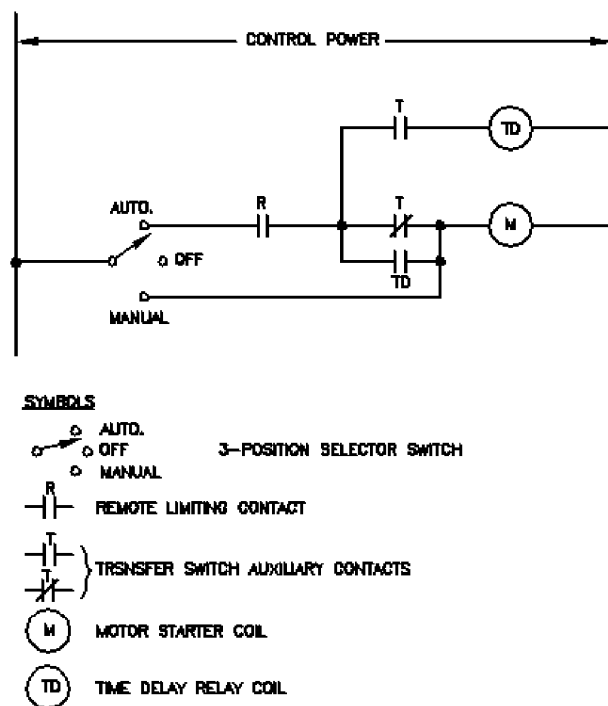


Figure 3-15—Time-delay relay in transfer switch of motor starter

3.9.1.2 Larger facilities

As health care facilities evolve and grow, they will require additional feeders for normal power loads and essential electrical power systems. The essential electrical system will thus require three or more transfer switches, some of which could be nonautomatic. Using several smaller transfer switches, in lieu of a large switch, will contribute to system stability and reliability. Further, reliability can be obtained by placing the transfer switches as close to the ultimate load as possible.

For example, Figure 3-16 shows two schemes for distributing power through vertical risers. When an outage occurs in the normal power supply, the transfer switches will direct an alternate power supply to the essential electrical system panelboards. However, if a specific normal feeder outage occurs, only Scheme A can sense the specific outage and restore power to the affected panel via the alternate power supply. Scheme A is more reliable than Scheme B, but is a more costly arrangement. Loss of normal power is sensed at the transfer device to initiate start-up of the emergency generator via auxiliary contacts. When the voltage and frequency of the emergency power is in proper limits, and stable, then relays initiate switching to the alternate power source. Finally, restoration of normal power causes the ATSS to return to the normal power source while initiating a shutdown of the emergency generator. Note that time requirements between switching events are documented in NFPA 99.

3.9.2 Double-ended system arrangement

Engineers should consider a double-ended substation for larger facilities, especially if two utility sources are present.

For example, Figure 3-17 utilizes a normally open circuit breaker that is interlocked with the main circuit breaker so that all three circuit breakers cannot be closed simultaneously. Upon loss of a single transformer or its feeder, the facility operator can automatically (or manually) close the tie circuit breaker and add its load to the remaining transformer. Additional benefits of the double-ended substation are lower fault currents than with a single, larger transformer. They also create opportunities to normally separate motor loads from lighting and x-ray loads that require a higher degree of voltage regulation.

When double-ended substations are installed, each transformer must safely carry the full load of the entire substation. Since core losses are a continuous power cost, it is important to minimize the “spare” capacity as long as safety, reliability, and good practice are maintained. During the time of outage of a single transformer, the increased voltage drop, the increased transformer losses, and the possible loss of transformer life (if overloaded) must be taken into account. Usually the outage time is minimal, but in the event of a transformer failure, replacement time may be in the order of weeks. Transformers can be safely overloaded in accordance with ANSI C57 standards with little or no loss of life; fans can be added to increase the emergency load capability of the transformer; and when transformers are purchased, they can be specified with a higher temperature insulation rating than is required for the normal full-load rating. “Oversized” transformers not only increase core-loss costs, but also usually increase the available fault current at their secondary and possibly require increased switchgear sizes.

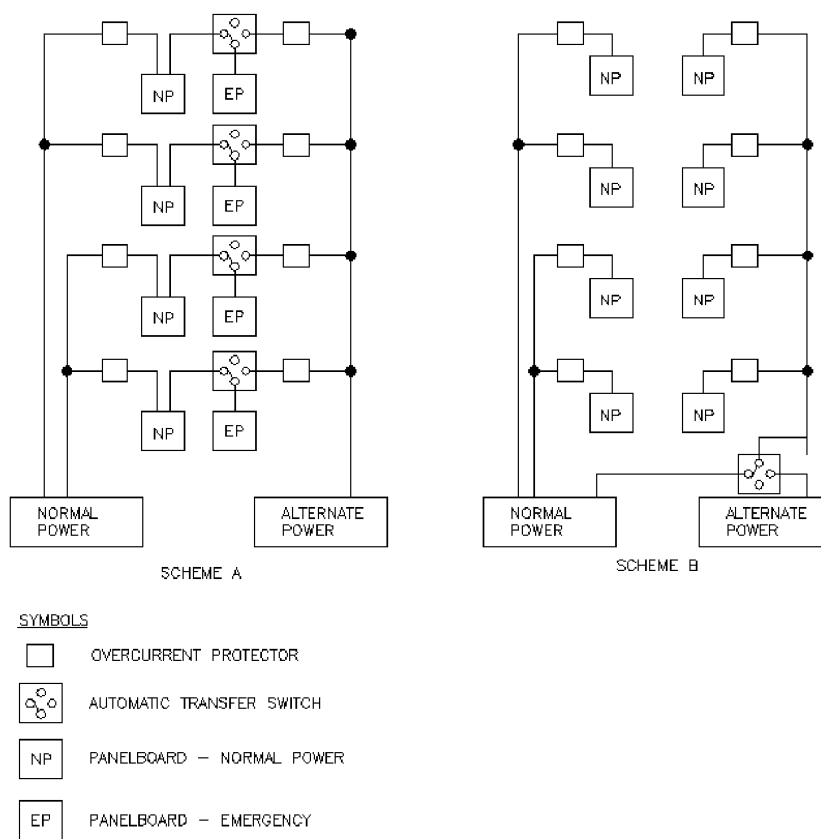


Figure 3-16—Two schemes for distributing power through vertical risers

Liquid-immersed power transformers rated 55/65 °C rise have a higher overload rating than units rated 55 °C rise. Dry-type power transformers rated 80 °C rise and with 220 °C insulation have a higher overload rating than 115 °C rise units with 220 °C insulation. For example, dry-type power transformers 500 kVA and over should be specified with a temperature rise of 80 °C (preferred) or 115 °C (alternate).

Liquid-immersed power transformers should be specified to include controls to start the auxiliary cooling system (fans and pumps) when the temperature at the bottom of the tank reaches the predetermined temperature.

If the double-ended substation scheme uses a normally open electrically operated tie circuit breaker that will automatically close upon loss of an incoming feeder, then additional control and protective relaying needs to be added to prevent the bus tie protector for closing when a main protector has tripped due to overload or short-circuit conditions.

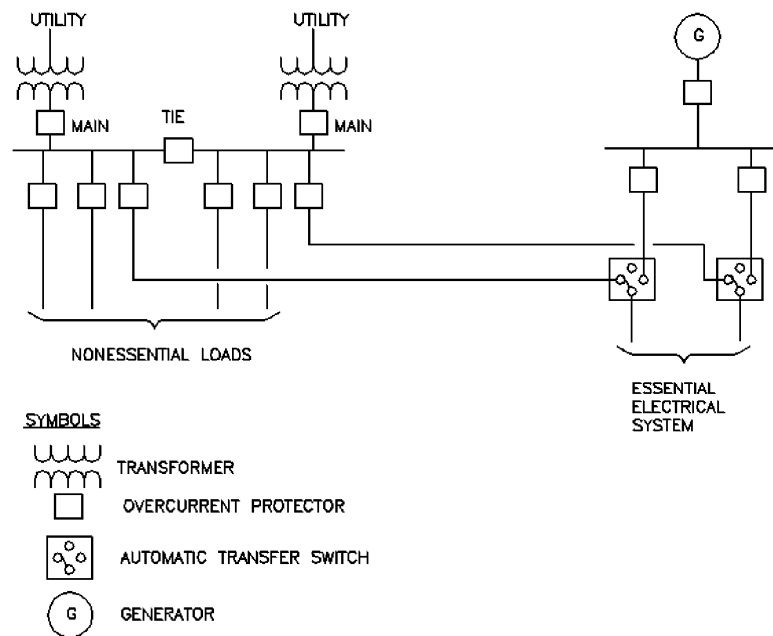


Figure 3-17—Normally open tie protector interlocked with the main protectors

In rare instances, a utility may permit a double-ended substation to be operated with a closed tie and main protectors. The advantages of using a double-ended substation with mains and tie normally closed are better voltage regulation and flickerless transfer upon loss of one power source. The disadvantages are greater complexity, greater fault current, greater cost, and loss of isolation between sensitive loads and high inrush loads. Also, reliability can be less since one failure, a bus fault, may cause loss of both buses. The greater complexity requires that the design engineer carefully coordinates and specifies the required additional protection to assure proper operation. Also refer to the NEC for reverse-current relaying requirements.

3.9.3 Network system arrangement

A network service consists of two or more transformers with their secondary bused together through network protectors as shown in Figure 3-18.

The advantages of network service are high reliability, no service interruption when one feeder is removed from service, and good voltage regulation. The disadvantages are high-cost, high-fault currents, and may include an inability to expand the network service without increasing the interrupting ratings and sizes of existing components. In metropolitan areas, a service supplied from the utility-owned network may be available. The utility's network in cities consists of many network transformers with their secondary tied into a grid of secondary cables covering a large area. This network usually allows one primary feeder to be removed from service at any time, or two primary feeders to be

removed from service during lightly loaded periods without causing undue low voltage on the secondary grid. Where demand is high, utilities may opt for a “spot network” consisting of two to four network transformers in close proximity with their secondary bused together, but not connected to the general urban network.

The network service is considered the most reliable, but also the most expensive type of electrical service. Life cycle costs may be reduced somewhat by having the hospital, rather than the utility, own and maintain the network transformers in order to qualify for the lower primary service rate.

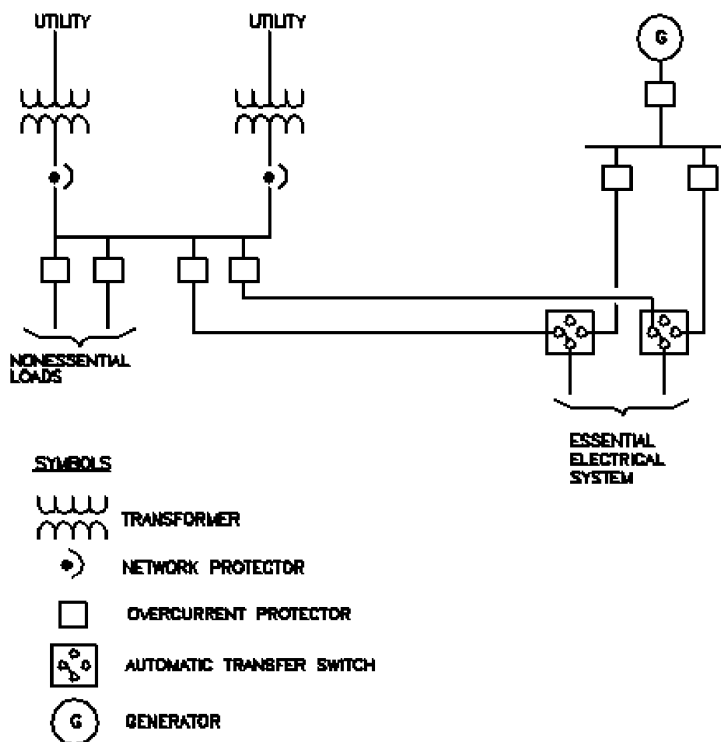


Figure 3-18—Network service

The network would be used for very large loads where multiple feeders are required for each service; no interruptions are permitted on switching of feeders, and the system is fully automatic. The open-ended double-ended substation does not do this.

3.9.4 Medium-voltage system arrangements

One of the most commonly used medium-voltage systems for hospitals is the primary selective system. For facilities with very experienced staffs, consider designing a loop system. Both of these systems allow a single cable section or feeder to be removed from service without a prolonged outage. The use of preformed separable connectors in

manholes and at transformers can expedite the isolation, but not the switching, of a faulted cable section. (As a safety consideration, only dead-front switchgear should be used for switching.) Also, fault current detectors can be attached to cables, in manholes and certain enclosures, to aid in locating cable faults. More detailed descriptions of the loop and selective primary systems can be obtained from IEEE Std 141 (*IEEE Red Book*).

3.9.5 Existing system arrangement

Where extensive new load is added to a hospital having an existing substation, it is often more convenient to add a new transformer to the distribution system, rather than to change the existing substation unless the existing unit is still adequately rated as shown in Figure 3-19. Adding a new substation might provide an excellent way to introduce 480 V distribution, if the older substation is operating at a lower voltage.

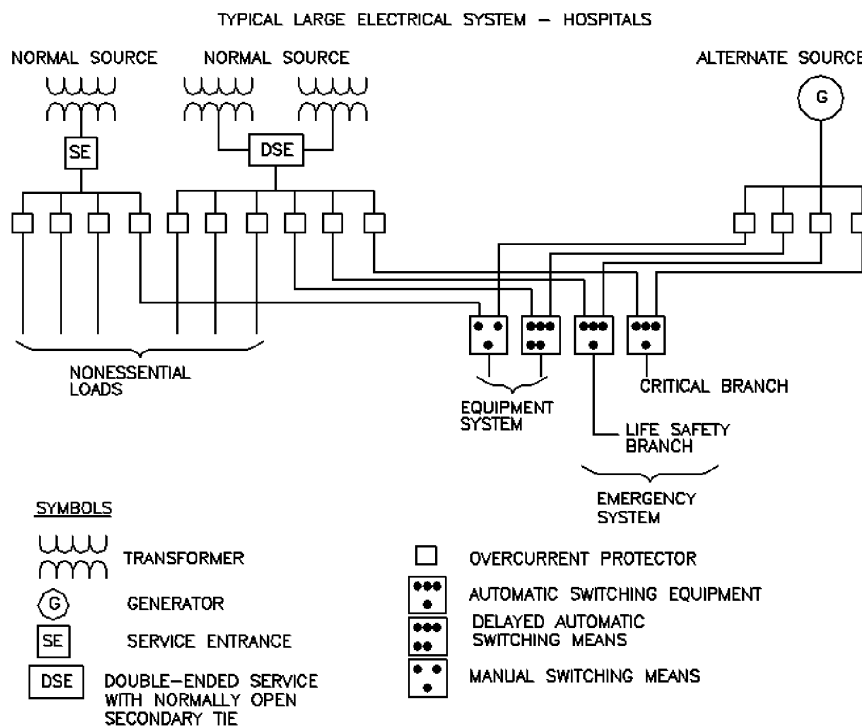


Figure 3-19—Adequately rated substation

3.9.6 Metering arrangement

Where a facility has more than one service entrance, the utility may bill each service independently. Since most utility rate structures are of a declining cost per block type for both power (kilowatt, kW) and energy (kilowatthour, kWh), the total utility bill for all service will be more than if a single meter were used. The utility may add the demands

(kW) and add the energy (kWh) consumptions and then calculate the bill as though one meter existed. This combined or additive bill will be less than the sum of the individual bills and is often referred to as *conjunctional billing*.

Even with just an additive bill for both kilowatts and kilowatthours, the advantage of diversity of loads for the demand will still not be realized. This can be obtained by providing features such as interwiring of demand meters to provide a totalized demand. This is often called *conjunctional billing with coincident demand*.

Modern electronic power consumption meters permit various combinations of types of metering including conjunctional and coincidence features, time-of-day metering, off-peak, or shoulder period metering. It is important that the engineer become familiar with the rate structures and options available, including special rate structures for certain categories of users (perhaps public buildings including health care facilities) before beginning negotiations with regard to electric service.

The design engineer should carefully evaluate the economics, maintenance, and operations associated with the purchase of medium-voltage vs. low-voltage power. If medium-voltage power is purchased, then the utility customer usually purchases the transformers necessary to transform from the utility distribution voltage to the service and low-voltage equipment, and is responsible for maintaining and operating this equipment. The utility usually will provide lower rates to compensate for the additional purchase and operating costs that the customer incurs. There may be technical design advantages to having a customer-owned, medium-voltage system such as distribution over large areas and for various switching schemes or even economic advantages in cost of power. However, maintenance of the medium-voltage system may introduce a level of (owner) responsibility (for safety), require a trained and experienced staff, and/or incur additional transformer losses and installation costs, any or all of which may not be justified.

3.10 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

Accredited Standards Committee C2, National Electrical Safety Code[®] (NESC[®]).

ANSI C57.12.10, American National Standard for Transformers—230 kV and Below 833/958–8333/10 417 kVA, Single-Phase, and 750/862–60 000/80 000/100 000 kVA, Three-Phase without Load Tap Changing; and 3750/4687–60 000/80 000 kVA with Load Tap Changing—Safety Requirements.⁴

⁴ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

IEEE Std 141, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (*IEEE Red Book*).^{5, 6}

IEEE Std 142, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (*IEEE Green Book*).

IEEE Std 241, IEEE Recommended Practice for Electric Power Systems in Commercial Buildings (*IEEE Gray Book*).

IEEE Std 242, IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (*IEEE Buff Book*).

IEEE Std 393, IEEE Standard Test Procedures for Magnetic Cores.

IEEE Std 446, IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (*IEEE Orange Book*).

IEEE Std 493, IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (*IEEE Gold Book*).

IEEE Std 739, IEEE Recommended Practice for Energy Management in Industrial and Commercial Facilities (*IEEE Bronze Book*).

IEEE Std 1100, IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment (*IEEE Emerald Book*).

IEEE Std C57.12.00, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

IEEE Std C57.12.59, IEEE Standard for Dry-Type Transformer Through-Fault Current Duration.

NEMA AB 3, Molded Case Circuit Breakers and Their Application.⁷

NEMA PB 2.2, Application Guide for Ground Fault Protection Devices for Equipment.

NETA Acceptance Testing Specifications.⁸

⁵IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

⁶The IEEE standards or products referred to in this clause are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

⁷NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

⁸NETA publications are available from the International Electrical Testing Association, P.O. Box 687, Morrison, CO 80465, USA (<http://www.netaworld.org/>).

NFPA 70, National Electrical Code® (NEC®).⁹

NFPA 70B, Recommended Practice for Electrical Equipment Maintenance.

NFPA 70E, Electrical Safety in the Workplace.

NFPA 99, Standard for Health Care Facilities.

NFPA 110, Standard for Emergency and Standby Power Systems.

NFPA 111, Standard for Stored Electrical Energy Emergency and Standby Power Systems.

NFPA 780, Standard for the Installation of Lightning Protection Systems.

3.11 Bibliography

Additional information may be found in the following sources:

[B1] American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) (www.ashrae.org/).

[B2] ANSI C57.12.20-2005, American National Standard for Overhead-Type Distribution Transformers, 500 kVA and Smaller: High Voltage, 34 500 Volts and Below; Low Voltage, 7970/13 800Y Volts and Below.¹⁰

[B3] ANSI C57.12.21-1992, American National Standard Requirements for Pad-Mounted Compartmental-Type Self-Cooled Single-Phase Distribution Transformers with High-Voltage Bushings; High-Voltage 34 500 GR YD/19 920 Volts and Below; Low-Voltage, 240/120; 167 kVA and Smaller.

[B4] ASHRAE/IESNA 90.1-2004, Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI).¹¹

[B5] Beeman, D. L., ed., *Industrial Power Systems Handbook*. New York: McGraw-Hill, 1955.

[B6] Blackburn, J. L., ed., *Applied Protective Relaying*. Trafford, PA: Westinghouse Electric Corporation, Printing Division, 1976.

[B7] Fischer, M. J., “Designing Electrical Systems for Hospitals,” vol. 5 of *Techniques of Electrical Construction and Design*. New York: McGraw-Hill, 1979.

⁹NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA (<http://www.nfpa.org/>).

¹⁰ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

¹¹ASHRAE standards are available from www.ashrae.org/.

[B8] IEEE Surge Protection Standards Collection (C62).

[B9] Mason, C. R., *The Art and Science of Protective Relaying*. New York: John Wiley and Sons, 1956.

[B10] Parsons, Robert A., *ASHRAE Handbook—Fundamentals* (Chapter 28, Energy Estimating Methods). Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 1993.

Chapter 4

Electrical power systems for delivering patient care

4.1 Overview

Proper distribution of electrical power throughout a health care facility is critical to the safe and effective operation of the facility. The electrical systems in the facility should support the ability of the staff to provide healing services. Fundamentally, the electrical systems should do two things. First, in keeping with the Hippocratic injunction, the system should do no harm. Second, the system should provide appropriate power when and where it is required by the caregiver, the staff, or the patients. The purpose of this chapter is to focus on the details of planning and laying out power distribution systems and power delivery devices to achieve these optimal levels of safety and efficacy.

4.2 Definitions

For the purposes of this document, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms* [B3]¹ should be referenced for terms not defined in this subclause.

4.2.1 critical care areas: Those special care units, intensive care units, coronary care units, angiography laboratories, cardiac catheterization laboratories, delivery rooms, operating rooms (ORs), post anesthesia recovery rooms, emergency departments, and similar areas in which patients are intended to be subjected to invasive procedures and connected to line-operated, patient care related electrical appliances.

4.2.2 general care areas: Patient bedrooms, examining rooms, treatment rooms, clinics, and similar areas in which it is intended that the patient will come in contact with ordinary appliances such as a nurse-call system, electric beds, examining lamps, telephones, and entertainment devices.

4.3 Electrical system safety

4.3.1 General discussion

Patients in a health care facility are often either ill or incapacitated. Patients often may not be able to act to protect their own safety. Many medical procedures make use of electrical power, and when caregivers expose an otherwise incapacitated patient to the hazards of potential contact with a source of electricity, the risk of mishap is greater than in other situations. Patients, especially those that are under anesthesia, are medicated, or who are very ill, have a lower tolerance to electric shock and cannot react to, or otherwise protect themselves from, electrical shock as can a normal healthy individual. These patients are frequently connected to electrical equipment, including catheters. In addition, potentials

¹The numbers in brackets correspond to those of the bibliography in 4.6.

that are normally not hazardous to a clothed, healthy person might be dangerous in a health care facility where a patient's skin is often in direct contact with medical devices. The nature of a patient's illness may lower his or her natural body resistance due to incontinence, perspiration, or open wounds. The process of diagnosing a patient can make that patient more vulnerable to electrical shock.

Similarly, health care facilities often contain hazards of various kinds, from oxygen-enriched environments to flammable sterilizing agents to fluids that can reduce human skin resistance to electrical currents. When combined with the abundance of electrical outlets and devices, the risks of hazard are significantly greater than risks in other types of facilities.

Codes and regulations mandate certain levels of safety for electrical systems in health care facilities. Regulations set a floor for the minimum levels of acceptable safety in electrical systems, and engineers obviously must meet these minimum requirements. Understanding the potential hazards, however, should allow engineers to make better decisions regarding the electrical systems in the health care facility.

This subclause starts with an exploration of the physiological parameters of the human body, especially during medical treatment. Then it describes various hazards peculiar to health care facilities and, finally, methods to mitigate those hazards.

4.3.2 Physiological parameters

A necessary foundation to understanding electrical hazards and mitigation strategies are the basic physiological parameters of electrical safety.

4.3.2.1 Tissue reaction to heat

Current flowing through a resistance generates resistant heat. When current flows through tissue, the tissue's electrical resistive properties cause energy to be dissipated in the form of thermal heating. If the current flow is sufficient, the resistance heat can cause harmful burning. Some surgical procedures use this very process to cut tissue and to coagulate bleeding sites.

4.3.2.2 Body/tissue resistance

Body tissue has, in general, a specific resistance that is useful in calculating expected currents that will be induced from various levels of electrical potential. The skin, in general, provides a high-impedance barrier to most sources from which leakage currents could flow. Well-prepared contacts for electrocardiographs (EKGs), etc., provide about 100 Ω between electrodes. Dry, calloused skin may have an impedance approaching 1 000 000 Ω . Wet or saturated body tissue may have considerably less than 1000 Ω of resistance.

4.3.2.3 Cell excitability

Chemical differences in individual nerve and muscle cells create small inside-to-outside electrical potential on the order of 90 mV. Inducing an imbalance in the chemical or electrical characteristics of the cells excites them to transmit nerve impulses or muscle contractions. Necessary levels to induce such impulses or contractions are nonlinear in amplitude and time so that creation of perceived shock and contraction is not a simple formula. To a certain extent, this explains the variances in expressing levels of shock in ranges rather than specific values.

Nerves react to electrical stimuli by sending a message to the brain that exposure to an unsafe condition has occurred. Applying a current density at a nerve location will cause stimulation to one or more nerve cells. The same current density, if applied to different areas of the body, will create different sensations.

Electrical stimuli to the hand will cause a severe contraction of hand muscles that can result in the grasping of an energized conductive object without the ability to let go. Heavy currents across the chest can cause contraction of thoracic muscles, affecting breathing and possibly causing suffocation.

Introducing a current into the heart can cause varying reactions, depending upon conditions. At low current levels, nonlinearities become a factor, so that the difference between a constant current source and a constant voltage source becomes important. Another extremely important factor in the effect of an electric current upon the heart is the current density. For example, introducing a current through the diffused connection provided by a liquid-filled catheter may cause no cardiac reaction, while the same current could produce a cardiac reaction if introduced through a very small metal electrode. Similarly, faulty equipment that produces improper stimulation of the cardiac muscle can create disorganized contractions called *fibrillation*, with little or no pumping of blood.

4.3.2.4 Shock levels

The susceptibility of humans to electrical current has often been documented in accidents involving contact with power lines. These accidents frequently produce burns, ventricular fibrillation, respiratory paralysis, hemorrhage, and neural dysfunctions. These same effects can also be caused by an exposure to electrical hazards of any cause.

The lowest level of current that is perceptible to a person start at about 100 μA . At this level, the current will generally only be felt if it is delivered through a very sharp pointed electrode, resulting in a high current density. A large contact area, such as a bed handrail, may require a current as high as one mA for perception.

Arm muscle contraction and pain may develop in the 1 mA to 5 mA range and is certain at 10 mA.

Uncontrolled sustained muscular contraction (“can’t-let-go”) can start at levels of 6 mA and higher. Up to 30 mA, these reactions increase in intensity, and although such currents

are usually not fatal, temporary respiratory paralysis can occur. Above 30 mA, the chances of a fatality from a variety of causes, including ventricular fibrillation, increase.

For the general patient, these levels may be lower. Many patients will experience these symptoms at lower levels of current. The patient may be weak, helpless to break free, suffering from a damaged or stressed heart, an infant, in a wet environment, or experiencing an increased electrical sensitivity because of drug therapy.

Patients that have direct electrical pathways to the heart (via pacing wires or fluid-filled catheters) are especially vulnerable to lower levels of current. In this case, stray current in the range of 20 μA to 300 μA at 60 Hz can be sufficient to cause ventricular fibrillation.

4.3.2.5 Cardiac fibrillation

Cardiac fibrillation is a phenomenon in which the muscles of the heart contract in a disorganized manner so that little blood is pumped. Cardiac fibrillation is a complex phenomenon related to concentration, location, and duration of current, and timing in the cardiac cycle. Part of the complication of determining a threshold level is that the mere physical placement of an electrode within the heart may cause fibrillation with no current. Under controlled conditions when fibrillation is intentionally produced by direct stimulation, currents of 80 μA and higher are usually required from constant current sources.

Other clinical parameters that may cause the heart to become susceptible to induced fibrillation in the presence of low levels of 60 Hz are the following:

- a) Alternating current and electrolyte imbalance
- b) Myocardial ischemia
- c) Hypothermia
- d) Hypoxia
- e) The use of drugs such as digitalis, alcohol, or vasodilators

Good engineering design today sets 10 μA at 60 Hz as the maximum allowable leakage current available from any device having leads that may enter the heart.

4.3.3 Potential hazards

4.3.3.1 Fire and explosion hazards

Many of the requirements for electrical safety were developed in the early to mid-1900s to reduce the fire and explosion hazards when ether and other flammable agents were used. The use of flammable anesthetics in the surgical suites (also called *operating rooms*, or ORs, in this chapter) and the potential problem of explosion required that special electrical safeguards be developed. Most explosions occurred either within the anesthetizing machine or within the patient. Static discharge, as well as sparks from electrically powered devices, introduced in the explosive atmosphere caused fires and explosions.

Since flammable gases can be ignited by static electric discharge, comprehensive methods reducing the buildup of static charge were developed.

Today, flammable anesthetics are rarely, if ever, used in the U.S., making these safeguards no longer necessary. However, in other parts of the world, caregivers still use flammable anesthetics, and these safety measures are still extremely important to prevent ignition hazards.

Despite the elimination of flammable anesthetics in the U.S., fires can still occur in ORs, largely because of ignition of patient curtains that are in close proximity to electrocautery devices. Electrical systems, however, are no longer a significant source of fires within ORs.

Several agents used in surgical areas (such as alcohol, which is used as a cleaning and antiseptic agent) may be ignited, if not properly used, by the spark from electrosurgery devices. Although flammable liquid germicides are prohibited by NFPA 99² where cautery or electrosurgery is performed, periodic fires in ORs have occurred due to the use of such agents.

The same fire hazards from electrical short circuits that cause fires in electrical devices in other environments can cause fires in health care facilities. These hazards may be aggravated in health care facilities by the fact that the air in these buildings may be more often enriched with oxygen than in other types of facilities.

4.3.3.2 Neutral-to-ground short circuits

Neutral-to-ground faults usually do not directly cause problems with equipment operation. In fact in most cases of these types of faults, the equipment will continue to operate normally without the activation of overcurrent protection devices. Such faults are common sources of stray ground currents, and they can produce serious secondary interference with sensitive equipment by creating common mode noise on the grounding conductor. Measurement devices such as electrocardiogram (ECG) and electroencephalogram (EEG) are more susceptible to the interference caused by the elevated reference voltage of the ground. Another potential source of these faults is the grounding method used by x-ray and other heavy-duty equipment with regard to the neutral. Sometimes these units use the ground as a neutral return. This may be more of an issue with equipment manufactured outside of the U.S.

4.3.3.3 Line-to-line and line-to-ground faults

Line-to-line faults are rare and occur when the impedance between energized phase conductors of two different phases within a system goes to zero. A line-to-ground fault occurs when the impedance between any energized phase conductor and ground goes to zero. The low impedances introduced by both types of faults will allow abnormally high levels of current to flow through the affected circuit. Such faults present two kinds of problems. First, they can deliver a shock to a person if the person completes the circuit by

²Information on references can be found in 4.5.

becoming the connection from the energized conductor to the ground (or to another energized conductor.) This kind of shock will produce the effects previously noted. The second kind of problem is that breakers in the system are designed to open to clear the fault, and their opening can mean a loss of power to portions of the electrical system that are essential to patient care.

When one of the aforementioned fault conditions occurs, the high magnitude fault currents can be potent enough to kill or injure a person, if the current flows through that person's body.

Branch circuits may serve devices in more than one room. When they do, a fault in one room will trip upstream overcurrent protective devices (OCPDs) and shut off power to the other rooms supplied by that same circuit. Engineers should therefore take care when laying out branch circuits to try to minimize the probabilities of a fault in one room unintentionally interrupting the power to critical functions within another room.

Similarly, if the OCPDs in the distribution system have not been properly coordinated (or if they fail to operate properly), a fault in one part of the distribution system can cause an upstream OCPD to operate rather than the OCPD closest to the fault. When this happens, unnecessary outages can occur in the facility, increasing the overall hazard. Care should be taken by the engineer to select OCPDs that coordinate.

Many older facilities are equipped with OCPDs that have aged beyond their useful life. Cases have been observed where continuous current well in excess of the rating of the OCPD did not cause it to operate. It is important to evaluate the branch circuit protection devices serving patient care areas for their ability to function as designed. Where devices are no longer capable of operating within design parameters, the devices should be replaced.

4.3.3.4 Electrical disturbances near transformer vaults locations and other electrical equipment rooms

There are several other types of electrical disturbances/phenomena that can have adverse effects on the electrical systems in a health care facility.

Like stray ground currents, stray magnetic fields can cause problems with EEG or ECG laboratory measurements. Engineers should take precautions to assure that electrical installations that might create stray magnetic fields are not located in adjacent areas containing this or other sensitive medical electronic equipment.

Switching devices can create electrical disturbances affecting sensitive electronic diagnostic and imaging equipment. A diagnostic or imaging device that is rendered incapable of providing the clinical staff with accurate information can pose a hazard to the patient. Inrush current transients from motors, transformers, or switching capacitors can create significant voltage disturbances. In order to avoid affecting the sensitive medical devices, equipment prone to creating local voltage disturbances should be fed from dedicated circuits and should not be supplied from panels that also supply sensitive electronic equipment.

4.3.3.5 Wet locations

On a conventionally grounded system, an electrical shock is always possible when a line power device is operated in the presence of grounded conductive material and a person can bridge the gap between the two.

Large metal decks and floors covered with water present such a possible hazardous condition. A water-covered floor is potentially more hazardous than a dry metal deck because water can penetrate shoes and make better electrical connection to the body. In addition, there is always the possibility of having water splashed into electrical devices, creating contact with electrical sources.

The location of electrical devices near tubs or pools of water where a patient may be treated or where patients swim presents the possibility of shock. The National Electrical Code® (NEC®) (NFPA 70) requires that ground-fault circuit-interrupter (GFCI) receptacles be used in these locations.

There are varying opinions as to whether ORs should be considered to be wet locations. Some engineers argue that all ORs are wet, due to the fluids that are intimate to the patient and to the staff who are also in close contact with electrical devices. Others maintain that some ORs, such as cystoscopy or orthopedic ORs (which use arthroscopic methods) are wet, while others are not. Finally, others believe that no OR should be considered to be a wet location.

The NEC and NFPA 99 allow the health care facility's governing body, which is familiar with the procedures being performed within each OR, to determine whether any OR or special procedure space should be classified as a wet location. The codes require that wet locations be protected with either ground-fault interrupter (GFI) receptacles, or if interruption of power cannot be tolerated in the room, with an isolated power system (IPS). These requirements are intended to provide added levels of protection against electrical hazards in areas that are normally subject to wet conditions while patients are present.

A bed with an incontinent patient could possibly be considered a wet location. There have been reports of serious shocks when electrical beds had cord controls operated at line voltage. Using sealed, low-voltage, or pneumatic controls reduces the possibilities of these types of shocks.

4.3.4 Electrical system hazard mitigation

4.3.4.1 Flammable agents

Surgical procedures in the U.S. no longer utilize flammable anesthetics. ORs designed during the era of flammable anesthetics incorporated many safeguards to mitigate the possibility of igniting any vapors.

Where flammable anesthetics are anticipated, protective measures in ORs should include conductive flooring, conductive footwear, clothing for reduced generation of static charge,

high-impedance conductivity of elastomeric tubing used within the anesthesia airway path, grounding of patient electrical devices and exposed metal (equipotential grounding system), and isolated power. Some non-U.S. hospitals may still use flammable anesthetizing agents. Such substances are heavier than air, so engineers shall treat these areas up to the 1.52 m (5 ft) level as a Class I, Group D location. As discussed earlier, the most likely source of flammable agents in today's ORs is in the form of germicides.

4.3.4.2 Wet locations

The NEC and NFPA 99 require GFCI receptacles or an IPS to provide personnel ground-fault protection. At this writing, the NEC requires GFCI receptacles to be installed in any room or area that has a basin with one or more of the following: a toilet, a tub, or a shower. This requirement is intended to protect against accidents that could occur when common household line-powered items such as toothbrushes, shavers, hair dryers, etc., are used in the presence of water. In any area where it is routine to have concentrations of conductive liquids on the floor while staff or patients are present, several precautionary steps need to be taken.

The first and most important step is to have equipment made for this type of environment properly installed, used, and maintained. If possible, provide splash guards. Metal enclosures containing line-powered equipment should be grounded with an insulated equipment grounding conductor. Line-powered equipment should be located as far from the wet area as is practical. Particular care should be given to positioning cord-connected equipment to prevent the cord from falling into a tub, basin, or pool. Electrocutions in home bathrooms have most often occurred when electrical appliances were placed near the tub and then were touched or fell into the tub.

In critical care areas designated as wet locations, if the power interruption caused by GFCI operation cannot be tolerated, engineers shall use an IPS.

4.3.4.3 Ground-fault interrupters

Some wet locations in a hospital can tolerate the loss of power upon occurrence of a fault. Such areas shall be provided with GFCIs for personnel protection. The GFCIs will continuously monitor ground current in a circuit and will de-energize that circuit when the ground current exceeds 4 mA.

4.3.4.4 Insulation

Energized conductors shall be insulated from each other, from ground, from patients, and from hospital personnel. This insulation is created both by the insulating material used and by space separation. Primary insulation protection of cardiac catheters can be provided by properly insulating the exposed end or by making the environment surrounding the catheter as safe as possible.

4.3.4.5 Overcurrent and ground-fault protection of equipment

Selective overcurrent coordination is a code requirement to minimize the extent of outages. Likewise selectively coordinated multilevel ground-fault protection of equipment (GFPE) is required for the larger sizes of electrical distribution equipment.

Little difference exists between the branch circuit overcurrent protection provided for health care facilities and that provided for other commercial buildings. Engineers should take care to obtain the highest quality and most reliable equipment available. As previously discussed, it is even more important to coordinate the overcurrent protection devices in health care facilities than in other types of facilities to maximally protect service to all areas of the health care facility. Engineers shall select overcurrent protection devices that can coordinate with the balance of the system.

Some applications in commercial buildings will accept nuisance tripping due to events like transformer inrush (from the transformer's magnetizing current). Nuisance tripping in the health care environment is not acceptable. Special care should be taken to ensure events like transformer inrush will not cause operation of the OCPD. High-efficiency transformers required for energy code compliance in many states have higher magnetizing currents than standard dry-type transformers.

4.3.4.6 Adequacy of power

With the ever-increasing use of electrical and electronic devices in the patient care areas, provisions should be made during the design stage for future load growth. These provisions include additional physical space in electric rooms, spare devices, spare capacity, and the ability to expand distribution equipment easily.

4.3.4.7 Continuity of power

See Chapter 5.

4.3.4.8 Mechanical protection of feeders

The NEC requires that emergency conductors be installed within conduit and segregated from the wiring of other systems in order to ensure continuity of service to these loads. There are a number of options available that have several economic and safety implications. One consideration is the use of either plastic or rigid metal raceways. Raceways provide physical protection of the power conductors. In addition, metallic raceways also provide a redundant grounding path. The physical protection is especially important in health care facilities because of the frequent renovations and changes that occur there. Demolition activities in existing facilities are among the most frequent causes of feeder damage.

A second consideration has to do with fittings. Engineers generally have options for using either compression fittings or set-screw fittings for electrical metallic tubing (EMT) conduits. Some engineers believe the set-screw fittings are less reliable, as they consist only of a device with one screw on either end, compressing each of the two pieces of

conduit. However, the set-screw device takes less time to install than do compression fittings, and the cost pressures for the use of set-screw devices are high.

4.3.4.9 Conductive flooring

As previously mentioned, conductive flooring is required only where it is necessary to control static electricity in anesthetizing locations where flammable anesthetic agents are administered. Therefore, conductive flooring is no longer required in the U.S. Historically, these floors were often constructed of special terrazzo that incorporated carbon to form conductive pathways throughout the floor. The floor usually included a metallic grid so that no point on the floor was more than a few inches from a grounded conductive element. The point of these floors was not to insulate them from ground, but to prevent the buildup of static electricity within the room through holding everything within the room at the same potential.

Some conductive floors are made of conductive ceramic tiles. This method results in a floor that is very stable with regard to the resistance but is apt to have tiles break loose when heavy equipment is rolled over it. The reason for this seems to be that when adhesives are made conductive, they lose those characteristics that contribute to their durability as an adhesive.

Another type of conductive floor is sheet vinyl, which may be manufactured with a cushioned backing. It maintains the proper conductivity very well but is prone to be damaged by wheeled OR tables and portable x-ray equipment, and it is easily cut when sharp surgical instruments are dropped on it. Another commonly used flooring material is seamless rubber.

Under current NFPA rules, it is not necessary to have conductive floors in nonflammable anesthetizing locations. In facilities that have conductive floors, they shall be tested at least once per year. There is no upper limit of resistance for conductive floors in these nonflammable anesthetizing locations, and the lower limit is 10 000 Ω to ensure that the conductive floor does not increase the hazards of electrical shock by offering too low an impedance to ground.

4.3.4.10 Grounding

Grounding provides a nonhazardous return path for leakage currents that exist and minimizes the hazard produced when a fault condition develops. Proper grounding provides a means for dissipating static charges and shunting fault currents and/or normal leakage currents away from patients and attendants. The NEC clearly spells out the grounding requirements for various kinds of health care facilities. Equipment grounding in patient care areas is more demanding than the general requirements for grounding found in Article 250 of the NEC. Also, the term *equipotential grounding* is no longer used in the NEC and NFPA 99. However, the electrical engineer designing a hospital facility should be cautioned not to assume that the elimination of this term also eliminates all of the special grounding requirements for patient care areas. Careful study of Articles 250 and 517 of the current NEC and of NFPA 99 should be made to determine exactly what special grounding provisions are required in all patient care areas.

Usually modern construction adds one or more parallel, redundant grounding paths to the green grounding wire in terms of metal conduit, metal piping, and metal structural members. These paths provide effective ground impedance at the receptacle in the order of 2 m Ω to 20 m Ω . In addition to providing low impedance, these elements provide a multipath grid for fault currents so that voltages that do develop within the patient vicinity, even during a severe fault, seldom cause hazardous conditions. Hazardous voltage conditions generally develop when device grounding wires or the connection to the distribution grounding system, or both, fail.

The redundancy in grounding provided by metal conduit is twofold. The conduit provides a redundant path to the ground. In addition, the physical mounting of the conduit to other conduit, metal studs, other piping, and structural steel members provides a network of redundant grounding paths. These design and inadvertent connections contribute to effective low-grounding impedance for current flow during fault conditions. Using electrical metallic tubing frequently produces effective grounding impedances in the order of 1 m Ω to 10 m Ω . These values are low relative to that provided by a #10 AWG wire having 3.28 m Ω per m (1 m Ω per ft) resistance.

An equipotential grounding system, as previously discussed, is required only where flammable anesthetics are used, and is optional elsewhere. These systems bond together all of the grounds within a room and connect them to a common point. All conductive surfaces in the patient vicinity that are likely to be energized shall be bonded to a reference grounding point with an effective conductance at least equal to #10 AWG copper wire. The system requires all receptacle grounding terminals to be grounded to the reference grounding point by means of an insulated copper conductor. The conductor is insulated for corrosion protection and to prevent arcing points between the conduit and the conductor in case of a fault.

Previous editions of the NEC required that conductive, moveable, nonelectrical devices be bonded together. The code required that designers include at least one ground jack in all critical care areas, and six ground jacks in ORs to achieve this bonding. A number of years ago, the code eliminated this requirement. The decreased need for the grounding jacks came about at least partly because of improvements in equipment (plastic cases in lieu of metal, better insulation) and the lower operating voltage of devices, which reduced the hazard of possible equipment failure. In fact, the use of ground jacks was problematic from the start since staff often lost the cords that were supposed to connect the equipment to the jacks and the outlets were never used anyway. Today, few hospital staff members even know what these outlets are for when they see them. There is no evidence to suggest that the jacks still provide any benefit.

Equipment grounding, through the ground conductors in the feeders and branch circuits and through the grounding conductor in the power cord, provides a low-impedance path to safely conduct fault currents or leakage currents back to the source. It also is a means of bonding all conductive surfaces together such that the potential differences between such surfaces are minimal. The grounding system in a health care facility should be designed to minimize the voltage potentials that can be created on ground conductor surfaces due to stray ground currents.

In a patient care area, branch circuits feeding receptacles and fixed electrical equipment that are likely to become energized and subject to personal contact are required to have redundant ground paths. These redundant paths may be in the form of an insulated copper equipment bonding/grounding conductor, plus a metal raceway system or a cable armor or sheath assembly. The NEC does not accept metal-clad (type MC) cable for branch circuits in patient care areas, even the health-care rated HCF type MC cable with two ground conductors for this purpose. The code clearly requires an insulated internal ground conductor and a continuous metal sheath. Certain kinds of armor clad (type AC) cabling (generally referred to as Hospital Grade AC Cable) do meet these requirements. The NEC does not permit the use of AC cable for emergency circuits except for a few limited exceptions.

4.3.4.11 Isolated power system

The use of isolated (ungrounded) power systems initially reduced the risk of electrical shock and eliminated the risk of explosion due to flammable inhalation anesthetizing agents. An especially important safeguard provided by the systems is that they substitute an alarm for a breaker tripping upon a first fault, thus increasing reliability of service. Although flammable anesthetizing agents are no longer used in the U.S., some hospitals still prefer to continue using IPSs. Generally, these hospitals believe that the OR is a wet location and thus a more hazardous location with respect to electrical systems. They may also believe that an IPS gives the surgical team greater control over their electrical environment because the first fault on the system only sounds an alarm instead of tripping a circuit breaker. Some hospitals believe that the complexity of the IPS causes ORs with IPS to experience more electrical problems than ORs without IPS.

The decision whether or not to install an IPS should be made jointly by the hospital administration, medical staff, hospital biomedical (clinical) engineering, hospital facilities engineering, and the hospital design engineer.

The term *isolated system* or *isolated power system* is normally used for an ungrounded electrical distribution system including (or comprised of) all of the necessary equipment as specified in NFPA 99 and in the NEC (Article 517). This system includes a shielded isolation transformer, a line isolation monitor (LIM), an input circuit breaker, output circuit breakers, power receptacles, and associated grounding equipment. Originally, engineers created these systems by assembling various elements together into a system. However, in the early 1960s, the isolated system package or *panel*, as it was then called, began to appear. Initial units contained the isolation transformer, circuit breakers, and a ground detector. Later, the LIM replaced the ground detector. In 1971, packages appeared that also contained power receptacles, ground buses, and grounding jacks. Most present installations make use of these packaged components. UL standards were established for these packaged units (UL 1047) and they are now available as labeled devices. Many engineers choose to locate the isolated power panel in the OR room it serves. Others choose to locate all of the panels in a sterile core, where they can be accessed without entering the OR.

Because of their benefits, IPSs were historically used not only for wet locations or areas using flammable anesthetics, but also for ICU/CCU areas where loss of power due to a

breaker tripping upon a fault could be life threatening. Some states still mandate the use of isolated systems in the wiring of those areas.

An IPS works by isolating the power supply conductors from ground by leaving the system ungrounded and essentially floating the power supply conductor voltage from the reference ground. Although capacitive coupling and resistive leakage between the power supply conductors and the reference ground does exist throughout the system, the impedance of this coupling is so high that any ground-fault current will be substantially reduced. As long as the total resistive and capacitive impedance, which includes equipment and wiring, remains above 24 000 Ω , a ground-fault current will only produce a current of 5 mA or less.

Although the magnitude of short-circuit current is drastically reduced by an ungrounded system, due to the extra impedance inherent in the isolating transformer, the ungrounded system response to a line-to-line fault is similar to that of a conventionally grounded system, in that it will activate the OCPD and interrupt power to the area. Most faults that occur within appliances are, however, line-to-ground faults as opposed to line-to-line faults, and a line-to-ground fault on a grounded system will cause equipment or system power loss compared with an ungrounded system that will continue to operate during a line-to-ground fault. It will continue to operate under a standby condition. Because an unsafe condition now exists, the OR supervisor will assess the problem and take corrective action.

The benefits derived from the ungrounded electrical distribution system are as follows:

- a) It limits the amount of current that can flow to ground through any single line-to-ground fault that may occur in the system. For all practical purposes, this eliminates the danger of massive electrical shocks (macro shock) to patients or personnel because of this type of fault. It also practically eliminates the possibility of arcing because of this type of fault and thus provides protection against the accidental ignition of explosive or combustible materials being used in the area. These features of the IPS permit typical practically sized grounding conductors to protect effectively patients who might be affected by very small amounts of electrical current.
- b) In a grounded distribution system, a line-to-ground fault on the system will operate the OCPD and interrupt power to the device or the area. In most cases, this is a highly desirable feature. However, in any hospital area where life support devices are used, this loss of power may create a life support hazard. The ungrounded electrical distribution system responds quite differently to a line-to-ground fault. With this system, the fault does not pose an immediate danger to the patient or to personnel, and power is not interrupted. Only a visual and audible warning is issued. In any case, the device in which the fault has occurred will continue to operate and can be safely used until replacement equipment is available.
- c) Periodic LIM readings can provide a continuous record of the system and its operation. The LIM is a one-time only cost addition as compared to the continuing cost of periodically checking the system and equipment. With continuous monitoring, the hospital engineering staff is kept on the alert to keep the

equipment in excellent operating condition so that the LIM does not go into an alarm condition.

The faults occurring within the medical appliances can be the result of slowly degrading insulation or components. When the potential leakage caused by these conditions increases beyond the limits set for the ungrounded system, the IPS LIM will go into alarm to warn the staff of the hazard condition. This feature is of great value even to institutions that have sophisticated preventive maintenance programs for their appliances and equipment.

The reason that an IPS works is that, even though it is ungrounded, the system is constantly leaking a certain amount of current to ground through the capacitance of its conductors. This capacitance effectively forms a high-impedance ground return path for the “fault current” that the system will detect when a “first fault” occurs.

When two conductors in close proximity are energized from the secondary of a distribution transformer, a small current flows between them due to the dielectric properties of the conductor insulation. When these conductors are run in grounded metallic conduit, there will also be leakage between the ungrounded phase conductor of a grounded system and the conduit. In an IPS, neither power conductor is grounded, so there will be leakage from both power conductors to ground (i.e., to the conduit or grounding conductor). Current does not normally flow in the conduit since there is no direct return path to the current source from ground. Table 4-1 illustrates the difference in leakage currents of conductor insulations, while Table 4-2³ illustrates the various leakage currents contributed by equipment typically found in the operating theater.

Table 4-1—Table of leakages contributed by wiring

Materials used	Result
TW wire Metal conduit Wire pulling compound with ground conductor	9.84 μA per m (3 μA per ft) of wire
XLP wire Metal conduit No wire pulling compound with ground conductor	3.28 μA per m (1 μA per ft) of wire

³Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the recommended practice.

Table 4-2—Table of leakages contributed by equipment

Device	Leakage ^a (μ A)
OR table light (single light without track)	75 to 175
OR table light (track-mounted)	300 to 400
Portable OR light	10 to 100
X-ray viewer (single)	50 to 150
Electrosurgery machine	100 to 300
Vacuum pump	50 to 125
Physiological monitor (single-channel)	30 to 200
Physiological monitor (eight-channel)	275 to 350
Heart-lung machine	350 to 450
Defibrillator	50 to 125
Portable x-ray (120 V capacitor charge)	30 to 50
Cardiac fibrillator	15 to 50
Respirator	100 to 150
Computer or computer terminal	100 to 500
Cardiac synchronizer	75 to 125
Hyperthermia unit (single patient unit)	125 to 175
NOTE—Excessive power cord lengths will add measurably to the total leakage of the equipment [i.e., a 18.29 m (60 ft) power cord can add from 60 μ A to 130 μ A of leakage to an electrosurgery machine].	

^aRanges given are from tests of equipment found in the field and in good working condition. Older equipment exhibited higher leakage currents.

Table 4-3 shows the portable equipment leakage current limits set by NFPA 99. The values are based upon physiological parameters and only after extensive debate by the technical committees responsible for these particular chapters of NFPA 99. The present limits for voltage and impedance of the grounding system in patient care areas are 20 mV and 0.1 Ω , respectively. In general, particularly for the voltage, the actual values measured at the time of acceptance should be much lower than these. Values approaching these indicate that something is wrong with the design or the installation.

Table 4-3—Maximum safe current leakage limits

Type of device	NFPA 99 (μA)
Portable equipment (patient use)	300
Portable equipment with non-isolated input patient leads	100
Portable equipment with isolated input leads	50
Portable equipment (hospital use, i.e., housekeeping, maintenance, etc.)	500

Specific inductive capacity (SIC) is a term used by wire manufacturers to describe the dielectric properties of the insulation characteristics of a particular wire. *Dielectric constant* is a term used to define the properties of insulating materials. These two terms, although closely related, are not exactly the same.

The NEC recommends that the secondary conductors of an IPS have insulation with a dielectric constant of 3.5 or less. Most manufacturers will state the SIC number, which is usually higher than the dielectric constant of the insulation material. Care should be taken to define a wire with characteristics appropriate for these low-leakage applications.

Capacitive coupling is determined by the dielectric constant of the insulation, the conductor length, and the spacing between the conductor and ground. Wire insulation with the lowest dielectric constant may have other properties that are unacceptable. Polyethylene has a lower dielectric constant than cross-link polyethylene (XLP), but it also has a lower temperature rating.

Although the magnitude of short-circuit currents is drastically reduced by an ungrounded system, due to the extra impedance inherent with an isolating transformer, the ungrounded system response to a line-to-line fault is similar to that of a conventionally grounded system in that it will activate the OCPDs and interrupt power to the area. Most faults that occur within appliances are, however, line-to-ground faults as opposed to line-to-line faults, and it should be noted that a line-to-ground fault on a grounded system would cause equipment or system power loss compared with an ungrounded system that will continue to operate during a line-to-ground fault. It will continue to operate under a standby condition. Because an unsafe condition now exists, the OR supervisor assesses the problem and takes corrective action.

An isolated ground electrical system is more expensive than a grounded system to install, since an isolation transformer and a LIM are provided. The package convenience of an isolated system in a single enclosure allows its installation in less time than installing individual components. Periodic tests should be performed on this equipment as well as the IPS, and records should be kept of the results of these tests. Ten minutes per month

should be allowed for each ungrounded system within the hospital. For a conventionally grounded system, maintenance to ensure the integrity of the ground, and to ensure that the ground-fault protection equipment is satisfactory, may be at least as demanding.

IPSS can create other problems as well:

- a) If the ground continuity of the LIM is lost, the total hazard current is not monitored on the LIM and this could give a false sense of security.
- b) While chances of microshock are reduced with an isolated distribution system, the LIMs hazard current alarm level of 5 mA (as well as the previous level of 2 mA) is still too high to completely prevent microshock current levels.
- c) High hazard current conditions can result in alarms that may be disturbing during normal operating procedures. Some hospitals have been known to disconnect their LIMS to “prevent” these nuisance alarms. Others simply learn to ignore them.
- d) The large footprint of isolation panels requires the use of valuable wall space within an OR.
- e) IPSS can contain only a limited number of branch circuits (usually no more than 16) because of the overall IPS leakage current limitations.
- f) IPS branch circuit wiring lengths must be limited because of the overall IPS leakage current limitations.

To eliminate some of the nuisance alarms, the NEC and NFPA 99 were changed to permit a 5 mA alarm level rather than the previous 2 mA alarm level. The 5 mA alarm level permits more equipment to be connected to the isolated distribution system without causing a nuisance alarm. However, the 5 mA LIM alarm level does not provide the same level of protection against shock as does the 2 mA LIM alarm level. If a hospital decides to use an IPS, a 10 kVA IPS should be adequate to supply a steady-state load of 7.5 kW. There should be a minimum of two 10 kVA IPS panels per OR, because the more circuits on a circuit, the more leakage current the system will have. Each unit should have the capability to accept the connected load of the entire OR. Each IPS should be supplied from a separate transfer switch supplied by the critical branch of the emergency system. Each receptacle in the OR should have a dedicated circuit. Normal grounded receptacles should be located at strategic locations within the OR. A monitor should be installed on each IPS to indicate when the electrical load has reached 90% capacity of the IPS. A remote audiovisual alarm could be activated if this situation occurs. A separate, three-phase IPS panel should be installed for laser and x-ray equipment. This unit should have the capacity to supply a controlled number of the dedicated laser receptacles, making power available to each OR laser receptacle on a selected basis. See Figure 4-1.

It should be emphasized that when an ungrounded electrical system is used, it does not diminish the need for an effective, low-resistance grounding system. While the ungrounded distribution system limits the amount of fault current that flows in the fault, it does not eliminate the fault current completely. The grounding conductor is an effective shunt for this current in parallel with the patient and personnel.



Figure 4-1—Isolated power

4.3.4.12 Three-phase isolated system power

In recent years there have been increasing demands for three-phase power within an anesthetizing location. Special three-phase ungrounded isolation systems are available with UL 1047 listing for these locations. It is generally neither advisable nor practical to try to derive both the three-phase power requirements and the single-phase power requirements from a single isolation system. It is best to provide a separate isolation system for three-phase equipment. Typical devices requiring three-phase power in the OR are laminar airflow devices, photo coagulating equipment (laser), special positioning, and electrical surgical tables. Since such loads are large power consumption devices often with

large inrush currents, designers should not supply sensitive electronic equipment from the same source.

While much of this equipment is also available in single-phase design, some of the devices are available only in three-phase design, with features not available in the single-phase machine that the medical team requires. Once a situation of this type is established, it is the responsibility of the design engineer to properly specify and design a three-phase isolation circuit that will give the hospital trouble-free service.

The general rules and conditions for the effective three-phase isolation installation are identical to those for the single-phase isolation system previously described.

4.3.4.13 Using the line isolation monitor

The LIM is an impedance measuring device used with IPSs that will sound an audible alarm and give a visual warning when the line-to-ground impedance of the system has degraded to the point where current flow from any of the power conductors to ground during a ground fault is in excess of the limits established by the standards.

All LIMs include a meter that continuously indicates how much current is flowing through a ground fault if it should occur. Note that the meter does not indicate current that is flowing, but rather predicts the current that will flow if a fault-to-ground occurs.

All LIMs shall provide a means of silencing the audible alarm in the area of use so it does not distract the attention of the medical staff from the procedure being performed at that particular time. The standards do allow that any medical procedure being performed at the time the alarm sounds can be brought to its completion before services be performed to remove the fault on the ungrounded system as indicated by the LIM. New procedures should not be started until the engineering or maintenance department of the hospital facility has located and corrected the problem and properly documented such action.

The *monitor hazard current* is the measure of degradation of the isolated system caused by connecting the LIM to the system. When a 2 mA trip level LIM is connected to a perfectly ungrounded system, and if the amount of current that will flow after connection from either line-to-ground is 25 μA , then it is said that the monitor hazard current is 25 μA . A 5 mA trip level LIM would have a monitor hazard current of approximately 50 μA .

LIMs are provided with a means for testing their function. This is accomplished by a test switch that, when energized, will place a simulated fault or other test on the LIM sufficient to cause it to alarm when operated at -15% or $+10\%$ of nominal rated voltage. This test verifies the proper function of the LIM and its associated alarms but does not verify the functioning of the total ungrounded electrical system. After installation, the system can be thoroughly tested by applying test faults at the receptacles. A minimum of one similar annual test should be performed thereafter. The LIM function should be tested monthly as covered by NFPA 99. When in the test mode, the ground connection to the LIM is disconnected automatically so as not to cause “second fault” on the system and possibly

endanger patients or personnel in the area where the test is being performed. All tests should be performed only when the system is not otherwise in use.

The LIM function test is not a means of checking the calibration of the LIM. Since most LIMs are basically complex network analyzers involving solutions of very complex network equations, it is desirable to have all calibrations performed at the factory where adequate and proper test equipment is available.

In an OR, a LIM reading of 5 mA means that the impedance of one line-to-ground has deteriorated to 60 000 Ω on a 120 V system and the decision will be whether to continue or not continue the surgical procedure. If a decision is made to continue the surgical procedure, then at the earliest opportunity after the surgical procedure has been completed, the plugged-in equipment should then be examined and the fault should be corrected.

If the indicator on the meter shows full-scale deflection, indicating a severe hazard condition, it indicates that one of the lines has shorted to ground, or it could be caused by a combination of high-leakage currents of several instruments. The isolated system is approaching a grounded system. This could create a serious hazard of electric shock to both the patient and to personnel in the event that a second fault occurs. The first fault should be located and corrected at least before starting another surgical operation. The full, let-through current of the circuit breaker could flow if any contact is made with a live (unshorted) conductor.

Because of the mentioned reasons, the LIM meter should be in a plainly visible place—in the operating theater. Means shall be provided for conveniently silencing the audible alarm.

4.3.4.14 Power quality for medical equipment

Types of medical equipment employed in the various departments of health care facilities are discussed in Chapter 8.

Power distribution systems serving multiple x-ray machine installations require special attention. Designers should always be guided by the specific data furnished by vendors supplying equipment for the specific facility. However, an excellent planning guide is available as a NEMA standard (NEMA XR 9-1984 [B5]) that was most recently reaffirmed in 2000 and should be consulted.

Quality of voltage supplied is important to x-ray installations. Again, an electrical service that is powered as direct as possible from the source is desirable. Minimum transient disturbance and voltage drop are essential on circuits serving medical equipment.

Radiologists and pathologists sometimes used power conditioners for computerized axial tomography (CAT, or simply, CT) scanners and multi-channel analyzers to protect devices from transients. As patient care areas become populated with computer chips, this may be the trend. The attenuation of the shielded isolation transformer typically produces as much as 50 dB reduction (300:1 voltage ratio) in the common-mode noise transient.

4.3.4.15 Design and testing of systems for safety

In addition to the testing required of other kinds of buildings, the electrical systems in health care facilities require additional types of testing. For example, isolated power and a hospital's equipment ground system are unique. It is recommended to have these systems tested and certified before use. This is one way to ensure proper installation and operation. Manufacturers of IPSs are generally equipped to test the installed equipment. The testing should preferably be done with the electrical contractor present.

All tests on the isolated system, ground network, and LIM should be in accordance with the NEC (Article 517) and NFPA 99.

The test and certification procedure covers the following:

- a) Operational check on all equipment
- b) Inspection of the complete installation for applicable code conformance
- c) In-depth testing of IPS
 - 1) Line voltage measurements
 - 2) Line-to-ground impedance measurements
 - 3) LIM calibration
 - 4) Recording of initial system hazard current readings from the LIM for hospital records (initial hazard current readings represent predicted current leakage with no devices connected to the isolated system)
- d) Testing of the ground network
 - 1) All power receptacle grounds
 - 2) All ground jacks
 - 3) All permanently exposed building material
 - 4) All permanently installed equipment
- e) Complete dissertation on the isolated system to the hospital personnel including
 - 1) Basic theoretical concept of benefits of isolated power
 - 2) Proper use
 - 3) Proper maintenance procedures
 - 4) Periodic testing and record keeping (a log book with initial hazard current readings is supplied to the hospital with a letter of certification including all recorded test data)

4.4 Delivering power to the caregivers and their patients

4.4.1 General

Hospitals have two sources of power available and two different distribution systems: a *normal distribution system* and an *essential distribution system*. The essential system consists of life safety, critical, and equipment branches. It is vital that the wiring devices on any branch of the essential power system be easily identified. This reduces the time

wasted locating receptacles to power life-support equipment when even seconds are critical. There are two ways to identify devices: (1) by a distinctive color, such as red, or (2) by labeling. Some states require red devices. Marking with a distinctive color is not only easier and less costly than labeling but can prevent confusion later. For instance, when painters remove the lettered emergency and normal cover plates, there is no longer a distinction between devices. Also, since codes require emergency receptacles in critical care areas to have panelboard and circuit number labels, the device cover plates tend to become cluttered. The distinctive color is also easily spread into other portions of the emergency systems (such as lighting control) to maintain uniformity. Consideration should be given to using lighted emergency power receptacles in any patient areas that do not have emergency lighting, thus making the receptacle easier to find in the near-darkness of a power outage.

Devices in a hospital need to be mounted for easy use by staff and patients. Since a large number of hospital patients spend time in wheelchairs, special attention should be given to “handicapped” requirements. These requirements are typical of occupational therapy areas [aids to daily living (ADL)] and are described in 4.4.27. It is to the advantage of all patients and staff if all receptacles are mounted 610 mm (24 in) above the floor (see 4.4.27). This mounting height will reduce the fatigue caused when staff members must repeatedly bend down to connect or disconnect a plug. Also, give consideration to ergonomics when placing devices—maybe it should not be necessary to move the ice maker out of the way to access the outlet powering it. The electrical engineer should carefully specify the precise elevation and locations of any receptacles that are needed in particular locations.

4.4.2 Identifying particular user needs

It is very important to have a very clear understanding of the expected use of various areas in a health care facility. Electrical codes, standards, and regulations have different requirements for the various areas in a health care facility as compared to other types of occupancies. Many hospitals frequently have continuing changes in requirements because of staff changes and because of advances in technology. Since cost is a very important consideration and since available funds are usually in short supply, it is very difficult to provide maximum flexibility in every area.

The first step is to review with the administrator or the owner of the facility, the expected initial use, and any anticipated modification in the future. Consideration should be given to changes in safety requirements as well as to possible changes in applicable codes and standards.

As an example, most hospitals actually need emergency power to more than “code minimum” locations for the hospital to remain truly functional during interruption of the normal power system. Many hospitals put all cardiac catheterization equipment on critical branch power so that procedures may continue during the interruption of normal power. Even cardiac catheterization labs that will tolerate interruption of a procedure typically need at least 1/3 of the equipment on critical branch power to safely terminate a procedure and remove catheters with the aid of still images. Some hospitals may classify cardiac catheterization equipment as imaging equipment and feed it from the equipment system

instead of the critical branch. Other equipment such as automatic drug dispensing machines and electronic sensor scrub sinks are also needed to remain functional. Certain cooling equipment may need to be connected to the equipment system to remain functional for more than a few minutes past the loss of normal power. See Figure 4-2.

Refer to the Guidelines for Design and Construction of Health Care Facilities and NFPA 99 for guidance on the minimum quantity of receptacles needed, but the client's clinical needs may exceed these minimums.



Figure 4-2—Typical patient room

In all patient areas, several items should always be kept in mind. Outlets of all types are installed for someone to use. Receptacles should be located in areas that will remain easily accessible to staff. As simple as this sounds, receptacles that are installed too close to the floor and behind beds and equipment can interfere with the staff's ability to provide safe, efficient patient care. In patient care areas, the ability to obtain the function desired quickly (respiration, cardiac level, etc.) could save a life or prevent permanent damage to a patient. It is for this reason that elevations of equipment and outlets should be checked. Medical gas outlets should never be mounted directly above electrical outlets, as the regulators will obstruct the receptacles. Receptacles should be mounted 588 mm to 1176 mm (24 in to 48 in) above the floor, to make them accessible to a visitor or to a

patient in a wheelchair and to lessen the fatigue on staff members who must constantly bend over to connect and disconnect equipment. Article 517 of the NEC requires normal and critical branch emergency power at patient bed locations, or two emergency power circuits served from two separate transfer switches. Critical care areas shall be provided with a dedicated critical branch circuit. Receptacles should be provided on both sides of each bed, so that staff can access them regardless of which side of the bed they are standing on.

Each vacuum outlet needs space not only for a regulator on the outlet but also for a vacuum collection bottle either on the outlet, on a slide, in a rack, or on the floor. If patients from one area can overflow into another, these overflow beds should be designed to the most stringent requirements.

Use Table 4-4 as a guide to the minimum requirements of receptacles at the patient headwall in typical patient areas. The quantities listed are minimums as reflected in some of the relevant codes. Many facilities have determined that the minimum requirements are not adequate.

NOTE—The respective code documents frequently change. Always review the codes and standards that apply to a particular project.

Table 4-4—Guide for power requirements at the patient headwall in typical patient areas

Room type	Area classification	Receptacles required by NEC and NFPA 99	Receptacles required by AIA Guidelines	Power sources	Comments
Medical surgical patient rooms	General care	4	2 duplex plus one for bed	Normal and critical power	
Well baby nurseries	General care	4	2 duplex per bassinet	Normal and critical power	
Intensive care units	Critical care	6	7 duplex	Normal and critical power	Review for isolated power
Trauma rooms	Critical care	6	8 duplex	Normal and critical power	Review for isolated power
Resuscitation rooms	Critical care	6	8 duplex	Normal and critical power	
Emergency Department exam room	Critical care	6	6 duplex	Normal and critical power	

**Table 4-4—Guide for power requirements at the patient headwall
in typical patient areas (continued)**

Room type	Area classification	Receptacles required by NEC and NFPA 99	Receptacles required by AIA Guidelines	Power sources	Comments
Emergency Department treatment room	Critical care	6	6 duplex	Normal and critical power	
General care exam or treatment	General care	4	2 duplex	Normal and critical power	
Post anesthesia care unit (PACU)	Critical care	6	7 duplex	Normal and critical power	
Operating room	Critical care	6	16 simplex or 8 duplex	Normal and critical power	At least 6 receptacles at patient head, review for isolated power
Dialysis	General care	4	2 duplex	Normal and critical power	GFI for dialysis machines

4.4.3 Hospital grade receptacles

In accordance with the NEC, hospital grade receptacles are listed as suitable for use in health care facilities. Health care facilities are defined in NEC Article 517 as: “Buildings or parts of buildings that contain, but are not limited to, hospitals, nursing homes, residential custodial care facilities, clinics, medical and dental offices, and ambulatory health care facilities, whether fixed or mobile.”

The receptacles, plugs, and cable connectors should be UL-listed *hospital grade* (see UL 498). The hospital grade receptacle meets UL’s additional test criteria for grounding path integrity through superior mechanical and electrical characteristics. Among these criteria, and perhaps of primary importance to the health care facility, are stringent minimum retention and ground resistance specifications. While it is true that some *spec grade* receptacles are of high quality and are similar to those UL listed as hospital grade, no formalized standards exist for a spec grade receptacle. Consequently, it is very difficult to control the desired quality level and minimum standards when a project or purchase order specification lists spec grade as its only requirement. Hospital grade receptacles are required at patient bed and exam table locations. However, it should be noted that most

engineers have been specifying and most hospitals have been using hospital grade receptacles in all patient care areas since they have become available.

Parallel blade devices should be mounted ground pin or neutral blade up. In this configuration, any metal that drops between the plug and the wall will most likely contact a nonenergized blade.

While either 15 A or 20 A receptacles are permitted, it is highly desirable to use only 20 A within a health care facility. This allows for greater flexibility in equipment usage and simplifies stocking of replacement receptacles. Additionally, it should be noted that where only a single receptacle is used on a 20 A circuit, it shall be rated 20 A.

4.4.4 Hospital grade isolated ground receptacles

Use these receptacles where separation of the device equipment ground and the building ground is desired in order to protect sensitive equipment from malfunction due to transient currents (electrical noise) on the equipment grounding path. This requirement normally applies when digital electronic equipment is used, including microprocessor-based instrumentation, computer cash registers, computer peripherals, and digital processing equipment. NEC requires careful planning of isolated grounding systems in patient locations to avoid compromising either low ground path impedance or effectiveness of the isolated ground system.

4.4.5 Hospital grade tamper-resistant receptacles

Tamper-resistant receptacles prevent contact with an energized contact in the receptacle unless a plug is inserted. Use these devices in pediatric locations, waiting rooms, or any area where children may be present for an extended time, exam rooms in the Emergency Department, and the psychiatric locations (only if the receptacle manufacturer specifically indicates suitability for psychiatric locations). When selecting tamper-resistant receptacles, the type that makes and breaks internal switching contacts is not generally recommended where life support equipment may be needed. While it is not a requirement, consideration should be given to the use of tamper-resistant mounting screws for switch and receptacle wall plates in pediatric and psychiatric locations.

It should be noted that certain dedicated psychiatric isolation rooms might be better served by not having any receptacles. In these cases, flush, tamper-resistant ceiling lights with the switch located outside the room would be indicated.

4.4.6 Hospital grade GFCI receptacles and GFCI circuit breakers

GFCI can be provided by either GFCI circuit breakers or GFCI receptacles. As previously discussed, the NEC requires GFCI protection for wet locations, where interruption of power is acceptable. GFCI receptacles offer the advantage of local trip indication and reset, at least where they are not used in the feed-through mode. This can be an important consideration when selecting between the circuit breaker and the receptacle integrated GFCI device.

4.4.7 Anesthetizing location receptacles

Certain UL-listed hospital only configurations are manufactured as both hazardous location and nonhazardous location devices. Hazardous location receptacles are interlocked with an internal switch. Hazardous location plugs will close the switch, whereas nonhazardous location plugs will not. These devices are required in any OR that uses flammable anesthetic gasses.

The use of explosive anesthetizing agents is virtually nonexistent in the U.S., and therefore the need for ORs designed for their use no longer exists in the U.S. The NEC permits the use of hospital grade receptacles within anesthetizing locations so long as they are within nonhazardous areas. The current trend is to equip anesthetizing locations with these devices. Engineers should carefully review additions to existing surgical suites before specifying receptacles, since generally a mix of *hospital only* and hospital grade receptacles is not desirable. Changing the plugs on dedicated equipment used in the OR suite or changing out existing hospital only receptacles may prove more costly than providing the addition with hospital only” type receptacles.

4.4.8 Mobile x-ray plugs and receptacles

X-ray plugs and receptacles should be non-interchangeable with any other equipment plugs. This prevents high-impulse loads on branches and feeders that were not designed for such service. Larger portable x-ray devices come in 50 A and 60 A models; 50 A plugs can be connected to either a 50 A or 60 A receptacle, while a 60 A plug can only be connected to a 60 A receptacle. When locating these receptacles, the designer should consider the force required to insert the plug. These receptacles have a spring-eject type feature that guarantees that the plug will be fully inserted. Because of the insertion pressure required, they should be mounted at a minimum of 735 mm (30 in) above the floor.

A patient-focused change in practice in some hospitals has been increased use of smaller portable x-ray devices in the patient rooms. The plugs that come with these smaller x-ray devices may be able to be inserted into standard 20 A receptacles. This approach minimizes the movement of the patient for some radiology procedures, but can also increase the possibility of high-impulse loads on such branches and feeders that were not designed for such service. This increasing practice requires dialogue between the designer and the users, along with appropriate design measures.

4.4.9 Wall plates

Any UL-listed wall plate is suitable for health care facilities. Nylon wall plates provide color matching, are cost-efficient, and cannot carry current in the event of a fault. Stainless steel wall plates are the most durable. Wall plates should be made of impact-resistant construction and manufactured of high-impact plastics, stainless steel (type 304 or better), or anodized aluminum. All plates should hold up under frequent cleaning with hospital cleaning chemicals. Tamper-resistant mounting screws should be used with switch and receptacle wall plates in pediatric and psychiatric locations.

Circuit identification is required for emergency receptacles in critical patient care areas. However, it is recommended practice to include this requirement on all circuits throughout the facility. Selection of wall plates should include consideration of circuit identification methods. Circuit identification assists maintenance personnel during routine maintenance procedures and during troubleshooting to identify the receptacle's source panel quickly.

4.4.10 Headwall units

Although they are expensive, prefabricated patient care units (headwall units) are now so prevalent as to be almost standard in both renovation and new construction projects. Headwall units can be and are used in all patient care areas of the hospital. The term *headwall* is general and applies to many units that are not even remotely similar to *walls*. Some patient headwalls are actually columns or ceiling mounted articulating boom arms.

Headwalls normally contain electrical power distribution systems as well as provisions for other building systems. While headwall units do contain both mechanical and electrical equipment, they could also be considered architectural and are, consequently, typically specified by the architect or the hospital itself.

Headwall units offer a number of advantages over building devices into structural walls. Some of these advantages are: future flexibility, ability to coordinate the location of many services in a compact area, no need for thicker walls to accommodate back-to-back patient services, serviceability, shortened construction schedule, superior appearance, and expenditure deferral.

Nursing staff will find the preplanned component locations accessible and convenient, resulting in fast, efficient patient service, thereby maximizing the patient's comfort. Hospital maintenance personnel find the quality headwall both durable and easily serviced. Hospital administrators find that they can defer the cost of the headwall along with all of the equipment it contains until just shortly before the hospital is scheduled to open. Architects and engineers find that both design and coordination of services are greatly simplified for both new and remodeling construction. Contractors find that their job site labor costs are significantly reduced and their coordination of service problems at the patient location can be greatly reduced.

Locating and specifying the headwall is every bit as complex, however, as locating and specifying individual services within a structural wall—indeed, sometimes more so. For example, headwalls may be “left-hand” or “right-hand.” That is, if headwalls are back to back, the location of devices with respect to the bed will change, requiring careful consideration in ordering. Whenever possible, the medical team responsible for that area of the hospital to be served by the headwall in question should be consulted as to quantity, location, and type of equipment required to serve the patients in that area. After a design has been selected, it is helpful (almost essential) to review the choice using a full-size mock-up or full-size drawing. Confirming locations and dimensions in this fashion can eliminate some undesirable surprises after the unit is installed. The architect will usually make the color selection. See Figure 4-3.

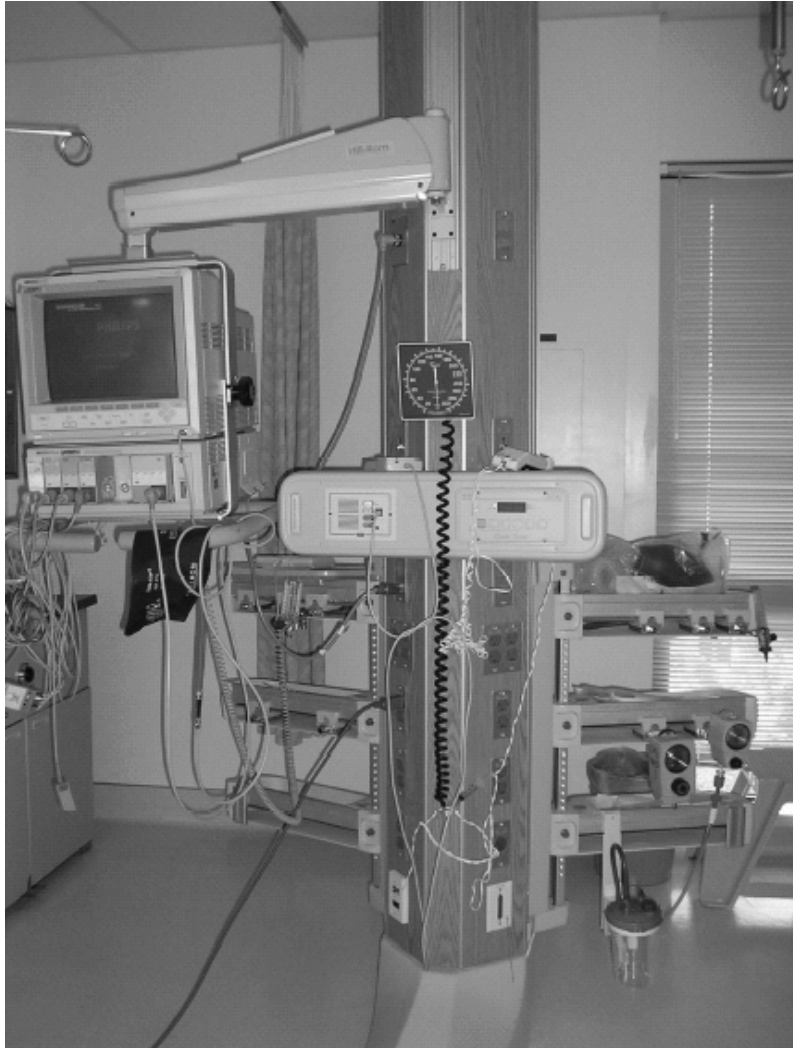


Figure 4-3—Patient column

The headwall unit can, and usually does, contain all of the electrical services required to serve the patient. Headwalls can be customized to include various systems and equipment required in the patient care area. The equipment should be coordinated with the clinical requirements of the area within the facility. Equipment that can be accommodated within the headwall includes patient and general lighting, examination lighting, power receptacles for both normal power and critical branch circuits, electrical distribution systems, clocks and timers, portable x-ray outlets, night lighting, low-voltage electrical lighting systems, nurse-call/code blue devices, telephone and data outlets, patient monitoring, bed receptacles, side-com outlets, bed locators, services for medical gasses, etc.

If the headwall contains nurse-call devices, the engineer should carefully coordinate all of the interconnections of the various systems, as well as which party, the headwall provider or a separate nurse-call vendor, provides the various equipment elements. In addition, the headwall can contain provisions for the telephone, data, and other services. These provisions should include a backbox of sufficient size to accept the equipment and raceways from that backbox to an appropriate junction box located at the top of the headwall. Installation should be possible without disassembly of the headwall other than that necessary to expose the entrance junction box at the top of the headwall. Conduit size should be carefully specified so that it will accommodate the necessary cable and connectors.

Almost any patient service item can be incorporated into a medical headwall. For example, physiological monitor provisions are usually furnished on a headwall intended to be used in an intensive care area. If the physiological monitoring system is to be included as part of the headwall unit, the manufacturer of the headwall system should be furnished with the correct brand and catalog number of the physiological monitor that the hospital intends to use. Sometimes this information is not available until after shipment of the headwalls is required. In that event, provisions for the monitor bracket can be made and shipment of the actual bracket is delayed until the hospital has made its choice of monitor. One duplex power receptacle should be located immediately behind the bracket for convenient connection of the equipment. The physiological monitor outlet (electronic signal) is handled in the same manner as the nurse call. That is, the box size should be specified, and this box should be connected to an entrance compartment at the top of the headwall with its own raceway or conduit. If a patient physiological outlet provision is desired, another box near the patient level is provided and connected to the physiological outlet junction box by separate conduit. Care should be taken in specifying the correct size conduit so that it will accommodate the necessary cable and connectors.

Headwalls may occasionally provide rough-in connections for systems such as hemodialysis. The provisions provided in the headwall for hemodialysis would be the correct electrical services as well as pressure water connections and drain connections. These connection points would be of the quick-disconnect variety.

Various mechanical devices can be provided in or on the headwall unit. As an example, the headwall manufacturer can furnish manual sphygmomanometers, or provisions for mounting them can be specified. Mechanical rail systems for hanging medical instrumentation can be supplied by many of the headwall manufacturers and accommodate equipment such as infusion pumps, respirators, etc.

It is difficult to write a general specification that would cover the wide variety of headwall units available in the marketplace today. Headwall specifications should be tailored to the specific designs that are finally selected. In selecting the equipment within a headwall unit, care should be taken to comply with all applicable codes and standards. Aside from local and state codes and standards, those of importance to hospital design are the Guidelines for Design and Construction of Health Care Facilities, the NEC, and NFPA 99. Overriding all of these minimum requirements, of course, are the needs of the caregivers who use these systems to care for patients.

Be certain to specify only headwalls for which UL has listed and labeled the entire unit. This listing should include all accessory equipment that is provided with the headwall, such as vacuum bottle tubs. This assures the electrical engineer and the user, as well as the local code authorities, that all currently recognized standards are being followed in the construction of the headwall and that the materials used will pass stringent flame spread and smoke emission regulations for this occupancy.

4.4.11 Patient consoles

A patient console is a strip of outlets and equipment. The console can be part of a headwall unit or self-contained. It provides a rigid, aligned mounting system, which consolidates many varied outlets into a homogeneous unit. It can also provide spaces for future expansion. When the console is self-contained, future additions of outlets will require some cutting and patching. This device can be difficult to mount in the headwall; steel studs, double studs, etc., should be designed into the wall. However, all the outlets will have a consistent appearance. These units are not designed for easy future flexibility.

4.4.12 Waiting rooms, offices

The designer should follow good, standard, commercial specifications when designing convenience power in these areas. Use tamper-proof receptacles in waiting areas where children are commonly found.

4.4.13 Corridors

Corridors historically have been high abuse areas as far as electrical receptacles are concerned. Oftentimes, corridor receptacles are used for supplying power to cleaning machines, which are taken into a patient room. Therefore, receptacles should be selected to withstand heavy physical abuse. Requirements would also include insulated equipment grounding conductors and metal conduit. Use hospital grade receptacles.

Receptacles located in corridors should be fed from normal power. This will prevent a faulty noncritical piece of cord-connected equipment (such as a cleaning machine) from tripping an emergency circuit or emergency panel that also serves a patient bed area. The exception is where critical medical equipment such as defibrillators are stored in an alcove in the corridor. In this case, the emergency receptacles should be dedicated to this equipment and clearly labeled as such.

Some hospitals do include receptacles in the corridors as part of planning for mass casualty events. In such hospitals, provide relatively more corridor outlets at relatively close spacing. Otherwise, space outlets on approximately 15.24 m (50 ft) cords for routine housekeeping use.

Some states require that a percentage of corridor receptacles be served from the critical branch. It is important to review the local requirements or the owner's needs for corridor receptacles.

4.4.14 Patient rooms

- a) *General care bed locations.* This type of area includes patient bedrooms, examining rooms, treatment rooms, clinics, and similar areas in which it is intended that the patient will come in contact with ordinary appliances such as a nurse-call system, electrical beds, examining lamps, telephone, and entertainment devices. Patients may be *connected* to electromedical devices (such as heating pads, EKGs, drainage pumps, monitors, otoscopes, ophthalmoscopes, intravenous lines, etc.).

Review the receptacle quantities and locations with user groups to ensure adequate coverage. Electrical outlet may be required for equipment such as:

- 1) Electric bed
- 2) Portable suction
- 3) Air boots
- 4) EKG machine for inpatient test or for an additional K-pad
- 5) Respiratory therapy equipment
- 6) Infusion pumps
- 7) Physiological monitors

Provide a system at each bedside for both patient and staff to summon help. A tone-visual or an audiovisual system can be used at a general care bed. Both systems should provide a means for the patient to summon the nursing staff. Depending on local requirements or institutional standards, a *code blue* or *staff emergency* call station may be located near the bedside. Communication systems are often integrated into the bed rail system or use a pillow speaker. Refer to Chapter 7 of this recommended practice for more information on these systems.

- b) *Critical care bed locations.* Critical care areas, as defined by the NEC, represent a large portion of the in-patient care areas in a hospital. These patients usually rely on machines of some type and require more nursing care than the general care patient. Critical care bed locations include intensive care units, coronary care units, angiography laboratories, cardiac catheterization laboratories, delivery rooms, ORs, and similar areas in which patients are intended to be subjected to invasive procedures and connected to line-operated, electromedical devices.

Requirements for receptacles and communication system devices in these areas should be coordinated with the equipment being supplied in the room and the functions to be performed.

4.4.15 Surgical room

There are many types of surgical areas, each with its own set of requirements. Among these are general surgery ORs and special ORs. Special ORs include cardiac ORs, cystoscopic ORs, neurosurgical ORs, orthopedic ORs, thoracic ORs, transplant ORs, combined labor and delivery rooms, C-section rooms, and others.

Chapter 9 of the Guidelines for Design and Construction of Health Care Facilities discusses three main classes of surgical suites and levels of care as defined by the

American College of Surgeons. Class A ORs are the simplest. They are used for minor surgical procedures performed under topical, local, or regional anesthesia without pre-operative sedation. Class A ORs are not used for intravenous, spinal, and epidural anesthesia; those uses are appropriate for Class B and Class C ORs. Class B ORs are used for more acute cases, such as minor surgical procedures performed in conjunction with oral or intravenous sedation or under analgesic or dissociative drugs. Finally, Class C ORs are used for major surgical procedures that require general or regional block anesthesia and support of vital bodily functions. Each class of ORs has its own criteria that are not reproduced here.

The variety of surgical procedures occurring in these areas is enormous and changes as medical practice evolves. The most important point in surgery room layout is how the room will function and to provide sufficient flexibility to allow the spaces to support different procedures over time. Coordinate electrical design with the medical planners description of function, typical procedures, and traffic patterns as well as with the medical equipment being specified.

Electric power outlets. The NEC requires that these bed locations be served by a minimum of six receptacles (single or duplex) at the patient headwall. The Guidelines for Design and Construction of Health Care Facilities require a minimum of 16 simplex or 8 duplex receptacles in each OR. At least one of the receptacles shall be connected to the normal system or from a critical branch source fed from another transfer switch. At least six duplex receptacles are required at the head of the table. The distribution and placement of these receptacles throughout the room should be determined after consultation with the surgical staff. Locate outlets to minimize interference with planned procedures. Often the receptacles most used are now located in medical gas columns located in the ceiling near the patient head, in order to allow equipment to be plugged in without having to use cords draped across the room to a wall.

Some hospitals prefer isolated power in their ORs because of its ability to alert OR personnel of a possible equipment failure. Refer to the discussion of these systems above. However, where IPSs are used, an excessive number of circuits can affect the performance of the system by adding so much leakage current as to render the system near to the alarm threshold under normal conditions. Similarly, the number of receptacles provided in the OR can have a negative impact on the IPS. The impedance of the system wiring is increased with the increased quantities of receptacles. Limit the length and number of branch circuits fed from isolated power panels to limit the leakage current. Alternatively, consider using multiple IPSs in order to minimize the leakage current on each system.

ORs should also include provisions to protect against the failure of an automatic transfer switch (ATS). Dual source isolated power panels fed from separate transfer switches or one from the critical branch and one from normal power will satisfy the requirements of Article 517 for normal and emergency receptacles in the OR.

4.4.16 Psychiatric care areas

Treat a psychiatric patient room similar to a general care patient room. For the number of circuits and outlets, see the NEC and NFPA 99. Psychiatric care areas are occupied by two types of patients, sedate and violent.

- a) *Patient room (sedate).* Sedate patients are normally treated in open-type dormitory housing. These rooms are very much like semiprivate dormitory rooms. Four electrical outlets (two duplex receptacles) should be provided per bed (one duplex receptacle on each side of the bed). All receptacles should be safety-type receptacles with tamper-proof screws. The extent of communications systems is determined by the staff in accordance with the level of care.
- b) *Patient care (violent).* Patients in this category range from physically violent to suicidal. These rooms should therefore be designed to provide as little danger as possible to both the staff and the patients. The staff usually continuously monitors these patients. Provide the fewest possible outlets for these rooms (zero is good). These also should be protected and securely concealed when not required, for example, in a shallow locked closet. The general configuration should be similar to acute care beds. Use only lighting fixtures designed for use in psychiatric applications. Fixtures should be configured to protect the patient from harm and prevent the patient from using a portion of the fixture as a weapon. Provide audio and/or visual monitoring via concealed devices. Provisions should also be made for staff to summon help.

4.4.17 Critical care patient rooms

The number of circuits and receptacles should conform to the NEC and NFPA 99. Redundant ground paths are required. Emergency power provisions are also mandatory by these standards. All receptacles shall be hospital grade. While isolated power is not mandatory, it can be used in areas where invasive procedures are common. When isolated power is used, the same specifications shall be followed as when it is used in an anesthetizing location. These specifications can be found in the NEC or NFPA 99.

4.4.18 Coronary care areas

Coronary care patients vary from electrically susceptible critical list patients to patients ready for release. Depending on the size and operating procedures of the hospital, noncritical patients may be transferred to step-down units.

Electrical power outlets. The NEC permits the use of single-phase grounded power circuits for this area. Some states still require the use of ungrounded, isolated power, and some hospitals still prefer to use them. Refer to the IPS discussion above. The Guidelines for Design and Construction of Health Care Facilities require a minimum of seven duplex receptacles.

The NEC requires that these bed locations be served by a minimum of six receptacles. At least one of the outlets shall be supplied from the normal power system or from an independent critical branch ATS. At least one branch circuit from the emergency system

shall supply an outlet(s) only at that bed location. All branch circuits from the normal system shall be from a single panelboard. Emergency system receptacles shall be identified and shall also indicate the panelboard and circuit number supplying them. Emergency power shall be supplied for use with a ventilator in coronary care. Circuit-breaker panels should be located within or as close as possible to the suite. All receptacles should be near the bed and clearly labeled with the panelboard and circuit that they are powered from. The electrical engineer should coordinate the number and placement of outlets due to the large quantities of equipment used in this area, including:

- a) Ventilator
- b) Intra-aortic balloon pump (IABP)
- c) Monitoring systems (physiological, oximeter, blood pressure, pulmonary pressures)
- d) Portable x-ray
- e) Electrical bed
- f) EKG machine
- g) Infusion pump
- h) Respiratory therapy equipment

Provide lighting as discussed in Chapter 6 of this recommended practice

An audiovisual patient station system is required at a critical care bed. This station will allow the patient to summon the nursing staff and communicate with them. In a coronary care area, a code blue or staff emergency call station is provided near the bedside.

4.4.19 Intensive care areas

The intensive care bed may be used for surgical post-operative patients, patients requiring artificial ventilation, patients requiring treatment for shock, patients requiring cardiac monitoring, patients requiring hemodialysis or peritoneal treatment, and patients requiring biochemical correction of severe metabolic disorders. These rooms require a much higher level of care than other patient rooms and will generally have many more outlets.

The NEC permits the use of single-phase grounded power circuits for this area. Historically, some hospitals have preferred to use ungrounded, isolated power in these areas because a first fault will not cause a breaker to trip. Where this is the case, specifications for isolation systems are the same as previously discussed. The Guidelines for Design and Construction of Health Care Facilities require a minimum of seven duplex receptacles per bed in these areas. The NEC requires a minimum of six receptacles per bed. Provide power to most of the outlets from the critical branch of the emergency system. At least one of the 6 shall be supplied from the normal power system or from an independent critical branch ATS. Locate circuit breaker panels within, or as close as possible to the area.

Provide lighting as described in Chapter 6 of this recommended practice.

Provide an audiovisual patient station system at all critical care beds. This station will allow the patient to summon the nursing staff and communicate with them. Typically, in an intensive care area, a code blue or “staff emergency” call station is provided near the bedside. Data and telecommunications provisions should also be included.

4.4.20 Recovery rooms

Recovery rooms are divided into the Phase I recovery (or primary recovery or PACU, post anesthesia care unit) and Phase II recovery (or step-down recovery or recovery lounge). The PACU needs seven duplex receptacles, the step down needs only two. Recovery areas are generally intensive nursing areas where the patient is held and observed until he or she recovers from anesthesia. Treat these areas as critical care patient care areas. Provide nurse-call devices as described in Chapter 7 of this document.

4.4.21 Emergency departments

An emergency department may contain trauma, treatment, and minor operating and exam rooms, where a variety of medical procedures take place. These procedures range from treating accident victims to delivering babies and to typical outpatient work during off-hours. Treat minor ORs as small surgery rooms. One class, or category of treatment, above the minor OR is the trauma room where somewhat similar operations take place. General anesthetics are not normally used in the emergency room but may be used in extreme situations. Both these rooms can involve invasive procedures, and special care should be used because these patients can be electrically susceptible. In some hospitals, babies will be delivered in an obstetrics/gynecology (OB/GYN) room on an emergency basis. The rooms in any emergency department shall be analyzed by the governing body of the hospital as to their probable use. Treat patient holding rooms as acute care beds as these are used to watch developments. Typically, design various emergency department rooms to be similar to the same type of room as found elsewhere in the hospital (i.e., a cardiac room is much like a CCU treatment room).

The emergency department also includes specialty rooms for pediatric care and secure holding. These areas, as well as waiting areas, require tamper-resistant devices.

NFPA 99 considers emergency departments to be *critical care areas*. Thus follow codes and suggestions for critical care areas electrical requirements.

An audiovisual patient station system is required at emergency department beds. Provide either a code blue or staff assist station near each bedside, depending upon how the particular facility responds to such emergencies. In many facilities, the emergency department staff is a *code team*, and they will not need to call for assistance from outside the unit in the event of an emergency.

4.4.22 Pediatrics

Pediatrics areas house and treat juveniles. Design pediatric patient rooms for the level of care intended to be performed. Generally, design these areas similar to areas for adults. Four electrical outlets or two duplex outlets per bed are recommended. All outlets should

be safety-type with tamper-proof screws. At least one duplex receptacle should be provided on each side of the bed. Communications provision should be similar to those in similar areas designed for adults.

For playrooms, provide only safety-type outlets with tamper-proof screws. Provide both staff communications and emergency help functions.

4.4.23 Nurseries

General nurseries. Nurseries where healthy newborns are housed. Infants normally occupy bassinets. Nursing care is minimal, while observation is important. Locate two duplex electrical outlets at each bassinet, one on each side. Supply one duplex outlet from the critical branch, and the second from normal power. Provide either a code blue or staff assist button near each bassinet, depending upon how the facility responds to such calls (see Chapter 7 for more on nurse-call systems). Some facilities choose to install a code pink button to alert in the event of an infant abduction. Refer to Chapter 6 of this document for suggestions for lighting all nursery areas.

Special care nurseries. Nurseries caring for newborns requiring specialized care. These infants occupy isolettes, which are larger than typical bassinets. Locate outlets to accommodate the sizes of the isolettes being provided. These units will need more electrical equipment for each infant and so will require additional electrical outlets at each headwall. Provide nurse-call devices and lighting similar to those in general care nurseries.

Neonatal intensive care nursery. These units care for premature babies or other infants needing the highest levels of care. Provide at least 12 single, or 7 duplex electrical outlets, together with one dedicated incubator outlet at each isolette/incubator location. Provide power to most of the outlets from the critical branch of the emergency system. Provide power to at least one of the outlets from either the normal system or a second critical branch transfer switch. Provide nurse-call devices and lighting similar to those in general care nurseries.

4.4.24 Heart catheterization rooms

Follow grounding procedures as outlined in the NEC and NFPA 99. Determine with hospital administration whether this is a multifunction room. If it is used as a general anesthesia area, follow anesthetizing location specifications as given in the NEC and NFPA 99. Careful and precise grounding, and hospital grade receptacles are mandatory in this area.

4.4.25 Procedure rooms in which only local anesthetics are used

These areas need not always be designed as inhalation anesthetizing locations. However, documentation of the intent of use should be obtained from the hospital administration and careful review with local code authorities should be made. In many cases the facts will indicate a full treatment as an anesthetizing location.

4.4.26 Inhalation anesthetizing locations

Follow specifications as they appear in the NEC and NFPA 99. Refer to discussions earlier in this chapter. Insulated equipment grounding conductor and hospital grade receptacles are mandatory in these locations.

4.4.27 Rehabilitation areas

In general, comply with the requirements of the Americans with Disabilities Act (ADA), and the guidelines written pursuant to it, as well as relevant state and local accessibility standards.

For drug and alcohol abuse units, equip patient rooms similar to dormitory-type psychiatric patient rooms (sedate). Provide detoxification rooms for medical treatment and observation of newly admitted patients. These should be similar to those for violent psychiatric patients, and equipped for medical treatment.

Occupational therapy areas are occupied mostly by patients with new handicaps. Take special care to make their transition back into society a smooth one.

In general, locate light switches 915 mm to 1070 mm (36 in to 42 in) above the floor. For convenience, do not provide more than two switches in a single plate. Switch action should be simple and positive. While large area “decorative” type rocker switches permit easier operation by forearm, elbow, etc., normal high-quality toggle-type switches are not impossible to operate. Normal toggle switches should have full-sized handles for this operation. Take care to locate all controls (switches, outlets, thermostats, etc.) away from corners and to avoid placing controls over counters, since these locations are particularly inconvenient for persons using wheelchairs.

In general, locate electrical outlets at least 610 mm (24 in) above the floor. In areas designed specifically for use by disabled persons, locate them 610 mm to 815 mm (24 in to 32 in) high.

Locate telephone handsets within 1220 mm (48 in) of the floor. Handsets should be on 915 mm (36 in) or longer cords. Equip telephones with a receiver that generates a magnetic field in the area of the receiver cap. Supply a volume control with any public telephone. Provide a clear floor or ground space at least 760 mm by 1220 mm (30 in by 48 in) to allow either a forward or parallel approach by a person using a wheel chair. Bases, enclosures and fixed seats should not impede approaches to the telephone. The telephone instrument or phone book shall have a maximum forward reach of 1220 mm (48 in) high and 380 mm (15 in) low and a maximum side reach of 1370 mm (54 in) high by 230 mm (9 in) low.

4.4.28 Wet locations

As mentioned many times, the codes require the use of GFCIs in wet locations areas such as those used for hydrotherapy. Where power interruption caused by the tripping of GFCIs cannot be tolerated, the use of isolated power is required by the NEC.

A controversy exists as to whether patient dialysis units should be considered wet locations. It depends upon the design of the unit, the type of equipment, and the intended operation. Operating or procedures rooms that often have spilled liquids, lots of metallic grounded objects, and grounded drains need GFCIs or IPS.

4.4.29 Laboratories

The special precautions for laboratories relate to the type of receptacle to be used. These should be the best grade available. Where these are mounted in a continuous raceway, it is very important to use a good grade of receptacle. Extra care is needed in specifying bonding between receptacle and raceway and various raceway sections in any single location or room. Insulated equipment grounding conductor is highly recommended and may be required by local codes. It is very important to have a high-integrity grounding system in laboratories that use electronic equipment for physiological data monitoring or measurement.

4.5 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

Guidelines for Design and Construction of Health Care Facilities.^{4, 5}

NFPA 70, National Electrical Code® (NEC®).⁶

NFPA 99, Standard for Health Care Facilities.

UL 498, Attachment Plugs and Receptacles.⁷

UL 544, Medical and Dental Equipment.

UL 1047, Isolated Power Systems Equipment.

⁴The current edition of the Guidelines is available from the American Institute of Architects (AIA) Academy of Architecture for Health, 1735 New York Ave., N.W., Washington, DC 20006 (http://www.aia.org/aah_gd_hospcons).

⁵Note that these guidelines have been adopted by reference or used as a regulation in more than 40 states, making them more requirement than guideline in practice in many locations if not in name.

⁶NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA (<http://www.nfpa.org/>).

⁷UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

4.6 Bibliography

Additional information may be found in the following sources:

[B1] AAMI ES60601-1-2005, Medical Electrical Equipment, Part 1: General Requirements for Basic Safety and Essential Performance.⁸ (supersedes ANSI/AAMI ES1-1993).

[B2] ANSI/AAMI ES1-1993, Safe Current Limits for Electromedical Apparatus (withdrawn and superseded by AAMI ES60601-1-2005).

[B3] IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition. New York, Institute of Electrical and Electronics Engineers, Inc.

[B4] The Joint Commission, Accreditation Manuals for Hospitals; available at <http://www.jcrinc.com/77/>.⁹

[B5] NEMA XR 9-1984 (Reaff 2000), Power Supply Guidelines for X-ray Machines.¹⁰

⁸Association for the Advancement of Medical Instrumentation (AAMI) publications available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

⁹The Joint Commission, formerly known as the Joint Commission on Accreditation of Healthcare Facilities (JCAHO).

¹⁰NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

Chapter 5

Emergency power systems

5.1 Overview

Local, state, and federal codes, as well as various accreditation standards, require health care facilities to have some kind of emergency power system. The most common components of these systems are generator sets, automatic transfer switches (ATSs), engine-generator controls, and engine-cranking starting systems. Other equipment may include synchronizing and paralleling equipment for multigenerator set installations, utility peak demand reduction controls, elevator emergency power selector systems, uninterruptible power supplies (UPSs), and bypass/isolation provisions. This chapter describes requirements, recommended equipment, and required operation of health care facility emergency power systems. The chapter covers suggested methods for system design, and installation, testing, and maintenance of these systems.

5.2 Definitions

Refer to *The Authoritative Dictionary of IEEE Standards Terms* [B9].¹

5.3 Generator sets

5.3.1 General

An engine-driven generator set with on-site fuel supply is the predominant type of emergency power source in hospital and health care facilities. Few designs use gas turbine driven sets because their starting time normally exceeds the 10 s “on line” requirement specified in the National Electrical Code® (NEC®) (NFPA 70) and NFPA 99.² However, turbine manufacturers have recognized this problem and some sets are becoming available with improved starting times. For a discussion on gas turbines, refer to IEEE Std 446™ (*IEEE Orange Book*™).

Engine-driven type sets have capacities ranging from approximately 5 kW (6.25 kVA) to 2000 kW (2500 kVA). Gas (natural gas or LPG) engines normally come in the lower ranges while diesel engines almost all have capacities of 100 kW (125 kVA) or more. Codes generally require on-site fuel storage, but they may, under certain circumstances, allow off-site natural gas supplying low-pressure, gas-driven engines when there is a low probability of both the electrical utility and off-site natural gas failing simultaneously.

¹The numbers in brackets correspond to those of the bibliography in 5.12.

²Information on references can be found in 5.11.

5.3.2 Ratings

Internal combustion engines are rated in horsepower or kilowatts, and on output at a given speed, intake air temperature, and barometric pressure or altitude. Although gas turbines use a gear reduction to produce a synchronous generator speed, gear reducers have not been widely accepted on gasoline or diesel engine-driven generator sets. Most internal combustion engines therefore operate at the synchronous speeds of 3600 rpm/min, 1800 rpm/min, 1200 rpm/min, 900 rpm/min, etc., to produce 60 Hz or lower for 50 Hz. As the speed decreases, the mass and cost increases in a generally linear relationship. However, 3600 rpm/min internal combustion engine-generator sets are, in general, limited to 50 kW output or below.

The engine kilowatt rating should not be confused with the generator kilowatt rating. As a rule of thumb, 1.5 hp is required from an engine to produce one electrical kilowatt from an engine-generator set. Some of the engine power is required to drive the radiator cooling fan, while the largest power loss is within the ac generator itself.

Non-turbocharged gasoline and diesel engines have an inherent limit on the power they can produce at a given speed. The limit is essentially established by the amount of air that can be pulled into a cylinder for combustion. If the engines use excess fuel, combustion is incomplete and the excess fuel goes out the exhaust as carbon (smoke or soot), carbon monoxide, and unburned hydrocarbons.

Turbocharged engines operate differently. With these engines, as the load increases, the turbocharger forces more air into each cylinder, which can now burn additional fuel to produce additional power. If the fuel or air is not limited by some means, this can become a self-sustaining continuity until stresses exceed the breaking point or something melts. Any turbocharged engine can be fueled to produce 10% additional power, but the useful life of the engine will probably be reduced. The engine manufacturer's published standby ratings of engines are normally the maximum ratings that the manufacturer believes, from experience and test, will give satisfactory service. Standby ratings are frequently published with no overload capability.

5.3.3 Generator power circuit breaker

The generator power circuit breaker serves two functions. First, it protects the separately excited generators against overload and short circuits (self-excited shunt generators are protected by inherent design). Second, it operates as a switch to close on inrush loads and to break continuous current as well as stalled motor currents. The breaker should be capable of repetitive operations. Air circuit breakers and insulated case circuit breakers are commonly used for the generator circuit breaker.

For more specific information on health care facility essential electrical systems including protection, coordination, and selectivity, refer to Chapter 3. However, it is important here to reiterate the need for selectivity in essential system overcurrent protective devices (OCPDs). The purpose of the generator circuit breaker is not to disconnect faulted circuits from the generator. This function is handled by load-side overcurrent devices that are selectively coordinated with the generator circuit breaker.

The generator power breaker should be of the five-cycle closing type and include dc shunt trip, alarm contacts, and interlock contacts for interfacing with the system. Sensing and trip units for proper coordination of trip curves within the distribution system are required with the breaker for overcurrent and short-circuit protection.

The code requires the OCPD to be located at the generator, which is the source of supply for the emergency conductors. For installations where the generator switchgear is not located immediately adjacent to the generator, separate switching devices for paralleling should be furnished in the generator switchgear cubicles.

5.3.4 Location

Locate standby generator sets on the ground floor whenever possible. Basement locations are more likely to experience flooding. These locations also require difficult and expensive ways to bring combustion air, cooling air, and exhaust gas systems to the engines. Generator sets installed above ground level will likely require vibration isolation between the generator set and the floor to prevent structural damage to the building and transmission of sound and vibration.

Ensure adequate ventilation airflow for cooling and combustion, whether the generator set radiator is unit mounted or remote mounted. Carefully consider the location of the standby generator set in order to minimize interruptions caused by natural forces common to the area (e.g., storms, tornadoes, hurricanes, floods, earthquakes, or hazards created by adjoining structures or activities). Other issues to consider include proximity to fuel supply, effects of generator noise on adjacent occupancies, location of exhaust stacks relative to fresh air inputs, and the ability to remove/replace the unit for maintenance or upgrades.

5.3.5 Mounting

Two cardinal rules for installing standby generator sets are as follows:

- a) Do not attach a generator set directly to a concrete floor; it will crack the structure and transmit unacceptable vibration.
- b) Do not directly attach any rigid system (radiator discharge air duct, exhaust, remote radiator cooling, fuel lines, nonflexible conduit) to an engine on vibration isolators without flexible connections to the engine. The relative motion will eventually fatigue and crack the attachment.

5.3.6 Vibration isolation

The least expensive and least effective vibration isolation solution is a sheet of fiberglass or waffle neoprene (rubber) mounting pads between the generator set base and the floor. Spring-type vibration isolators are a more effective solution. Spring isolators mount between the generator set base and the floor. Spring-type vibration isolators have different load ratings. Select the correct number of properly sized isolators to support the total generator set (including water and oil) weight. Locate the isolators so that no isolator is overloaded. Spring-type vibration isolators typically have an efficiency of 95% or better,

meaning that less than 5% of the generator vibration will be transmitted to the floor. With spring-type vibration isolators, the generator set rocks around the crankshaft-generator shaft axis during start-up and shutdown. It also rocks during single step load changes of 50% or more of generator capacity. Because of this movement, be sure to require flexible connections in external lines such as electrical conduit, exhaust pipe, fuel lines, coolant lines, lube oil makeup and drain lines, and engine air intake.

The design can further reduce vibration transmission by including additional generator set foundation mass. The foundation mass may be increased by attaching an inertia block weighing one or more times the generator set package weight. The increased mass further absorbs and dampens the vibration energy. Spring isolators between the inertia block and the supporting structure further reduce transmitted vibration (see Figure 5-1). Generators mounted on floors above the ground level often require this kind of arrangement. On the first floor, engineers can use the same design by pouring a rubber gasket between the two surfaces (see Figure 5-2). Table 5-1 lists the load bearing capability of various materials. Lining the inertia block excavation with tamped sand or gravel will minimize the vibration transmitted through the earth to nearby equipment.

5.3.7 Standby temperature considerations

Maintain the generator room at not less than 4 °C (40 °F) and the engine water jacket temperature at not less than 21.1 °C (90 °F) to ensure reliable engine starting. Different engine manufacturers may have different recommended temperatures. Electric coolant heaters are the most common method of maintaining the engine coolant temperature. Settings may also vary depending on the engine design. Thermostatically controlled tank-type jacket water heaters provide coolant circulation that heats the entire engine, and should only operate when the engineer is not running. Electric oil immersion heaters may be used to maintain lubricating oil temperatures. Control oil heaters by the same thermostat as the jacket water temperature.

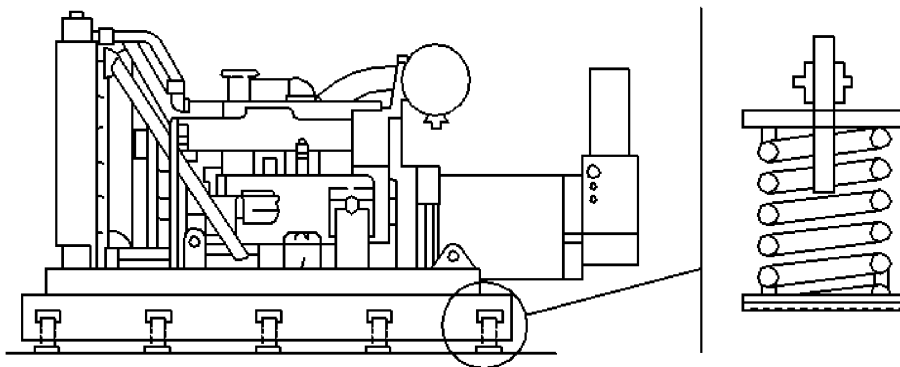


Figure 5-1—Steel-concrete inertia spring mounts

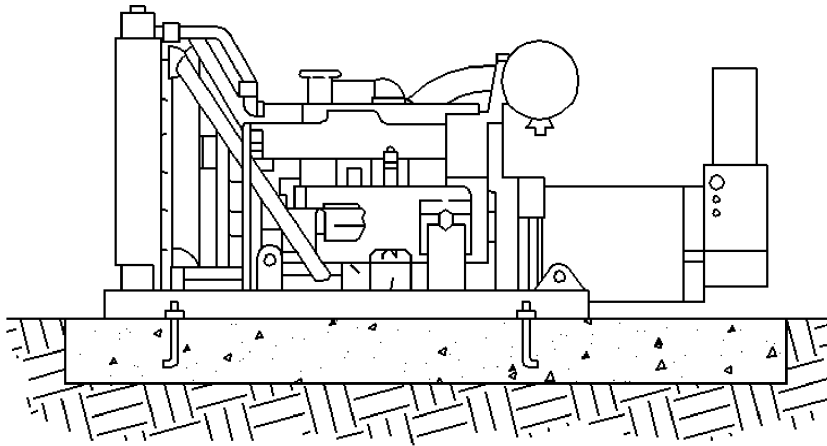


Figure 5-2—Poured rubber gasket between two surfaces

Table 5-1—Load-bearing capabilities of various materials

Nature of bearing material	Safe bearing capacity (lb/ft ²)
Hard rock—granite, etc.	50 000 to 200 000
Medium rock—shale, etc.	20 000 to 30 000
Hardpan	16 000 to 20 000
Soft rock	10 000 to 20 000
Compacted sand and gravel	10 000 to 12 000
Hard clay	8000 to 10 000
Gravel and coarse sand, compacted fine sand	8000 to 8000
Medium clay	4000 to 8000
Loose fine sand	2000 to 4000
Soft clay	2000

5.4 Generator system accessories

5.4.1 Exhaust system

In order to produce rated power, the exhaust system restriction at the engine cannot exceed the engine manufacturer's recommendations. In addition, the exhaust system components cannot impose undue stress on the engine exhaust outlet connection. Weight, inertia, relative motion of components, and thermal growth from temperature change all contribute to stress on the engine exhaust outlet. The exhaust system should also prevent water from entering the turbocharger or the engine proper. Common sources of water are rain, snow, and condensation of exhaust gas. As a final consideration, the exhaust gas should exit the building so that it does not have an adverse effect on the air cleaner, the cooling system, the generator set ambient temperature, or the operator.

If an engine works against excessive back pressure in the exhaust system, its usable power will go down. Also, the air-fuel ratio will go down (because the cylinders cannot be completely scavenged), the fuel economy will go down, and the exhaust temperatures will increase.

The exhaust back pressure imposed in a given engine installation depends on the size of the exhaust pipe, the number and type of bends and fittings, and the selected silencer. Tight 90° bends usually contribute the most to high-exhaust back pressure, so wide radius elbows work better. Back pressure is inversely proportional to the fifth power of pipe diameter, so a small increase in exhaust pipe diameter dramatically reduces system back pressure. The engine manufacturer can normally provide the exhaust gas flow and temperature. Figure 5-3 provides a way to determine the pressure developed in the pipe. The exhaust silencer manufacturer can provide the pressure drop through the silencer for a given flow and temperature. The pressure developed in the pipe and elbows plus the pressure drop through the silencer gives the back pressure at the engine.

Ensure exhaust piping can move with respect to the engine so that no damaging stresses will be imposed on the exhaust system components because of moving engines or thermal growth. A 50 ft length of pipe expands over 3 in when the temperature rises from 21.1 °C to 426.7 °C (70 °F to 800 °F). The most common method of obtaining flexibility is through the use of flexible piping (spiral- or bellows-type). Flexible sections occur in the piping between any components where either relative motion or thermal growth will subject the components to excessive stresses. The optimum location for the flexible section is within 4 ft of the engine exhaust outlet. Do not use the flexible pipe to form pipe bends or compensate for misalignment. To reduce the loading imposed on the exhaust manifold or the turbocharger, support long lengths of piping from the surrounding structure. Maintain flexibility through the design of the support and the use of flexible connections. Engineers should design the system to support the weight of all external engine exhaust piping so as not to impose any deadweight loads on the engine exhaust outlet connection. If pipe weight is not a factor, black iron schedule 40 pipe may be a preferred material.

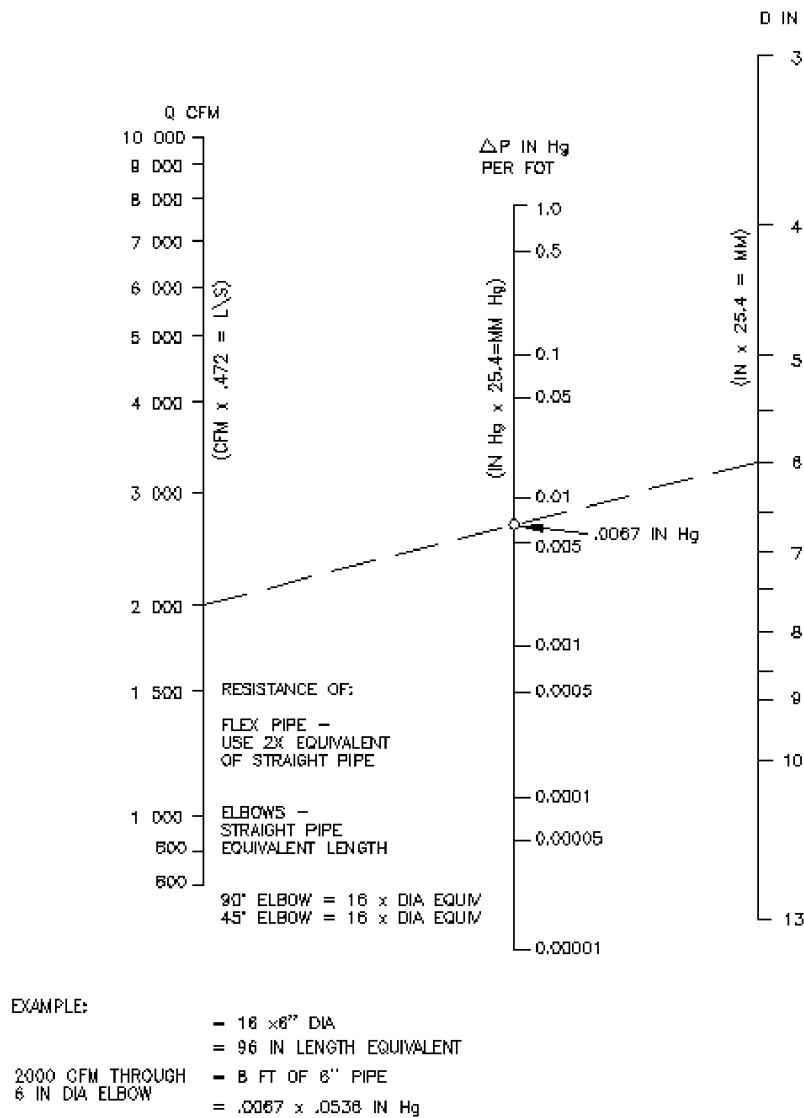


Figure 5-3—Back pressure nomograph

The silencer and exhaust piping can add considerable radiated heat to the generator set room. This additional heat will increase the ventilation airflow required to maintain reasonable room ambient temperature rise and prevent the engine from losing power or shutting down on over-temperature. Consider insulating the exhaust silencer and piping to reduce the heat load, but not the turbochargers.

Locate exhaust outlet openings to prevent rain and snow from entering them. Engineers should also consider the prevailing wind direction. For many such installations,

counterbalanced flapper-type rain caps can protect the openings. Conical and other ventilating covers produce a relatively high exhaust pressure or may not be suitable for operation in the prevailing exhaust temperature. Exhaust outlets that point upward do not direct the exhaust noise toward adjacent structures. Where the noise in a specific direction is not a problem, the exhaust outlets can be horizontal, but engineers should be careful to prevent the system from drawing the exhaust gases back into the engine room with the ventilation air, or worse, into one of the outside air intakes. Cutting the end of the pipe at a 45° angle with the top extended is normally adequate to prevent the entrance of rain and snow.

Aside from the obvious aesthetic effect of having an exhaust stack sticking out of a building, such stacks will produce carbon staining on the side of the building from the exhaust gas.

Finally, when diesel (or other fuel) burns, it forms water as a by-product. To remove the water, provide a condensate trap and drain valve in the exhaust system. Locate the condensate trap as close to the engine as practical and at the lowest point in the system.

5.4.2 Air supply

A generator set requires air for combustion and cooling. Even generators with remote radiators or heat exchanger cooling systems require airflow to the engine to remove the heat it produces and the heat radiated by the engine and exhaust system.

Generator set cooling systems normally have ratings for 40 °C (104 °F) ambient temperature with 0.5 in water column (WC) total external ventilation restriction. If the outside air intake will be higher than 40 °C (104 °F) minus the room ambient air temperature rise, then select one with a higher rating. For example, if the room ambient air temperature rise with a given airflow will be -4 °C (25 °F), and if the outside ambient air is more than 26 °C (79 °F), then the generator set output will require derating. For higher outside air temperature operation, consider higher ventilation airflow to reduce room ambient temperature rise. Generator set manufacturers generally offer optional cooling system packages rated at 50 °C (124 °F) with 0.5 in WC total external ventilation restriction.

The engine manufacturer can give the engine combustion air requirements at rated load and will define the maximum air restriction permissible and the recommended air intake temperature range. The engine air intake system should be able to supply clean combustion air to the engine without excessive restriction and within the manufacturer's temperature range. Dirt is the basic cause of wear in an engine. The effectiveness of the air cleaner and air piping system has a significant impact on engine life and maintenance costs. Dry-type air cleaners filter the air through a replaceable pleated-paper element. The efficiency of a dry-type air filter is normally greater than 99.9% at any airflow. Dry-type air cleaners do become plugged and then restrict air excessively. Dry-type air filters generally work better for standby generator sets.

Most standby generator sets for hospitals have an engine-mounted air cleaner that meets the engine requirements for adequate clean air.

When a generator set has a set-mounted radiator and fan, the fan pushes the air in the room through the radiator and out of the building. Under load, the air from the radiator is normally at 65 °C to 85 °C (150 °F to 185 °F). If the airflow were reversed, the room temperature would approach 65 °C to 85 °C, which is much too hot for the engine, the generator, or people. When the fan pushes radiator air out of the room, the generator needs adequate area for air to enter the room. Knowing the radiator fan delivery, the engineer can calculate a maximum air intake velocity. An air intake velocity of up to 20 mi/h (30 ft/s or 9 m/s) will usually work. If the fan delivery is unknown, an air intake area equal to one and one-half times the radiator core area is a reasonable rule of thumb.

Locate the air intake area behind the generator set. Fresh air then flows around and through the generator, past the engine, and through the fan and radiator. Some designs require the intake air to enter at the top or sides of the room. In such cases, check airflow outside the room to make sure the radiator and engine exhaust will not reenter the room with the intake air. Regardless of location, equip the fresh air intake with a fine mesh screen to minimize the accumulation of dirt, insects, and debris in the generator set room.

Many standby generator sets do not have a fan and radiator in the engine room, but use a remote-mounted radiator or heat exchanger. These installations require auxiliary room ventilators to remove the heat from the room. The heat produced by the generator and radiated by the engine at rated load is approximately 35% of the kW rating of the generator. This percentage can be 5% higher for units under 100 kW and 5% lower for units over 500 kW. Uninsulated exhaust pipes and mufflers within the generator set room add to the heat the auxiliary ventilation system needs to remove.

The auxiliary airflow required is determined by the heat that is to be removed and by the acceptable temperature rise in the room. Many engines begin to have a significant loss of power when combustion intake air temperature exceeds 49 °C (120 °F). Maximum ambient air temperatures vary widely. A 37.8 °C (100 °F) ambient covers most of the more populous regions of the world. The difference or acceptable temperature rise is 11 °C (20 °F). The specific heat of air at constant pressure ($C_p = 0.24$ Btu/lb °F) is essentially constant for air over a range of 27 °C to 54 °C (80 °F to 130 °F). The density of air changes with barometric pressure and altitude. At standard conditions, air density is 0.075372 lb/ft³ at 500 ft. Multiplying the specific heat by the density at 500 ft gives a heat coefficient of 0.018089 Btu/ft³ °F or about 0.018 Btu/ft³ °F. The airflow is the rate of heat rejection divided by the heat coefficient and the acceptable temperature rise, as shown in Equation (5.1):

$$C = \frac{Q}{0.018T} \quad (5.1)$$

where

- C is airflow in ft³/min
- Q is heat rejection in Btu/min
- T is acceptable temperature rise in °F

One kilowatt is the equivalent of 3412 Btu/h, or 58.87 Btu/min. Substituting this in Equation (5.1) yields Equation (5.2):

$$C = \frac{kW \cdot 10^3}{0.305T} \quad (5.2)$$

where

- C is airflow in ft³/min
- kW is heat rejection to room in kilowatts
- T is acceptable temperature rise in °F

Example: A 250 kW generator set will be installed in a hospital basement. The radiator and fan are remotely mounted on the roof of the building. The maximum outdoor design temperature is 105 °F. The engineer room temperature should be no more than 120 °F.

The temperature rise in the room (δT) is 120 °F – 105 °F = 15 °F.

The heat produced in the room at rated output will be approximately 35% of rated output, or $0.35 \times 250 \text{ kW} = 87.5 \text{ kW}$. From Equation (5.2), the airflow is shown in Equation (5.3):

$$C = \frac{8.75 \times 10^3}{0.305 \times 15} \quad \text{or} \quad 19\,126 \text{ ft}^3/\text{min} \quad (5.3)$$

5.4.3 Cooling

Almost all standby generator sets 50 kW and larger use liquid-cooled engines. Get the cooling airflow requirements for air-cooled engines from the engine manufacturer. The room design and the availability of water will dictate whether a liquid cooled engine should use a radiator or heat exchanger. Given a choice, generator-mounted radiators are better. The radiators do not depend on external water sources and getting adequate combustion and cooling air is usually pretty easy. Set-mounted radiators also have no coolant flex connection, long coolant lines, pumps, or coolant shutoff valves, any of which could fail.

5.4.3.1 Liquid cooling

Liquid-cooled engines usually have a generator set mounted radiator and engine drive fan. Select the radiator core, fan, shroud, guards, fan drive ratio, etc., to provide adequate cooling of the engine and alternator. Base the selection on maximum external restriction of 0.5 in WC. The manufacturer or generator set assembler normally lists the quantity of air required.

Remote radiators do provide a means of removing fan noise to a noncritical location. Heat exchangers do not consume engine power, but do require emergency power at the remote electric fan motor. A heat exchanger cooled unit can normally deliver 3% to 5% more power from a particular generator.

Remote radiators fall into two categories as follows:

- a) Radiator located horizontally remote from the engine
- b) Radiators located vertically remote (above) the engine

The design of remote radiator systems should take into account both the static head on the engine and the friction head of the piping system and radiator. Generator set manufacturers will provide the maximum static head and friction head data. For horizontally remote radiators, ensure that the water pipe resistance to flow does not exceed the engine driven water pump capability. (The engine manufacturer will provide the total permissible pressure on the pump and the maximum allowable external friction head.) See Figure 5-4. External pipe should be free of obstructions, excessive bends, elbows, tees, or couplings. It should be clean and free of rust, scale, weld slag, or corrosive material. It should not collapse while being formed or while in-service. The internal diameter should be greater than the water pump inlet diameter. Figure 5-5 and Figure 5-6 may be used for estimating pressure drop in pipe, fittings, reducers, etc. Connect the external circuit to the engine via a flexible connection.

Since many engine coolant systems cannot work with an auxiliary booster pump, consult the engine manufacturer before adding one to a system. Health care facilities should avoid designs that depend on auxiliary power systems energized by the system that they support or other external power systems subject to the same disturbance.

Installations with radiators below the engine level are rare and can cause problems. The primary problem is usually an air lock that prevents water circulation. In such installations, ensure the proper location of air vents in areas where air pockets are likely to form in the cooling system.

For the preferred installations where the radiator is above the engine level, the static pressure that can be imposed on the cooling system seals and gaskets will limit the maximum height of the radiator above the engine. The friction head should still be within the engine manufacturer's limits and may be estimated from Figure 5-5 and Figure 5-6.

For higher radiator positions, separate the engine from the radiator circuit. Figure 5-7 illustrates such a system, although many variations are possible. Both circuits circulate from a common reservoir, commonly called a *hot well*, *hot tank*, or *compound cooling* system. With the basic hot well, the engine merely pumps coolant to and from the tank. The tank acts as a blending and expansion tank, and it holds the radiator and line coolant when the radiator auxiliary coolant pump shuts down. For vertical radiators, putting coolant in at the bottom of the radiator will keep the radiator filled during operation. Vent the tank to the atmosphere to accommodate the large changes of coolant volume in the tank. A sight glass on the hot tank is helpful, with markings for the "run" and "stopped" levels as well as high and low marks for both. Slightly oversizing the cooling system components help to extend operating life by better accommodating component degradation.

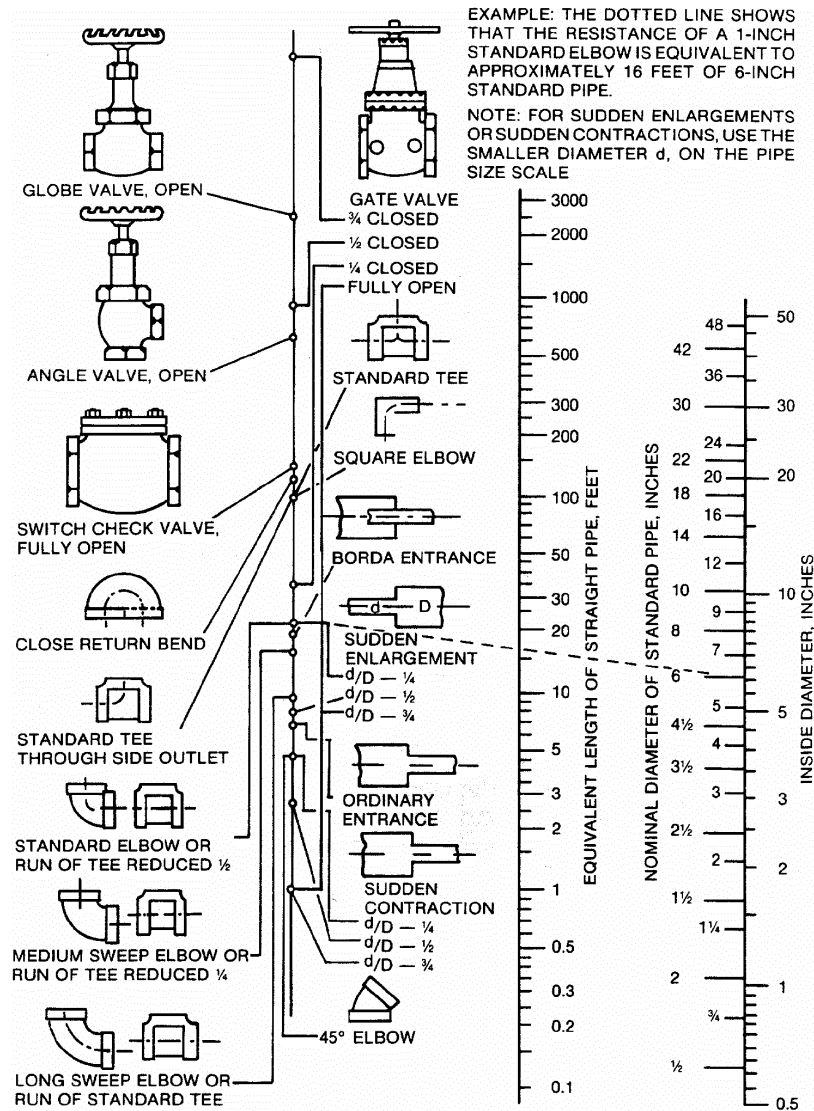


Figure 5-4—Resistance of valves and fittings to flow of fluids

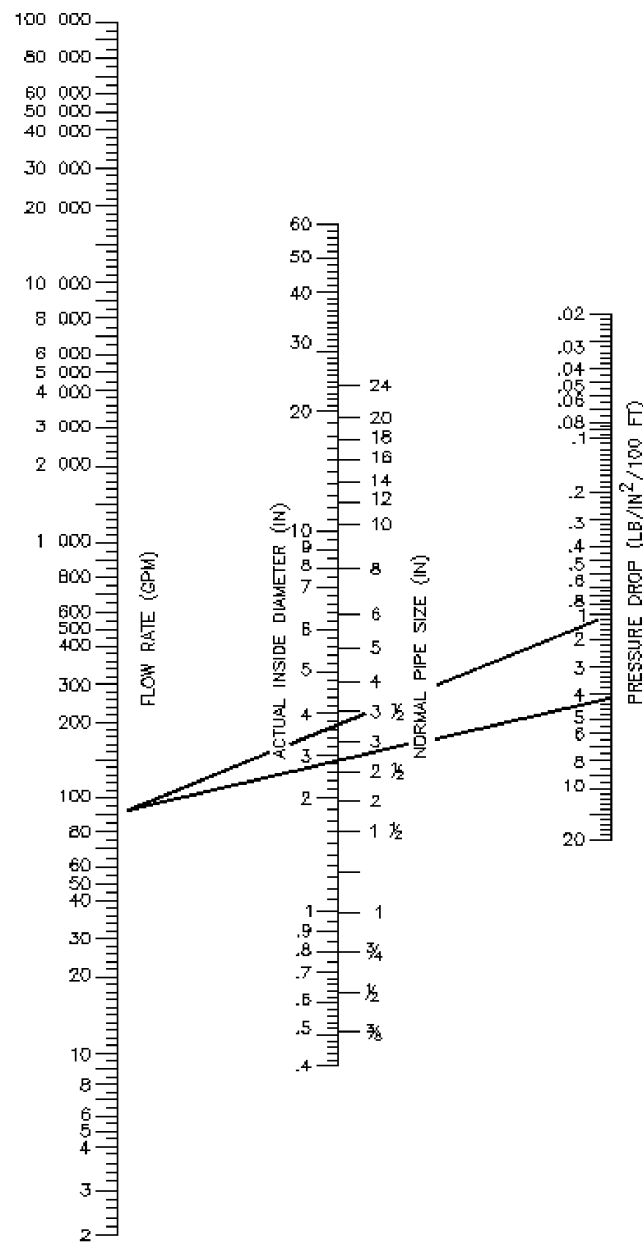


Figure 5-5—Fluid flow in pipe

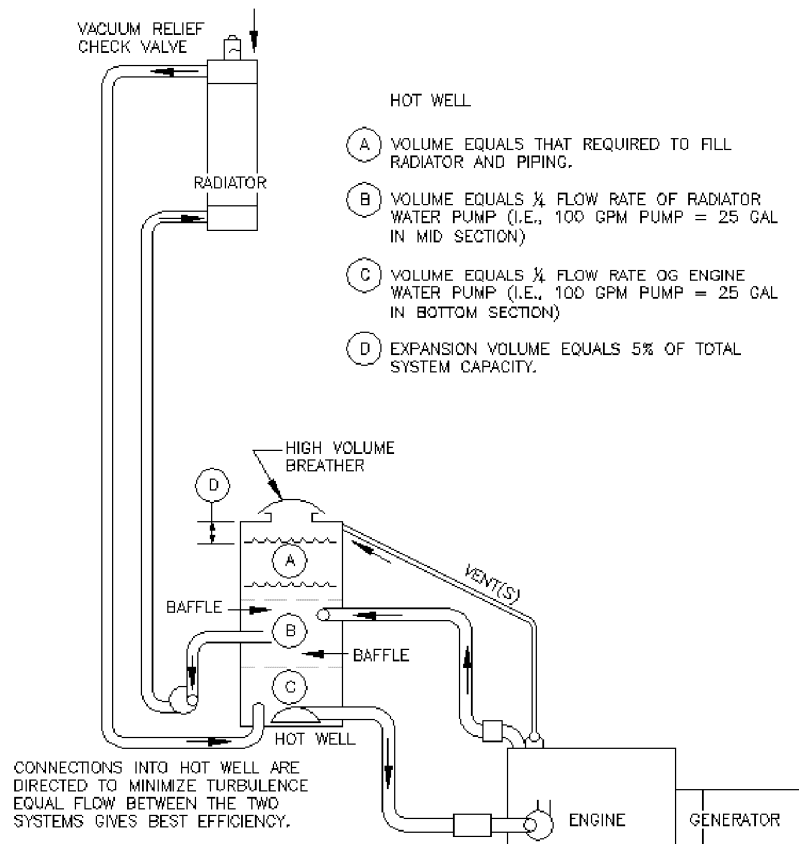


Figure 5-6—Hot well cooling system

Heat exchanger cooling systems can be used if a source of cool water is available. Sources of water may be from a city water supply, or from sea, river, lake, or well water. In this system, the engine cooling water flows in a closed loop from the engine to the heat exchanger and back to the engine. Raw water from the city, sea, etc., flows in a separate circuit within the heat exchanger and removes heat from the engine cooling water. This is a bad system for health care facilities as it depends on an external source that may not always be reliable. Also, if the water from the heat exchanger is to be dumped into the sewage system, it should not violate local conservation or natural resource ordinances, or overload the sewage system. Some heat exchangers may require a pressure reducing valve to limit the pressure supplied by a city water system to an acceptable value for the heat exchanger.

The least preferred option is a combination heat exchanger feeding a remote radiator. This system has all the disadvantages of both systems and costs about four times the cost of either individual system. Since the cooling capacity of both the heat exchanger and radiator depend on the temperature difference of the cooling media, both of them will be approximately twice the size of conventional units.

Always provide valves and couplings between the engine and the remote cooling system. Closing these valves allow servicing the engine without draining the entire cooling system. Of course, unintentional closing of these valves can also cause the unit to shut down because of overheating.

5.4.3.2 Air cooling

Some designs may require ducting to take the radiator hot air outside. Such ducts need to be smooth and free from obstructions, seams, fins, leaks, or sudden bends. If the ducts must bend, consider turning vanes to reduce pressure loss. Ducts that discharge through louvers or grills should make a smooth transition from the frontal area to the larger opening. As a rule of thumb, the effective opening area (taking louver restriction into account) should be at least equal to the radiator area.

5.4.4 Governor

Although gear reduction couples gas turbines to ac generators, this method is not often used on internal combustion engines. When an engine is directly coupled to an ac generator, the engine must run at 3600 rpm/min, 1800 rpm/min, 1200 rpm/min, or other lower synchronous speeds to produce 60 Hz or proportionately lower for 50 Hz. The alternative is a governor to regulate the emergency generator set engine speed, which is directly proportional to frequency. A governor regulates the amount of fuel delivered to the engine at various loads to keep the speed or frequency relatively constant.

Traditional mechanical and hydraulic governors use rotating flyweights to sense speed and a “speeder” spring as a reference. More sophisticated flyweight governors use hydraulic pressure to turn a shaft connected to the engine throttle or rack. Many hydraulic governors can operate isochronously, or at the same speed at no load and full load, and still maintain the speed or frequency steady-state stability within $\pm 0.25\%$.

Electric and electrohydraulic governors sense speed from pulses generated by a magnetic pickup mounted adjacent to an engine gear, usually the flywheel ring gear. Electric governors provide the same characteristics as hydraulic governors, but operate faster. Electric governors are also available with numerous accessories that may be useful in specific applications, including the following:

- a) Electric load sensing for isochronous load sharing among paralleled generator sets
- b) Electric load sensing for “load anticipation” to further reduce response time
- c) “Ramp acceleration” to provide a controlled acceleration rate and reduce frequency overshoot on start-up
- d) Electronic speed adjustment to adjust engine speed for synchronizing generators
- e) Reverse and forward power monitors that provide an output signal if power flows toward the generator, or when a preset output power level has been reached, or both

A reduction in the frequency response time of single unit generator sets with the “load anticipation” option can be seen on a frequency strip-chart recorder, but it is so slight that

the facility occupants will not notice it. “Load anticipation” on single-unit generator sets essentially doubles the governor cost and is more difficult to connect correctly. Load sensing governors for single-unit engine applications are rare.

5.4.5 Fuel supply

In order to operate properly, an engine should have an adequate supply of fuel that meets the engine manufacturer’s recommendations. All installations should incorporate a fuel filter to remove flakes, dirt, metallic chips, and water from whatever source, including condensation.

A day tank, sometimes called a *service tank* or *ready tank*, is recommended for all standby generator set installations. A day tank provides an ample supply of clean fuel at a relatively constant head, regardless of the fuel level in the bulk storage tank. Despite its name, the day tank should have capacity to contain enough fuel to supply the generator(s) for two hours (NEC, Article 700). A day tank provides a readily available supply of fuel independent of bulk storage and acts as an emergency supply in the event of failure of the auxiliary fuel pump, the connecting fuel lines, or the float-control switch. For diesel engines, it also acts as a relief and bypass tank for diesel fuel that it returns from the injectors. If warm fuel will return to the day tank, the engineer should oversize it to prevent hot fuel from being introduced to the engine. When the bulk storage fuel level is far enough above the day tank to give adequate gravity flow, a float valve or float switch and fuel shutoff solenoid should be used. In other installations, specify a day tank fuel transfer pump. Provide a primary filter between the bulk storage tank and the day tank. In multiple engine installations, consider a single common day tank with fuel isolation valves for the maintenance of individual systems. Similarly, a system can use a set of duplex fuel transfer pumps (each pump with the capacity to accommodate the fuel demand of all generators) at the bulk storage tank to maintain the day tanks full. In such systems, provide over-fill return piping to the bulk storage tank with float switches and solenoid shutoff valves to control the demand for fuel to each day tank.

The expected length of a disaster that might interrupt fuel delivery determines the capacity of the bulk storage tank. Since this is a difficult criteria to use, most bulk storage tanks should be between a 30-day supply and a 3-day supply.

Many diesel engines operate satisfactorily on Number 2 fuel oil. When the building also contains oil-fired boilers, a common bulk storage tank can provide a more economical source for both the furnace and the emergency diesel generator set.

A facility can generally store diesel fuel for up to one year. Water condensation and contamination is the primary problem with long-term storage. There will also be some evaporation, particularly of the more volatile parts of gasoline. Facility operators should take samples of the stored fuel at 6-month intervals to assure that it has not deteriorated. Check for water in the fuel storage tank every 2 weeks, particularly in aboveground storage tanks. Chemical additives can extend fuel storage time. Codes require that the critical branch supply power to the fuel transfer pumps.

5.4.6 Alternators

The alternator should be sized based on two types of loading. These are the maximum continuous load the alternator will carry and the motor load that the alternator will be required to start. Where nonlinear loads are connected, it may be necessary to oversize the alternator to minimize voltage distortion induced by harmonic load currents.

First, consider the maximum connected load. This load includes the lighting, heating, and running motor loads that the alternator will be required to carry at one time.

As an example, consider a small facility with a 100 kW lighting load, 50 kW of water heaters, a 25 hp blower motor on the heating and air-conditioning system, a 50 hp air-conditioning compressor motor, and two 25 hp elevator motors.

Therefore, the total connected running load is as shown in the following equations:

25 hp Code G blower motor [see Equation (5.4)]:

$$\text{kW} = \frac{68 \text{ running A} \times 230 \text{ V} \times 0.8 \text{ pf} \times 1.73}{1000} = 21.7 \text{ kW} \quad (5.4)$$

50 hp Code G air-conditioning compressor motor [see Equation (5.5)]:

$$\text{kW} = \frac{130 \text{ running A} \times 230 \text{ V} \times 0.8 \text{ pf} \times 1.73}{1000} = 41.4 \text{ kW} \quad (5.5)$$

25 hp Code G elevator motor [see Equation (5.6)]:

$$\text{kW} = \frac{68 \text{ running A} \times 230 \text{ V} \times 0.8 \text{ pf} \times 1.73}{1000} = 21.7 \text{ kW} \quad (5.6)$$

25 hp Code G elevator motor [see Equation (5.7)]:

$$\text{kW} = \frac{68 \text{ running A} \times 230 \text{ V} \times 0.8 \text{ pf} \times 1.73}{1000} = 21.7 \text{ kW} \quad (5.7)$$

Total motor running load = 106.5 kW

Lighting load = 100 kW

Water heaters = 50 kW

Total running load = 256.5 kW

Now consider the total motor load the alternator will be required to start. It is virtually impossible to start all four motors at the same time; however, since there is nothing to prevent it from happening, consider this to be the worst-case condition. Since most motor starters will drop out at about 60% voltage, we should limit the voltage dip on motor starting to 35%. Motor starting capability of alternators will vary depending on the alternator, type of exciter, voltage regulator, and voltage regulator accessories used.

Most present-day alternators have a minimum across-the-line motor starting capability of 0.5 hp/kW with a 35% voltage dip. The total connected motor load in the example is 125 hp; therefore, the required alternator motor starting kilowatts would be as shown in Equation (5.8).

$$\text{kW} = 125 \text{ hp} \times \frac{\text{kW}}{0.5 \text{ hp}} = 250 \text{ kW} \quad (5.8)$$

Various computer programs, often available at no cost from generator manufacturers, make much more precise calculations. These programs accurately match specific generators and allow the designer to input data on the various types of loads found in modern electrical systems of the building, including nonlinear and medical imaging loads. Manufacturer's representatives often perform this service for the designer.

The continuous running load of 256.5 kW is slightly larger than the 250 kW motor starting requirement and would be the determining load. Since the demand for electric power is continually increasing with new appliances and lighting added from time to time, an allowance for future requirements could be made. A general industry practice is for the load to be not more than 80% of the alternator rating on a new installation. Applying this rule to the example, as shown in Equation (5.9), the requirement would then be an alternator of:

$$\frac{256.5 \text{ kW}}{0.8} = 320.6 \text{ kW} \quad (5.9)$$

Since this is not an even rating, the alternator would be of next higher rating or 325 kW.

Systems with a significant number of variable speed drives, or other nonlinear loads (static UPS systems, computer power supplies, battery chargers, etc.) often experience high harmonic current loads. This harmonic current distortion is usually more severe when supplied by the generator since a generator is not as "stiff" as the utility. Since many motors, such as elevators and air compressors, cycle on and off, the resulting voltage dips can occur at many times other than initial generator starts. Engineers should design these systems to keep these voltage dips within the 10% (maximum) often required by computers, monitors, and other electrically sensitive equipment.

5.4.7 Voltage regulators

Two basic types of voltage regulation systems include the following:

- a) The brushless self-excited automatic voltage regulator
- b) The brushless separately excited automatic voltage regulator

Both basic types provide typical voltage regulation of 0.25% to 2%. Either system can work for health care facilities, provided the connected loads can withstand the voltage variations. Refer to Chapter 8, which deals with voltage variation susceptibility of hospital medical equipment and instrumentation.

- 1) *Brushless self-excited automatic voltage regulator.* The brushless self-excited automatic voltage regulator also takes its supply from the main starter windings for both the reference input and the power input. The reference voltage and control portion of the regulator control the input power. The system rectifies the power to dc to create the output to the exciter starter. The regulator is self-exciting from the residual voltage of the alternator. Typically, the contacts of a normally closed relay or a solid-state relay apply the alternator residual voltage directly to a full wave bridge and to the exciter field. As the ac voltage builds up, the relay picks up, disconnecting the built-up circuit (see Figure 5-7).
- 2) *Brushless separately excited automatic voltage regulator.* The separately excited automatic voltage regulator receives input power from a separate source but receives reference voltage input from the alternator windings. A permanent magnet generator mounted on the same shaft as the exciter and main rotors usually provides input power.

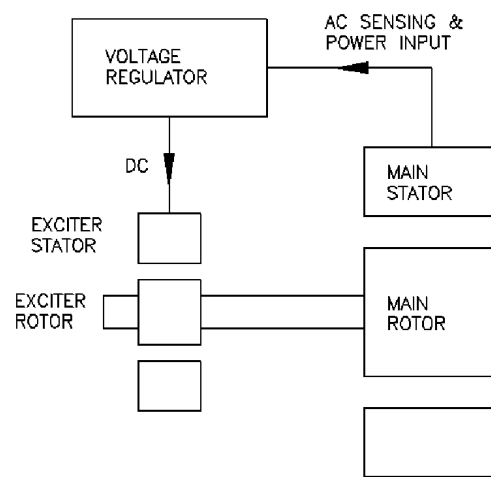


Figure 5-7—Self-excited regulated system

The permanent magnet generator provides a nearly constant power source under all operating conditions and does not vary with load. Excitation is greater than the full-load requirements of the alternator and is usually high enough to sustain a short-circuit current of three times the rated current.

The static exciter-regulator, the self-excited voltage regulator, and some separately excited regulators sense a lower than normal output voltage and “turn on” to increase the excitation to the exciter field to bring the output voltage back up to normal. Some separately excited voltage regulators work in reverse. Since the permanent magnet generator always provides more excitation than is required for normal voltage output, the voltage regulator suppresses the excitation. So when the regulator senses a lower than normal output voltage, it “turns off” to increase the excitation to the exciter field to bring the output voltage back up to normal (see Figure 5-8).

This system has a fast response to load changes and has the motor starting ability of 3/4 hp/kW with a 35% voltage dip.

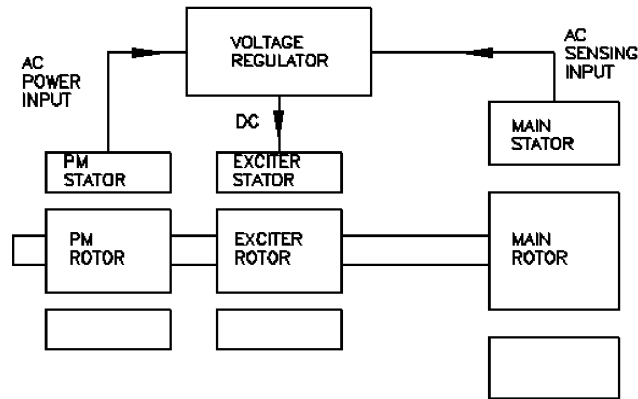


Figure 5-8—Separately excited system

5.4.8 Exciters

The basic exciter in use today is the rotating brushless exciter. The rotating brushless exciter is actually a three-phase generator with a rotating armature on the same shaft with the main generator rotor. The voltage regulator supplies excitation current and voltage to the stationary field. A three-phase rotating bridge rectifies the three-phase output from the rotating armature and supplies the dc voltage to the main generator field. The power input to the brushless exciter for a 200 kW generator is 0.3 kW.

5.4.9 Remote annunciator requirements

Health care facilities require a remote annunciator panel (see Figure 5-9) to provide visual and audible indication of the following:

- a) Low fuel level
- b) Low water temperature
- c) Low oil pressure
- d) High water temperature
- e) Overspeed
- f) Overcrank

Visual indication only is required for the following:

- 1) Battery charger malfunction
- 2) Generator is supplying the load

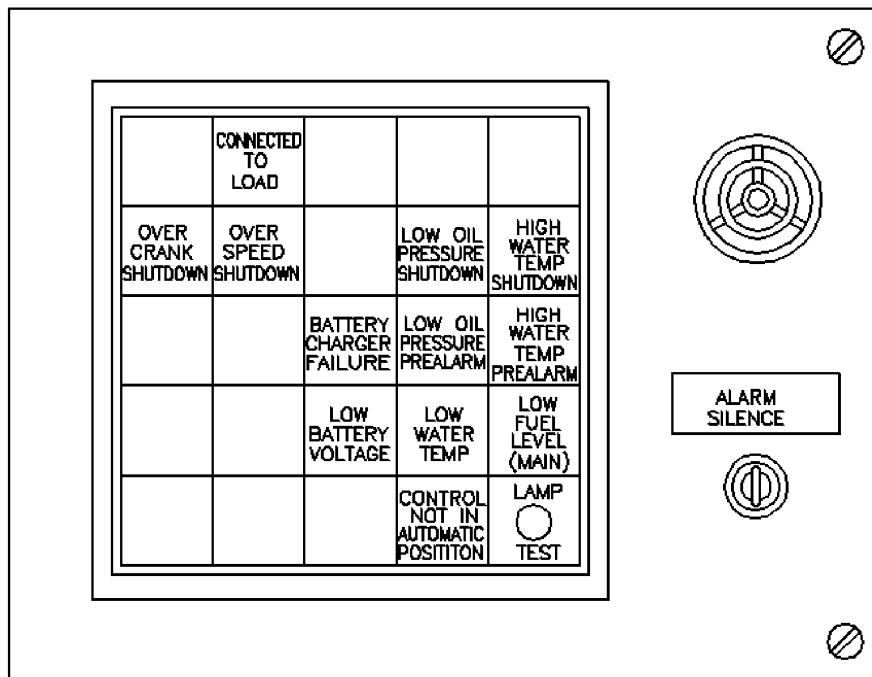


Figure 5-9—Typical remote annunciator panel

In addition, a derangement contact should be supplied to close for signaling to a continuously attended workstation that an alarm condition has occurred.

5.4.10 Starting methods

5.4.10.1 General description

The most common cranking methods for standby generator sets are battery electric systems and compressed air systems. System selection depends on the type of engine and customer preference. Each system has certain advantages under specific conditions. For further detail, please refer to EGSA 100B.

Electric cranking is the most common starting method and offers a compact, convenient, economical, and dependable method of cranking engine-driven standby generator sets. The engine portion of the system consists of a cranking motor, batteries, and some method of connecting and disconnecting the cranking motor to the batteries. A battery charger, powered by the critical branch or priority one system, will maintain and keep the batteries charged.

Many engine-cranking motors are “positive engage” type. For these motors, the starter pinion fully engages with the engine ring gear before cranking commences. The system works quite well about 98% of the time. However, approximately 2% of the time a pinion

tooth abuts directly with a ring gear tooth and the motor does not crank. “Cycle cranking” eliminates this problem by alternating the cranking period and reset periods in which the cranking motor pinion turns slightly so that the probability of successive tooth abutments approaches zero. Cycle cranking also reduces heat rise in the starter motor windings. The timing of the crank and rest cycles is usually combined in an automatic cranking panel. The automatic cranking panel should also include some means to terminate cranking when the engine starts and a method of disabling the engine safety shutdown controls (other than overspeed and overcrank) during starting.

NFPA 110 requires the battery capacity to be sufficient for two successive cranking attempts, either two 75 s cycles consisting of 15 s of cranking followed by 15 s off, or two 45 s cycles of continuous cranking. The engine manufacturer will normally define the battery capacity required to meet this requirement.

When a plentiful supply of compressed air is available, air can be an economical method of starting a standby generator set. Two types of compressed air starting are used:

- a) *Air motor.* An air motor drives a ring gear from the air starter motor pinion. This works similar to the electric starter. It is usually used on 1200 r/min and 1800 r/min engines.
- b) *Direct air injection.* An air distributor injects compressed air into the individual cylinders. This system is usually found on only the larger engines that operate at 900 r/min or below. It has the advantage that it produces full engine torque during cranking, producing rapid acceleration.

To prevent problems, air starting systems require a sufficiently sized air tank and an auxiliary source of compressed air. An air tank with sufficient capacity to provide five 10 s cranking attempts, as required by NFPA 99, consumes a lot of space. Most air systems use electric motor-driven air compressors to recharge the air tanks, but during a utility power failure, these compressors are obviously unavailable. Health care facilities should therefore have a small auxiliary gasoline engine-driven air compressor to provide a standby source of air.

5.4.10.2 Battery chargers for cranking batteries

Many different battery chargers are available. The type selected for a generator set installation will depend upon the electrical equipment used on the engine. Most chargers fall into two categories:

- a) *Full battery recovery.* The full recovery-type charger is required on standby generator set installation when a charging generator is not used to restore battery charge. It is usually an automatic high-low rate charger. The high rate will recharge the battery, and the low rate will maintain the batteries in prime starting condition.
- b) *Maintenance trickle charge.* The trickle-type charger is sometimes used when the engine has a charging generator. With a trickle charging rate of 2 A, it maintains the battery condition at whatever level was attained when the charging generator stopped. It is not designed to recharge a discharged battery, and for this reason, it

may be more reliable to provide a high-low full battery recovery charger even if a charging generator is furnished on the engine.

A battery charger for engine-cranking batteries is similar, if not identical, to a dual rate battery charger for standard float application. The primary difference between the chargers is sizing. In engine-cranking applications, the battery load is usually several hundred amperes (possibly a few thousand amperes) for only a few seconds. The batteries often need to be relatively large to provide the high breakaway and rolling currents for the cranking motor. On the other hand, the charger is usually small in comparison to the battery ampere-hour capacity, because only a small amount of battery capacity is removed with each crank cycle. For example, as shown in Equation (5.10), 1000 A for 15 s equals:

$$1000 \text{ A} \frac{(15 \text{ s})}{(3600 \text{ s/h})} = 4.2 \text{ Ah removed} \quad (5.10)$$

In lead-acid batteries, the individual cell voltages will begin to drift apart and will need to be brought back to the full charge by increasing the charger voltage approximately 10% for 25 h to 30 h every 30 days. This is referred to as *equalizing* the battery. Nickel-cadmium batteries have much less self-discharge over longer periods of time under similar conditions.

Whether lead-acid or nickel-cadmium, both types of batteries need a high rate of charge to achieve a fully charged state.

Many nickel-cadmium battery users may believe that because their type of battery does not require periodic “equalizing charges” similar to lead-acid batteries, they do not need a dual rate battery charger. However, a single-rate charger will not recharge a fully discharged battery to more than 85% at float voltage regardless of the charger capacity. And with each successive discharge, the nickel-cadmium battery in this kind of charging circuit will continue to lose capacity. This phenomenon is known as the *memory effect*. However, it is simply a result of inadequate recharging of the battery and can be reversed with a sequence of several high charge and deliberate discharge cycles.

5.4.10.3 Charger ratings

Engineers need to size the continuous duty output current rating to supply the engine-cranking battery charging current plus all auxiliary load requirements. The type of battery and the number of cells to charge dictate charger output voltage rating.

Float voltage ranges per cell at 25 °C (77°F) are as follows:

- Lead-plate at 1.210 d electrolyte 2.15 V to 2.19 V
- Lead-antimony at 1.210 d electrolyte 2.15 V to 2.19 V
- Lead-antimony at 1.265 d electrolyte 2.29 V to 2.33 V
- Nickel-cadmium at 1.35 V to 1.45 V

Equalize voltage ranges per cell at 25 °C (77 °F) are as follows:

- Lead-plate at 1.210 d electrolyte 2.25 V to 2.35 V
- Lead-antimony at 1.210 d electrolyte 2.25 V to 2.35 V
- Lead-antimony at 1.265 d electrolyte 2.4 V to 2.5 V
- Nickel-cadmium at 1.50 V to 1.60 V

The ac input ranges for 60 Hz are as shown in Table 5-2:

Table 5-2—AC input ranges for 60 Hz

Nominal voltage	Minimum	Maximum
120	106	127
208	184	220
240	212	254
277	245	293
480	424	508
575	508	608

The rated ac supply frequencies are 50 Hz or 60 Hz.

Rated ambient temperature range is 0 °C to 50 °C (32 °F to 122 °F).

5.4.10.4 Charger sizing

The worst-case load on the charger occurs when the battery is discharged and the system calls on the charger to recharge the battery and to power the load. Many other considerations such as the number of cells, voltage window of the load, input voltage, input frequency, single-phase, three-phase, output regulation, ripple, recharge time, etc., can also affect the charger selection.

In general, because engine-cranking batteries seldom discharge deeply, Equation (5.11) gives a good estimate of charger size:

$$I(\text{chg}) = \frac{0.6(Ah)}{HR} + I(\text{load}) \quad (5.11)$$

where

$I(\text{chg})$ is current capacity of charger

Ah is ampere-hour capacity of charger

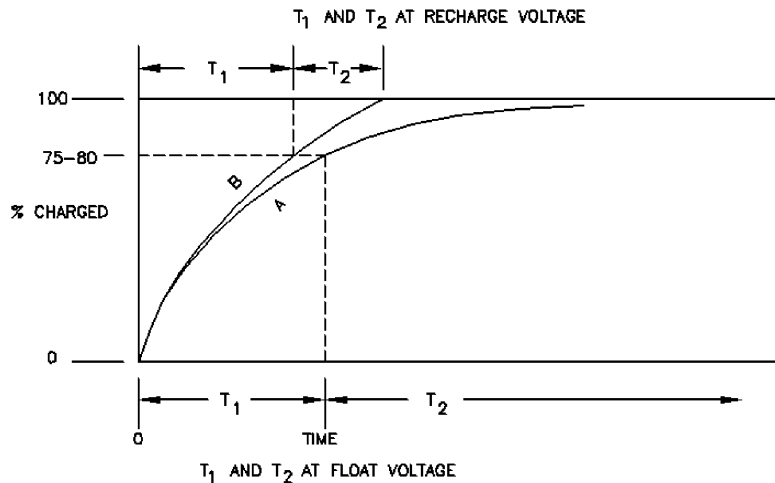
HR is hours to recharge

$I(\text{load})$ is continuous dc load on the system

Note that battery recharge time actually relates to two different parameters of the charger:

- The current capacity of the charger
- The voltage setting of the charger

Refer to Figure 5-10. T_1 is almost completely determined by the current capacity, but the charger's current capacity has almost no effect on T_2 .



T_1 = The time required to recharge a fully discharged battery to 75–80% charge.
 T_2 = The time required to bring the battery from 75–80% charged to 100% charged.

Figure 5-10—Battery recharge time

T_2 is almost completely determined by the output voltage setting of the charger, although this setting has virtually no effect on T_1 .

The charger will be in its current limit mode during the first part of T_1 and, as the battery voltage begins to increase, the charger will come out of current limit. Curve A is typical. Doubling the charger current capacity cuts T_1 in half.

The only way to shorten T_2 is to shift up to a higher charging curve, such as shown in curve B, by applying more V/cell to the battery. This is done by adjusting the “recharge” mode (“equalize” for lead-acid systems) of the charger output up to a higher voltage. However,

- Lead-acid batteries are more sensitive to high charging voltages than nickel-cadmium. The extra heat buildup in the plates may cause plate warpage.
- The voltage window of the applied load may not accommodate the increase in charger voltage.

The charger can be adjusted up to 1.65 V/cell to 1.7 V/cell for pocket-plate nickel-cadmium cells without any damage to the battery, but all loads have some maximum voltage above which serious damage will result. One of the following two standard methods is commonly used to effect desired recharge times without damage to the load:

- a) *Method 1 (oversizing)*. Since T_1 is a function of current capacity of the charger, but only restores the battery to 75% to 80% of full charge, the battery can be oversized by 25% and a larger charger used. Even though the battery will not be fully recharged during time period T_1 , it will be recharged sufficiently to carry another duty cycle for the specified time period.

NOTE—When specifying the charger, it may be desirable to require “a charger that will restore the battery sufficiently to carry another duty cycle as specified for the battery” instead of “fully recharged” in a given period of time.³

- b) *Method 2 (dropping diode)*. Although damage to the battery is possible for lead-acid batteries being rapidly recharged, the nickel-cadmium pocket-plate battery can accept current as quickly as it can release it. There is no danger to the battery as long as the electrolyte level is kept above the surface of the plates (see Figure 5-11).

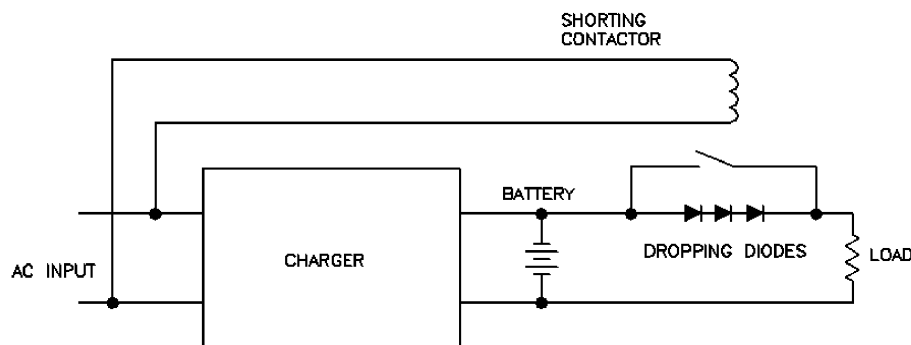


Figure 5-11—Dropping diode circuit (CEMF)

5.4.10.5 Comparison of battery types

Although the lead-acid battery and its nickel-cadmium counterpart can be used interchangeably in most applications, there are certain advantages and disadvantages to each type. The primary advantage to the lead-acid battery is its lower initial cost. The primary advantage to the nickel-cadmium battery is that it is a lower maintenance, longer lived, more physically rugged battery. For engine-cranking applications, a properly sized and maintained nickel-cadmium battery will have an expected useful life of 18 to 20 years, compared with 2 to 4 years for the engine-cranking lead-acid battery. Since specifiers may not adequately describe the quality features required in a lead-acid battery, it has been

³Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the recommended practice.

common for lead-acid batteries furnished with generator sets to be of minimal quality, whereas nickel-cadmium batteries are usually made to only one high grade design.

5.4.10.6 Typical performance features

- a) The battery charger should be a solid-state, constant potential device whose output potential is regulated by sensing the battery voltage.
- b) The charger should deliver full rated capacity to a discharged battery with input voltage variation as shown in 5.4.3.
- c) The output float voltage should be maintained within +1% of the nominal setting.
- d) The output equalize voltage should be maintained within +2% of the nominal setting.
- e) The charger should change the output voltage from float to equalize when conditions warrant.
- f) The charger should have controls to adjust the voltage over the range specified in 5.4.3 (float voltage ranges and equalize voltage ranges).
- g) The back drain from the battery should not exceed 50 mA with the loss of ac input.
- h) The battery charger should be self-protected, and the output current should be limited to a safe value under cranking loads.
- i) The charger should have surge suppressors to protect the rectifier from line and load transients.
- j) The input and output circuits should be protected with fuses and/or circuit breakers.
- k) The charger should have an output current ammeter with minimum accuracy of 5%.
- l) The charger design and manufacture should satisfy the performance and safety codes of NEMA PE 5 and EGSA 100C.

5.4.10.7 Optional accessory features

- a) A voltmeter.
- b) Charger output alarm.
- c) High dc voltage alarm devices to actuate when the charger output voltage exceeds the preset alarm level.
- d) A low dc voltage alarm device for when the charger output voltage falls below the present alarm voltage level. This level should be adjustable from float voltage to 1.75 V/cell lead-acid or 1.0 V/cell nickel-cadmium.
- e) AC power failure alarm devices.
- f) An equalize timer to cover a range of 0 h to 24 h or 0 h to 72 h. When manually activated, this timer will place the charger in the equalize mode. At the end of the specified time period, the timer will automatically return the charger to the float mode.

- g) An automatic equalize timer to be activated by ac power failure or low dc battery voltage to place the charger in the equalize mode. At the end of the specified time period, the timer will return the charger to the float mode.

5.4.10.8 Installation and maintenance data

- a) Size the wire between the battery charger and the battery to minimize voltage drop.
- b) Provide adequate clearance to allow convection cooling of the charger.
- c) Connect all auxiliary loads to the dc panelboard supplied from the battery bus. Do not connect loads to battery terminals or charger terminals.
- d) Install the charger in accordance with the NEC and NFPA 110.
- e) Periodically inspect the charger for dust and dirt removal and connection tightening.

5.5 Transfer switches

NEMA standards define an *automatic transfer switch* (ATS) as self-acting equipment for transferring one or more load connections from one power source to another. The switch automatically retransfers the load back to the normal source when it is restored. Because of its crucial role in the reliability of the electrical system, the transfer switch should be a highly reliable device with a long life and minimum maintenance requirements. Transfer switches for health care facilities should be appropriate in terms of the following:

- a) Types of load to be transferred
- b) Voltage rating
- c) Continuous current rating
- d) Overload and fault current withstand ratings
- e) Type of OCPD ahead of the transfer switch
- f) Source monitoring
- g) Time delays such as on transfer or transfer-back
- h) Input/output control signals
- i) Main switching mechanism
- j) Ground-fault protection considerations
- k) System operation
- l) Bypass/isolation switches
- m) Nonautomatic transfer switches operation
- n) Multiple transfer switches vs. one large transfer switch per system
- o) Need to transfer system neutral

5.5.1 Voltage ratings

An ATS is unique in the electrical distribution system in that two unsynchronized power sources connect to it. This means that the voltages impressed on the insulation may actually be as high as 960 V on a 480 V ac system. A properly designed transfer switch should provide sufficient spacings and insulation to meet these increased voltage stresses.

For this reason, the electrical spacing on a transfer switch should not be less than those shown in UL 1008 (Table 22.1), regardless of what type of component may be used as part of the transfer switch.

NEMA ICS 10 standard voltage ratings of ATSs are normally 120 V, 208 V, 240 V, 480 V, or 600 V, single or polyphase. The standard frequency is 60 Hz. ATSs can also be supplied for other voltages and frequencies when required for dc and international applications.

5.5.2 Continuous current rating

Transfer switches differ from other emergency equipment in that they continuously carry the current to critical loads, while engine generators supply power only during emergency periods. Current flows continuously through the transfer switch whether the switch is in the normal or the emergency position. ATSs are available in continuous ratings ranging from 30 A to 4000 A.

Most transfer switches are capable of carrying 100% of rated current at an ambient temperature of 40 °C. However, some transfer switches, such as those incorporating integral OCPDs, may be limited to a continuous load current not to exceed 80% of the switch rating.

Engineers need to size transfer switches based on the maximum continuous load current the switch will carry. Momentary inrushes, such as occur when lighting or motor loads are energized, can be ignored provided that the switch is UL 1008, *total systems load* rated. For new projects, the engineer may specify a transfer switch that will be able to carry future anticipated loads. In such cases, the switch should have a continuous current rating equal to the future total anticipated load.

5.5.3 Overload and fault current withstand ratings

Transfer switches are often subjected to currents of short duration that exceed the continuous duty ratings. The ability of the transfer switch to handle higher currents is measured by its overload and fault current withstand ratings. Additional information on overload ratings and fault current withstand ratings can be found in Chapter 3.

5.5.4 Protective device ahead of transfer switch

The type and size of the overcurrent device ahead of the transfer switch plays a significant role in transfer switch application. Refer to Chapter 3 for a discussion on coordinating the protective device and the transfer switch. Protective devices should be coordinated

throughout the system so that a fault is cleared by the device nearest to the fault, thereby minimizing load disruption.

5.5.5 Time delays

Time delays operate to prevent the ATS from unnecessary starting and transfer to the alternate supply. An adjustable momentary outage time delay will override momentary interruptions and reductions in normal source voltage but will allow starting and transfer if the reduction or outage is sustained. The time delay is generally 1 s, but may be set higher if line-side automatic throwover arrangements and reclosers on the high lines take longer to operate, or if expected momentary power dips frequently exceed 1 s. If long delay settings are used, ensure that sufficient time remains to meet the 10 s power restoration requirements.

Once the load transfers to the alternate source, another timer delays retransfer to the normal source until that source has time to stabilize. Preferred source voltage monitors in the ATS control this delay, which is adjustable from 0 min to 30 min. Most facilities set their retransfer at 30 min. Another important function of the retransfer timer is to allow the engine-generator set to operate under a load for a preselected minimum time to drive out moisture and ensure continued good performance of the set and its cranking system. This delay should be automatically bypassed if the alternate source fails and the normal source is available as determined by the voltage monitors.

Engine-generator set manufacturers often recommend a cool-down period following retransfer to the normal source. A third time delay, usually 5 min, provides this operation. The delay helps to prevent inadvertent high water temperature alarm and lock-out when the set shuts down. Running an unloaded engine for more than 5 min can cause deterioration in engine performance.

Some applications may benefit from sequencing the transfer of the loads to the alternate source where more than one ATS is connected to the same engine generator. Such a sequencing scheme can reduce starting kilovoltampere capacity requirements of the generator. A fourth timer, adjustable from 0 min to 5 min, will delay transfer to the alternate source for this and other similar requirements. NFPA 99 requires the delay on certain equipment system loads.

5.5.6 Input/output control signals

When the transfer switch control panel detects a sustained failure of the normal source, a set of contacts, one normally open and one normally closed, operates to signal starting of the alternate source generator set. These contacts should be rated to handle the dc voltages encountered on engine automatic starting systems.

Additional dry contacts, normally open and normally closed, should be provided on the transfer switch unit for remote annunciation of transfer switch positions and other control functions.

5.5.7 Main switching mechanism

The main switching mechanism of a transfer switch should have the following characteristics:

- a) *Electrical operation.* The transfer switch should derive control power from the source to which the load is to be transferred. This arrangement ensures an adequate source of power for switch operation.
- b) *Mechanically held.* Electrically held transfer switches are limited in size, will drop out and disconnect the load if the main coil fails, and have very low fault current withstand ability. Mechanically held mechanisms are not limited in size, will not drop out, and can withstand higher fault currents.
- c) *Mechanically interlocked—double-throw.* Normally, the switch mechanism should be of the mechanically interlocked double-throw-type, permitting only two possible positions—closed on normal or closed on emergency. If the interlocking permits both sets of contacts to close at the same time, a system-to-system short circuit can occur. Exceptions are made for closed transition schemes.

5.5.8 Bypass/isolation switches for automatic transfer switches

In many health care facilities, it is difficult to perform regular testing or detailed inspections on the emergency system because some or all of the loads connected to the system are vital to human life. De-energizing these loads for any length of time is difficult. This situation results in a lack of maintenance. In such installations, a bypass switch in the ATS can bypass the critical loads directly to a reliable source of power without downtime. The transfer switch can then be isolated for safe inspection and maintenance.

These switches can perform the following three functions:

- a) Shunt the service around the transfer switch without interrupting power to the load.
- b) Allow the transfer switch to be tested without interruption of power to the load.
- c) Electrically isolate the transfer switch from both sources of power and load conductors to permit the inspection and maintenance of all transfer switch components.

These functions are accomplished by operating two handles in an easy-to-follow sequence. The equipment can be furnished as a complete automatic transfer and bypass/isolation switch for new installations, or as a replacement for existing equipment. Some arrangements can be supplied with a drawout mechanism so that the transfer switch can be easily removed for maintenance.

In addition to the two-way switches, one-way switches can bypass to only one preselected source. Two-way bypass/isolation switches allow either power source to be selected to feed the load during bypass. The operator can choose the source that is the more dependable at that time. Furthermore, when the transfer switch is in the test or open position, a two-way bypass/isolation switch can be used to transfer the load to the

alternate source if the source to which it has been bypassed fails. (See Figure 5-12.) One-way devices cannot provide these features.

5.5.9 Nonautomatic transfer switches

Authorities having jurisdiction (AHJs) may sometimes permit nonautomatic transfer switches for certain code-defined portions of the equipment system load and for various non-essential loads. For these installations operating personnel operate the switch and engineers should only use them for loads that do not require immediate automatic restoration of power.

The NEC requires that a portable or temporary alternate source of power be made available whenever the emergency generator is out of service for major maintenance or repair. How this is to be accomplished is left up to the system designer. Whatever approach is used, it should be in accordance with standard practice and equipment for emergency use. One suggestion might be to use a nonautomatic transfer switch.

Devices used as nonautomatic transfer switches should have the same electrical characteristics, rating, and features as an ATS. Operators open and close these switches either through an externally operable manual operating handle or by electrical remote push-button control.

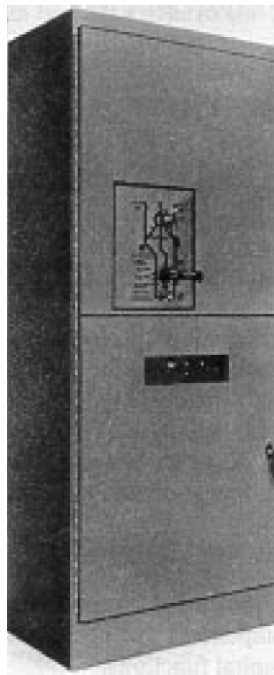


Figure 5-12—Typical automatic transfer and two-way bypass/isolation switch

5.5.10 Multiple transfer switches vs. one large transfer switch

In small hospitals and nursing homes with a maximum demand of 150 kVA on the essential electrical system, the NEC permits one large transfer switch rather than multiple branch transfer switches. The engineer should consider the following in determining the best approach:

- a) One single large ATS close to the incoming service controlling the entire emergency load, in lieu of individual ATSS in each branch of the emergency system, may reduce the overall reliability and design flexibility of the system. Locating the transfer switches as close to the loads as possible provides the maximum protection. When closer to the loads, the ATSS monitor the utility and generator power supplies but also the power circuit conductors to the switch.
- b) Maximizing physical isolation of the separate branches and feeders in the essential electrical system may be accomplished by using separate transfer switches in each feeder. Separate transfer switches, in each of the essential load feeders, increase total system reliability because separation of the conductors is maintained all the way back to the utility and generator main distribution switchboards. If one large transfer switch were used, it might require a long power conductor run downstream of the switch. If something happened to this one conductor or the single ATS, the complete essential electrical system would be shut down, whereas with the multiple ATS approach, only one branch of the system would be affected.
- c) Where a system needs sequential load transfer, more numerous, smaller transfer switches are much easier on the system than fewer larger ones.
- d) Using fewer larger switches is, however, usually a less costly design.

When branch circuits on the load side of the transfer switch are required to be extra reliable because they are life sustaining, consider area protection relays. These relays can sense failures at the load side of the individual panelboard overcurrent devices or directly at the point of utilization. Such relays can signal for remedial action when overcurrent device opening (inadvertent, mechanical failure, or overcurrent tripping), circuit wiring failure, equipment failure, or unintentional equipment disconnection occurs.

5.5.11 Ground-fault protection considerations

Ground-fault protection of electrical systems that have more than one power source (e.g., a load supplied by a utility and engine-generator set) requires special consideration. When the neutral conductor of the engine-generator set is grounded at the generator location, the transfer must also switch the neutral to avoid creating multiple neutral-to-ground connections. Without this kind of design, the system will be prone to improper sensing of ground-fault currents and nuisance tripping of overcurrent devices.

5.6 Uninterruptible power supply systems

UPS systems are highly efficient (85% to 92%) power converting devices that provide a regulated ac voltage at their output terminals regardless of the quality of the source at their input terminals.

In the event of a total power loss at the UPS input, output power comes from a bank of batteries. An additional benefit of the UPS is its ability to filter power aberrations from the ac source between the input and output terminals. These power problems could result from natural causes or buffer line disturbances on the utility power, or they could be caused by disturbances, such as load switching, within the facility itself. Uninterruptible power is generally not specified by code requirements for hospitals or health care facilities. However, UPS systems are increasingly being incorporated into such electrical designs. Typical applications include backup support for sensitive laboratory and diagnostic equipment, life-support equipment in intensive care units, data processing systems, and for illumination in life-support areas.

UPS systems are generally static (power electronic) devices, although there are hybrid systems available that combine static and mechanical components. Static UPS systems are nonlinear loads that cause harmonic distortions on the distribution system. A careful evaluation should be made to prevent the distortion from having adverse effects on other loads and equipment including overheating of the engine-generator set(s) (see Davis [B5]). Acceptable harmonic distortion should be specified to ensure full warranty.

A static UPS consists of a rectifier to convert the input ac power to dc, a bank of batteries, an inverter to reconstitute the ac sine waves, and a static switch. Refer to Figure 5-13 for a typical single-line diagram.

The static switch is part of a bypass system that provides a means to bypass the critical load back to utility power without interruption in the event of a system short circuit or overload, an inverter malfunction, or for planned maintenance.

The battery most often used in UPS installations is the lead-calcium cell. It is usually used due to its low cost, its discharge characteristics, its low hydrogen evolution, and consequently its low water usage. It is extremely important to be able to predict the number of discharge cycles and the depth of discharge when specifying batteries for a UPS system. Alternate batteries that can handle more and deeper discharge include lead-antimony and pure lead batteries.

The normal UPS configuration is called *reverse transfer*. This term is used because the output of the UPS inverter supplies power to the critical load during normal operation. The system transfers to the utility only in one of the alternate modes of operation, as previously noted.

UPS systems are frequently fed from the load side of a transfer switch for sustained operation. UPS manufacturers frequently recommend closed transition transfer switches to reduce stresses caused by the momentary interruption experienced with open transition switches (see Castenschiold [B4]).

The rectifier is supplied from the utility and in turn supplies dc power to the input of the inverter. In the event of loss of utility power, the inverter receives its power from the battery. When the input voltage and frequency returns to the predetermined level, the rectifier begins supplying power to the inverter and also begins recharging the discharged battery bank.

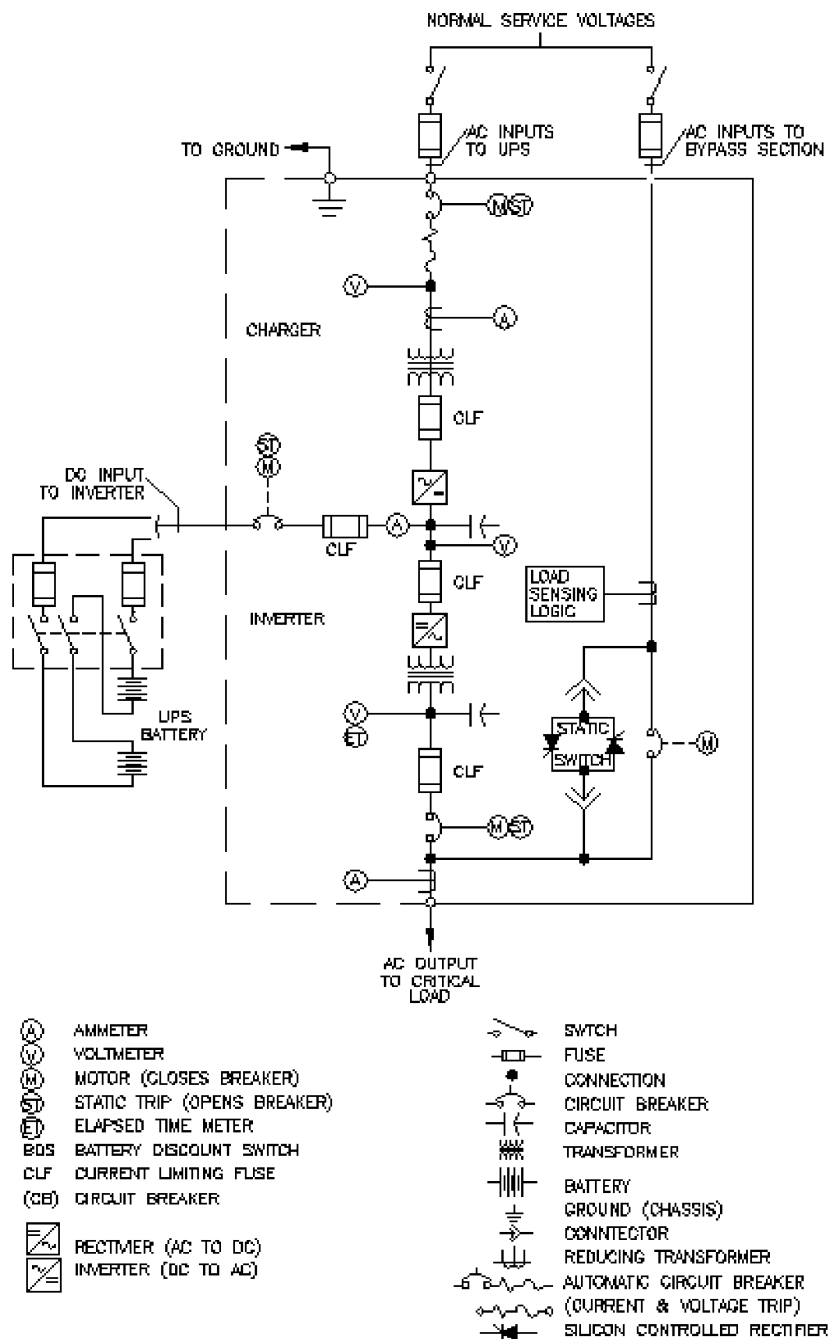


Figure 5-13—Typical UPS one line

Reverse transfer UPSs can supply single-phase or three-phase outputs. Single-phase output units can have either a single-phase or a three-phase input. Typical single-phase units are sized to supply a load ranging from 0.5 kW to 50 kW, and three-phase units from 15 kW to 600 kW. UPS manufacturers have the capability of paralleling units for additional capacity. They can also offer a forward transfer unit in the 0.5 kW to 10 kW range that prepackages the UPS and batteries in a common enclosure.

The design of a UPS system involves both electrical and environmental considerations. The first step is to calculate the UPS module ratings (rectifier, battery, inverter, static switch, and wraparound maintenance bypass switch combination). Determining factors are the present load, power factor, diversity of application, and future load additions and deletions. An alternate approach would be to size the UPS module to handle the anticipated load and the battery bank for the present load. Expansion can be achieved by paralleling an additional battery bank in the future. A common reserve time for the battery bank is 15 min.

The power connections to a UPS involve the battery bank, the input to the rectifier, the bypass circuit, and the output. The output and bypass feeders should be sized to handle the output capability of the UPS module. The rectifier is sized to handle the output of the inverter plus recharging a discharged bank of batteries. The input feeder and the generator set (when applicable) should be larger than the load to handle the additional current. The battery feeder is determined by the maximum dc discharge current and to limit voltage drop to specified conditions. As the battery begins discharging, the dc current rises as the voltage falls. Maximum dc current occurs at the point of low dc voltage shutoff. A rule of thumb is to allow a maximum 2 V drop in the conductors (calculated at maximum dc current).

A separate disconnecting/overcurrent device should be provided for both the input and the bypass feeders. Additionally, an overcurrent/disconnection device should be incorporated in the total scheme and located near the battery bank for required protection. In larger UPS modules, care should be taken to limit the dc voltage to 250 V as required by the NEC. A convenient method of achieving this would be to split the battery bank into two equal segments and connect the two across the center pole of a three-pole battery disconnect switch, as shown in the single-line diagram in Figure 5-13.

Isolation of the UPS module can be incorporated into the design through a maintenance bypass scheme. This is accomplished by first placing the UPS in a bypass mode, then closing a maintenance bypass device, and last, opening a nonautomatic circuit breaker or unfused device at the output of the UPS. The UPS is then completely isolated both from the critical load and from the building electrical system. This transition is accomplished without an interruption in the power supply to the critical load.

UPS system manufacturers can supply a remote annunciator panel, when specified, to monitor the status of the UPS system. This feature is good practice and should be located in the same area as code-required annunciator panels.

A final electrical consideration in the UPS design is the coordination between sizing of the protective devices at the output of the UPS inverter (usually a circuit breaker) and those on

the load side. Consideration should also be given to the same coordination for the situation when the UPS is in either its bypass or maintenance bypass modes.

The following are three environmental considerations in the installation of a UPS:

- a) The heat output of the UPS
- b) Maximum ambient operating temperature and relative humidity of both the UPS module and the batteries
- c) The hydrogen emission of the batteries

The heat output of the UPS depends on the module efficiency (typically 85% to 92% at full load). The UPS needs to get rid of this heat to operate effectively. Generally, the maximum operating temperature of the UPS module is considerably higher than a temperature that would adversely affect the batteries.

Provisions should be made for sufficient diffusion and ventilation of hydrogen emitted from the batteries to prevent the accumulation of an explosive mixture. This means keeping the hydrogen from reaching a level of 1% by volume of the room. If the battery room is air-conditioned, the exhaust air should not be returned to the building's air distribution system. The battery room should have its own exhaust system connected to the outdoors.

Ideally, the batteries should be located in their own room. If the batteries are not the cabinet-mounted, valve-regulated type, a substantial screen should partition them off to limit access only to qualified persons. There are a variety of rack configurations available. Consult the battery manufacturer and the UPS manufacturer to determine proper space and location limitations. Consult the building code to determine the seismic zone and specify seismic-rated battery racks accordingly. An eyewash area should be located in the vicinity of the battery bank in accordance with the Occupational Safety and Health Administration (OSHA).

UPS systems are state-of-the-art designs to which technical improvements are constantly being made. An example of this is the use of microprocessor diagnostics that enable the rapid identification of equipment problems based on critical point monitoring. This feature is of particular benefit to the health care industry where uptime of the UPS is important to its proper operation.

5.7 Transfer considerations for types of loads

5.7.1 General load classification

UL 1008 classifies loads as follows:

- a) Total system loads
- b) Motor load
- c) Electric discharge lamp loads
- d) Resistive loads
- e) Incandescent lamp loads

UL 1008 requires the marking of transfer switches to indicate the type of load they are capable of handling. The marking *total system loads* indicates that the transfer switch can be used for any combination of the loads described in items b) through e). However, the incandescent load may not exceed 30% of the total load unless the transfer switch is specifically marked as suitable to transfer a higher percentage of incandescent lamps. Most transfer switches are rated for the transfer of total system loads, although some may be marked *resistance only*, *tungsten only*, etc., or a combination of these markings. The burden of the system designer is lessened when the switches chosen are listed and rated for total system loads.

5.7.2 Motor loads

Consider two special design considerations when alternate power sources supply motor loads:

- The need to avoid nuisance tripping of protecting circuit breakers or fuses and possible damage to the motor and related equipment when the motor switches between two unsynchronized but energized power sources.
- The need to shed motor loads prior to transfer and delay reconnection to prevent overloading the power source to which the load is being transferred.

Engineers can design systems to deal with these needs. The situation is similar to paralleling two unsynchronized power systems. Various control methods that are being used to overcome this problem are as follows:

- a) *In-phase transfer*. In-phase transfer schemes have been applied to health care facility equipment loads for many years. As shown in Figure 5-14, in-phase transfer is often used for transferring low-slip motors driving high-inertia loads on secondary distribution systems.

A primary advantage of in-phase transfer is that it permits the motor to continue to run with little disturbance to the electrical system and the process that is being controlled by the motor. Some motor loads should not be interrupted and shut down. For motors that should be left to operate, in-phase transfer is the best approach.

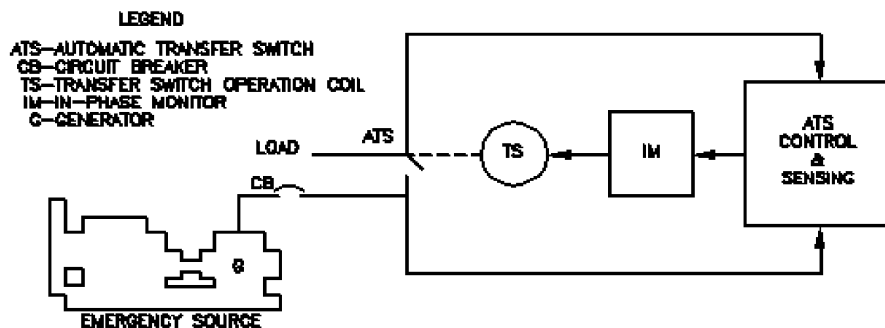


Figure 5-14—In-phase motor load transfer

In-phase transfer works by applying in-phase control to a transfer switch capable of fast transfer (less than 10 cycles) between available sources. The monitor samples the relative phase angle between the two sources. When the two voltages are within the required phase angle and are approaching zero phase angle, the in-phase monitor signals the transfer switch to operate. The faster the transfer switch operates, the wider the frequency difference can be between the two power sources without exceeding normal motor starting current at time of transfer (see Gill [B8]).

In-phase monitors need filtering and sensing to minimize the effects of waveform distortions such as harmonic current.

- b) *Load disconnect control circuit.* Motor load disconnect control circuits, such as shown in Figure 5-15 and similar relay schemes, are also a common means of transferring motor loads (see Kelly [B10]). This arrangement, timed center-off position, and load voltage decay control methods should be used only if the motor loads can be de-energized momentarily during transfer between available sources. Momentary de-energization may result in unacceptable disturbances to the electrical system and the process being controlled by the motor.

As Figure 5-15 indicates, the motor load disconnect control circuit is a pilot contact on the transfer switch that opens to de-energize the contactor coil circuit of the motor controller. After transfer, the transfer switch pilot contact closes to permit the motor controller to reclose. For these applications, the controller should reset automatically. The motor load disconnect circuit positively isolates each motor through its own controller, thus preventing possible interaction with other system loads.

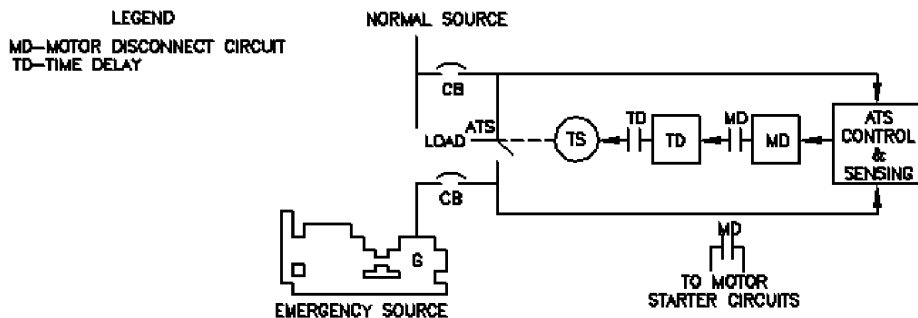


Figure 5-15—Motor load disconnect circuit

A proper motor control disconnect circuit should open the pilot contact for approximately 3 s before starting transfer to the alternate power source. Depending on the motor's time constant, or whether timed reclosing is provided in the motor controller circuit, the motor load disconnect control circuit may also need a second delay in the motor load disconnect control circuit. If the motor controller circuit does not have timed reclosing and the motor's time constant exceeds 3 s, provide an additional delay in the motor load disconnect control circuit of approximately 3 s. Large high-inertia motors with time constants of 4 s to 5 s may require 6 or more seconds for the residual voltage to decay to an acceptable value for reclosing.

When several motors are being transferred, simultaneous reconnection may cause excessive starting inrush currents. In this case the delay can be a sequencer with several timed pilot contacts (one contact for each motor controller circuit).

As these arrangements require interconnection of control wires between the transfer switch and the motor controller, design the system to minimize control line runs. One way to accomplish this is to locate the transfer switch adjacent to or within the motor control center.

- c) *Timed center-off position.* Transfer switches with a timed center-off (neutral position) have been applied to health care facility equipment loads for many years as a means of switching motor loads. Figure 5-16 shows a typical arrangement. This arrangement achieves results similar to the motor load disconnect control circuit described earlier. One advantage of this system, if there is no need for timed sequence reclosing and if the controllers are auto-reset, is that interconnections between the transfer switch and motor controller are unnecessary.

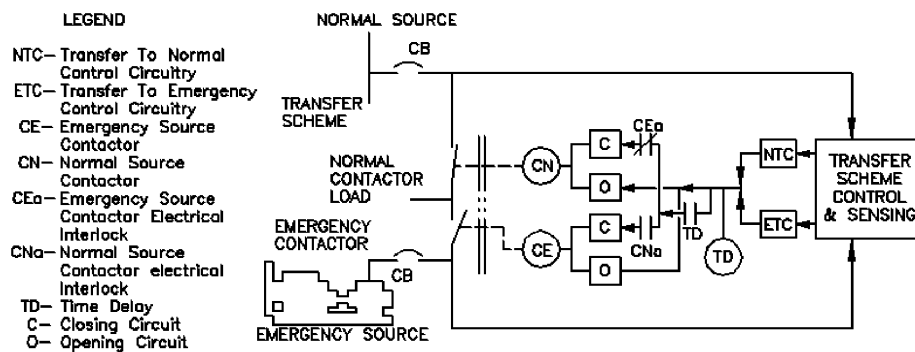


Figure 5-16—Neutral off position

- d) *Closed transition transfer.* Closed transition transfer with momentary paralleling of the two power sources is an ideal but costly solution (see Figure 5-17). An uninterrupted load transfer obviously provides the least amount of system and process disturbance. Closed transition transfer can only be achieved when both power sources are present and properly synchronized by voltage, frequency, and phase angle. In the case of a failing source, closed transition transfer may be extremely difficult, if not impossible, to achieve. Closed transition transfer is only possible during intentional transfer between two available sources, such as transfer test, utility peak load reduction applications, and retransfer back from the generator to the utility when both sources are at full voltage.

With closed transition transfer, the on-site engine generator momentarily connects in parallel with the utility source. This design usually requires advanced approval from the local utility company. In the past, obtaining such approval was often a problem. However, with the increased acceptance of cogeneration, the picture has changed considerably. In fact, today many electric utilities encourage interconnections with on-site power as an alternate to the uncertainties of building new power plants.

5.7.3 Transformer loads

Dry-type transformers are generally located on the load side of the transfer switches supplying the life safety and critical branches of the essential electrical system. Isolation transformers are frequently used in anesthetizing locations and in special environments of health care facilities (see Chapter 4). The electrical and mechanical construction of some of these transformers is such that very high magnetizing inrush currents frequently occur when the transformer is reenergized during a transfer operation. The inrush currents may be as high as 20 to 25 times rating and may sometimes cause nuisance tripping of one or more OCPDs. These transformers use grain-oriented square loop steels. The amount of magnetic flux is determined by the conditions that existed when the circuit was last interrupted and is unpredictable. The phenomena exist whether or not the secondary is connected.

There are various solutions to overcome nuisance tripping depending on the manufacturer of the transformers. Sometimes series reactance, impedance starting, and special overcurrent devices are considered as solutions. A solution beyond the transfer switch is necessary because other interruptions, such as momentary outages on the high lines, can cause a similar problem. However, for health care facilities where periodic testing is mandated, a closed transition transfer switch can ameliorate the condition.

5.8 Elevator loads

5.8.1 General

The need for limited continuous elevator service in hospitals, nursing homes, and related health care facilities is obvious. For this reason codes require that such limited electrical service be maintained. For hospitals, both NFPA 99 and the NEC require that elevators be on the equipment system of the essential electrical system, and both require the following:

- a) Elevator service that will reach every patient floor, ground floor, and floors on which are located surgical suites and obstetrical delivery suites, including connections for cab lighting and control-and-signal systems, must be on emergency power.
- b) In instances where interruption of power would result in elevators stopping between floors, provide throwover facilities to allow the temporary operation of any elevator for the release of patients or other persons who may be confined between floors.

This does not require that all elevators in multi-bank installations be served from the essential electrical system, but does require that each elevator be capable of being connected to the system one at a time on a selective basis. The obvious advantage of such a system is to keep the use of the alternate source generator within reasonable limits without unduly compromising passenger safety or the movement of patients during an interruption of normal power.

In designing such systems, consider the problem created by regenerative power and the problems associated with providing proper controls to establish sequencing of the

elevators when they receive power from the generators. Elevators using silicon-controlled rectifiers in lieu of motor generator sets can be particularly devilsome. Consult with elevator manufacturers proposing the use of such equipment to avoid complications.

Regenerative power refers to the phenomena that under certain load conditions, an elevator actually generates electrical energy that is fed back into the power supply. For example, a fully loaded elevator moving in the down direction produces energy that ultimately takes the form of electric power. This same situation also occurs to a lesser degree when an empty elevator travels up. This phenomenon produces two problems. First, where a relatively small emergency generator supplies the system, the regenerative power from the elevator can actually cause overspeed of the emergency generating set and possible speed governor tripping. Solve this problem by making certain that the total emergency power load connected to the emergency generator is at least twice the size of the elevator load. If the load is distributed in this manner, the regenerated power from the elevator system is easily absorbed by the other devices that comprise the emergency power load. For example, if the total electric load imposed by the elevators that are required to operate on emergency power is 150 kW, then the total emergency power load, including these elevators, should not be less than 300 kW.

The second regenerative problem becomes more evident during the actual transfer from normal to emergency power, or from emergency to normal. If this transfer is permitted to take place at a time when the elevator system is regenerating voltage that is out of phase with the power source to which it is being reconnected, power transients can be introduced into the supply source that may trip the circuit breakers controlling the power supply. The solution to this problem requires that the transfer function take place only when the sources are in phase or the elevators are at rest. Intentional time intervals to permit the elevators to come to rest before transferring to the alternate power source is one solution. Operation is normally initiated via control contacts on the transfer switch.

A transfer switch with an “in-phase monitor” is another solution. The elevators do not have to be at rest prior to restoring the service from emergency to normal power, or when switching to emergency power during a routine test of the emergency generator set while normal power is available. This problem could also be solved with a timed center-off position transfer switch. This device would normally function with an off time of 25 cycles to possibly 60 cycles. It could also have time delays beyond these values if desired. Utilizing such a device would allow normal starting current surges for motor applications.

5.8.2 Sequence of elevator operation on emergency power

On normal power supply failure, an automatic brake brings all elevators to a stop and holds them in that position. This braking almost always results in “trapping” elevator passengers in the stalled car between floors. Once the alternate source comes online and the elevators are able to operate on emergency power, one elevator in each group of elevators descends automatically to a lower floor, where it parks with its doors open in an inoperative condition. Each elevator in each group then goes through this same sequence until all elevators have returned to the lower floor. At this time, one preselected elevator in each group resumes normal automatic operation. The elevator control system prevents more than one elevator in each group from operating at any given time in order to avoid

overloading the emergency power supply source. All elevators will continue to be illuminated.

When the system is ready to return to normal power service, each elevator in emergency condition will stop at the next available floor, where it will park inoperative with its doors open. At this time, the system transfers back to normal power operation and all elevators resume normal service. If an elevator has been removed from automatic service for inspection, independent service, fire service, etc., it does not receive an automatic return signal.

If an elevator failure occurs during the sequential lowering operation that takes place after transfer to emergency power, that car is automatically removed from service, and the next car in order assumes the lowering sequence. If an elevator is in normal service operating on emergency power and it becomes inoperative, that car is automatically removed from service, and another elevator starts operating from the emergency power supply.

The following are available as emergency features:

- a) *Automatic car selection, express to lobby.* In the event of normal power failure, the elevators can be arranged to automatically return on emergency power to a preprogrammed floor, one car at a time. After all cars return to this floor, one preselected elevator remains on emergency power.
- b) *Manual car selection, express to lobby.* In the event of normal power failure, a manual selector switch in the lobby control panel controls the elevators. This manual selector switch determines which elevator will receive emergency power. After receiving emergency power, the elevator will automatically express directly to the floor where the selector switch is located. After all elevators return, the operator may select one elevator at a time to operate. Operational features such as independent service are overridden, allowing the elevator return.
- c) *Automatic car selection, stop at nearest floor.* In the event of a normal power failure, the elevators can be arranged to automatically start on emergency power, travel to the nearest floor and shut down. After all cars have been stopped at a floor, a preselected elevator remains on emergency power.

All controls for the elevators, including all of the equipment required for the automatic power selection, should be provided as an integral part of the elevator system. Elevator specifications should be checked to see that these features are included.

In some cases, it may be impractical to incorporate the controls and devices required for emergency power transfer into the elevator manufacturer's equipment. Systems are available that provide group mounted ATSS, control logic devices and sensing, and a remote selector panel. The operation of the system is essentially as described for the integral systems. The system should be carefully coordinated with the elevator manufacturer to ensure proper operation. One advantage of the independent system is that it can be designed such that the equipment system ATS can be smaller than with integral systems (see Figure 5-18).

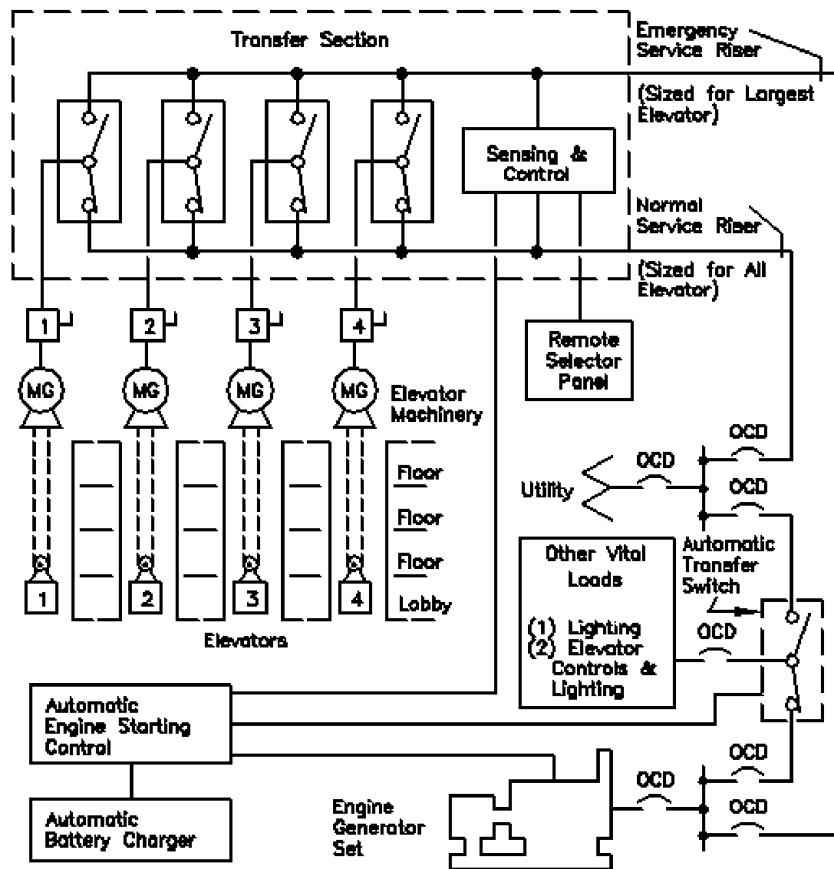


Figure 5-18—Elevator emergency power transfer system

5.9 Engine-generator controls

5.9.1 General

The engine-generator control panel contains the devices that monitor and control the status and operation of the engine-generator system. Interfacing with control components on the engine and the transfer switch is generally required. Locate the control panel near the engine-generator set, and protect it from vibration.

NFPA 99 requires that the generator set(s) be equipped with certain visual pre-alarm and alarm devices, automatic safety shutdown, and an audible alarm device to indicate activation. It requires a remote annunciator to indicate alarm conditions outside of the generating room at a regularly attended workstation.

5.9.2 Safety controls

If a generator begins to malfunction, the operator may decide to shut it down to correct the problem rather than continuing to operate it and possibly destroying it. In other cases, timely warnings can allow interventions and corrections that can prevent engine shutdown. For this reason, codes require the following:

- a) Engine shutdown for
 - 1) Overspeed
 - 2) Low lubricating oil pressure
 - 3) Excessive engine coolant temperature
- b) Pre-shutdown alarms for
 - 1) Low lubricating oil pressure
 - 2) Excessive engine temperature
- c) Additional indicator lights and/or alarms for
 - 1) Overcrank (failure to start)
 - 2) Battery charger malfunction
 - 3) Low fuel level
 - 4) Low water temperature, e.g., coolant heaters not operating
 - 5) Emergency generator set operating
 - 6) Low coolant level
 - 7) Excessive room temperature
 - 8) Remote radiator fan failure
 - 9) Others as desired by the operator

5.9.3 Automatic starting

The ATSs automatically start and stop the alternate source generator set(s) in health care facilities as a function of a control contact on the ATS. The control contact closes to initiate engine start and run, and opens to initiate engine stopping. The contact should be arranged for fail-safe operation.

The engine-generator control panel (see Figure 5-19) includes an automatic engine start control that operates upon signal of the control contact on the transfer switch to control the various devices on the engine for engine start and run. For example, on a diesel engine, a fuel solenoid valve may be energized to permit fuel to flow into the fuel injectors. At the same time, the cranking motor relay circuit is energized to initiate cranking.

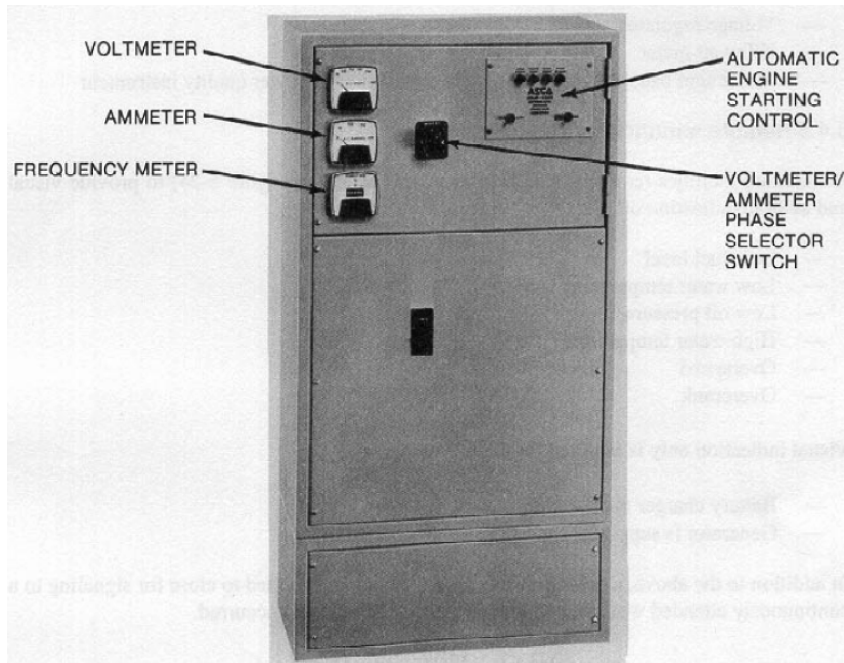


Figure 5-19—Typical engine-generator control panel

When the engine starts and attains a minimum speed setting, the cranking circuit automatically disconnects via the speed governor switch, oil pressure switch, ac generator voltage buildup, or battery charging generator voltage buildup. The engine manufacturer can recommend the best crank disconnect method.

The automatic engine starting controls also monitor the various engine protective devices previously described to sound alarms, to give visual indication, and to shut the engine down when failures occur. The failure lock-out circuit requires resetting before the engine can be restarted.

5.9.4 Typical engine-generator set control panel features

In addition to the automatic engine starting control, the engine-generator control panel may also include the following:

- a) Voltmeter
- b) Ammeter
- c) Frequency meter
- d) Voltmeter/ammeter phase selector switch or separate switches
- e) Current transformers (CTs)
- f) OCPD
- g) Vibration isolators when engine mounted

- h) Remote annunciator interface
- i) Elapsed time meter
- j) Panel illumination lamp with on/off switch
- k) Governor motor raise-lower speed switch
- l) Voltage adjust rheostat
- m) Kilowatt meter
- n) Instrument panel test block to enable connection of power quality instrument

5.9.5 System operation

The essential system generators must be arranged so that, in the event the normal source fails, the generators start and assume the load of the system within 10 s. The basic building block of this system is the ATS. An ATS consists of two major components: an electrically operated, double-throw transfer switch, and a control panel (see Figure 5-20).

The transfer switch contains a voltage monitor to read the utility power source. When the monitor senses a drop in voltage, it starts the transfer process. The engineer should carefully set the sensor based on a careful study of the voltage requirements of the load.

Chapter 3 describes the overall essential electrical system. As shown in Figure 5-20, when it senses the failure of the normal source, the ATS automatically starts the alternate source generator after a short delay (TD1). When the alternate power source attains a voltage and frequency that satisfies minimum operating requirements as sensed by the combination voltage/frequency monitors (V/FM), the transfer switch automatically transfers to the alternate power source through the transfer controls (TC) and the main transfer switch operator (TO).

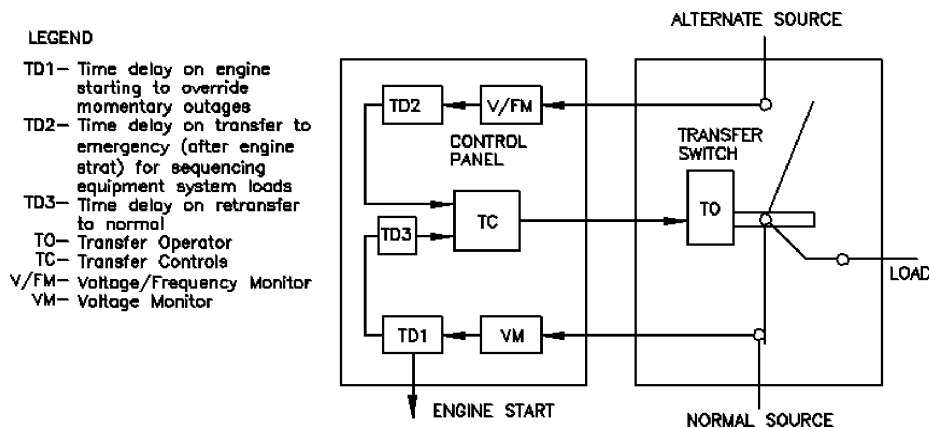


Figure 5-20—Automatic transfer switch (consists of the control panel, left, and the switch unit, right)

When the normal power source is restored, and after a time delay (TD2), the ATS disconnects the alternate source of power and connects the loads to the normal power source.

If the emergency power source should fail and the normal power source has been restored, retransfer to the normal source of power is immediate, bypassing the retransfer delay timer.

5.9.6 Source monitoring

The normal source is most often from an electric utility company whose power is transmitted many miles to the point of utilization. The transfer switch control logic continuously monitors the voltage of all phases. Because utility frequency is for all practical purposes constant, ATSs usually monitor only the voltage. For single-phase power systems, the ATS monitors the line-to-line voltage. For three-phase power systems, they monitor all three line-to-line voltages.

In addition to feeder failure, monitoring protects against operation at reduced voltage, such as brownouts, which can damage loads. Since the voltage sensitivity of loads varies, ATS pickup (acceptable) voltage settings and dropout (unacceptable) voltage settings should be adjustable. Typical range of adjustment for the pickup is 85% to 100% of nominal while the dropout setting is 75% to 98% of the pickup selected. The usual settings for most loads are 95% of nominal for pickup and 85% of nominal for dropout. The electrical engineer should specify pickups consistent with the voltage needs of the equipment being served.

Upon loss of voltage in one phase, polyphase motors will single-phase, which may lead to burnout of the motor. While the motor is normally protected by the overload relays in the controller, close differential voltage supervision should be applied to the ATS for motor installations so that transfer to the alternate source can be initiated. Differential voltage relays with a close adjustment of 2% for dropout and pickup values will aid in the detection of phase outages and help provide protection when single phasing occurs.

As long as normal voltage is available at or above the preset limit, all ATSs should remain connected to the normal source. Likewise, if voltage is lost to only one of several transfer switches, then only that transfer switch should transfer to the alternate source. The remaining switches should stay on normal.

Sensing of the alternate source voltage need only be single-phase since most applications involve an on-site generator with a relatively short line run to the ATS. In addition to monitoring voltage, the ATSs should monitor the alternate source's frequency. Unlike utility power, the engine-generator frequency can vary during start-up. Frequency monitoring will avoid overloading the engine generator during starting and can thus avoid stalling the engine. Combined frequency and voltage monitoring will protect against transferring loads to an engine-generator set with an unacceptable output.

5.9.7 Load pickup

Motor starting is the most severe requirement for the generator set in terms of voltage dip. As stated earlier, initial starting voltage dip should not exceed 35% in order to prevent motor starters from dropping out. Voltage drops from cycling motors during operation should not exceed 10%. The engineer should perform a study to ensure proper voltage levels to all of the equipment in the building. The engine power required during motor starting is initially relatively small since the power factor is low, in the 0 to 0.4 range, but as the motor accelerates to about 80% of rated speed the power factor and engine power required increases to a maximum.

Full-load pickup at rated power and 0.8 power factor will cause a voltage dip in the area of 15% to 40%. However, this is a more severe requirement for the engine. Since the real kilowatt load will not cause a large voltage dip, the engine needs to pick up full load. This is usually not a problem for smaller, naturally aspirated engine-generator sets, but on larger sets with turbochargers the sudden loading can cause the engine to stall before the turbocharger can return to full speed. Most automatic voltage regulation systems include frequency sensing to reduce excitation and thus output voltage in proportion to the frequency dip. These regulation systems allow for greater kilowatt block load capability on turbocharged engines.

Another way to deal with voltage dip from block loading is to allow the generator systems to pick up the loads in sequence. They will first pick up the loads that codes require to be online within 10 s, and follow with other blocks of loads.

5.9.8 Sequential loading of the generator

Article 517 of the NEC requires that the equipment system load (primarily motor load) transfer switches in hospitals be equipped with time-delay relays that will delay transfer of the connected load to the generator set. The purpose is to assure that the more important emergency system loads are connected first and established within 10 s of failure. The transfer switches supplying the motors are then sequentially transferred to the generator set.

Another reason for load shedding is the need to “power down” certain loads, such as those utilizing silicon controlled rectifiers (SCRs) to avoid damage to, or failure of, those components during transfer. Various solutions in use today to help solve these problems by adding circuit features to transfer switches are:

- a) *Transfer switches with individual time delay circuits on transfer to emergency.* This arrangement is in frequent use today. If there are several transfer switches in an installation, each can be set at slightly different times so that the transfer switches close sequentially onto the generator. Consider individual motor inrush requirements, the remaining available starting kVA of the generator, and the importance of the respective loads when determining the sequence of transfer.
- b) *Transfer switches with signal circuits for definite disconnection of a single load prior to transfer and reconnection after transfer.* With the additional delay, the control circuit not only assures that the motor is disconnects before transfer, but

also prevents the motor load from reconnecting until several seconds after the switch transfers and reconnects any other loads that are fed by the same transfer switch.

- c) *Transfer switches with timed center-off position.* Transfer switches with this feature can be used to transfer loads utilizing SCRs and also to shed loads from an overloaded emergency bus fed by paralleled generators.
- d) *Transfer switches as in item b) but with multi-signal circuits to sequence several loads onto the generator.* A further refinement of the system described in item b) utilizes several signal circuits when several motors are to be fed by the same transfer switch and they need to reconnect sequentially rather than all at once. Two to nine circuits are commonly provided. The time delay between reconnection steps is adjustable from 2 s to 60 s to allow the starting current to reduce to a safe value before the next motor reconnects. Once the delay is set, it is the same for each step.

5.9.9 Peak shaving

5.9.9.1 General

The control of utility peak demand within a health care facility is somewhat different from the usual peak demand control systems employed in most other types of facilities. Health care facilities generally have few loads that can be completely shed at the time that coincides with the peak demand without significantly affecting operations. Other facilities can control peak demand by using programmable load demand controllers to de-energize things like electric space heating, electric water heating, air conditioning chillers and auxiliaries, blowers, fans, and other comfort loads. In health care facilities, utility peak demand reduction can be achieved by transferring some of the essential electrical system loads over to the emergency generator set(s), if other regulatory restrictions can be met.

5.9.9.2 Load demand controllers

Power management is usually accomplished by a microprocessor that receives information from a kilowatt-hour meter with a pulse initiator. The microprocessor accumulates this information during the demand interval (e.g., 15 min) and computes the average kilowattage. The controller receives these signals continuously, and updates its prediction of peak demand. The controller thus becomes a predictor of when a predetermined peak demand will be reached, and also when the load will fall to acceptable levels. The controller initiates control of the load demand control system, so that loads will transfer to the on-site generating system when the demand approaches the predetermined level, and then retransfers to the utility as the load reduces back to the acceptable level.

5.9.9.3 Types of load demand control systems

Engineers can accomplish load demand control in one of two ways: operation in parallel with the utility, and operation independent of the utility. The selection of the system to use is based on the policies of the utility company. If the utility company permits parallel

operation with its service, parallel operation is usually preferred. However, many utility companies prohibit this practice or require protective relaying that may make it impractical for the health care facility. In this case, operation independent of the utility is mandatory.

a) Type I—Operation in parallel with the utility

Operation in parallel with the utility—Semiautomatic. When the load demand controller senses that the preset peak demand is being approached, the controls will start the generating set and operate an audible and visual signal to alert the operator of the condition. The operator will then manually synchronize the output of the generator with the utility source and transfer its portion of the load through the systems controls. When the load falls back to within acceptable limits, a second set of signals will direct the operator to manually transfer the load back to the utility, and after the prescribed unloaded running time, shut down the generator. If during the operation of the system in the load demand control mode the utility power should fail, the system will revert to an emergency power system, serving the essential electrical system through the system's automatic (and manual) transfer switches.

Operation in parallel with the utility—Automatic. When the load demand controller senses that the preset peak demand is being approached, the controls will start the generating set, automatically synchronize its output with the utility, and cause the generators to assume its portion of the load. Engine governors can operate to cause engines to assume only that portion of load in excess of the demand limit or a constant preset kilowatts, whichever is desired.

b) Type II—Operation independent of the utility

Unlike systems operating parallel to the utility, operation independent of the utility requires an interruption of power to the various loads. Because of the necessary interruption, essential system loads may not lend themselves well for this application. Rather, use loads like noncritical electric cooking equipment, air conditioning chillers, fans, pumps, and cooling towers, electric heat, and loads of a similar nature.

When the load demand controller senses that the preset peak demand is being approached, the controls will start the generating set, and operate an audible and visual signal to alert the operator of the condition. The operator should take the following steps to transfer the loads to the output of the generator:

- 1) Trip the overcurrent device(s) serving the load demand control panel(s) from the utility source.
- 2) Remove the key from the key interlock device for the overcurrent device in item 1), place it in the key interlock device for the overcurrent device(s) serving the load demand control panel(s) from the generator, and operate it.
- 3) Close the overcurrent device(s), placing the loads on the output of the generator. When the load demand controller senses that the load has decreased to within predetermined limits, a second set of signals will be initiated, notifying the operator to manually retransfer the loads by reversing the procedure previously described.

If during the operation of the system in load demand control mode the utility system fails, the system will revert to an emergency power system.

This system can also be arranged for complete automatic operation. With increasing use of closed transition transfer switches, loads can transfer without power interruption.

5.9.9.4 Cogeneration

A cogeneration system is defined as any system where a single source of thermal energy (fuel) drives two separate processes. An on-site generating system with heat recovery fits this definition.

In a conventional engine-driven generator set, considerable energy is dissipated in the form of heat lost to exhaust and to jacket water. In a cogeneration system, this heat loss is minimized by systems that convert the otherwise wasted heat energy to usable energy for process systems requiring heat.

Similar to load demand systems, the electrical generating portion of the cogeneration system operates in one of the following ways:

- a) Isolated from the utility
- b) In parallel with the utility

When operating in parallel with the utility, in addition to the standard controls, the utility will likely require additional protective relaying. Figure 5-21 shows a typical cogeneration system operating in parallel with the utility. It is identical to a utility peak load demand reduction system except that the engine-generator sets would be equipped with a heat recovery system. The recovered heat may be applied to domestic hot water or to absorption chilling.

A basic design objective of all utility paralleled systems is that there be an immediate separation of the two electrical power sources whenever transient phenomena, such as transmission disturbances or reclosing actions, occur on the utility power lines. Immediate separation isolates the small on-site power plant from possible damage. The same protective relaying that protects the on-site plant from unsatisfactory utility disturbances also serves to prevent backfeed from the on-site system into a dead utility line.

Device 52A in Figure 5-21 is the circuit breaker that ties the on-site cogeneration bus to the utility service. A typical protective relaying scheme is shown for Device 52A. An automatic synchronizer connects across Device 52A to ensure proper conditions for paralleling. The synchronizer controls generator voltage, frequency, and phase angle to match the utility source parameters.

Protection against malfunction or abnormality when the utility service and generator(s) are operating in parallel is provided to immediately open Device 52A. Such operation ensures isolation of the two sources. This is essential to personnel safety. It ensures that the generator(s) do not backfeed the utility grid or the rest of the building load.

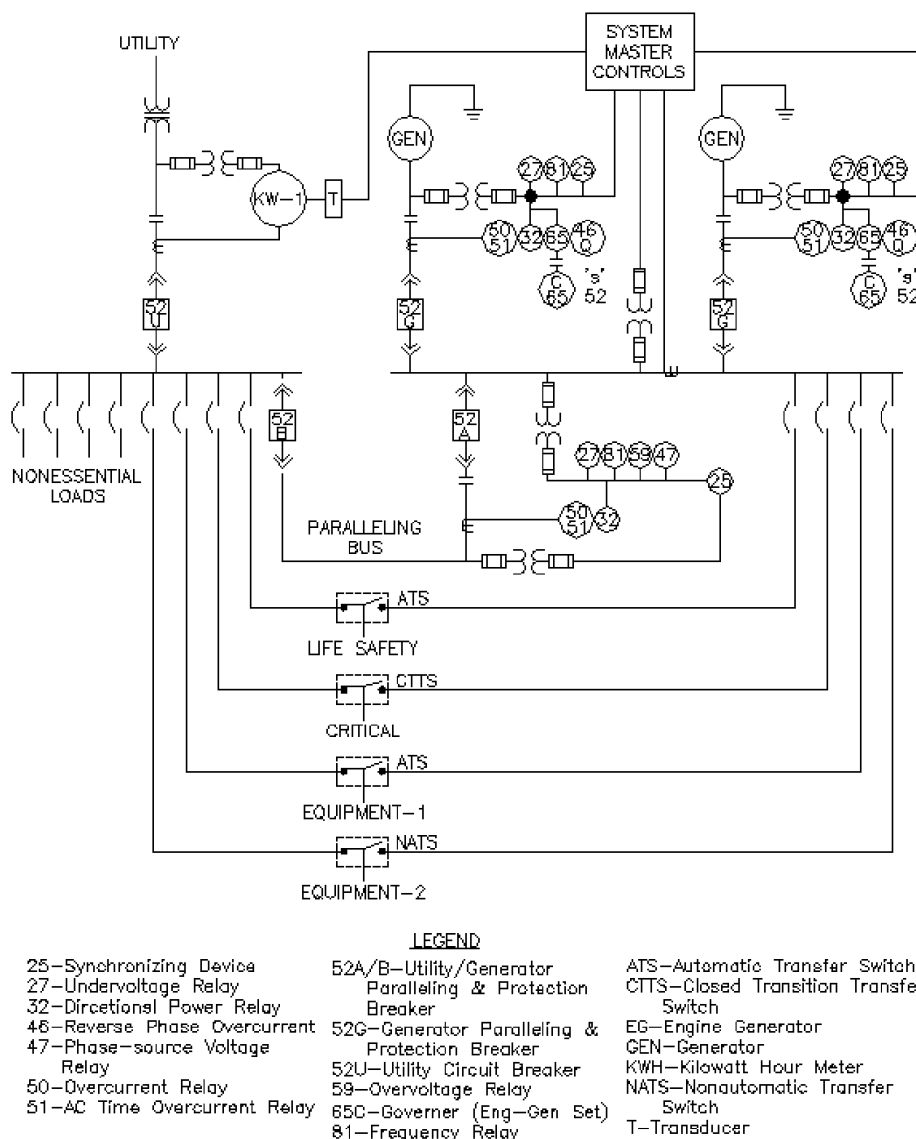


Figure 5-21—Conceptual one-line diagram illustrating the utilization of an on-site paralleled emergency generator system for utility peak load demand reduction or cogeneration in a health care facility

A typical protective relaying arrangement and circuit breaker (Device 52G) for each generator set is also shown.

An additional accessory to consider for the generator control system is a var/power factor (var/pf) controller. A var/pf controller biases the generator voltage regulator so that a constant operating power factor is maintained on the generator. Generator voltage can therefore track the normal excursions of the utility service without kilovoltampere overloading.

The var/pf controller continuously adjusts generator field excitation to produce a generator current that varies inversely with system voltage. Because the power factor is set at a constant 0.9 pf, the actual load on the generator in kilovoltampere remains constant. At constant kilovoltampere and constant power factor, the real workload on the engine also remains constant, assuring optimal life for the generator set.

In parallel with utility applications, the speed of the engine does not vary; therefore, the governor will not call for changes in fuel setting. A loading control interacts with the governor through the load sharing lines to cause kilowatt output to go to a preset level. The control measures the input from the utility source and causes the output of the generator to vary to maintain constant power import from or export to the utility.

System control layout varies from installation to installation, so that only a general idea of design can be given here. To ensure that the system meets all specialized design requirements, including operating in parallel with the utility, the system designer would work very closely with the equipment manufacturers and the utility company during the preliminary design stages for guidance in selecting appropriate controls and relaying to assure proper coordination.

5.9.10 Synchronizing and paralleling control systems for multigenerator set installations

To supply large loads, two or more engine-generator sets can operate in parallel on a common bus as an emergency power supply. Successful operation of multiple engine-generator sets in parallel requires a control system that provides all the functions needed to operate the generator automatically, plus automatically handle the synchronizing, load sharing, isochronous operation, and load control operations.

The system designer is faced with a number of considerations. Some of the more important are as follows:

- a) When to parallel
- b) Engine-generator set governor and voltage regulator considerations
- c) Random access paralleling
- d) Dividing the load
- e) Establishing load priorities
- f) Load sharing
- g) Load shedding

- h) Load switching means
- i) Typical system operation
- j) Sensing
- k) Control logic
- l) Instrumentation

5.9.10.1 When to parallel

Many situations today require multiple paralleled engine-generator sets. Parallel operation is usually justified for one or more of the following reasons:

a) *Economy*

When renovating an existing distribution system, it may not be practical to split an existing large load bus into several sections to be handled by separate generator sets. In this case, two or more generators can be paralleled to match the bus capacity. Often, the total installed cost of several small sets may be less than the total installed cost of one very large system.

Where the load is expected to grow substantially, but the project has insufficient capital to invest in additional generator capacity, the engineer could design the distribution system to accommodate future generating capacity by making initial provisions for paralleling at moderate cost.

b) *Reliability*

Paralleled systems are generally more reliable than single units, as there are more things that would have to fail before an entire generating system would be completely down. When there is a power failure on the normal line, all sets are signaled to start at the same time. The probability that at least one set will start is higher than with an installation with only one set. The first one ready to handle the emergency load does so. Then the other sets pick up the remaining loads as generators become ready.

c) *Minimizing downtime*

When preventive maintenance or overhaul is being done on an engine, the NEC requires the engineer to provide backup power. In a paralleled installation, the additional sets are there and available.

5.9.10.2 Engine-generator set governor and voltage regulator considerations

The engine-generator sets should be furnished with electronic governors and voltage regulators to make them suitable for unattended automatic paralleling and load sharing. Electronic governors provide isochronous operation (constant speed regardless of load) and automatic proportionate load division to enable automatic paralleling of dissimilar size sets. The electronic governor will permit paralleling at any time without necessitating adjustment or requiring droop. Similarly, voltage regulators should be able to achieve automatic reactive load division to provide constant voltage systems.

5.9.10.3 Random access paralleling

Random access paralleling to the bus uses a synchronizing device for each engine-generator set in the system. The reliability of the paralleling control system is high because of a redundancy of parallel logic paths. Random access paralleling permits simultaneous synchronizing of each set to the bus and therefore achieves parallel operation of sets in the shortest possible time. This is important in health care facilities because of the often cited “10-second rule.”

In a random access paralleling system, the first set to achieve nominal voltage and frequency connects to the bus to make emergency power available within 10 s to the emergency system transfer switches and their respective loads, and to provide a basis of comparison for synchronizing the remaining sets. As the remaining sets come up to voltage and frequency, they synchronize and parallel to the bus, at which time the equipment branch transfer switches transfer in delayed sequence to connect the equipment loads.

5.9.10.4 Dividing the load

When paralleling two or more engine-generator sets, engineers need to consider the capacity of each set relative to the total load. Arrange the system to inhibit the connection of loads to the alternate source power bus until sufficient generating capacity is on the bus. The system does this by dividing the load into blocks of load that can safely connect to the alternate source bus without overloading the engine-generator sets. The size of the load blocks will be a function of the individual engine-generator set capacity.

For example, if the load is 1800 kW and the engine-generator sets are to be 500 kW each, then the load may be divided into three blocks of 500 kW each, with a fourth block at 300 kW. Such a system would require four 500 kW engine-generator sets. However, if two 900 kW engine-generator sets were used, the same load could be divided into two blocks of 900 kW each.

Sometimes it is necessary to examine the load in terms of how it can be suitably divided and still satisfy the needs of the various essential loads. In this case, the size of the load blocks determines the size and number of generator sets needed.

5.9.10.5 Establishing load priorities

Once the load block size is determined, then the sequence for adding the loads should be decided upon. Each load block will have a priority rating. This rating specifies how many engine-generator sets must be on the bus before a particular load may be transferred. For example, the first priority would be the emergency system loads, the second priority would be the “delayed automatic” equipment loads, and the third priority would be the manually switched (nonautomatic) equipment loads.

5.9.10.6 Load sharing

To operate two or more generators in parallel, the generators should share the reactive load current proportionally and avoid circulating currents. Proportional sharing of the real kilowatt load current is controlled by adding load sharing controls that provide input to the individual engine governors.

Both self-excited regulators and the separately excited regulators are capable of parallel operation when equipped with parallel provisions.

The two methods of controlling or sharing reactive load current when paralleling generators are the voltage droop method and the crosscurrent compensation method.

a) *Voltage droop method*

- 1) The parallel module for the voltage droop method consists of a low secondary CT installed in generator phase 2 when the regulator sensing is from line 1 to line 3. A system using three-phase sensing includes a second CT installed in phase 1. Figure 5-22 shows a single-phase sensing arrangement. The CT develops a voltage signal across an adjustable resistor connected across the CT secondary that is proportional in amplitude and phase to the generator line current. This voltage connects in series with the voltage applied to the voltage regulator sensing circuit. The result is that the voltage applied to the voltage regulator sensing circuit is the vector sum of the generator ac voltage and the voltage developed by the paralleling module. The voltage supplied by the paralleling module is small in comparison to the generator voltage.
- 2) When a resistive load (unity power factor) is applied to the generator, the voltage across the paralleling resistor leads the sensing voltage by 90° , the vector sum of the two voltages is nearly the same as the original sensing voltage, and no change occurs in the generator output voltage.

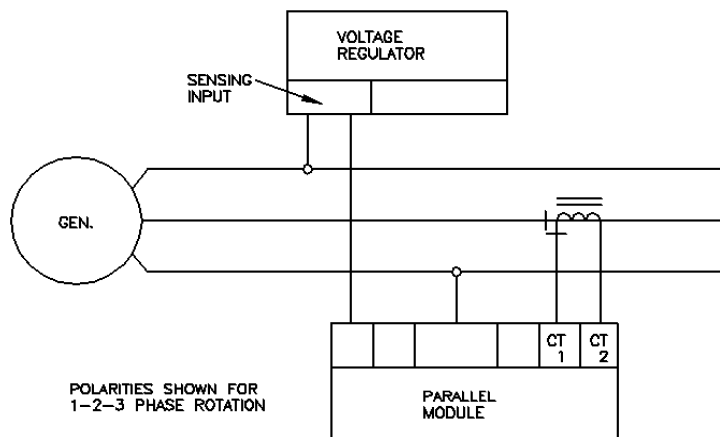


Figure 5-22—Interconnection—Single-phase sensing

- 3) When a generator assumes a lagging power factor (inductive) load, the voltage across the paralleling resistor becomes more in phase with the sensing voltage and the vector sum of two voltages results in a larger voltage being applied to the sensor circuit. Since the regulator maintains a constant voltage, as in sensing terminals, the regulator reacts by decreasing the generator voltage.
 - 4) When a generator assumes a leading power factor (capacitive) load, the vector sums result in a smaller voltage at the regulator sensing terminals and the regulator reacts to increase the generator output voltage.
 - 5) With two generators operating in parallel, if the field excitation on one generator becomes excessive and causes circulating currents to flow between generators, the current appears as a lagging power factor (inductive) load to the generator with excessive field current and a leading power factor (capacitive) load to the other. The parallel compensation circuit will cause the voltage regulator to decrease the field excitation on the generator with the lagging power factor load so as to minimize the circulating currents between the generators.
 - 6) This action and circuitry is called *parallel* or *voltage droop compensation*. It allows two or more paralleled generators to proportionally share inductive loads by causing a decrease or droop in the generator system voltage.
- b) *Crosscurrent compensation method*
- 1) The parallel modules described for the voltage droop method of paralleling provide the necessary circuit isolation for the crosscurrent compensation method of paralleling. Crosscurrent compensation allows two or more paralleled generators to share inductive reactive loads with no decrease or droop in the generator system output voltage (see Figure 5-23). This is accomplished by the action and circuitry described in the voltage droop method and the addition of cross connecting leads between CT secondaries. The output of the first unit CT is connected to the input of the second unit CT, the output of the second unit CT is connected to the input of third unit CT, etc., until all CTs are connected in series.
 - 2) The final step is to connect the output of the last CT to the input of the first unit CT. This forms a closed series loop that interconnects the CTs of all the generators to be paralleled. The signals from the interconnected CTs cancel each other when the line currents are proportional and in phase (no circulating currents), and no drop in system voltage occurs.
 - 3) Crosscurrent compensation works only if the regulators are identical and if they operate on a common bus interconnected into a crosscurrent loop. Generators of different kilowatt ratings may be operated with crosscurrent compensation if parallel CTs are selected that give approximately the same secondary current at each generator's rated load.
 - 4) If the voltage on one of the paralleled units is higher than the other, it will try to take the reactive load. The higher reactive load will cause the generator voltage to droop, thus decreasing the voltage and balancing the reactive load between both generators.

Voltage droop compensation does not require this interconnection between generator regulators nor matching CT output for different size generators. For this reason, and because of its simplicity, the voltage droop method is the most popular method of paralleling generators.

5.9.10.7 Load shedding

As with adding loads to the bus, the ability to shed loads is also determined by the size and number of engine-generator sets. Load shedding is necessary when the connected load exceeds the capacity of the online engine-generator sets. This situation can occur upon malfunction of an engine-generator set or upon a drop in bus frequency. The initiation of load shedding and resulting reduction in connected load will allow the surviving engine-generator sets to service the highest priority (emergency system) loads without interruption in, or degradation of, the power delivered.

5.9.10.8 Load switching means

There are several ways to switch loads on and off the generator bus. Obviously, appropriate control of the ATSs can perform this function. It is generally a simple modification to cause the ATS to be controlled in both directions for load connect and load shed operation. Transfer switches with center-off positions may also be used for this purpose, by switching its load to the “off” position.

When more than one class (priority) of load is fed from a given ATS, a remote control switch can control the lower priority load on the load side of the ATS. Another method would permit the load connect to be controlled by the ATS, with the load shedding achieved by shunt tripping circuit breakers. However, care should be taken in the application of the shunt trip approach when molded case circuit breakers are used, because shunt tripped breakers can only be manually reset unless equipped with electrical operators.

5.9.10.9 Typical system operation

A typical multi-engine automatic paralleling system depicting some of the load switching schemes previously mentioned is shown in Figure 5-24. The following sequence of operation refers to the line diagram in Figure 5-25. The system is comprised of three engine-generator sets as the emergency source. Any one engine-generator set has sufficient capacity to supply priority one and priority two loads.

The operation is for a random access paralleling system. The generator sets are connected to the bus in random order as they become available.

The loads connect to the emergency bus in ascending order of priority beginning with priority one. For load shedding, the loads disconnect in descending order of priority beginning with the last priority of load.

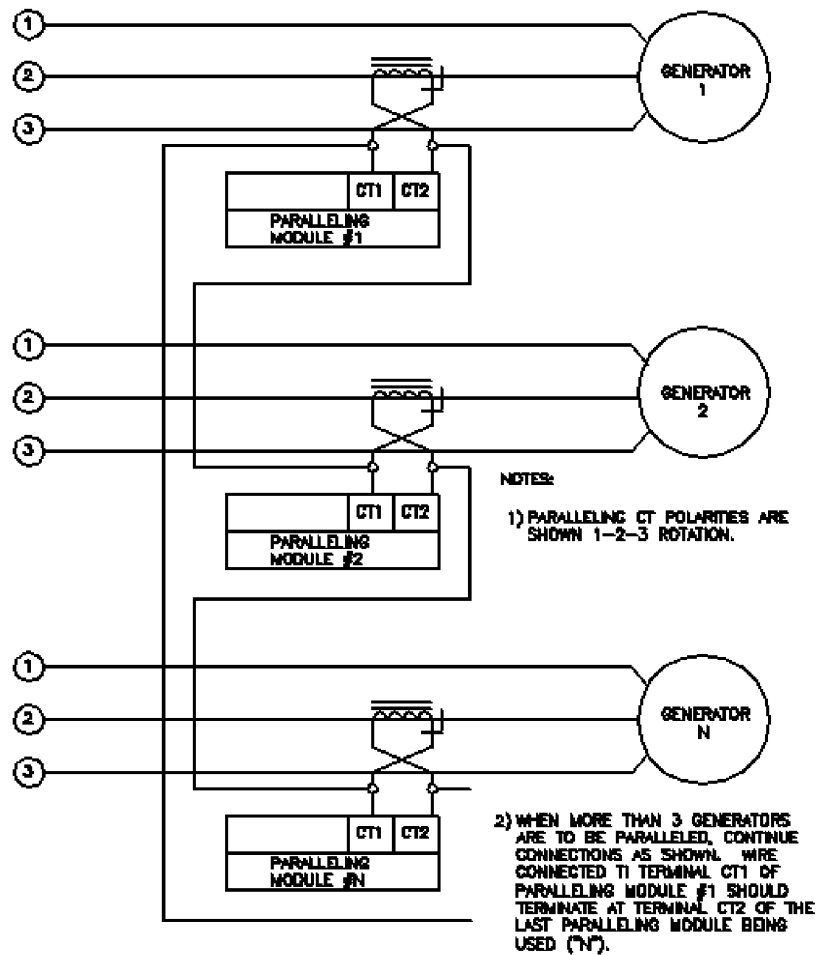


Figure 5-23—Crosscurrent compensation CT interconnection

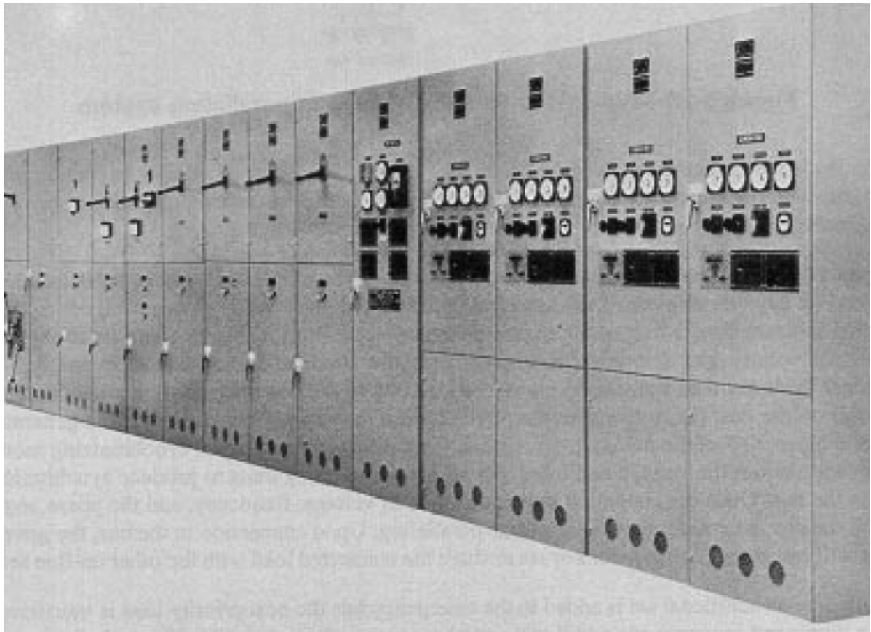


Figure 5-24—Typical automatic paralleling system for four engines

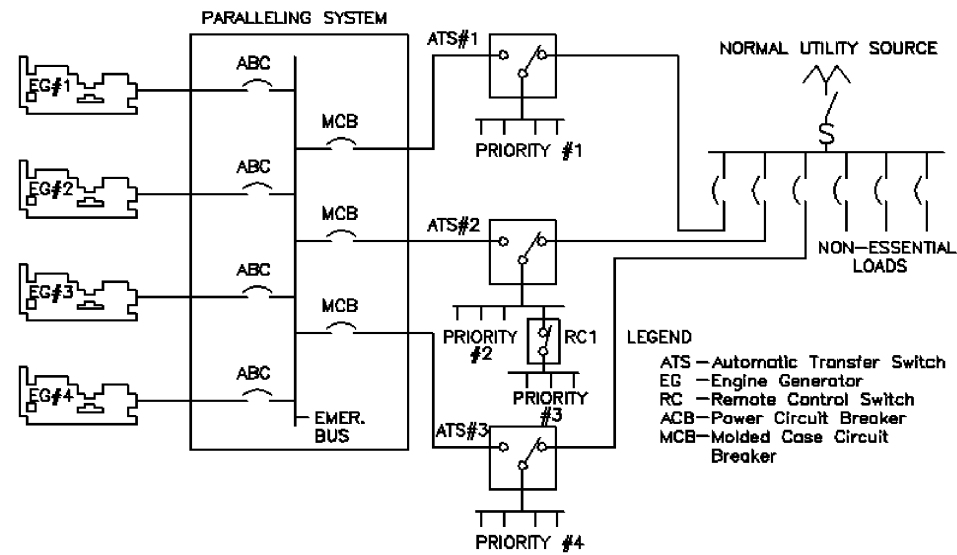


Figure 5-25—Typical multi-engine automatic paralleling system

Upon loss of normal source voltage and expiration of the momentary outage delay as determined by any one of the ATSSs, a signal initiates the starting of all engine-generator sets. The first set to come up to 90% of nominal voltage and frequency connects to the alternate source bus. Life safety and critical loads are then transferred to the bus via ATS #1 and #2 upon sensing availability of power on the bus. (RC1 opens before ATS #2 transfers.) As the remaining engine-generator sets achieve 90% of the nominal voltage and frequency, their respective synchronizing monitors will control the voltage and frequency of these oncoming units to synchronize them with the bus. Once the oncoming unit is matched in voltage, frequency, and the phase angle with the bus, its synchronizer will initiate paralleling. Upon connection to the bus, the governor will cause the engine-generator set to share the connected load with the other online sets.

Each time an additional set comes onto the emergency bus the next priority load transfers in a numbered sequence via additional switches, such as RC1 and ATS #3, until all sets and essential loads connect to the bus. Control circuitry should prevent the automatic transfer or connection of loads to the bus until there is sufficient capacity to carry them. The system has provisions for manual override of the load addition circuits.

Upon restoration of the normal source of supply as determined by the ATSSs, the engines run for a period of 5 min to 15 min for cooling down and then shut down. All controls automatically reset in readiness for the next automatic operation.

The system is designed so that reduced operation is automatically initiated upon the failure of any generator set through load dumping. This mode overrides any previous manual controls to prevent overloading the emergency bus. Upon sensing a failure mode on an engine, the controls automatically initiate disconnect, shutdown and lock-out of the failed set, and reduce the connected load to within the capacity of the remaining generator sets. Controls should require manual reset under these conditions.

Protection of the engine and generator against motoring is provided. A reverse power relay, upon sensing a motoring condition on any generator set, will initiate load shedding, disconnect the failing generator set, and shut it down.

5.9.10.10 Sensing

The paralleling system is subject to various transients in voltage and frequency that result from changes in system load. The sensing devices should ignore these transients but respond to harmful ones. Paralleling systems use four kinds of relays:

- a) *Voltage relays*
 - 1) There are various methods of sensing the magnitude of an ac sine wave. For example, there are peak, peak above average, and rms detection. Each method has its own distinct characteristics. The rms method is preferred.
 - 2) The advantage of rms detection is that the trip settings of the relay are directly related to the ability of the power line to supply the load. Therefore, the trip points of the relay will coincide exactly with the values determined from rms metering regardless of power line distortion. Other relaying

techniques may provide erroneous trip points when compared to rms metering on high-distortion power lines.

- 3) Because generator power capacity is small in comparison to the utility, load changes may generate large voltage transients, so that relays will have to differentiate between transient and long-term conditions. Thus, the relay must have a means of distinguishing this difference. A preferred method is to include an adjustable time delay within the relay to override momentary system transients. The time delay should start the instant the power line voltage goes below the preset relay limits; it should reset to zero when the voltage is restored within those limits. This, in effect, provides zero differential around the monitor trip settings.

b) *Frequency relays*

- 1) As in voltage detection, there are also many techniques for sensing frequency. Therefore, careful consideration should be given to selecting the proper type of frequency relay to meet the needs of the power system and the load. The most important considerations in selecting a frequency relay are the effects of waveform distortion, line voltage regulation, line transients, and ambient temperature on the relay trip settings.
- 2) Waveform distortion is more often caused by nonlinear loads connected to the power distribution system. The distortion becomes more pronounced as the load causing the distortion approaches the size of the power source. Distortion often occurs when the load is fed by static power converters utilizing SCRs and thyristors. These devices are commonly found in UPS systems, variable frequency ac motor drives, computers, and other electronic equipment. For example, where thyristors are “gated on” well within the voltage cycle, as in phase control, high currents can flow over only a portion of the cycle, resulting in nonlinear loading and waveform distortion. Figure 5-26 is a graphic representation of the effects of distortion on a fundamental sine wave.
- 3) Sudden load changes may, in addition to voltage transients, cause momentary frequency shifts. The frequency relay selected to protect the power line should have the capability of discriminating between momentary and sustained frequency variations. The typical methods of protecting against momentary or sustained outages are to provide trip point differentials and time delays. The advantage of a trip differential is to provide acceptance of a power line frequency that may be perfectly adequate under sustained load conditions. Time delay on trip is normally used to prevent false relay response due to large frequency transients.
- 4) To obtain the best possible operation, both types of protection should be incorporated into the same relay.

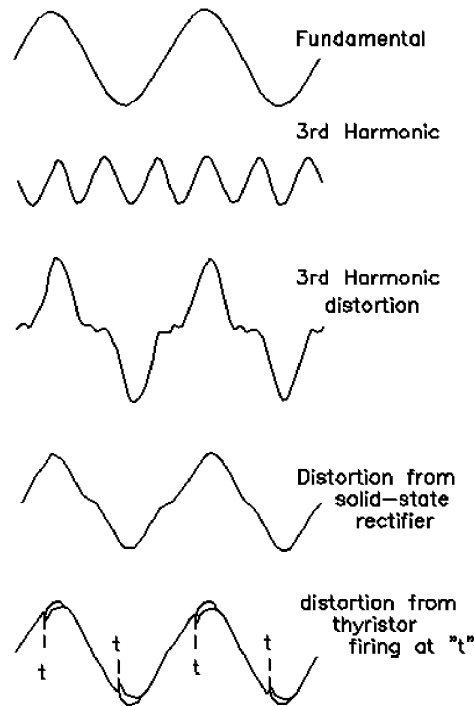


Figure 5-26—Distorted voltage wave shapes

c) Reverse power relay

- 1) When power sources operate in parallel on a common bus, the voltage and frequency of each source is common. Neither voltage nor frequency relays, nor any combination of them, can distinguish a malfunctioning engine-generator set from an acceptable one. The only way to determine proper operation on the bus is to measure the power output of each engine-generator set. When a set is delivering power to the bus, it is operating properly. When a set is drawing power from the bus, it is motoring, and there exists the possibility of a malfunction. It is normal to have power flow to the set from the bus for short periods when the bus is lightly loaded. Five to ten percent or less of set capacity is normal. At this load level, all that keeps the sets in synchronism is the exchange of synchronizing (circulating) currents causing this reverse power. Therefore, the relay measuring for this condition should be set high enough to ignore this harmless condition, while being set low enough to detect a malfunction. How much is enough depends on the engine. Some engines will draw only 1% to 2% of their full-load rating when motoring, while others will draw 8% to 10%. This determines the range of adjustability of the trip setting (that is, between 0% to 10%). In the absence of manufacturer's data, field tests may have to be run to determine proper settings.

- 2) Many kinds of reverse power relays are available. They fall into two general classifications: electromechanical and electronic. The electromechanical type uses induction disc sensing and is reasonably inexpensive. However, it needs annual or biannual calibration checks due to its sensitivity to temperature, dust, age, moisture, etc.
 - 3) The electronic type is a solid-state reverse power relay that provides repetitive accuracies without the need for regular recalibration. Whichever type is used, it should have an integral adjustable time delay to ignore transient conditions caused by light loading and switching large blocks of load. Single-phase sensing is adequate since the generator, when acting as a motor, is a balanced load.
- d) *Synchronizing*
- 1) Sources are synchronized when their sine waves are equal with respect to phase angle, frequency, voltage, and rotation. All four of these conditions should be satisfied when paralleling engine-generator sets. Figure 5-27 shows five voltage sources. No two of them are synchronous. To produce minimum disturbances, the differences should be minimized. The Electrical Generating Systems Association (EGSA) states that the maximum allowable differences are as follows:

Voltage: 5% Frequency: 0.5 Hz Phase angle: 5°

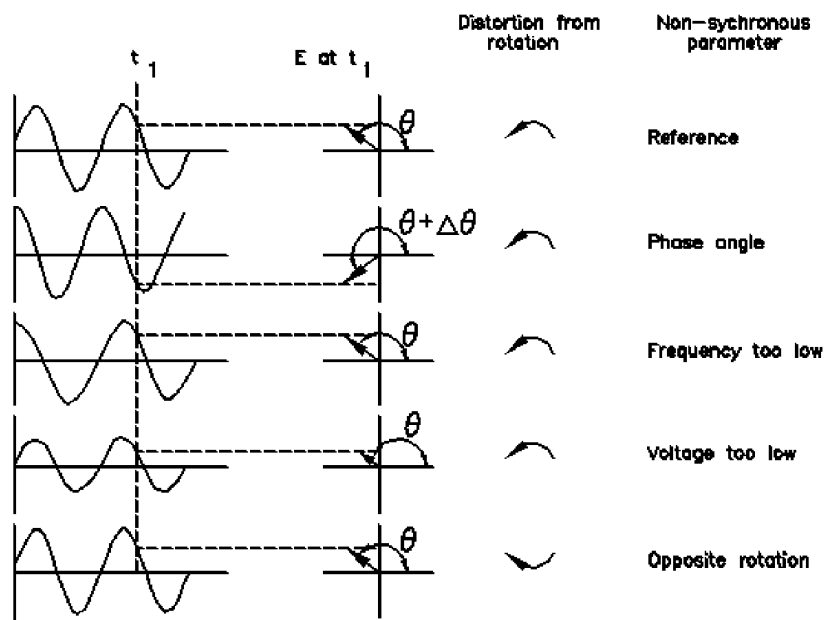


Figure 5-27—AC sine waves representing differences in phase angle, frequency, voltage, and rotation

- 2) The synchronizer should sense the existing difference in voltage, frequency, and phase angle, and take corrective action to reduce the differences to the acceptable limits stated by EGSA. Electronic governors control the speed of the engine-generator set. These governors are basically analog devices. Thus, the direct input of an analog signal proportional to the frequency difference will produce the necessary speed adjustment. This eliminates the need for a motorized potentiometer assembly, which can be a potential source of malfunction.

5.9.10.11 Control logic power sources

In the design of a control system for paralleling engine-generator sets, the choice of power source is limited to the generator output, the engine starting batteries, or switchgear batteries.

a) *DC control power*

- 1) Generators do not run when the utility power is available. So upon loss of utility power and before the generators start, the only available power source is from batteries. There are good reasons for using the same batteries for control power as are used for engine cranking. For example, utilization of all engine batteries provides redundant power sources for the control logic. The minimal control power drain does not normally require any additional considerations in the sizing of the batteries. The control circuit burden is typically less than 1% of the engine battery ampere-hour rating. In addition, this drain is only imposed while the system is in operation. When in the standby mode, the system draws minimal control power for indicating lights. Choosing the engine starting battery as a control power source instead of a separate switchgear battery eliminates the need for maintenance and charging equipment for an additional set of batteries.
- 2) When engine-cranking batteries are used, they provide redundancy in control power availability. An uninterruptible control power source selector device can provide for drawing control power from any combination of batteries with respect to an individual battery's ability to supply power. Such a device should provide positive isolation as well as prevent a fault in one bank from discharging the other batteries.

b) *DC control logic*

- 1) The dc control logic provides for the starting, stopping, and monitoring of the engines. When malfunctions occur, dc control logic removes the faulty set from service and initiates appropriate action to protect the remaining sets. In addition, the control logic for multiple generator set systems should operate at the voltage levels it is subject to.
- 2) The dc control logic should accept the generator online signals in whatever order they occur to cause loads to be connected in a predetermined order of priority. The logic should also accept generator availability signals as determined by the respective generator voltage and frequency relays to permit the first unit available to be connected to the bus.

- 3) Each system should have an audible alarm to annunciate a malfunction, and with a visual alarm identify the source of malfunction. When a silencing circuit is used in conjunction with the audible type alarm, it should reset automatically, either upon correction and clearing of the malfunction or upon the occurrence of another malfunction.
- c) *AC control power*
- 1) AC can be used in the control system only when the functions are such that they occur while a generator is operational and where load transients will not affect the operation. For example, it is desirable to use the generator as a power source for closing the generator main power circuit breaker. Closing this circuit breaker at ac potentials requires substantially less current than at dc battery potentials. The opening current for this circuit breaker should come from the battery source so that a generator set can be removed from the line upon the loss of ac generator output. As shunt tripping requires substantially less current than closing, battery capacity is generally adequate for tripping purposes, but needs to be calculated for the anticipated sequence of events representing “worst case.”

5.9.10.12 Instrumentation

Instrumentation helps to facilitate periodic inspection, preventive maintenance, and calibration essential to proper system operation and longevity. Since the relays and controllers in the system are highly accurate (up to $\pm 0.25\%$), the instruments that measure the performance of these devices should also be accurate. Switchboard-type 1% accuracy instruments are preferred, as the application is comparable to service entrance type applications. The minimum complement of instruments should include the following:

- a) An ammeter for each generator with a means of switching to measure current in each line
- b) A voltmeter with switching means to measure each line-to-line and line-to-neutral voltage
- c) A frequency meter, preferably having a 55 Hz to 65 Hz scale with division for 1/10 Hz, to measure engine speed
- d) A wattmeter to indicate engine performance, and optionally, a varmeter to indicate reactive load sharing

The ammeter furnishes data on generator loading and voltage regulator performance and adjustment. The voltmeter permits adjustment of the voltage regulator for proper operating voltage. The frequency meter permits adjustment of the governor for proper operating frequency. The wattmeter permits adjustment of the governor for proper load division between engine-generator sets operating in parallel. The wattmeter also permits engine adjustments based on loading.

5.10 Maintenance

NFPA 99, generally considered a minimum by AHJs, requires certain testing and maintenance procedures. Appendix C, included in NFPA 99 for information purposes only, provides a maintenance guide to assist in the facility engineer.

NEMA, NFPA, and equipment manufacturers have publications prescribing recommended minimum requirements. Rapid diagnosis of trouble or system failure is made easier by performing the acceptance testing and maintenance procedures established by the equipment manufacturers.

For new facilities, where testing and maintenance programs have not been previously established prior to start-up, a manual should be prepared that includes the following:

- a) General description of operation
- b) Manufacturer's technical manuals
- c) Test log
- d) Maintenance log
- e) Piping diagrams
- f) Wiring diagrams
- g) Spare parts list
- h) Special tools
- i) Source of emergency assistance
- j) Maintenance schedule

Testing may be automatic or nonautomatic. Both require staff. Many hospitals prefer manual testing since there is always the risk of a nonscheduled surgery being performed at the time an automatic timer may call for a load interruption test. For installations with limited personnel capability, a maintenance and testing contract may be an option.

When transfer switches are installed in remote, infrequently accessed locations, it will help the facility engineers to provide an annunciator at the building operator's central control room to permit remote monitoring and testing.

Extended no load or light load (less than 10% of nameplate kilowatt) operation of diesel engines eventually results in unburned fuel in the exhaust system (wet stacking) and in the formation of carbon within the engine. Engine-generator set manufacturers typically recommend no less than 30% of nameplate kilowatt loading. The generator set should be exercised as defined in NFPA 110.

In order to determine compliance with NFPA 99, the engineer should establish that the mean period between service overhauls will not be decreased to less than 3 years. The mean period between service overhauls will be a function of the expected hours of operation of the engine as an emergency power unit, the expected hours of operation in the peak demand reduction or cogeneration mode, and the manufacturer's anticipated mean

operating hours between major service overhauls. Table 5-3 provides recommended baseline assumptions for various scenarios.

Table 5-3—Mean period between service overhauls

Engine speed (r/m)	Minor overhaul operating hours ^a	Major overhaul operating hours
1 800	6 000 and 12 000	18 000
1 200	8 000 and 16 000	24 000

^aA minor overhaul is defined as replacement of valves, inserts, valve guides, injection capsules, rings, and gaskets.

5.11 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

EGSA 100B, Performance Standard for Engine Cranking Batteries Used with Engine Generator Sets.⁴

EGSA 100C, Performance Standard for Battery Charges for Engine Starting Batteries and Control Batteries (Constant Potential Static Type).

IEEE Std 446, IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (*IEEE Orange Book*).⁵

NEMA ICS 10, Parts 1 and 2, Industrial Control and Systems—Part 1: Electromechanical AC Transfer Switch Equipment; Part 2: Static AC Transfer Equipment.⁶

NEMA PE 5, Utility Battery Chargers.

NEMA MG 1, Motors and Generators.

NFPA 70, National Electrical Code® (NEC®).⁷

⁴ EGSA documents can be obtained from the Electrical Generating Systems Association, 1650 South Dixie Hwy, FL 5, Boca Raton, FL 33432 (<http://www.egsa.org/>).

⁵ IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

⁶ NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

⁷ NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA (<http://www.nfpa.org/>).

NFPA 99, Standard for Health Care Facilities.

NFPA 110, Standard for Emergency and Standby Power Systems.

UL 1008, Standard for Safety Transfer Switch Equipment.⁸

5.12 Bibliography

Additional information may be found in the following sources:

[B1] “Area Protection Assures Emergency Power When Failures Occur Down-Stream,” *AscoFacts*, vol. 2, no. 6, Automatic Switch Company, Florham Park, NJ.

[B2] ASME A17.1-2004, Safety Code for Elevators and Escalators.⁹

[B3] Averhiil, E. A., “Fast Transfer Test of Power Station Auxiliaries,” *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-95, no. 3, May/June 1977.

[B4] Castenschiold, R., “Closed Transition Switching of Essential Loads,” *Transactions on Industry Applications*, vol. 25, no. 3, May/June.

[B5] Davis, W. K., and Stratford, R. P., “Operation of UPS on Emergency Generation,” *Petroleum and Chemical Industry Conference*, IEEE PCIC 1987 Annual Meeting.

[B6] Electrical Generating Systems Association, *On-Site Power Generation: A Reference Book*, Chapter 7, p. 147.

[B7] Fischer, M. J., “Designing Electrical Systems for Hospitals,” vol. 5 of *Techniques of Electrical Construction and Design*. New York: McGraw-Hill, 1979.

[B8] Gill, J. D., “Transfer of Motor Load Between Out-of-Phase Sources,” Conference Record, *Industry Applications Society*, IEEE-IAS 1978 Annual Meeting.

[B9] IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition. New York: Institute of Electrical and Electronics Engineers, Inc.

[B10] Kelly, A. R., “Relay Response to Motor Residual Voltage During Automatic Transfers,” *AIEE Transactions*, vol. 74, pt. II, Applications and Industry, Paper 55-427, September 1955.

[B11] Lewis, D. G., and Marsh, W. D., “Transfer of Steam-Electric Generating-Station Auxiliary Busses,” *AIEE Transactions*, vol. 74, pt. III, Power Apparatus and Systems, Paper 55-96, June 1955.

⁸UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

⁹ASME publications are available from the American Society of Mechanical Engineers, 3 Park Avenue, New York, NY 10016-5990, USA (<http://www.asme.org/>).

[B12] SAE J537-2000, Storage Batteries.¹⁰

[B13] Squires, R. B., “Analytical Studies of Large Induction Motor Behavior During Bus Transfer,” *Conference for Protective Relay Engineers*, Texas A&M University, College Station, Texas, 27 April 1973.

¹⁰SAE publications are available from the Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096, USA (<http://www.sae.org/>).

Chapter 6

Lighting

6.1 General discussion

Lighting technologies and design methods, as well as our understanding of visual needs, have advanced at a pace rivaling that of health care techniques, methods, and understandings. Good design now recognizes the psychological and physiological impact of lighting upon humans, and health care lighting schemes must incorporate these demands to be successful. Such considerations supplement the obvious requirements of the medical and nursing staff for the fulfillment of their responsibilities. Moreover, the technologies used in the health care field have changed, and the addition of such devices as computer screens and patient monitoring systems create visual demands often akin to those in modern offices. Indeed, the very diversity of tasks that occur in any given space of a health care facility greatly increases the complexity of the design process, as the engineer should accurately understand both the proposed uses of the spaces and the visual requirements for those uses. Users and architects continue to demand more aesthetic solutions to the challenges presented to the lighting designer. The electrical engineer designing a hospital therefore seeks to achieve a visual environment dramatically different from the one of the past—one that not only fulfills the needs of the staff, but is also healing and humane for patients and their families.

Modern concepts of lighting are “task/ambient oriented,” that is, lighting should provide precisely the light that is required to efficiently perform specific tasks while maintaining an acceptable ratio of task luminance to background luminance. In other words, the engineer should provide a lighting system that permits the task to be performed and in which the lighting quantity and quality are not detrimental factors in the task’s successful completion. Most health care tasks are inherently difficult, requiring great accuracy and speed, and are performed by a variety of people possessing great variations in visual acuity. The task itself should be evaluated for its requirements of size, shape, color, degree of difficulty, and the haste in which the work will be performed.

The fundamental principles of good lighting design described briefly in the first part of this chapter should serve to provide guidelines and references sufficient for the intelligent and studied application of lighting to the health care environment. Many health care support tasks such as routine clerical, accounting, and other office-related tasks, food service, maintenance, parking, and housekeeping may be treated in the same manner as similar tasks in commercial and industrial buildings. This chapter will treat only those tasks and situations that are unique to health care facilities. The unique application of the basic principles to the health care environment, then, is described in the second part of this chapter. Finally, the lighting system as a whole must be integrated into the essence of the building, so that the needs for maintenance, control, energy efficiency, and sustainability are met. The entire environment should be evaluated and planned in concert with the interior designer, the architect, the mechanical engineer, and the appropriate staff (both medical and building maintenance). The success of the lighting design cannot be measured in footcandles, but by patient comfort, task efficiency, and overall satisfaction.

6.2 Lighting design for hospitals

6.2.1 General discussion

Fundamentals of lighting design have been the subject of a number of excellent books. A complete recap is not the intent here; some knowledge on the part of the user is assumed and this chapter will include only those aspects of lighting design of special relevance in the health care facility. The engineer is directed to other literature for more comprehensive treatments of all of the principles of good lighting design. Most notable is the literature published by the Illuminating Engineering Society of North America (IESNA) and in other IEEE materials.

In particular, the uniformity of illumination and the luminance ratios set forth in the IESNA guidelines should be adhered to in the design.

In addition, other firms, institutions, and individuals are addressing lighting for medical facilities, as well as the effects of lighting on our physical and psychological well-being. Recent developments and research are available from the Lighting Research Center at Rensselaer Polytechnic Institute [B8].¹

The National Council on Qualifications for the Lighting Professions (NCQLP) [B12] exists to aid in the education and qualification of lighting design professionals. The NCQLP offers excellent sources of general information about lighting design, many listed in the bibliography.

6.2.2 Quality factors in lighting

6.2.2.1 Glare—direct and reflected

The engineer should provide illumination without annoyance or discomfort from luminaires or windows that are sources of glare. Reference to visual comfort probability (VCP) data, available from luminaire manufacturers, is helpful in the selection of luminaires that will not cause uncomfortable glare. The VCP data is calculated by the manufacturer using empirically derived data regarding the brightness characteristics of individual fixtures, room characteristics, and room finishes. Note that this data is calculated under “normal” office-type viewing conditions; in health care facilities it may not be applicable. It is important to note that VCP data in itself does not guarantee glare-free lighting. The engineer should be able to review and understand manufacturers’ candlepower distribution curves and the interactions of the light sources with room surfaces and finishes. For instance, the patient is often on his back looking directly up at a ceiling fixture.

Windows often present a source of discomfort. The harsh brightness from the outside, when compared to the indoor levels, can cause eye fatigue. When this ratio of lighting levels exceeds 8 to 10, fatigue is caused by the iris’s need to constantly adjust as the

¹The numbers in brackets correspond to those of the bibliography in 6.6.

person sees within the room. Also, glare will result from the direct view of the sun, clouds, sky, or bright buildings. For this reason, windows should have shades, blinds, draperies, low-transmission glass, or other suitable shielding to control and/or reduce the brightness in the field of view. Hospital staff should not normally face windows in performing their work. Patient rooms should be able to be darkened totally for sleep or comfort. Research indicates that the patient room needs to be totally darkened in order to promote the production of melatonin, a hormone essential for regulating circadian rhythms.

The reflectance of room surfaces is an important factor in the efficient utilization of light and, therefore, of lighting energy. It is also important to visual comfort because brightness should be within certain well-established limits (ratios) in areas where demanding visual tasks are performed. For best utilization of light, the ceiling should be painted a light color with 80% reflectance. The walls, floor, and equipment finishes should be within the recommended reflectance ranges of Table 6-1. To promote visual comfort, luminance differences between task and other areas in the field of view should be limited to the following:

- a) The luminance of adjacent surroundings should be no less than 33% of that on the task.
- b) For remote, darker surfaces, it should be no less than 25%.
- c) For remote, light-colored surfaces, it should be no less than 20%.

Table 6-1—Recommended surface reflectance

Surface	Reflectance equivalent (%)
Ceiling finishes ^a	80 to 90
Walls	50 to 70
Furniture and equipment	25 to 45
Floors	15 to 30
Surgical gowns, surgical drapes	< 30

^aReflectance for finish only. Overall average reflectance of textured acoustic materials may be somewhat lower.

To get even higher utilization of light, proposals are sometimes made to employ finishes on walls, floors, and furniture with reflectance even higher than those in Table 6-1. Finishes significantly higher or lower in reflectance may cause legitimate complaints about glare and may upset the brightness relationships necessary for visual comfort. The lighting engineer should be sure to consult with those having the responsibility for finish specifications before designing electrical systems. Note that certain portions of walls or trim surfaces or room appointments may have higher or lower reflectance than the limits of the ranges of Table 6-1 if these areas are thought of as accents and restricted to no more than 10% of the total visual field.

6.2.2.2 Color quality

Color is a complex subject involving both physical parameters that can be expressed in mathematical terms and psychological factors that relate to individual interpretations of color. Certain colors are warmer (redder) in character while others are considered cooler (or bluer). Light sources have such characteristics, and their color should be a factor in source selection in order to compliment a warm, cool, or neutral color scheme. Source colors also help to create a desired atmosphere (or mood) and to delineate different functions within a given area. Warmth or coolness in a color scheme and light source may also be a factor in perceived temperature by occupants of a space and, therefore, in energy usage. Fluorescent lamp color is expressed in degrees Kelvin (K). A color temperature of 2700 K is similar to incandescent lighting in warmth. The higher the degrees Kelvin, the cooler the lamp color. Daylight is 6500 K. Typically 3500 K will serve most functions within a hospital. For consistency of color and to facilitate maintenance, one lamp color should be chosen for an entire facility.

The ability of a light source to accurately render color is measured by its color rendering index (CRI). CRI is rated on a scale of 0 to 100. Tungsten halogen is rated at 100; low-pressure sodium at -47 . Fluorescent light sources used in hospitals should have a CRI of at least 80. Certain light sources, such as high-pressure sodium, may have high efficacy of light production with fair or poor color rendition. Others, like tungsten halogen, may have excellent color rendition with only moderate efficacy. These factors should be weighed, along with many others, in light source selections for particular applications. A balance should be achieved to choose light sources that are both efficient and accurately render skin tones.

6.2.2.3 Veiling reflections, distribution, reflections, and shadows

Veiling reflections in tasks reduce visibility by lowering the contrast between details of the task and its background. They occur when a light fixture, bright ceiling, or window and the eye of a viewer are at the mirror angle of reflection with a specular portion of the visual field. They are often difficult to “dodge” by shifting the viewing angle when luminaires (or windows) that produce the effects are of substantial area, large number, and/or wide distribution.

The most important single tactic for minimizing the veiling reflection effects is geometry. If the sources that light the task can be positioned out of the mirror angle of reflection with respect to the task and the viewer's eyes, visibility and comfort will be heightened. This approach is frequently practical in single-occupancy rooms where the work location is known. This approach is also possible with built-in workstation lighting, if lights are located to illuminate the task from both sides. Unfortunately, on many such workstations, the sources are positioned under a shelf or cabinet directly in front of the task, often the worst possible location. If this is the case, a fixture with a lateral spread lens should be used.

In some spaces it is best to position workstations in between rows of ceiling luminaires, with occupants facing parallel to the rows so that most of the light on the tasks comes from the sides and not from luminaires on the ceiling immediately in front of the workstation.

Certain lighting distributions may also reduce the effect of veiling reflections such as polarizing lighting panels, bat-wing lenses, parabolic louvers, or indirect lighting. Indirect lighting works best in large rooms with relatively high ceilings. The objectionable veiling effects are least when the ceiling is uniformly lighted.

6.2.2.4 Further considerations

Individual reaction to a space is largely subjective. In recent years, studies of the psychology of lighting have provided statistically significant data as to how groups of people would react to various kinds of lighting. Criteria have been developed that would allow the use of lighting to create impressions of a “public” or “private” space, for example. These criteria could be helpful in applying lighting in such areas as entrance lobbies, patient rooms, dining areas, conference rooms, corridors, and offices. The *IESNA Lighting Handbook*² discusses this subject in greater detail.

6.3 Hospital lighting applications

6.3.1 General

Given the general guidelines for lighting design previously discussed, it is now in order to discuss the application of those principles to health care facilities. A space-by-space discussion of lighting application will not be attempted here; rather, the reader is urged to refer to the *IESNA Lighting Handbook*, or Chapter 10 of IEEE Std 241TM (*IEEE Gray Book*TM) for this information. This chapter will focus instead on some of the unique lighting needs of health care facilities.

6.3.2 Examination and patient observation

Patient examination is a critical portion of the health care practice, and facilitating that task is therefore a primary task of the lighting system in the patient care portions of the facility. The design engineer should make every effort to determine these needs in the various spaces and to provide for them in designing a lighting system that is at the same time free from glare, properly distributed, of adequate illumination levels, with good color rendition, quiet, and controllable.

In determining lighting levels, care should be taken to remember that examination tasks are performed by wide varieties of persons with wide varieties of visual ability. The lighting can be provided by fixed luminaires, luminaires with adjustable parts, or portable luminaires. The specific types should be coordinated with the users and the building maintenance department. Patient and treatment rooms typically require relatively shadowless high-intensity light at the center of a 2 ft diameter exam area where the peripheral intensity is at least 50% of maximum intensity, or a 2:1 ratio. In other words, spaces such as operating rooms (ORs), which use surgical lights to focus a tremendous amount of light onto the patient, should be lit to an ambient level high enough to produce sufficient visual comfort without producing eye fatigue or glare in the eye of the examiner.

²Information on references can be found in 6.5.

Controls should be designed so as to allow varying levels of lighting, if possible. The placement of fixed light sources for both examination and general illumination is critical. Disability glare from specular surfaces may obscure the patient. Indirect fixtures, large, low-brightness luminaires, or fixtures with louvers or baffles to cut glare are the preferable choices where possible.

Another element important to proper examination is consistency. The fluorescent luminaires selected, for instance, should utilize the same lamp throughout the patient care area so that patient skin tones appear consistent throughout. The lamps should typically be chosen to achieve a high color rendition in order to make skin-tone perceptions more accurate. Similarly, in areas using high-intensity exam lights, the color and color rendering of the lamps for ambient illumination should approximate as closely as possible that of the exam light. In addition to consistency of colors and color renditions, the engineer should pay attention to consistency in lighting levels. As already mentioned, too great a discrepancy between the intensity of an exam light and the room's ambient light can cause problems with fatigue and glare. Similarly, the balance of the operating suite should also have a moderately high lighting level that approximates the ambient lighting level in the OR in order to allow the surgical team's eyes to become accustomed to these levels. Lighting the vertical surfaces surrounding the operating theater will decrease contrast within the space, reducing fatigue.

Lighting in patient corridors should be able to be reduced at night to help the eye of the nurse who views a patient in his relatively darkened room. Similarly, the lights at the nurses' station should be controllable so that the levels can be reduced at night to reduce the contrast with the corridor. Finally, any such lighting should provide excellent cutoff features so as not to intrude light into other darkened areas.

6.3.3 Psychological factors and patient comfort

6.3.3.1 General

The patient in the health care facility is emotionally vulnerable, as are the patient's family and friends. Patients are understandably frightened or apprehensive. The engineer should design a lighting system that helps put patients at ease. Patients are frequently unable to adjust their position or surroundings to avoid discomfort, and since the visible world is the primary outside influence on the patient, discomfort in lighting is particularly objectionable. Strange, uncomfortable, or embarrassing treatments add to the patient's trauma and to the challenge of producing a lighting environment that supports the patient's comfort, well-being, and emotional stability. Indeed, the indications are that the lighting system cannot only minimize the patient's discomfort, but also may in some cases help to speed his or her recovery. The lighting system should intrude as little as possible into the patient's consciousness, and ideally, it should help to create an atmosphere (such as that of "home" in the patient room) that enables the patient to relax, feel good, and heal.

Human beings require adequate light with a small amount of ultraviolet (UV) for most robust health and alertness. The ultraviolet light helps the body generate vitamin D. Vitamin D helps the body process calcium into bones and teeth and thus fights the degeneration of the skeletal system that inevitably occurs from non-use. However,

evidence indicates that UV light can harm the visual systems of newborn infants, so care should be taken in neonatal units to avoid UV. Light also stimulates the hypothalamus and the adrenal and pineal glands, dilates the blood vessels, helps rid the body of toxins, increases protein metabolism, and lessens fatigue. Recent medical studies have shown that light can be used successfully to treat seasonal depression and to help soothe hyperactive children. The engineer should strive to incorporate as much daylight as possible into the patient's life, in addition to artificial sources with high quality color properties. Fluorescent lamps specified as having a CRI of at least 80 and a color temperature of 3500 K or 4100 K are preferable in most patient care areas.

6.3.3.2 "Stress relief" in procedure and treatment rooms

Procedure and treatment areas are the greatest anxiety-producing locations in a health care facility and their lighting systems should therefore be designed to minimize the patient's stress. Exam lights, for instance, should be out of the patient's direct line of sight and be as unobtrusive as possible, yet still perform their intended functions. Many spaces, such as diagnostic imaging rooms, do not require direct illumination of the patient at high levels and so may be lit with indirect cove luminaires and incandescent fixtures on dimmers to create a more subdued, relaxed environment. In an ideal world, exam rooms would not be lit with 2×4 parabolics or lensed fixtures, so patients are not forced to look into a lot of direct light.

6.3.3.3 Room lighting

The lighting in a patient room is particularly important to the mental well-being of the patient. This room also is the area where the patient spends most of the time, where visitations occur, and where the patient needs light for self-grooming. For achieving the most optimistic and, therefore, healthful attitude, the patient's self-view should be as pleasing and healthy as possible. The lighting in a patient room must, of course, answer several needs, but among them is boosting the morale of the patient. So, lighting that makes the skin appear gray or sallow should not be used. Again, fluorescent lamps with a high CRI should be used for these rooms. The addition of incandescent luminaires further warms the appearance of the space, as well as helps to achieve the home-like atmosphere so important in making the patient feel comfortable. Similarly, patients typically feel a lack of control as they are being treated. Patient control in the variety and level of room lighting can thus be extremely beneficial to their sense of well-being. Lighting fixtures located above the patient bed or patient care area should be lensed to contain any glass or broken lamps from falling on the patient.

6.3.3.4 Corridor lighting

The corridor lighting schemes so much in favor in older hospitals—that is, direct fluorescent fixtures spaced periodically throughout the corridors—can no longer be recommended as the method of choice in health care facilities. The regular spacing of overhead fixtures causes an unpleasant strobe effect for the patient being wheeled underneath them. Open downlight fixtures provide glare directly into the eyes of a patient lying on a gurney. Open downlight fixtures can also create glare on highly polished floors, which can be uncomfortable and disorienting to elderly patients. Indirect systems or linear

systems along the sides of the corridor are therefore the preferred method, again using fluorescent lamps with a CRI of at least 80 and a color temperature of 3500 K or 4100 K. Such a system also helps to create a less institutional look for the facility. See Figure 6-1 and Figure 6-2.



**Figure 6-1—Patient corridor, striving for residential feeling
(note window treatment at end of corridor and nonglare floor covering)**

6.3.3.5 Daylighting

Many codes now require windows in patient rooms. The benefits of daylighting to the patient have been briefly touched upon earlier. Another benefit of a window, besides the view it provides, is a sense of the passing of night and day. This sensation helps the patient maintain circadian rhythms. Various studies recently have found that sunlight deprivation may disturb mineral metabolism, as well as blood formation, renal and hepatic function, and sexual cycles. Daylight may help increase endurance and resistance to disease, as well as lower blood pressure and improve muscle tone. Adequate daylight also may help to alleviate depression in patients. Adequate daylighting has similar effects upon the health care staff, with the consequent benefit to the patient of maintaining a higher standard of care. In short, the engineer should be careful to work with the architect and owners to ensure an adequate amount of daylight for the patient.

6.3.3.6 Circadian rhythms

As light enters the retina, electrical signals are sent to the suprachiasmatic nucleus (sch), which sets daily activity patterns including the wake/sleep cycle, the rhythms of hormonal release, and the increase and decrease of body temperature. Understanding the rhythms and changes of the human body can aid in the treatment of hospital patients. Some diseases can show different states at different times of the day. Knowing when a drug will

best be metabolized can affect the course of treatment. For example, cancer is 34 times better treated in the evening, while allergies are more effective when administered in the morning. While it was thought that circadian rhythms were set by the rising and setting of the sun, it has since been discovered that circadian rhythms can be reset with the use of electric light. Studies also show that newborn infants develop more quickly with circadian rhythms.



Figure 6-2—Exam room with daylight, indirect ambient light

6.3.4 Housekeeping services

The final “typical” need for lighting in health care facilities that cannot be ignored is the housekeeping services function. The mandated requirements for housekeeping services in a health care facility are vastly different from such functions in other facilities; moreover, the sometimes specialized designs for lighting systems in various treatment rooms should not fail to also provide sufficient lighting for this crucial function.

The dropping of small objects, the spilling of liquid, and patient-related accidents require additional light in order to clean hidden floor areas around beds and other furniture. Often, it requires no more than proper switching of groups of lights to provide the proper ambient light. Such lighting should be controllable by the nurse or other staff personnel as they enter the room. In patient rooms, direct fluorescent illumination from the ceiling area outside of the patient’s curtain tracks is a possible solution since the angle of the light cast into the bed areas will improve the seeing of objects beneath furniture and between beds. Finally, the lighting equipment selected should lend itself to the need for the high level of cleanliness required in hospitals.

6.4 Considerations in lighting system design

6.4.1 Lighting system design

In designing the lighting system for a health care facility, the engineer should be careful to avoid working in the proverbial vacuum. The lighting for a health care facility, as crucial as it is, should be integrated properly into the building as a whole. In particular, the engineer should consider the impact of light design upon the other trades; for example, the heat generated by the luminaires must be removed from the space by the air-conditioning system. The lighting design dramatically affects the overall aesthetic appeal of a space and should be coordinated with the architect and interior designer. The lights and light system voltage should be chosen with due deliberation in order to achieve both the lighting system objectives and a good, efficient, cost-effective electrical distribution system. Finally, the system should be designed with an eye toward the overall energy usage of the facility and the ease of maintaining it in order to facilitate the continued proper operation of the system.

6.4.2 Integration with other building systems

As a dynamic, functioning system, lighting should be integrated carefully with the other systems in the building. The luminaires chosen can substantially increase the cooling load of a particular space, for instance, and certain luminaires can act as diffusers for mechanical systems. The physical placement and dimensions of the luminaires can also impact the routing of ductwork, sprinkler piping, public address speakers, and fire detection systems, especially above crowded ceilings. These problems become particularly acute in areas such as ORs, which require very high levels of light (and, therefore, of cooling) as well as strict environmental requirements mandating more than the usual amount of ductwork and diffusers. The lighting, too, significantly affects the aesthetic appeal of a room environment, and the designs should be coordinated with the architect. All of these considerations should be negotiated in order that the lighting system be able to perform its proper functions while at the same time harmoniously interact with the other building systems.

6.4.3 System voltage

Typical interior lighting fixtures manufactured today require either 120 V or 277 V single-phase power. Incandescent luminaires typically operate on 120 V, while compact fluorescent and low-voltage incandescent sources can operate at 120 V or 277 V. Fluorescent fixtures can operate at either 120 V or 277 V. The choice of lighting system voltage, then, hinges partially on the numbers and types of luminaires required.

In a smaller health care facility, especially a hospital, a 120 V system may be the better choice. Since hospitals require several branches of power, three of which (normal, critical, and life safety) will contain some amount of lighting, and power loads that are almost exclusively 120 V, the selection of lighting fixtures can result in duplication of panels for these systems. If critical branch exam lights can be restricted to 120 V and life safety fixtures can be restricted to 277 V, duplication of all branches of power required throughout the hospital can be minimized.

For medium to large hospitals, 277 V systems may be the preferred choice for system voltage. The higher system voltage permits the use of smaller conductors, raceways, transformers, transfer switches, and possibly a reduced number of panelboards, thereby reducing the electrical room sizes. All of this may offset the costs of providing the extra switchgear previously mentioned. The higher voltage, with the correspondingly lower currents, similarly results in lower line losses and operating costs. Finally, 480Y/277 V systems can often be more flexible in allowing future expansion than can a corresponding 208Y/120 V system. All of these variables should therefore be taken into account when selecting the particular system voltage.

6.4.4 Energy

Hospital engineers should be concerned with conservation of energy in the facility. In some jurisdictions, designs shall comply with energy codes. While medical task and exam task lighting will most likely be exempt, the remainder of the facility will need to comply with the energy code in effect. If there is no local energy code, at a minimum, the engineer should comply with the requirements of ASHRAE/EISNA 90.1. Certain measures can be taken to reduce the lighting energy consumed without simultaneously reducing the efficacy of the system for its more important visual performance. Of fundamental importance in the wise use of energy for lighting is careful attention to the design for each space. The engineer should take care to choose and locate the luminaires as required for proper performance of the tasks for the space and not merely to achieve some “correct” footcandle level. The engineer should be sure, however, that task and ambient lighting levels are provided as recommended and are not over- or under-lighting a space. The engineer should also work with the architect and users to ensure the proper location of portable task lighting in order to supplement the fixed luminaires.

Another potential for energy savings can be realized through the specification of light sources. Newer, more efficient sources can be chosen where appropriate in order to maximize the light produced for the power consumed. These newer sources produce light of various temperature colors and should be applied judiciously in order that the overall lighting quality is not needlessly sacrificed in critical areas. Other limitations of the luminaires may be lack of dimming capability (fluorescents require appropriate ballasts and dimmers), short life (low-voltage, though their lamp lives are still longer than those of incandescent lamps), long restart times (metal halide), low power factors (some compact fluorescent), and higher first cost. The compromises demanded by such limitations are very often worthwhile in terms both of reduced energy usage and aesthetic appeal when the luminaires are properly applied. Low-voltage and color-corrected, lower wattage ceramic metal halide luminaires can add pleasing effects to lobbies, corridors, cafeterias, and other public spaces. LED sources with very low energy consumption and extremely long lamp life can be used for exit signs and for patient room night-lights. Proper use of such luminaires will also lower the amount of energy lost as waste heat that must then be removed by the air-conditioning system, and so use of these fixtures has a two-fold impact on the lowering of energy usage.

Lighting control systems can likewise be specified so as to help reduce use of energy. Switching of lights, such as the use of occupancy sensors in equipment rooms, bathrooms, conference rooms, and offices can help to hold down the wasteful usage of lighting

energy. Infrared or ultrasonic occupancy sensors may be used in selected spaces to respond to movement or body heat and to ensure that lights turn off when those spaces are unoccupied. Dimmer switches can also be used, as can separate switching of both ballasts of two-ballast fluorescent fixtures in offices and exam rooms. Effective use of daylighting in conjunction with switching and dimming can also lower energy usage.

Three other methods for energy savings are often proposed; namely, using energy-saving or electronic ballasts, using daylight to obviate the need for luminaires, and using reflectors in fluorescent luminaires. Electronic ballasts, though they cost somewhat more to purchase initially, can help reduce energy usage, without decreasing lighting quality. They also allow the use of daylight compensation, dimming, and lamp lumen depreciation compensation techniques.

Daylighting can be a practical way of saving energy when appropriate, especially in consideration of the psychological and physiological benefits discussed previously. However, the engineer should take care to evaluate windows on their overall energy implications for both the lighting and the heating and cooling requirements. That is, energy saved in electric lighting should be balanced against heat gains and losses through the windows to determine their overall impact on energy use.

Polished metal or foil “specular” reflectors for fluorescent luminaires are frequently touted as a way to get the light of a four-lamp luminaire out of a two-lamp luminaire, thus reducing by half the energy required. Reflectors actually do little to increase the light output of a comparable new and/or properly maintained fixture, but rather, help to focus the light. The reflectors may be used in two ways—to retrofit into existing four-lamp luminaires or purchased new in lieu of four-lamp luminaires.

Very often, retrofit luminaires with reflectors are compared to existing luminaires that are old and dirty. Lighting levels are also often measured at only one location—directly under the fixture—so that the “test” results may be deceiving. That is, the light distribution of luminaires equipped with reflectors differs from those without reflectors, and so, the overall lighting uniformity of a retrofitted system using reflectors may be compromised. Further, standards for the manufacture of reflectors do not exist, nor have reflectors been in service long enough to accurately determine their life or their ability to withstand cleaning. Finally, the cost to purchase the reflectors and then to install the reflectors in existing luminaires may be hard to offset by future energy savings. The reflectors, of course, will be subjected to the same dirt and lack of cleaning over time as their predecessors, with a corresponding degrading of their light output (i.e., the smaller amount of energy used may not produce the promised equivalent lighting levels).

Several manufacturers produce luminaires with polished metal reflectors. And some evidence does suggest that an installation using new “reflectorized” luminaires may reduce lighting energy use by 25% over systems of similar luminaires with more lamps. So the additional first cost of the reflectorized luminaires may be offset by future energy savings, provided their lifetimes are equivalent and that they are kept properly cleaned and maintained. Judicious use of reflectors may therefore be appropriate, but the engineer is urged to carefully specify reflectors to be engineered specifically for the luminaires to be used, and to carefully examine their photometrics to ensure that the ultimate lighting

performance of the room lighting system is not compromised. The baked white enamel reflector in most standard fluorescent fixtures is still 90% reflective.

6.4.5 Maintenance

Finally, the engineer designing the health care lighting system should remember that the system will remain in service for a long time and that the system design should facilitate its maintenance. The engineer should take care both to ensure easy access to luminaires and to specify ones that will facilitate maintenance. Luminaires with “doors” should be installed so that the doors can operate properly. Luminaires that are to be installed in drywall ceilings should be specified to be easily removed. Often the location of the luminaires in the space is critical, as for instance in atriums where impossibly long ladders would be required for access.

The luminaires themselves should be carefully specified to provide optimum reliability, serviceability, and sanitation. Luminaires are frequently subjected to wash-downs using corrosive cleaning compounds and agents. Sanitation and the resultant frequent cleaning require luminaires with no crevices or cracks that may harbor dirt or other unsanitary miscellany. Lenses, particularly those frequently subject to cleaning or to patient contact, should be gasketed to prevent entry of cleaning agents or patient care fluids. Gasketing should be cleanable; that is, bare or, if foam type, closed-cell foam with a smooth exterior surface. The fixtures should be likewise rugged enough to withstand this cleaning and should be easily removed and disassembled through plug-in devices to allow for quick and easy relamping, cleaning, and repair. Ideally, the engineer should examine a sample of each luminaire specified in order to ensure its meeting these needs.

The overall lighting system should also be designed with consideration given to future maintenance. Lighting fixtures that are painted following fabrication have fewer sharp edges and are easier to service and maintain. Minimizing the number of different lamps for a facility reduces spare parts inventory and makes spare lamp storage easier. Similarly, minimizing the number of different lamps makes relamping both easier and more accurately performed in the real world. Consistency in choice of lamps in a facility offers the additional benefit that skin tones appear consistent in all areas, rather than appearing different in different areas as a result of different specified lamps. Easily cleanable luminaires are more likely to be cleaned, and easily repairable fixtures are more likely to be repaired.

All of this attention to design for maintenance is crucial since lighting systems degrade over time, and maintenance of the systems is crucial to their continued performance. Facility maintenance engineers should make sure that luminaires remain clean and are relamped on a regular basis in order to ensure the efficient, cost-effective performance both of the system and of the tasks to be performed in the visual environment.

6.4.6 Need for flexibility

Medical procedures change rapidly, and these changes require not only modifications in power requirements for a space, but also in illumination of the space. The system should thus also be chosen to allow for easy future renovation. Adjustable, dimmable, and

relocatable luminaires should be used where possible to help solve this problem. Flexible wiring systems with easily relocatable luminaires can help make the task of transforming areas from one function to another much more easily accomplished.

6.4.7 Sustainability

There is now a great desire to construct buildings that are not only energy efficient but are built green and environmentally sound, thereby maximizing their economic and environmental performance. *Green buildings* embody a design intent to balance environmental responsiveness, resource efficiency, and cultural and community sensitivity. The hospital design team may choose to pursue Leadership in Energy and Environmental Design (LEED) certification, which means that the engineer should be aware of the LEED Green Building Rating System™. The rating system grants various points for compliance with ASHRAE/IESNA 90.1 or local energy codes, and implementation of controls.

A link between sustainable theory and practice, LEED is the road many have taken toward sustainable design. LEED is transforming the building market much the way energy codes transformed the lighting industry when first implemented in the early 1980s. Developed by the U.S. Green Building Council (USGBC) in 1993 to define green buildings, the LEED process includes a broad range of supporters, adding richness to its process and product.

There are several areas where exterior lighting design interfaces with the LEED process. The first one is for reducing light pollution (credit 8.1, Sustainable Sites) by not exceeding IESNA recommendations for illumination levels, using cut-off luminaires and eliminating off-site direct beam illumination. The other major impact for lighting is under the Energy and Atmosphere section for reducing energy use. Some smaller contributions can be made in the Materials and Resources section by specifying materials that are manufactured and assembled near the project site and by using materials with recycled content. Developing daylighting and controls strategies also gets points in the Indoor Environmental Quality category.

6.5 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ASHRAE/IESNA 90.1, Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI).³

³ASHRAE publications are available from the Customer Service Department., American Society of Heating, Refrigerating and Air Conditioning Engineers, 1791 Tullie Circle, NE, Atlanta, GA 30329, USA (<http://www.ashrae.org/>).

IEEE Std 241, IEEE Recommended Practice for Electric Power Systems in Commercial Buildings (*IEEE Gray Book*).⁴

IESNA Lighting Handbook.⁵

IESNA RP 29, Lighting for Hospitals and Health Care Facilities (ANSI).

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Chapter 7

Communication systems

7.1 System design considerations

7.1.1 Introduction

Communication systems make possible the efficient and timely operations of health care facilities. The ever-increasing cost of health care, together with the accelerating levels of technological sophistication of health care equipment, mandates that communication systems be planned with a thorough understanding of their operational and engineering requirements, as well as the economics of their implementation.

When designing a health care facility for new construction or remodeling, it is necessary to consider all systems and to plan accordingly. Each of the major categories of communication and signal systems, together with their nominal physical plant space infrastructure requirements and installation requirements, are included in this chapter. Although more and more systems are functioning as integrated systems, they are often designed as separate entities. Therefore, this chapter treats each system as separate and distinctive with information and trends on integrated systems.

7.1.2 Planning

Advanced technologies, a large number of integrated system possibilities, and a wide range of different available functions make evaluating various systems difficult. The value of a system is not determined by the number of functions it can perform, but by its ability to improve the user's daily communication. The functions should be logical and simple to operate or they will not be used, rendering the investment in the system a waste of valuable capital dollars. Before deciding upon a system, address the following points:

- a) *Analysis.* Properly integrated communications in a facility should be one of the key factors in analyzing and designing spaces, equipment, and personnel requirements for each health care function. Properly designed communication systems can help reduce operating expenses and can increase the effectiveness of staff, both of which may be translated into improved patient care.

In the earliest planning stages of a project, analyze the current and future communication needs. In order to be effective, planning of communication systems should address all of the facility's communication needs—all modalities, all information formats—all users in all locations. All of these systems should work together operationally and technically. Many of these systems can physically interface with one another. Many of these systems can accomplish similar kinds of results in certain areas. In preparing a communication systems plan, the design team should consider current operating techniques of the facility as well as potential future technologies. Designers should also consider possible changes to the organizational structure that could change communication patterns. These changes might include university affiliation, mergers, feeder hospitals, extended care facilities, psychiatric facilities, day-care centers, and others.

- b) *New technologies.* Cycle times for new technologies are shorter and shorter. Hospitals will thus replace their technologies several times during the life of the building. The number of systems, location of devices, layout of signal conduits and raceways, size of conduit and junction boxes and their location can make a significant impact upon the initial installation and an even greater impact upon the future installations. The original design should include reasonable estimation of future communication requirements and, if possible, should minimize the downtime associated with the eventual replacement of the system or its components.
- c) *Technology integration.* More and more, the various communication systems are beginning to integrate. In the past, each system comprised its own little stand-alone network. While many specialty vendors still cling to this model as a buffer to competition, more and more medical systems are becoming capable of integrating. *Integration* is a word that carries many meanings, but the essence of the idea is to minimize the number of devices and infrastructure to perform more and more formerly discrete functions. As an example, the outputs from medical monitoring equipment can be fed directly into the patients' electronic health records (EHR) so that physicians can view patient monitors remotely—from any PC connected to the network—or even from their offices and homes. Doctors and nurses will be using personal digital assistants (PDAs) to communicate and track patient information.
- d) *Data network.* The future of health care is written in strings of ones and zeroes. These ones and zeroes comprise the millions of bits of information flowing through the digital veins of a hospital. This system is the circulatory system for mission critical systems such as picture archiving and communications system (PACS), EHR, Voice over Internet Protocol (VoIP), nurse-call systems, telemedicine, patient portal technologies, digital video recording (DVR) for security surveillance, and video teleconferencing. The traditional data network, made up of network switches and routers, has become the primary transport mechanism for scores of applications used in numerous departments. Far beyond the classic role of file sharing, information retrieval, e-mail services, and connectivity to the Internet, the “network” is truly an information highway carrying voice/video communications and life safety data to physicians, nurses, and support staff.
- e) *Picture archiving and communication systems.* The PACS are one of the largest consumers of memory and bandwidth in a health care facility. More and more facilities are implementing PACS, but still cling to film images. Most historical images are still stored only on film, and the transition away from film will take many years.
- f) *Electronic health records.* Another important planning consideration is changing to EHR. In the past, all medical records were stored on paper, and the need was for physical space. Tomorrow's hospitals will have electronically stored records, and the need will be for infrastructure to support access to these records. Again, however, as with PACS, there will be a significant time of transition for conversion from the paper system to the electronic one.

- g) *Communication and signal systems program.* After completing the preliminary communication analysis, the engineer should develop a communications program. This program will outline the specific communication requirements in the various departments of the facility and suggest possible ways of satisfying these communication needs.

The planning team should prepare a detailed evaluation of the internal and external communications network, including traffic and feasibility studies for each and every department. These studies should show how each department communicates, with whom it communicates, why it communicates, where it communicates, and what is accomplished by the communication.

The study should include a comparative economic analysis of the proposed alternatives, including cash flow and life cycle cost analysis.

- h) *System suppliers.* The owner should consider what firms it will contract with to supply and service its technology equipment. The owner needs to consider both the technical features of a particular system as well as the service and repair costs and ability. Many suppliers can now remotely monitor and correct software functions, and dispatch trained maintenance or repair technicians with qualified test equipment to the facility. Response time for remote monitoring should be immediate; response time for on-site facility repairs should be as agreed upon by the owner.

7.1.3 Communication and centralized command centers

Every communication system should be designed to work as part of an operation. Each system moves a piece of information from one place to another, and the arrival of this information should trigger some appropriate response. Thus, the engineer should understand this flow and anticipate the desired response. Current codes dictate some of the end points for communication systems; medical gas alarm panels, generator alarm annunciators, and code blue annunciators should all be at a continuously monitored location. Staffing choices have made the traditional location—the telephone operators—potentially non-existent within the hospital, with the result that the engineer designing a facility should understand very well who will be on the receiving end of the various alarms and how they will be expected to respond. To facilitate coordinated response, many facilities choose to implement centralized command centers within the health care facility. These centers may be diverse (i.e., a facilities reporting location, a security monitoring station, and a telephone operators' room) or combined into a single command center. Some facilities may have one such command center, and some may have a redundant command center, often located in the emergency department nurses' station to meet the requirement for round the clock supervision. As systems become more and more capable of independent action, the need for these attended stations is likely to decrease, and the codes and the designs will need to evolve to keep pace with the capabilities of the systems. Engineers should plan these critical areas in detail to facilitate effective staff utilization. Accomplishing this planning requires a thorough knowledge of the program and procedures to be carried out at each location—gained through discussions with hospital staff—and a thorough knowledge of the equipment available for each system—gained through contact with vendors and through experience. The following checklist includes equipment that might be found at the centralized control centers:

- a) Telephone attendant consoles
- b) Nurse-call central answering consoles
- c) Code blue annunciator
- d) Staff, patient, and equipment tracking consoles
- e) Wireless telephone assignment console
- f) Physician and staff register annunciator (or PC)
- g) Public address (PA)/emergency paging zone selection console and microphone
- h) Radio-paging system encoder
- i) Emergency generator annunciator
- j) Fire alarm control, annunciator, and smoke control
- k) Medical gas alarm annunciator
- l) Emergency elevator control and annunciator
- m) Patient information system PC
- n) Bed control “board” (or system)
- o) Blood bank alarm
- p) Clock (connected to synchronized clock system)
- q) Two-way radio base stations for maintenance, security, transportation, etc.
- r) Security video surveillance and access control command console
- s) Staff badge protection and enrollment console

7.1.4 Power supply

7.1.4.1 General

All electrical communications and signal systems with local control equipment require at least one connection to the building power distribution system to obtain operating power. Applicable codes largely dictate the way to make these connections. The goal of these requirements and of good practices is to ensure a high reliability of communication and signal systems essential to patient safety. Of particular importance are the following national standards:

- National Electrical Code[®] (NEC[®]) (NFPA 70)¹
- NFPA 99
- NFPA 101[®]
- Guidelines for Design and Construction of Health Care Facilities

7.1.4.2 Design considerations—Clinics, outpatient facilities, and medical and dental offices

Code requirements for communication and signal systems for these buildings govern the fire alarm system and emergency call systems. Where the system is a local energy type,

¹Information on references can be found in 7.22.

the ac power source should comply with NFPA 72, which requires two sources of supply and a dedicated circuit for the fire alarm system. Wiring methods should comply with Article 517 of the NEC. If a building in these occupancies contains elevator controls, security, radio-paging, voice-paging, or visual-paging systems, the designer should add a second source of supply (battery) for each system.

7.1.4.3 Nursing homes and residential custodial care facilities

These categories cover a wide range of acuity. Again, codes dictate minimum requirements for these buildings, largely as a function of whether patients depend on electrical life support systems, and whether staff perform surgeries requiring general anesthesia.

If the answer to both of these questions is *no*, and if the occupancy has a 1.5 h alternate power source complying with Section 517-40 of the NEC, then the engineer should ensure that lighting in communications areas and all alarm systems within the building connect to the alternate power source.

Where the answer to either of these questions is *yes*, the facility should have an essential electrical system, as described by Article 517 of the NEC. In these occupancies, the life safety branch of the essential electrical system should provide power to the following communication and signal systems (and only these systems):

- a) Fire alarm
- b) Medical gas alarm
- c) Communications systems used for issuing instructions during emergency conditions

In addition, the critical branch should provide power to the following communication and signal systems (and others, if needed for effective facility operation):

- 1) Elevator communications (sometimes via the telephone system)
- 2) Control systems and alarms required for operation of major apparatus

Remaining communications and signaling systems not already mentioned and associated with patient care may also connect to the critical branch.

7.1.4.4 Hospitals

The code requirements for connection of ac power to hospital communications and signaling systems are as follows:

- a) Life safety branch (no other systems may be connected)
 - 1) Fire alarm
 - 2) Medical gas alarm
 - 3) Communications systems used for issuing instructions during emergency conditions
 - 4) Elevator communications (sometimes via the telephone system)

- b) Critical branch
 - 1) Telephone system
 - 2) Nurse-call system
 - 3) Nurse-assist system
 - 4) Code blue system
- c) Equipment branch
 - 1) Control systems and alarms required for safe operation of major apparatus
 - 2) Controls for compressed air systems serving medical and surgical functions

Under both the critical branch and equipment branch headings, the code will allow connection of equipment necessary for effective hospital operation. All communication and signal systems not already mentioned and associated with patient care should be connected to the critical branch.

7.2 Telecommunications infrastructure

7.2.1 Introduction

Well-planned telecommunications infrastructure, designed to accommodate both present and future needs, pay dividends throughout their lifetime.

Communications systems are a critical resource for health care facilities. Clear organization and effective management, especially in telephone and data cable plant systems, greatly increases the long-term performance, maintainability, and therefore, value of these resources. An appropriate goal is to design cable support systems to last the life of a building and to design communications cable systems to serve two or more generations of communication equipment. To maximize the investment, engineers should design “backbone” cable systems to accommodate several years of growth and, perhaps, to support a change of the station cable system. Specific system goals vary over a wide range; therefore, documented design criteria are a valuable tool.

Communications system design criteria should address many questions, including:

- a) Where are system components located?
- b) What is the topology of device interconnection?
- c) What are the wiring requirements of each type of device?
- d) What are the communication equipment requirements? Size? Environment? Power? Wire management?
- e) Where are the spaces dedicated to communication systems and how are technology components integrated into these spaces?
- f) What standards and codes are applicable?
- g) How often will the system change? How fast will it grow? How will change and growth be accommodated?
- h) Who will install the system?
- i) When should the system be installed? Should it be commissioned?

This subclause outlines several broad topics at a cursory level. The intent here is not to describe communications systems, but to describe ways to support communications systems in health care facilities. Understanding essential concepts related to communications systems makes supporting them easier.

7.2.2 TIA/EIA telecommunications building wiring standards

The Telecommunications Industry Association/Electronic Industries Association (TIA/EIA) publishes a compilation of telecommunications standards that provide state-of-the-art guidelines for effective and adaptable installations. The EIA standards documents are developed within Technical Committees of the EIA and the standards coordinating committees of the EIA standards board. The TIA conducts its standards activities through the EIA organization. Particularly important standards for health care buildings are:

a) TIA/EIA-568

This standard specifies a generic communications cabling system for commercial buildings that will support a multi-product, multi-vendor environment. It covers horizontal cabling, backbone cabling with media including unshielded twisted-pair (UTP), shielded twisted-pair, optical fiber, and hybrid cables. It also provides an overview of infrastructure requirements for telecommunications closets, equipment rooms, and entrance facilities.

b) TIA/EIA-569A

This standard provides in depth information on telecommunications spaces and recognizes three fundamental concepts related to telecommunications and buildings: a) buildings are dynamic, b) building telecommunications systems and media are dynamic, and c) telecommunications is more than just voice and data.

c) TIA/EIA-606A

Applications change several times throughout the life of a building. This standard provides a uniform administration scheme independent of applications. It establishes guidelines for owners, end users, manufacturers, consultants, contractors, designers, installers, and facilities administrators involved in the administration of the telecommunications infrastructure.

d) TIA/EIA-607

This standard enables the planning, design, and installation of telecommunications grounding systems within a building with or without knowledge of proposed telecommunications systems. The telecommunications grounding and bonding infrastructure supports a multi-vendor, multi-product environment as well as the grounding practices for various systems that may be installed in buildings.

7.2.2.1 BICSI telecommunications distribution method model

The Building Industry Consulting Service International (BICSI) was established to build consistent communications between the construction and telecommunications industries. BICSI, in turn, established the Registered Communications Distribution Designer (RCDD) program to recognize members who demonstrate a high level of expertise in integrating the needs of the telecommunications and building industries.

The BICSI Telecommunications Distribution Methods Manual (TDMM) is a compilation of codes, standards, and established practices for use by the communications distribution designer.

7.2.3 Design concepts

Great engineering practice is about defining and implementing excellent performance at the lowest cost. This is true of communications system engineering also. However, technology is changing so fast—especially network and computer hardware—that measuring cost for communications systems is all about dynamics. When will an upgrade occur? How will the operating costs change over time? When will the next business application roll out? These are the kinds of questions businesses ask all the time. Thus, in addition to the basic measures of procurement costs and performance, we should address other issues in order to measure success. The following concepts are not exhaustive by any means—they help establish a framework for understanding the impact of communications technology on health care facilities.

7.2.3.1 Capacity

Communications systems tend to grow fast in health care facilities. An increase in the number of new applications, increasing use of multimedia and virtual reality, PACS, privacy requirements, and increasing demand for immediate medical information all contribute to growth. Not only does it grow, but also it changes over time, so designers need to consider equipment replacement in their planning. Most communication systems will require operational replacement several times during a building's lifetime. Support space should accommodate a new component while the existing component continues to operate. For example, replacement of a telephone switch involves installation and programming of the new switch in parallel to an operating switch for 2 or 3 weeks.

7.2.3.2 Resource sharing

Sharing resources can reduce technology costs, but the cost-quantity curve has a bump. Integration of two circuits, two technologies, or two applications often incurs a cost for integration or a cost for operational management. Often it takes three or four “users” before sharing helps reduce overall costs.

Occasionally, a resource is limited, e.g., a single conduit or cable serves a building site. Then, integrating communications systems is a means of avoiding an upgrade or replacement of the resource, sometimes saving considerable expense.

7.2.3.3 Reliability

Increasing use of communications technologies for critical health care functions requires higher reliability systems. Infrastructure requirements to support high availability systems will require both capital investment and space. High levels of redundancy may seem extreme, but when system components serve (or connect) multiple sites, then the cost of a system failure can be extraordinary. Best practices currently dictate this kind of

redundancy to ensure patient safety, to avoid lost revenue, or to avoid increased operational costs.

7.2.3.4 Information security

Secure equipment space is part of an overall information security plan. With the application of data switching technology in the Ethernet arena came the ability to support logically segregated local area network (LAN) segments for increased data security. Virtual LANs (VLANs), network monitoring, reasonable encryption schemes, and access control for network equipment spaces combine to provide an overall good level of security. Data system designs and device locations should also comply with the requirements of the Health Insurance Portability and Accountability Act of 1996 (HIPAA) to ensure the privacy of EHR.

7.2.3.5 Collaborative technologies

Health care applications should support team efforts. Many building spaces are designed to support group activities, including group communication between building sites or between cities. A department communication space—a teleconference center is a simple example—houses a collection of audio, video, and communications technologies. Their combined impact on group spaces heightens the need to integrate technologies so their use is most effective.

Examples of collaborative spaces include conference rooms, videoconference rooms, presentation spaces and training rooms, auditoriums, banquet rooms, reception areas, executive offices, etc. The proportion of spaces focused on communications technology continues to grow.

7.2.3.6 Threshold of quality

Every collective application of technology should exceed a threshold of quality in order to hold the user's attention. It should make the user's job easier, not more difficult. A system should identify and address every potential problem in order to reach an effective operational level. For example, the best videoconference system may be difficult to use in a poor acoustical environment. Technology applications for collaborative spaces heighten the requirements for many building systems, including the following:

- a) Lighting and lighting control
- b) Acoustical treatment and acoustical separation
- c) Wall surfaces and colors
- d) Mechanical capacity and noise

7.2.3.7 Time paced implementation

The budgeting process often causes network planning to suffer. In some cases, capital budgets establish plans for networks, allowing planning for equipment that will come online 5 or 6 years hence, or that the organization will buy now with the intent of providing continuing service for 5 or 6 years. Facilities buy equipment thus to avoid

increasing operating budgets, e.g., to minimize network equipment costs in subsequent years. In other cases, network plans ignore expansion requirements so that when a “few” users or additional applications come online after opening, the network will reach a point of failure.

Neither of these approaches is cost-effective. In the first case, procuring technology equipment before it is needed means it will be obsolete more quickly than necessary. New network capabilities and speeds are available every 2 to 3 years. And the price nearly always drops year to year for equipment at the same level (speed and capability). In the second case, the negative impact on health care translates into delays, wasted time, and disappointed staff. Also, the “failure” is often associated with a new application rollout, shaking confidence in the new system. A second attempt to build confidence in a new user group is much more difficult than the first.

Thus, with high costs associated with both of these extremes, the middle ground is the best approach: procure network equipment when it is needed, i.e., build network capabilities just in time to match application requirements. This approach is easier to describe than to execute. It requires both a planning approach that includes projected applications (including operating system upgrades) and a flexible budget.

7.2.4 Voice and data cable systems

During the last decade the new approach to data system cabling and the tradition of telephone system cabling have merged. Voice and data cables have not yet completely merged, but each system follows a similar set of rules and usually use parallel—often identical—pathways through a building. They do so because of the following:

- a) Better economy of building resources by sharing pathways and rooms between voice and data systems.
- b) Opportunity to define a structured cabling system (SCS), handling voice, data, and other systems on the same cabling components, thus economizing the cable plant system.
- c) Technology is moving toward a greater level of integration. Many new voice systems run on data networks and VoIP applications are increasing.

Other applications use cabling that matches voice and data cable specifications. These applications include the following:

- 1) Security
- 2) Closed-circuit television (CCTV)
- 3) Fire alarm reporting
- 4) Wide area network and dial-up circuits
- 5) Facility monitoring
- 6) Intercom
- 7) Nurse call
- 8) Patient monitoring and telemetry
- 9) Imaging systems and PACS

- 10) Surgical video
- 11) Lab analyzers and management systems
- 12) Pharmaceutical and supply distribution systems
- 13) Patient and staff educational and interactive video

Several of these specialty systems rely on the voice and data cable plant for all of their connections—others still use some proprietary cabling—but clearly the trend is toward increased use of standard structured infrastructure systems to support special circuits.

Effective cable system design involves identifying a model system that supports each proposed application and finding a method for documenting the model so managers can use it effectively. The final design and construction record, combined with a labeling scheme, forms the basis for communications systems management.

7.2.4.1 Cable plant model

The cable system consists of several components. Station outlets serve individual devices, often via an outlet near a user's desk or workspace. Station cable, also called *horizontal cabling*, provides the path from distribution rooms to the station outlets. Distribution rooms house data network equipment and voice and data cable terminal equipment. *Riser cables*—often called the *backbone cable*—connect distribution rooms. Most buildings house a main communications room where the building riser terminates and where cables tied to other buildings or communications service providers enter the building. The collection of rooms, conduits, cable tray, cable rings, etc., is called *support structure*.

7.2.4.2 Voice cable model

A telephone switch allocates “trunk” (shared) circuits to an individual telephone. Trunks may be connected via large pair count copper cables, coax (unusual today), or fiber-optic cables. Individual telephones connect via single or multiple pairs of copper wire or via a radio extension (wireless) circuit. Voice cable is organized around individual circuits connecting telephone sets (or radio base stations) to station ports in a telephone switch. When a single telephone switch serves several floors in a building, a large pair count copper cable is the least expensive way to connect collections of telephones on separate floors to the switch. Small-pair count station cable provides service to individual telephones.

7.2.4.3 Structured cabling model

The SCS provides a platform for connecting virtually all communications systems, building systems, and medical equipment including patient monitoring, telemetry, imaging systems, PACS, laboratory instruments, surgical robots, surgical video systems, pharmaceutical and materials management systems, and others. The SCS also connects with the outside world to support business and clinical operations of the entire health delivery enterprise. The SCS should be robust and flexible enough to carry routine telephone and data communications, as well as more exotic formats including medical imaging, educational and surgical video, and real-time patient monitoring. The SCS

should be capable of growing to support future building expansions and to grow with the hospital as operations evolve, new services are added, and new technologies deploy.

7.2.5 Support structure

7.2.5.1 Telecommunication rooms

In a broad sense, telecommunication rooms form the basis for the support structure for communication systems. These rooms contain wire and fiber terminations, and equipment. They usually distribute in a hierarchy with satellite rooms, main rooms, and central or building rooms. A single room may contain equipment and wiring of several communication systems (e.g., telephone terminals, nurse-call controller, patient physiological monitor controller, television system distribution cable, PA system equipment, or data transmission equipment).

The designer should carefully design the relative arrangement and particular location of each cabinet and telecommunications room (TR) containing communications wire, terminals, network or system equipment as it forms the backbone of a support structure that, if designed carefully, will serve several generations of communication equipment over the life of the building. Weigh the following criteria appropriately for each project. Once located and sized, treat these spaces as solid and permanent parts of the “structure” of the building.

- a) Location criteria
 - 1) Locate cabinets and rooms in the area they serve to reduce the total length of distribution cables and to satisfy maximum distance requirements of the most restrictive system accommodated.
 - 2) Locate rooms such that they do not inhibit future renovations. Suitable locations are adjacent to major corridors, core areas, and stairs. Beware of locations adjacent to duct or piping shafts which may need to distribute ducts or piping over the TR.
 - 3) Locate rooms so that mechanical ducts or pipes are not above or below.
 - 4) Locate riser rooms in a “stacked” arrangement.
 - 5) Locate closets such that each floor has separate communications rooms and electrical power rooms.
 - 6) Consider whether voice and data systems should be separate from biomedical and other building systems communication equipment, or whether they can be co-located.
- b) Space requirements
 - 1) Allow sufficient space to accommodate all communication and network equipment, wire, and terminals, keeping in mind any plans for future expansion associated with each system.
 - 2) Allow sufficient space to conform to all codes governing minimum clearances.

- 3) Allow sufficient space to install a new system without removing the existing one, for each system that may require a high continuity during remodels and expansions in the future.
 - 4) Because network switches and routers are typically rack-mount components, provide specific clearances in front and behind each equipment rack. A standard telecommunications rack is 2.13 m (7 ft) tall and 48.3 cm (19 in) wide. Sizing a TR can be quite difficult, particularly if the contents of the rooms have not been clearly defined. Designers should gather specifications for all the equipment to be placed in the main TR prior to sizing this room. Most hospitals need a room no less than 3.05 m (10 ft) by 3.66 m (12 ft). This size will provide the necessary clearances to install and maintain rack-mount network devices: 91.4 cm (3 ft) in front, 91.4 cm (3 ft) in back. The size of the facility may demand that the TR be larger to support the amount of equipment.
- c) Interconnections
- 1) Size the raceway, cable tray, or sleeves serving each room to accommodate all systems including expected future systems.
 - 2) Add sufficient riser support to replace existing systems without taking them out of service.

7.2.5.2 Equipment spaces

Locate main (central) equipment spaces where space is less valuable to the operation of the facility but as close as possible to the center of the facility to minimize cable plant costs. Design all communications spaces to accommodate each piece of equipment as suggested in 7.2.5.1. Other criteria for equipment space design are as follows:

- a) *Lighting.* Provide 50 fc task illumination at maintenance locations. Provide controls to decrease light levels at maintenance terminal locations.
- b) *Water.* Avoid pipes that enter this space except as required for fire-extinguishing systems and water-cooled air-conditioning units serving that space.
- c) *Raised floor.* May be considered in large facilities; where used, maintain an under-floor height of 30 cm to 49 cm (12 in to 18 in).
- d) *Floor finish.* Provide a dust-free finish to maintain a clean environment. If the floor is concrete, specify a sealed finish to minimize dust.
- e) *Ventilation.* Provide adequate ventilation. Most equipment generates heat and will malfunction above certain temperature limits. Consider how power failures affect operation of the cooling and ventilating systems, and possible effects on system operations.
- f) *Room finish.* Avoid spray-on fireproofing of any exposed structure to maintain a clean environment. If fireproofing is required, specify a dropped ceiling.

7.2.5.3 Environmental control

Maintain the temperature in the main TR between 18 °C and 24 °C (64 °F and 75 °F) with 30% to 55% humidity. On average, each network equipment rack will generate

3000 Btu/h to 7000 Btu/h. Server equipment generates approximately 12 000 Btu/h to 15 000 Btu/h in a fully populated server cabinet. In particularly critical telecommunication spaces such as a server room or data center, consider redundant HVAC systems to ensure proper heating/cooling. The rate of change in heat produced by data equipment continues to grow at an exponential rate, requiring designers to continue to study the actual and projected cooling needs of a particular project.

7.2.5.4 Electrical power

Power requirements for a TR are typically 40 W/ft² for TRs and 90 W/ft² for server rooms and data centers. These requirements vary a great deal depending upon the type and density of installed networking equipment. Service is normally 208Y/120 V, ac, three-phase, 4-wire, 60 Hz. Some large computing equipment needs 400 Hz that comes from a frequency converter. Steady-state voltage requirements are typically +10%, −8% with a frequency variation of 0.5%. The duration and rate of change of any variation should be taken into account. Generally, a 20% transient, lasting longer than 30 ms, or a voltage outage, lasting longer than 15 ms, may cause errors, loss of information, shutdowns, or equipment damage.

7.2.5.5 Grounding and power protection

Networking equipment needs grounding, bonding, and electrical protection to ensure optimized performance. All grounding, bonding, and electrical protection should meet the requirements of the NEC and TIA/EIA-607. Solid copper grounding bus bars, referred to as a telecommunication ground bus bar (TGB), (typically 0.64 cm (0.25 in) thick and 10.2 cm (4 in) high with a variable length depending on the amount of equipment to be grounded) should be installed in each TR. Ground all racks, cabinets, sections of cable tray, and metal components of the technology system that do not carry electrical current to this bus bar. Connect bus bars by a backbone of insulated #6 AWG (minimum) stranded copper cable, between all TRs, and connected back to the telecommunications main grounding bus bar (TMGB) in the entrance facility or main TR. Connect the main grounding bar back to the building main electrical service ground. Use only green colored or appropriately labeled cabling for bonding conductors.

All inter-building copper backbone cable that contains metallic shielding should have its shield bonded to the TMGB bar. All intra-building copper backbone cable that contains metallic shielding should have its shield bonded to the TGB.

Equip all inter-building copper backbone cables with building entrance protection, terminated within 15.24 m (50 ft) of entering the building, containing heat coils for sneak current protection. Terminate each pair of copper cable on the protector block and bond each grounding lug of the protector blocks to the TMGB.

Networking equipment at the core and distribution layers typically contains dual power supplies for redundancy and is typically served by some form of uninterruptible power supply (UPS). The facility essential electrical system should serve the UPS.

7.2.6 Cable plant

Cable plant provides a signal path between user apparatus and central control equipment for most communication and signal systems. The term covers not only the insulated conductors themselves, but also wall outlets, wire terminals, and cross-connect frames. Support structures include the methods and materials used to support and protect the cable plant.

The signal characteristics of the particular communication system dictate the choice of conductors used for the signal path. Conductor size and number, insulation type and color, shielding, and jacketing are all essentially system-dependent (as is discussed elsewhere in this chapter). The choice of methods for support and protection of these conductors is dependent on system characteristics and local codes. The choice depends on the classification of the physical spaces housing the cable plant. The following subclauses discuss three basic methods for support and protection of communications conductors in health care facilities.

7.2.6.1 Area classification for cables

Communication cable is classified by the type of space in which it is installed. Typical classifications are as follows:

- a) Interior spaces
 - 1) Exposed to physical damage
 - 2) In ducts or plenums
 - 3) In noncombustible ceiling blind spaces
 - 4) In concealed spaces
 - 5) In shafts
 - 6) In hoist ways
- b) Exterior of building
 - 1) Aerially
 - 2) Aerially, over roofs
 - 3) Underground
 - 4) On buildings, exposed to physical damage
- c) Both interior and exterior in locations that are hazardous due to the presence of flammable or explosive materials, almost always requiring raceways
 - 1) Ducts or plenums used for environmental air (not permitted in most locations within a hospital)
 - 2) Concealed spaces
 - 3) Hoist ways
 - 4) Shafts
 - 5) Hazardous locations
 - 6) Underground

Refer to Articles 640, 725, 760, 770, 780, 800, 820, and 830 of the NEC for exceptions to the requirement for raceways. Communications systems that are not power-limited and life safety systems always require conduits. For power-limited communication circuits, raceways may not be required depending on the system's use.

The NEC further classifies communications systems under one or more of the following articles:

- Article 640: Audio Signal Processing, Amplification, and Reproduction Equipment
- Article 725: Class 1, Class 2, and Class 3 Remote-Control, Signaling, and Power-Limited Circuits
- Article 760: Fire Alarm Systems
- Article 770: Optical Fiber Cables and Raceways
- Article 780: Closed-Loop and Programmed Power Distribution
- Article 800: Communication Circuits
- Article 810: Radio and Television Equipment
- Article 820: Community Antenna Television and Radio Distribution Systems
- Article 830: Network-Powered Broadband Communication Systems

The respective articles discuss required wiring methods for its classification of communications system. The engineer should be familiar with these articles and with local interpretation by code authorities.

Where communications conductors are installed without raceway, they are considered to be open cabling, and they should be installed as described in 7.2.6.2.

7.2.6.2 Open cabling

Open cabling is a wiring method for communications conductors that allows insulated conductors to be installed without the use of an enclosing raceway. Open cabling may be installed within a building, aerially between buildings, or underground.

The installation of open cabling will have to comply with state and local codes governing these wiring methods. Engineers should work with the building owners and operators to select the preferred cabling method. Consider the following criteria: include installed cost, system operating requirements, local codes, and the level of system flexibility desired.

Analyze communications system under consideration for open wiring from the following standpoints:

- a) Is raceway required to ensure protection of conductors from impact or other physical damage? Refer to the NEC.
- b) Is raceway required to provide shielding from electromagnetic interference (EMI)?
- c) Is it more economical to expand or extend the system if raceway is employed?

If the answer to these questions is *no*, then open cabling may be appropriate for the system. Open cabling may also be less expensive to install and, in the case of accessible interior spaces, easier to maintain and modify.

Ensure open cabling installation to minimize physical stress on the cables. Ensure proper training and support of cabling to facilitate future maintenance. Accomplish this goal by supporting the cable from the building structure at regular intervals. The most common methods for cable support are nylon ties, bridle rings, and cable tray. Nylon ties are the least expensive method initially, but they become less economical if frequent cable rerouting is required. Cable tray provides the most accessible and continuous support but is initially expensive. Outside the building, open cabling will be either direct buried cable, messenger supported aerially or supported from the building structure in the same manner as indoor runs.

Whenever an engineer designs with open cabling, the engineer should be familiar with the specific article of the NEC covering the communications system. The open cable installation methods allowed by these articles contain restrictions on adjacencies to power and lighting conductors, vertical cable runs, penetration of fire barriers, aerial conductors exposed to lightning, etc.

7.2.6.3 Open cabling in plenums

Where open cable wiring methods are selected for installation in air-handling ducts or plenums, the methods for supporting the cables will be the same as previously discussed, but the cable insulation materials should be specified to meet special code requirements. Such cable is frequently referred to as *plenum cable*.

The installation of open cabling in air-handling plenums should comply with state and local codes governing this wiring method. The engineer should choose between cable-in-raceway and open cabling, based on installed cost and required system reliability.

Designers should consider the need to limit the spread of fire and products of combustion. Communications cabling is frequently insulated with combustible materials, and the cabling usually extends throughout the building, concealed in hollow spaces, above ceilings, and in return-air plenums.

The NEC addresses this potentially hazardous situation in Article 300, Sections 300-21 and 300-22. Section 300-21 requires the engineer to design electrical installations within “hollow spaces, vertical shafts, and ventilation or air-handling ducts” so that the possible spread of fire or products of combustion will not be substantially increased. This section also requires approved fire-stops at openings in fire barriers. Section 300-22 specifically discusses four different hollow spaces where electrical installations are restricted. The following sentences paraphrase these code restrictions:

- a) No wiring of any kind is permitted in ducts for dust, loose stock, or vapor removal.
- b) Some kinds of wiring, but not open wiring, can route through “ducts or plenums specifically fabricated to transport environmental air.”

- c) Some kinds of wiring, including “other factory assembled multi-conductor control or power cable which is specifically listed for the use” may route through “other spaces such as spaces over hung ceilings which are used for environmental air handling purposes.”
- d) NEC 645 permits open wiring in spaces under raised floors under certain conditions.

Engineers should be familiar with Section 300-22, because it defines potentially hazardous “hollow spaces” in a clear way and broadly states what wiring methods, if any, are allowed in each type of space. However, the engineer should also be familiar with the articles pertaining to the specific communication system to be installed, before reaching a full understanding of the NEC wiring requirements for such spaces.

7.3 Wireless networks

7.3.1 Introduction

Wireless systems can serve most applications and most technologies within a hospital, and an increasing number of devices are moving into the wireless world. These devices are using either their own proprietary radio spectrum or industry standard devices in the IEEE 802.11TM [B6]² family of standards. These devices may include, but are not limited to, the following:

- a) Computer data connections
- b) Patient telemetry and physiological monitoring
- c) IV pumps
- d) Wireless phone systems
- e) PDAs
- f) Nurse-call systems

Designers of new facilities should identify both the types of devices that the hospital wishes to use on a wireless medium and the applications they wish the wireless systems to support. Defining these objectives will dictate what types of wireless systems the facility needs. This subclause discusses the IEEE 802.11 family of standards [B6]. Proprietary systems from individual vendors have their own requirements and operating parameters that designs should accommodate. However, each manufacturer’s system is different, and this subclause does not attempt to cover every manufacturer’s systems.

Wireless signal transmission operates essentially the same way as transmission over cabling. Comparisons of the cabled and the uncabled systems use the terms *bounded medium* and *unbounded medium* respectively. In both cases, signals travel over a range of frequencies chosen to propagate the maximum possible distance over the medium without degrading below the minimum acceptable threshold of the receiver. Generally, signals traveling over bounded media (especially optical fiber) can achieve higher data transfer

²The numbers in brackets correspond to those of the bibliography in 7.23.

rates due to the greater immunity of cabling to EMI when compared to unbounded media. Codes limit the maximum allowable power levels of the transmitted signals in wireless systems in most countries, both for health concerns and to minimize the possibility of interference with other devices operating in the same area.

Bounded medium designs allow an individual cable to serve each computing device, creating a point-to-point link between the devices at the ends of a cabling channel. If the system uses switches, each device connected to the network has exclusive access to its cabling channel, which it can use at any time. Wireless networks cannot provide this kind of exclusivity since all signals should travel through the same open-air medium. Moreover, a given type of wireless network has a limited range of allowable frequencies, or channels, making it impractical to assign a channel exclusively to a single network device.

To allow fair access to a shared wireless channel, wireless local area networks (WLANs) compliant with IEEE standards use a variation of the *carrier sense multiple access with collision detection* (CSMA/CD) protocol originally developed for shared Ethernet networks. The modified form of this protocol is called *carrier sense multiple access with collision avoidance* (CSMA/CA). The change is required because it is difficult for a wireless network device to detect another signal while it is in the process of transmitting—the emitted signal overpowers the incoming signal. A device ready to transmit on a wireless network can only sense the open air around itself to see if it is clear for signaling. It cannot sense the open air around the receiving device to confirm the availability of the receiver.

Vendors of wireless networking systems provide typical values for the operating range of their equipment. Unlike cabling specifications, where it is possible to consistently provide a maximum channel length for a given type of cable, the allowable distances for a wireless system depends on the characteristics of the site where the system will operate. The network design depends upon inspections and tests performed at the site (also referred to as *site survey*, *site verification*, or *environment analysis*). The design should accommodate both physical and electromagnetic barriers.

This subclause applies primarily to short-range radio signal systems using standardized or proprietary protocols, antenna and transmitter-receiver units, and frequency bands, intended for communication within buildings or a campus. Additional information on radio systems for longer range communications is found in 7.8.

7.3.2 Planning

The first step in planning a health facility wireless system is to define the applications and devices the network will support, and at what frequencies. A matrix depicting each system and the frequencies used can organize the information leading to design that will provide the facility with the appropriate infrastructure and can also help identify potential conflicts in devices.

- a) *Definition.* Define the various components that will utilize a wireless medium. In particular, pay attention to the frequencies that each component utilizes and the potential impacts of these signals on other equipment in the facility.
- b) *Frequency matrix.* Develop a matrix for the technology components used by listing the frequencies used and the modulation used. This attention is particularly important with WLAN systems that are typically either frequency hopping spread spectrum (FHSS) or direct sequence spread spectrum (DSSS). Each system uses different modulation, but both reside in the same frequency spectrum.
- c) *Number of users.* When developing a list of technologies that will use a wireless network, the engineer should also develop an estimated number of users for each technology. This number can form the basis of the plan for the density of devices required and relates directly to the bandwidth allocations of the system.
- d) *Bandwidth requirements.* Bandwidth is the amount of information that can be transferred in a period of time. It is typically measured both by the maximum amount of bandwidth available and the bandwidth available per user on a system. Defining the bandwidth for each application as part of the planning process is imperative if the wireless systems are to function appropriately. Each system defines the actual throughput measurements in different formats, but the kilobits per second (kb/s) measurement is the most common in data communications.
- e) *Coverage area.* When defining each of the preceding systems, also define the area where the coverage needs to occur. Common classifications include: hospital-wide, emergency department only, campus-wide, campus and outlying clinics, etc.

7.3.3 Wireless networking concepts

A wireless network or wireless LAN is the common definition for a group of network types defined by the IEEE 802.11 standards [B6] and regulated by the Federal Communications Commission (FCC).

7.3.3.1 Spectrum allocation

The FCC has defined specific spectra for wireless LAN usage. These bands include both licensed and unlicensed bands grouped into separate ranges.

- a) The IEEE has defined ranges inside these bands assigned by the FCC. In some cases, the IEEE definition of the band is slightly different from the FCC range.
- b) Industrial, scientific, and medical (ISM) bands

The ISM bands are unlicensed bands located at 902 MHz, 2.4 GHz, and 5.8 GHz. These bands are illustrated as follows:

ISM at 902 MHz to 928 MHz

A small collection of wireless devices, particularly cordless phones, still use this ISM band. Its usage in WLANs has diminished with the advent of less expensive hardware in the 2.4 GHz range. Devices utilizing this band can achieve a throughput up to 1 Mb/s.

ISM at 2.4 GHz

The 2.4 GHz band covers 100 MHz as defined by the FCC, from 2.4 GHz to 2.5 GHz. The IEEE 802.11 standards (IEEE Std 802.11-2005 [B7], IEEE Std 802.11bTM, and IEEE Std 802.11gTM [B6]) use this band from 2.4 GHz to 2.4835 GHz due to the power output specifications imposed by the FCC.

ISM at 5.725 GHz

This ISM covers 150 MHz, ranging from 5.725 GHz to 5.875 GHz. WLANs do not utilize this band, but do use the UNII bands. There is, however, some overlap between the ISM band at 5.725 GHz and the UNII band at 5.725 GHz.

c) **Unlicensed national information infrastructure (UNII) bands**

The UNII bands are unlicensed bands located in the 5 GHz range. The three bands in this range are allotted 100 MHz each. These bands are commonly used for IEEE 802.11 based networks that operate in the 5GHz range.

d) **Licensed vs. unlicensed bands**

The majority of commercial “off-the-shelf” wireless devices operate in the unlicensed bands. This means that the user needs no specific license to operate a wireless network utilizing these bands. This does not mean that these networks are exempt from adhering to standards/regulations, particularly those enforced by the FCC. In most cases, the devices are preset to adhere to these standards and will not allow a user to configure the device outside of these parameters (including signal strength).

7.3.3.2 Channelizing

All radio frequency (RF) communications require a little segment of the total RF spectrum to transmit their signal. These individual segments of the spectrum are called *channels*. In order to allow multiple simultaneous signals, different channels have to different frequencies. This type of multiple access is called *frequency division multiple accessing* (FDMA). FDMA is the most common type of multiple accessing used in RF communications.

Channels are named by their center frequency, but they contain a range of frequencies both above and below the center frequency. This range defines the channel bandwidth. Channel bandwidth depends on several factors, such as frequency and modulation technology. In general, the more information you are trying to send over the channel, the wider the channel bandwidth.

7.3.3.3 Wireless transmissions

All wireless communications use electromagnetic energy to transfer signals from source to destination. Examples of electromagnetic radiation include radio waves, light particles, and x-rays.

National and international communications agencies use a subset of the spectrum to create a RF allocation chart. This chart displays the allocated and available frequencies for the purposes of radio wave communications in a given area. The chart issued by the Office of

Spectrum Management in the U.S. Department of Commerce spans the frequency range from 3 kHz to 300 GHz (300 000 000 kHz).

Many devices and applications use radio frequencies, creating the possibility of interference in a given location. To minimize disruption caused by simultaneous transmissions at the same frequency, regulatory agencies allocate and control usage rights to specific radio band frequencies in every geographic area within their jurisdiction. A narrowband license, for example, provides its holder with the exclusive right to transmit over a limited frequency range in a specific geographic area.

In addition to licensed narrowband frequencies, unlicensed frequency bands give the right to transmit over them freely available to anyone. An example is the 2.4 GHz ISM band, which is used by Bluetooth wireless personal area networks (WPANs) and several IEEE WLANs. Other devices such as microwave ovens and cordless telephones also operate in this range, at various power levels. This type of frequency sharing in unlicensed bands can cause disruptions in network communications if such devices operate in close proximity to a wireless network.

Most wireless network devices exchange messages using RF signaling, although they could use light beams. RF signaling can be narrowband or spread spectrum. Narrowband RF is associated with fixed base to fixed base signaling, also referred to as *wireless point-to-point* or *wireless bridge*. In such cases, the devices at both ends of the wireless link should remain fixed.

7.3.3.3.1 Spread spectrum

Spread spectrum is a communications technique characterized by wide bandwidth and low peak power. Spread spectrum communication uses various modulation techniques in wireless LANs and has many advantages over its precursor, narrowband communications. Spread spectrum signals are noise-like, hard to detect, and even harder to intercept or demodulate without the proper equipment. Jamming and interference have a lesser effect on a spread spectrum communication than on narrowband communications. For these reasons, the military has long favored spread spectrum.

7.3.3.3.2 Frequency hopping spread spectrum

In FHSS signaling, the frequency band consists of many channels—79 in most countries for the 2.4 GHz ISM band. The transmitting device sends a segment of its message over one channel and then moves, or hops, to another frequency and sends the next segment. This process repeats until the entire message is sent. Before message transfer, the sending and receiving devices select a common hopping sequence from a set of available patterns. Since each frequency is used for a very short period, many pairs of devices can communicate simultaneously over the same frequency band assuming each pair uses a unique sequence. If interference occurs on a given frequency due to its simultaneous selection by two or more sending devices, each device resends its segment after hopping to the next channel in the sequence.

7.3.3.3.3 Direct sequence spread spectrum

In DSSS signaling, each bit in the data stream to be transmitted is converted into a specific sequence of bits. For example, a bit value of:

Zero (0) can be represented by the sequence 11000100110

One (1) can be represented by the sequence 00111011001

These sequences are referred to as *chipping codes* or *chipping sequences*, where each bit in the code is called a *chip*. After conversion, each sequence transmits over a range of frequencies in the available band. The receiving device is synchronized to the transmitting device and listens for the presence of either of the two chipping codes, ignoring all other frequencies.

Instead of using a relatively high level of power at a single frequency to send the original bit value, DSSS uses lower power and multiple frequencies to send a sequence of bits recognizable only to a receiver that knows the chipping code. To an unintended receiver, the DSSS signal appears to be low power wideband noise. A lower spreading ratio uses less bandwidth, making the transmission less secure and more susceptible to interference, but it increases the availability of the network at any given time.

7.3.4 Design concepts

Wireless radio communication is a two-part process. In this process, a transmitter generates and sends the signal through the air, and a receiver detects, reads, and processes it. Most WLAN units are bi-directional and include both transmitting and receiving circuitry. Combined, the two types of circuits form a unit called a *transceiver*.

At the time of transmission, the antenna attached to the transceiver emits one or more signals, which radiate through the air in a pattern influenced by the design of the antenna and the obstructions present in the environment. The strength of the signal decreases as its distance from the transmitting antenna increases, since the fixed level of energy in the signal should cover an ever-expanding area.

The overall effectiveness of a WLAN design depends mostly on the presence or absence of physical and electromagnetic obstacles in the path between sending and receiving antennas. Physical obstacles in the path of a signal can reflect, deflect, or absorb all or part of the signal, causing signal loss or data corruption. If other devices operate in the same frequency band as the WLAN, their signals can create enough interference to make it impossible for the antenna on a network device to detect a valid message. Using spread spectrum signaling minimizes this type of interference, making the identification and avoidance of physical obstacles the key consideration in WLAN design.

7.3.4.1 Coverage area planning

An omni-directional (or omni) antenna has a uniform coverage pattern, radiating its signals equally in all directions. An antenna that sends signals in a specific direction is

called a *directional antenna*. Examples of directional antennas include dipole, Yagi, and parabolic.

The coverage zone of a wireless device relates directly to the transmit power of its transceiver and inversely to the operating speed of the network. As the transmit power increases, the coverage zone increases. The amount of increased coverage varies, since physical and electromagnetic obstructions are rarely identical in any two locations.

It is also possible to increase the coverage zone by decreasing the operating speed of the device. For example, a WLAN device may have a typical indoor range of 30 m (98 ft) when operating at 11 Mb/s, and a range of 90 m (295 ft) at an operating speed of 1 Mb/s. In some cases, a second antenna is added to a network device [e.g., an access point (AP)] to improve its reception ability. The term *diversity reception* describes this technique. The backup antenna only receives signals, while the primary antenna both transmits and receives. The device uses the antenna with the best reception to read an incoming signal.

Properly spacing access points depends on the following:

- a) Manufacturer of the system
- b) RF of the system
- c) Type of antenna used (coverage pattern)
- d) Power level of the access point output
- e) Bandwidth required by the end-user devices
- f) Estimated number of concurrent sessions on each access point

Each manufacturer will have a recommended spacing based on these parameters. This spacing can vary between 6.10 m to 36.58 m (20 ft to 120 ft), so it is critical to identify these requirements up-front.

7.3.4.2 Channel identification

As indicated above, the frequency allocated to a particular band is segmented into channels. In a typical IEEE 802.11b deployment, these channels would be designated as 1, 6, and 11. When assigning the channels to individual access points, it is important to assign them so that no two channels are adjacent to each other (wherever feasible). This is done to avoid cross-channel interference (CCIF) as this interference can drastically reduce the overall performance of devices on the wireless network. When planning channel assignments in a complex structure, particularly in a hospital, the engineer should plan the facility three dimensionally, as there is a considerable amount of vertical bleed on most wireless LAN antennas.

7.3.4.3 Dynamic channel assignment

Many devices, particularly those designated as wireless “switch” environments or “centralized” wireless solutions, have software that can dynamically assign channels to access points. This means that the systems themselves can determine the most effective

channels for each access point and will adjust the deployment based on changing conditions.

7.3.4.4 Aesthetic issues

Wireless access points (WAPs) come in a variety of forms. Make sure to review the aesthetics of the environment when selecting a WAP or antenna. This is an often overlooked step in designing a wireless LAN. Be sure to understand any aesthetic requirements prior to deploying a wireless LAN to avoid users concealing the antennas with materials that may affect signal strength. If aesthetics are a major concern, consider antennas that are integral to ceiling tiles or enclosures that are specifically designed for WAPs.

7.3.4.5 Combined distribution antenna systems

It is possible to combine the signals from a wireless LAN on a single distributed antenna system, also used to radiate radio signals from various bands throughout a facility. These solutions can be quite effective in maintaining uniform signal strengths in a facility, but can restrict the available bandwidth of a wireless LAN. Before deciding to deploy a combined solution, carefully evaluate the bandwidth and concurrent usage requirements of the devices intended for use on the wireless LAN. A standard distributed antenna system combined deployment will result in the equivalent bandwidth of three access points for the entire area covered. This can be quite effective for small areas, but can be extremely restrictive when entire floors or facilities are covered, as the shared bandwidth frequently does not support a broad range of applications.

7.3.5 Support structure

A wireless network is only as effective as the telecommunications and network infrastructure on which it resides. Refer to 7.1 for more information on effectively designing these systems in a health care environment.

7.3.5.1 Cabling

At each wireless access device (typically installed in the ceiling or on the wall), consider provisioning two or more data connections. This allows for expansion of the system and replacement of the antennas as technology is replaced over time.

7.3.5.2 Electrical provisions

There are four basic approaches to electrical provisioning of a wireless network. In each scenario, the radios (or access points) receive the power and then radiate signals through the antennas.

- a) *Centralized.* In a centralized distribution, power is provided at the access points, typically located in a communications room. Cabling for the antennas runs from these locations out onto the floor.

- b) *Decentralized*. In a decentralized approach, provisions for electrical connectivity are made at each access point location (typically in the ceiling or on the wall).
- c) *Power over Ethernet (PoE)*. IEEE Std 802.3AFTM governs PoE standards and is used to supply power over the copper unshielded twisted pair (UTP) cabling that supplies data connectivity to the access point.
- d) *Proprietary power*. Several manufacturers have deployed systems similar to IEEE Std 802.3AF, but that do not comply with the standards themselves. These systems are proprietary to the individual manufacturers, but are similar for the purposes of describing the distribution and provisioning of the electrical components.

Carefully define which approach to use before starting design. Each scenario has associated benefits and trade-offs. In the centralized approach (as well as the proprietary or PoE approach), the power required is centrally located and typically less expensive to provision. However, the heat generated by centralizing the equipment needs to be removed. PoE components can generate as much as four times the amount of heat as non-PoE components. From a mechanical/cooling perspective, this should be taken into account when designing for the heat loads in the communications spaces.

7.4 Network switching platforms

7.4.1 Introduction

With so many critical applications and services utilizing the network backbone, reliability, bandwidth, and uptime are essential to patient safety, business efficiency, and profitability. Design the network to support the needs of today and tomorrow. As technology officers, information technology (IT) directors, and network engineers prepare their digital infrastructure to meet the mounting demand, several factors should guide their network planning.

- a) Network design considerations
- b) Component design considerations
- c) Environmental design considerations

7.4.2 Network design considerations

The following categories address general considerations as well as specific concepts that collectively protect network integrity. Integration of these items into the network design requirements is a critical step in building a scalable, reliable, and sustainable network.

7.4.2.1 Modular, hierarchal design model

Hierarchal design models dissect the enterprise network into three distinct tiers or layers: access, distribution, and core. The modular design model segments these layers even further into distinct modules based upon function. The combination of these two design models into a single unified format has two advantages. First, its structure allows designers to evaluate how the architecture addresses relationships between the various

functional divisions of the network. Second, it allows network architects to evaluate and implement strategies and policies on a module-by-module basis rather than attempting to tackle the entire enterprise at once. The following illustration (Figure 7-1) demonstrates the most basic representation of the modular design model. Conceptually, the *campus network* module includes client devices, access/distribution/core switches, and servers. The *network edge* module includes firewalls, WAN components, VPN concentrators, and Web and public servers. While outside the bounds of the corporate enterprise, the *service provider edge* module is included in this composite because of design considerations that are directly related to components and features offered by various service providers.

This composite can be divided further into modules based on function, as shown in Figure 7-2. Each module performs specific tasks in the network and may require specific design requirements. Clearly, the fluid nature of most enterprise networks will lead to deployments that cannot be so simply dissected into definite modules. The hierarchal division between *core*, *distribution*, and *access* layer devices is plainly seen in the campus network module. This division is again related to specific functionality that network architects design into each module.

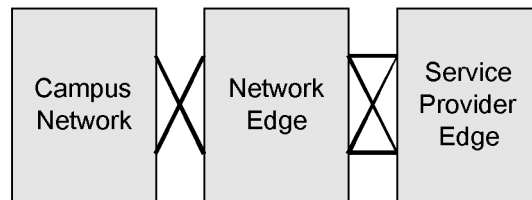


Figure 7-1— Campus network design composite

The network *access layer* module is the point at which end users connect to the network. In most situations, networks users do not have local access to all services (centralized databases, IP telephony, business applications, central storage, internet access, etc.). In these cases, user traffic for these services is switched to the next layer in the model, the distribution module. Switchgear in the distribution module performs internal routing, segmentation, filtering, and security. The primary function of the core module is to provide quick transport to the desired enterprise service.

The application of the hierarchal, modular design model improves an information services group's ability to plan implementations, upgrades, modifications, and troubleshooting. Organized policy distribution, operational efficiency, network reliability, survivability, and maintenance scheduling become measurable tasks that can be evaluated across the network as a whole or as specific modules. Utilization of the model allows engineers to treat network traffic as a measurable and predictable network entity rather than an obscure anomaly.

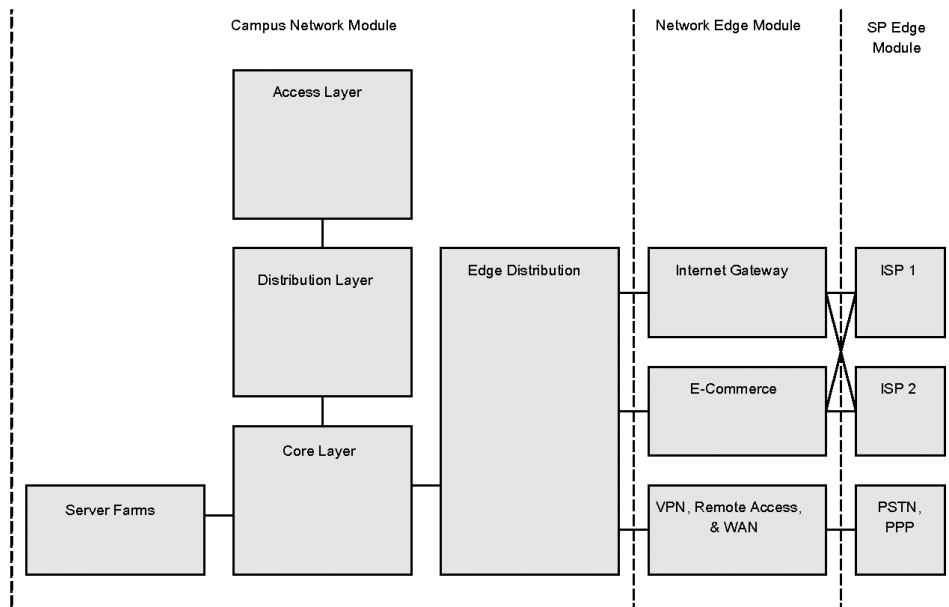


Figure 7-2—Campus network design detail

7.4.2.2 Service provider redundancy

The concept of network redundancy can be summed up with the simple phrase “two paths to any location.” This practice is regularly implemented throughout the campus network and network edge modules, but is only rarely in the service provider edge module. Carefully crafted redundant paths through the network funnel traffic back to a single point of failure (SPOF) when an organization engages a single service provider for its Internet services and/or WAN services. Diversification of these services across two or more separate providers moves some of those “eggs out of one basket” and into the protection of redundant failover. This level of redundancy, once considered an optional luxury, is a critical point of reliability for the network.

7.4.2.3 Quality of service

Network designers should evaluate current and anticipated traffic loads to determine appropriate bandwidth for the various modules of the campus network. Typically, the budget limitations and the limitations of technology itself will only allow for uplink capacities that meet the average bandwidth requirements. For the most part this will provide sufficient transport services for network applications that are not noticeably impacted by latency. However, if network capacity is reached or exceeded, data packets will be delayed or even lost. Nothing could be more disastrous for time-sensitive applications such as VoIP or other streaming media.

Implementing quality of service (QoS) issues priority to certain traffic types. These priorities can be assigned by network address, application type, network user, etc.

7.4.2.4 Virtual local area network implementation

Intended to divide network broadcast domains into smaller, manageable segments, campus-wide virtual VLAN deployments provide several benefits when carefully designed and implemented: security, segmentation, and flexibility. By grouping select users into a common broadcast domain regardless of their physical location, VLANs improve performance and security by controlling broadcast traffic propagation.

While the benefits of VLAN implementation are clearly known throughout the technology community (layer 2 connectivity between devices located in the same populations of interest, dynamic VLAN implementation based on network authentication, and centralized access control configurations), it does have downsides to consider when planning for deployment including scalability limitations and troubleshooting complications.

Both downsides relate directly to a lack of hierarchy when using campus-wide VLANs. VLANs can be a helpful tool in managing security and traffic flows, but they should be carefully integrated into the hierarchical, modular design model. This combination harnesses the benefits of VLANs with the scalability and manageability of multilayer switching. An alternative to enterprise-wide VLAN segmentation is network subnetting.

7.4.2.5 Network addressing (subnet design and implementation)

Breaking the campus network into smaller segments, or *subnets*, makes network address use more efficient. This process, called *subnetting*, consists of dividing large address networks into smaller networks. Subnetting requires routing functionality throughout the network but represents the foundation of designing a multilayer, hierarchical network. Designing the campus-addressing framework can be a painstaking process involving a thorough evaluation of current addressing needs as well as anticipated growth, stretching available network addresses to meet the demand (*supernetting*), and balancing host address requirements with network addressing requirements.

7.4.2.6 Traffic load balancing

Rollover redundancy requires a link, while providing failover protection is a complete waste of potential bandwidth. Introducing a load balancing policy into the campus network, network edge, and service provider edge modules can distribute the full weight of traffic loads across these redundant links. Failover redundancy is preserved and all available bandwidth is now used. Standards and provisions for implementing load balancing vary by manufacturer and should be closely considered when developing such a policy.

7.4.2.7 Bandwidth planning (calculating over-subscription)

An essential step in predicting and relieving traffic congestion is calculating over-subscription ratios at specific points in the network where bottlenecks occur. Congestion can cause packet loss because of improper or even unknown over-subscription ratios. These ratios are derived by adding the potential bandwidth requirements of a particular path and dividing the total by the actual bandwidth of the path. Allowing a link to have less bandwidth than required to sustain a peak load recognizes that average bandwidth utilization is much lower than the maximum. An acceptable over-subscription ratio is typically about 3:1.

For example, a switch with 24 10/100 Mb/s ports has a total of 2.4 Gb (or twice that at full duplex) of potential bandwidth. This potential bandwidth needs to have access to the network core. If that switch were equipped with a single gigabit Ethernet uplink, 1 Gb (or 2 Gb full duplex) of actual bandwidth is available to the core. Obviously, the switch is oversubscribed: 2.4 Gb potential bandwidth vs. 1 Gb actual bandwidth to the core. However, the resulting ratio is 2.4:1 and well within the acceptable range for over-subscription.

The following ratios are advised to avoid congestion from over-subscription:

Access layer 3:1

Distribution layer 2:1

Core layer 1:1

Servers 1:1

7.4.2.8 Uplink redundancy

Designing fault tolerance into the network involves extending the redundancy fundamental to every level. Fiber and Ethernet switch uplinks are no exception. Each switch requires two routes to the core. The core, in turn, should have two routes to the service provider edge. See Figure 7-3 for a single-line diagram of such a topology.

7.4.2.9 Security brief

General security considerations include complex password protection on all network equipment, intrusion detection systems, network management systems, “light ’em as you need ’em” port activation policy, stringent lock down of unused remote access features on network equipment, and granular file and directory access policies. Security implementations should be planned and coordinated in accordance with the *network global security policy*. This policy defines the parameters, policies, objectives, and operations of tech staff with regard to managing network access, password formatting, data encryption, parameter defense, disaster recovery measures, and breach detection.

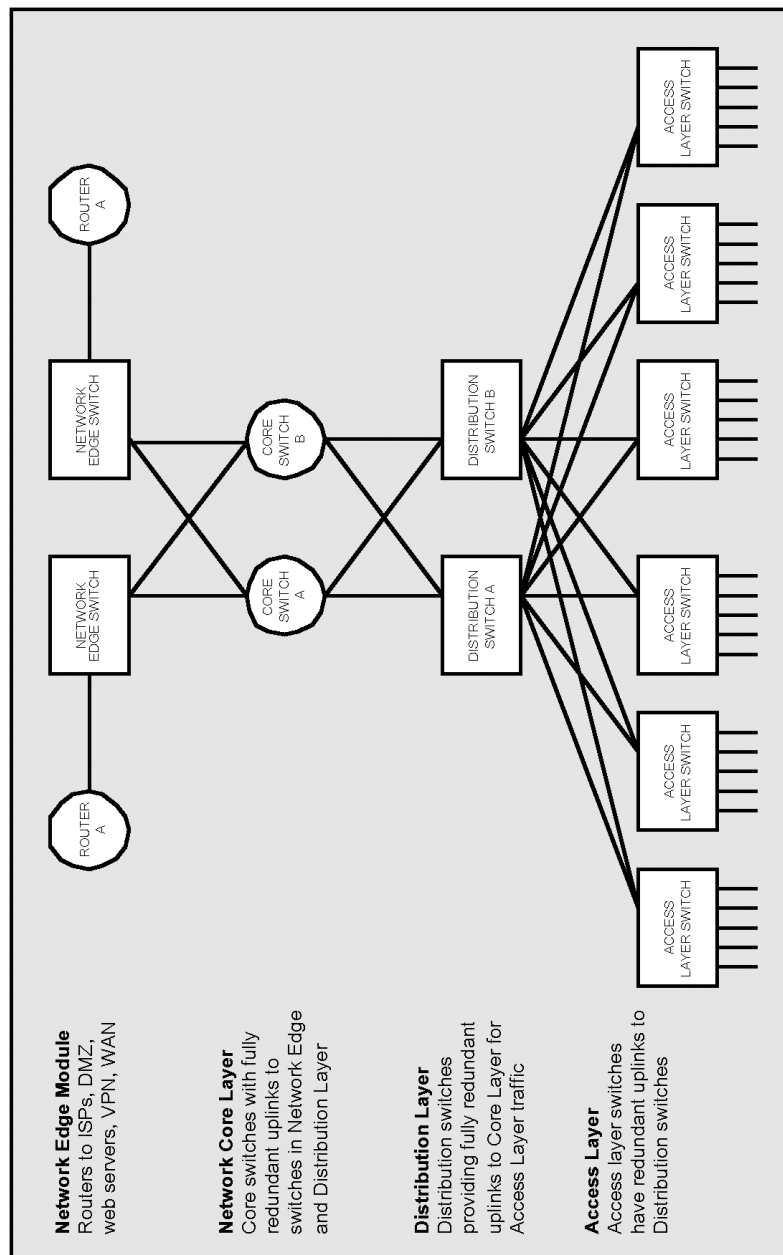


Figure 7-3—Network redundancy model

7.4.2.10 Voice over IP

Traditional issues related to VoIP are network latency and network reliability. Reliability of the network is essential for transportation of voice traffic across the network. Network design, component selection, and maintenance should all focus on maximum uptime so that no applications experience data loss. Assuming the network operates reliably, it may still experience latency. Latency means traffic load is reaching over-subscription levels and uplinks to the core cannot accommodate the full load of traffic. Data packets here experience delays. This delay period is called *latency*. Not all applications are time-sensitive, but voice is time-critical. Implementing QoS in a properly designed environment by marking voice traffic as high priority will ensure that even when uplink capacity is exceeded, priority traffic will always be forwarded first.

7.4.3 Component design considerations

Evaluation, selection, and implementation of the network's active components involve several distinct considerations: holistic function of the device, device and modular redundancy, and equipment specifications.

7.4.3.1 Device function

Thus far, this chapter has approached key topics such as redundancy, addressing, reliability, and load balancing from a high level view of the various modules in the network. The following subclause will address these topics and others specifically to the various active components of the network. The network components will be located within the distinct network layers. Consequently, some review seems appropriate.

As described earlier in the chapter, hierarchical networks are built upon three layers. Each layer is designed to perform particular functions and consequently may include equipment with various levels of performance and complexity. Figure 7-4 indicates these network layers.

7.4.3.1.1 Access layer

As the name implies, the access layer is the point at which end users connect to the network. In cases where requested resources are available locally, traffic is confined between the user, resource, and switch. In most networks, the majority of network resources (such as centralized storage) are not available locally; VoIP call managers, Web access, and global databases. In these cases, user traffic for these services is directed to the next network layer, the distribution layer.

7.4.3.1.2 Distribution layer

Marking the point between the access layer and the network core, the primary function of the distribution layer is routing, filtering, security, WAN access, and network segmentation. This layer provides policy-based connectivity, because it determines if, how, and when traffic can access the core. After determining the quickest way for a user request to be forwarded to the respective server, the distribution layer chooses the path and

forwards the request. The core, in turn, quickly transports the request to the appropriate services.

7.4.3.1.3 Core layer

The core layer, otherwise known as the *backbone layer*, switches traffic as quickly as possible to the appropriate destination. The fundamental design criterion for the core is speed. Typically, the core consists of high-performance, multilayer switches supporting redundant management modules, hot-swappable interface modules, and passive backplane. Reliability is critical at the core.

Many networks combine the functions of the core and distribution layers into the same network switching equipment. Commonly referred to as a *collapsed core* topology, this configuration can be a superior design model depending upon the specific applications and services that are being provided across the network.

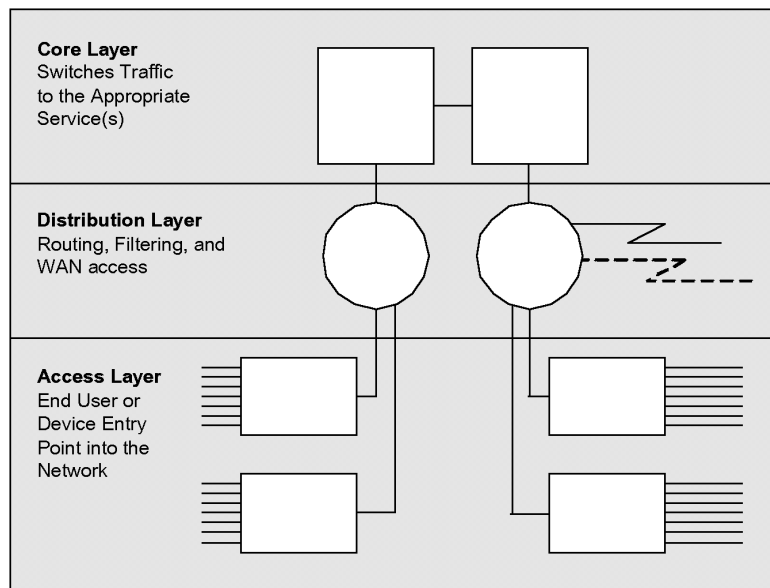


Figure 7-4—Hierarchical network layers

7.4.3.2 Redundancy

7.4.3.2.1 Redundant routers and switches

Switching and routing equipment should be redundant to provide fault tolerance to mission critical applications and resources. If a core switch fails, the network will effectively go down. If a distribution switch fails, an entire floor of a hospital will lose network connectivity. Given the paramount importance of these devices in providing services, the design should provide for redundant equipment. Not only is equipment

redundancy effective in mitigating downtime, it allows network engineers to perform software upgrades and routine maintenance without disrupting network connectivity.

7.4.3.2.2 Redundant switching modules

Advancements in switching equipment have introduced the increased performance of multilayer switches to the LAN. Switches with router functionality now deliver traffic to network segments with the complexity of a router and the raw speed of a switch. This extended functionality is made possible by installing routing modules into certain switch chassis. Redundant modules are critical. If the route module were to fail, traffic will not be forwarded.

7.4.3.2.3 Redundant power supplies

Providing more than failover reliability if a power supply unit fails, redundant power supplies can plug into separate UPS units. This extends reliability beyond a single UPS. Additionally, UPS units should be attached to separate circuits to further enhance reliability of the power source to routing and switching equipment, servers, and critical workstations.

7.4.3.3 Equipment specifications

Performance specifications for equipment vary as greatly as the number of available products. Network planning involves balancing reliability, speed, application requirements, and security. Vendors provide a wide variety of equipment to meet this challenge. Equipment features vary greatly and many so-called “benefits” increase cost while delivering moderate benefit. The following items are features that deliver measurable benefit.

7.4.3.3.1 Modular components

Equipment architecture based on modular chassis allows engineers to customize based upon the specific needs of their network. Hot-swappable functionality provides for module installation and configuration without having to power down and restart the switch.

7.4.3.3.2 Non-blocking architecture

Device capacity, which can be limited by hardware architecture, is crucial in network design. Network switches can be blocking or non-blocking. In terms of capacity, blocking architecture cannot meet the full-duplex bandwidth requirements of its ports, resulting in packet loss. Non-blocking means that the device’s internal capacity matches or exceeds the full-duplex bandwidth requirements of its ports and will not drop packets due to architecture.

An example might be a device with 1.2 Gb of backplane capacity. If it has 48 10/100 Mb/s Ethernet ports, the backplane could not handle the 9.6 Gb of full-duplex

input capacity because it is a blocking architecture. The backplane could only support six 10/100 Mb/s ports equaling 1.2 Gb full duplex.

7.4.3.3.3 Wire-speed routing

Traditional software-based routers forward traffic in the 500 000 packets per second range. Layer 3 switches forward up to 48 million packets per second. Although both route packets, the integration of forwarding using hardware-based application-specific integrated circuit (ASIC) technology is the key differentiator between layer 3 switches and traditional software-based routers.

7.4.3.3.4 Quality of service

Particularly when considering a migration to IP telephony (VoIP), network switches should be capable of prioritizing traffic and forwarding appropriately. Voice applications are extremely time-sensitive, and network latency will create poor quality voice signaling or congestion will cause packet loss. Selecting equipment that uniformly supports QoS features prepares the network for handling voice traffic.

7.4.3.3.5 Diverse protocol support

Large hierarchal networks can develop complex network addressing structures with equally complex route mapping. Enabling the network equipment to dynamically and intelligently determine best traffic routes makes for a scalable and lower maintenance network. Equipment selection should include a thorough evaluation of configuring routing protocols [such as open shortest path first (OSPF)] into the network architecture. Additionally, this equipment should support security and management protocols that will lower operational upkeep costs, improve return on investment (ROI), and provide flexibility as the network grows.

7.4.3.3.6 Port density

When totaling the number of ports found in the entire network, the vast majority will be in the access layer. Many of these are not even used, but are necessary to provide connectivity to new client devices as they are deployed on the network. Fixed chassis equipment is typically installed because of lower cost per port.

7.4.3.3.7 In-line power support

PoE is a tremendous tool for various applications, particularly VoIP phones and wireless access points. However, with vendors providing various proprietary flavors of PoE, network planners should determine compatibility of equipment purchased. IEEE Std 802.3AF has quickly become the industry standard, but some proprietary equipment is still available. In many cases, PoE functionality can integrate into the switching equipment. In cases where existing equipment does not support PoE or cost-per-port increases are too high, rack-mounted power-injection systems can be used to inject voltage onto select horizontal cabling.

7.4.4 Environmental design considerations

Networking equipment represents a substantial investment of capital as well as the significantly greater cost associated with network downtime. Downtime can mean the difference between life and death in certain situations and most certainly represents lost revenue in most other situations. Environmental planning for the rooms that will house this critical equipment is as important as the network design itself. The specifics of environmental planning will vary by organization and location, but several guidelines can be consistently applied to most network installations.

7.5 Telephone systems

7.5.1 Introduction

A health care facility's telephone system, at its most basic level, is an extension of the global public switched network. It provides two-way access between the facility and the rest of the world. But the telephone system can furnish and connect to a wide array of services that augment the usefulness of the basic telephone.

Telephone services have several forms. Switching devices range from VoIP to the electronic key telephone system (EKTS), through the private branch exchange (PBX) system, to the central office. The EKTS, hybrid, PBX, and VoIP systems usually reside in the facility (or on the campus) that they serve. The central office consists of utility equipment and usually resides some distance from the facility. The feature list of each system type is long. Each system type best serves a specific set of criteria.

7.5.2 Design criteria for telephone systems

Many health care institutions use a portion of their resources to market themselves to the public. A prospective client's first contact with the institution is often by phone. Therefore, the telephone system should furnish, among other things, an effective channel of communication from the public to the appropriate hospital staff. Though the general goals of each system vary for the particular institution, the engineer should consider:

- a) Efficient and gracious handling of incoming calls, especially for first time callers, information requests, and people in need of medical assistance.
- b) Providing easy-to-use patient telephone service. This may involve collecting billing information for long-distance calls.
- c) Providing access for visitors to the public network. This is typically accomplished by providing free access for local and credit card calls, especially near family waiting rooms, etc.
- d) Providing an efficient communication base for administrative and operations staff.
- e) Providing access to the public network for personal use by staff.
- f) Being a platform for connecting with telephony-related auxiliary systems, such as voice mail, FAX distribution, and call center systems.

- g) Performing as a simple computing station for access to Web-based data processing services on local or World Wide Web servers (IP telephones).

7.5.3 System types

7.5.3.1 Voice over Internet Protocol

VoIP telephone systems are currently available from virtually every traditional PBX manufacturer as well as a few computer-networking manufacturers that never made traditional telephone systems. The use of the term *Internet Protocol* (IP) in this name does not mean that the system is connected to, or is dependent upon, the Internet. It only means that the data packet transmission protocol that is used on the Internet is the one that is used to route telephone conversations in a private VoIP telephone system.

As of 2004, the cost of VoIP telephone systems became almost exactly equal to the cost of traditional directly wired telephone systems, in most cases. The cost issue will continue to swing to the advantage of the VoIP systems. However, there is more than the direct initial cost of the telephone system to consider. Many health care organizations have fairly large telephone administration and maintenance staffs, which are not in the same organizational lines as the data processing/networking part of the organization. To successfully operate a VoIP telephone system, it is absolutely essential to have an integrated telephone and data-networking support organization.

A VoIP telephone system will use the organization's LAN to make voice connections between telephones and the common switching equipments or *servers*. One or more of the servers in a system are designed to function as *gateways*. Gateways have port connections on them for the same kinds of trunks that typically connect PBXs to the telephone company central offices [i.e., T-1, direct-inward-dialing (DID), integrated services digital network (ISDN), or analog central office (CO) trunks].

A major advantage to VoIP telephony is that "off-premise" locations can have telephones that simply plug into the LAN at the remote location, and do not require "tie-lines," remote switches, or separate "off-premise extension" loops rented from the local telephone company, to connect those locations. There are reliability and backup issues to deal with when taking advantage of this capability.

Security can be a concern with VoIP telephone systems, both with respect to the possibility of hackers "eavesdropping" and the possibility of computer viruses that can cause *denial of service* (DoS). In the latter case, a virus creates so much traffic in the network that calls cannot go through. All telephone manufacturers, and most system vendors as well as qualified user network engineers, know how to protect against these effects. VoIP systems do require a higher degree of network redundancy, backup power provisioning, and discreet maintenance scheduling than are found with many data networks that do not support telephony.

A successful VoIP telephone system requires the implementation of a network feature called *quality of service* on the owner's LAN/WAN system. This feature gives priority tags to voice and other forms of communication (such as video) that allows the most

critical communications to pass first when the circuit is near traffic saturation. This feature is analogous to HOV lanes in a freeway system. Without it, voice conversations in a VoIP system can be broken, or connections can be lost. Conversely, the delay to data communications in these conditions is very slight and unnoticeable.

7.5.3.2 Private branch exchange

The PBX system includes a broad range of sizes. Depending on the manufacturer, they may economically serve from 40 to 20 000 telephones.

Most PBX systems provide support for proprietary digital telephones, simple analog phones, and VoIP phones. The first two types require copper cabling directly from each phone to a port on the PBX frame, whereas VoIP phones connect to an Ethernet LAN, which connects to the PBX central components through an IP gateway. Proprietary digital multi-button (sometimes called *electronic set*) telephones and VoIP phones provide direct access to features via the buttons. Some of these also use liquid crystal display (LCD) to reflect feature selection steps or to present back information to the user from remote information servers. In health care facilities, especially in-patient hospitals, the owner may wish to equip patient beds with the simple analog phones for two reasons: patients can use them more easily without special training or instructions, and they are sufficiently inexpensive that the telephones themselves can be discarded after serving patients where there may be concern over infections.

The basic capacity of a PBX system is described in terms of several parameters. The number of station lines corresponds to the stations required to serve the facility. Attendant consoles are counted separately from other stations. The number of trunks should support the volume of calls to and from the public switched network whether local or long-distance calls. Services like PA paging, radio paging, and dictation have specialized interfaces to the system.

7.5.3.3 Electronic key telephone system

The EKTS is a direct logical replacement for the outmoded mechanical key system that was common in many health care facilities into the early 1990s. The EKTS serves from 2 to 80 telephones. EKTS functions have been replaced in the marketplace by hybrid PBXs and small-scale VoIP systems.

These are compact, feature-laden telephone systems. They only lack the ability to expand into larger systems. The EKTS and hybrid systems are easy to use and therefore often serve departments within a larger facility, themselves being connected to PBX or central office switching equipment.

7.5.3.4 Hybrid systems

The hybrid system, between the EKTS and the PBX both in features and size, serves from 20 to 400 telephones. The hybrid system attempts to maintain the ease of use associated with the EKTS via push-button access while adding the support required for small PBX systems. Some of these systems actually have a PBX mode and an EKTS mode, but do not

allow both types of services at an individual instrument. This combination can be advantageous in regard to a couple of features listed in 7.5.4.

7.5.3.5 Central office switching

Central office switching serves systems from 1 to 10 000 or more telephones. Central office packages provided by local telephone utilities can be tailored to look like local PBX systems. Currently, central office type systems are available in both “digital” (directly wired) and VoIP types of service. The latter may use simple telephones for the voice conversation, controlled by computer programs (application clients) in an associated workstation computer, or actually run voice through the computer’s sound card. Such services may be offered by traditional telephone companies [known as *incumbent local exchange carriers* (ILECs)], or by other technology service companies known as *service providers*. This arrangement leaves the provider responsible for system maintenance, and the server system is normally shared by many customers. This arrangement allows much more effort to be put into system reliability components. Central office switching is a viable option for many institutions.

7.5.3.6 Instrumentation

Telephones come in many flavors. The simplest single-line telephone, with its keypad, will run on most systems, but may not be able to access all of a system’s available features. Buttons, lights, speakers, digital readouts, headphones, computer terminal displays, and slow-scan video are available in varying combinations on the ascending ladder of instrument cost. Many of the features of a particular instrument depend on the equipment it is connected to. Most instrumentation is proprietary and will operate only with the equipment for which it was developed. The instrumentation available with a particular system will often determine its applicability in an installation.

7.5.4 System features

The list of available telephone system features may be 300 items long. The following features are but a small selection, chosen to highlight a few design issues and to help differentiate the system types previously outlined.

7.5.4.1 Speed dialing

Simply dial a code or press a button, then dial a shorthand number to place a commonly made call. Many instruments will dial five or ten common numbers at the touch of a single button. Most systems offer speed dialing. It saves time, and falls under the general category of efficiency. On systems that integrate with the computer network, a user may be able to dial telephone numbers from a workstation computer by simply clicking on an entry in the computer directory.

7.5.4.2 Intercom

Telephonic intercom describes the ability to dial a number and ring another person on the same switching system. Usually the number is short (2, 3, or 4 digits). Intercom

instruments have an item not found on a standard single-line telephone: a speaker separate from the handset. (In fact, some intercom instruments have no handset.) Many health care organizations have stand-alone loudspeaking intercom systems that are confined to specific areas such as nursing areas, intensive care units/coronary care units (ICU/CCUs), etc. These allow quick calling to a desired party, and the desired party can answer without having to go to a set. On some telephone systems, a telephone can have a speaker that serves as an intercom station, allowing the called party to answer without touching his or her handset (i.e., hands are free). Loudspeaker auto-answer systems can sometimes present patient security issues, which have to be considered and mitigated.

7.5.4.3 System interconnection

From a telephone instrument staff might be able to leave dictation, perform a PA voice page, or send a code to a pocket pager. Most systems have these capabilities. These connections add to the telephone switch load, tie up telephones and, if not specifically controlled, allow universal access to special services. Most telephone systems respond to these concerns, including the ability to control access to special services.

On more modern telephone systems, equipped with capabilities described as *unified messaging*, extensive interconnection occurs. A call may come to a telephone where the user is unable to take the call and proceed to that user's voice mail box. The message that is left is turned into a *wave* (.WAV computer file) and sent to the individual's e-mail address, where it can appear on a desk or laptop computer, and also on the user's portable PDA. If the caller's telephone number is in the called party's directory, the e-mail message subject will carry the person's name. Similarly, a FAX message sent to the user will appear as an e-mail message on the user's computer, eliminating the need for human delivery of paper FAX, and the delivery delays associated with that method.

7.5.4.4 Multiple- and automatic-attendant answering

In larger facilities, multiple-attendant positions might need to handle incoming calls. Most systems support multiple-attendant consoles and alternate answering locations, but some can only support small numbers, such as 2 or 4. A facility's communication needs should be reviewed so that specific switches considered for purchase will accommodate these needs and not present limitations that could make the switches obsolete.

Attendant answering functions can also be handled through automatic call distribution (ACD) systems, passing each arriving call in turn to the attendant who is available first. These systems also permit "auto-attendant" functions that give callers prerecorded information about commonly asked questions, so callers do not have to wait for the availability of an attendant. These systems also permit predirection of callers to those attendants or agents who are best equipped to answer specific call requirements.

7.5.4.5 Direct inward dialing

DID is a mechanism for calling an individual telephone (or department attendant) instead of the main operator. DID is available on PBX systems, on most hybrid systems, VoIP, and via central office switching. This feature can provide the public direct access to

several locations in the facility without having to burden the main operator with every call.

7.5.4.6 Voice mail

Voice mail resembles a large answering machine, except that users can access it remotely (by both sending and receiving parties). This tool is excellently matched to simple message passing between people on different time schedules. Some people love it; however, it should not be applied in situations in which an urgent message might be slowed, nor should a person new to the system be automatically connected to voice mail (especially a public call). Measure the use of each tool against the general goals of the system.

7.5.4.7 SMDR and SMDA (CDR)

Station message detail recording (SMDR) and station message detail accounting (SMDA) allow larger systems to track and record telephone use and produce cost accounting reports reflecting telephone activity. The feature may also be called *call detail recording* (CDR). The reports may include sufficient detail to allow assignment of telephone expenses to patient accounts. All system types can support these features to varying degrees. Generally SMDR/SMDA/CDR features run on an optional microcomputer connected to the switching equipment. These are management tools that aid in both monitoring the effectiveness of the system and furnishing a metered service to patients. Many modern systems have “Web-based” operation and interface, so they can be accessed by anyone with a computer Web browser and the proper password.

7.5.4.8 Automatic route selection

Supported by PBX systems and by some hybrid systems, automatic route selection (ARS) uses a data reserve to select long-distance call routes that minimize long-distance bills. This feature reflects the need to consider the total system, including utility connections and usage patterns, when analyzing the economy of various systems.

7.5.4.9 ISDN compatibility

ISDN is a standard interface description for utility connections. ISDN is becoming the standard for health care trunking because it offers several unique features. These include text messages identifying the calling party and better integration of voice and data services. More importantly, it allows outgoing 911 calls to be identified back to the location of the specific calling extension. In many areas, local law requires this kind of alarm. Every large PBX should be ISDN-compatible. The communication needs of a health care facility will change. They will likely include a higher level of data services in the future. The selection criteria of any large PBX should include provisions for data services and compliance with the latest industry transmission and signaling standards.

7.5.4.10 Tandem switching

This is the ability for one PBX to talk with another (usually of the same manufacture) so they appear to operate as one switching system. This capability can allow an effective growth path and can provide an economical solution to cable plant design in large complexes. In the past, this capability was enabled through the use of E and M or T-1 tie-lines between the systems. On current systems, the most efficient communication between systems is accomplished by IP, which can run over T-1 line(s) or be integrated with the organization's data network connections between locations.

7.5.4.11 Remote diagnostics

Many vendors can provide maintenance and programming assistance from the vendor's site. The alternative to this is the purchase of a maintenance terminal for a PBX, although many systems connect this capability through a *Web browser*. Some systems furnish maintenance operations through an attendant console terminal. Remote diagnostics are especially effective with mid-sized systems where it may not be economical to purchase a maintenance terminal. The system selection should include a review of maintenance and change procedures in light of ease of use. Some systems come with step-by-step on-screen menus, including all maintenance functions.

The issues of maintenance and reliability blend. Battery backup associated with a telephone switch is generally an inexpensive (and worthwhile) option for those types of equipment using battery voltage directly. Other systems may require the use of a UPS. With either type of backup power, the owner should provide a documented process of routine maintenance and testing to assure that the backup power system is capable of supporting the telephone system in a real emergency.

Other means of increasing reliability include redundant common control, essentially a duplication of the switch logic circuits. Redundant common control is a pricey option, but it is found on some large PBX systems and on many central office class switches. On VoIP systems, engineers usually specify processors.

7.5.4.12 Wireless telephones

Almost all available telephone systems have wireless sets that can augment or replace traditional desk telephones. In health care facilities, nurses, security staff, and others who need to have continuous access to telephone service while roaming the various locations of the building will find the wireless devices much more useful than the desk-mounted devices.

There are two types of wireless phones: those that require a dedicated cable and antenna plant, and those that run over a mobile data communications network, meeting the requirements of IEEE Std 802.11a™ or IEEE Std 802.11b/802.11g [B6]. Use of the latter is advancing rapidly, but requires the basic telephone system to be capable of a VoIP gateway to the network of IEEE 802.11 wireless access points (WAPs).

Wireless phones requiring a dedicated wiring plant with unique antennas are usually proprietary to the make of the PBX, although some generic systems can connect to any PBX analog line. (The latter only provide those features at the wireless phone that can be associated with an analog telephone line.) All of these systems require a network of radio transmitting and receiving units with antenna at intervals throughout the area of the building requiring service. Each receiver/transmitter/antenna unit can support either three or four simultaneous conversations. The maximum range of the radio devices (generally about 22.9 m to 30.5 m (75 ft to 100 ft)) determines device maximum spacing intervals. Locating the devices more closely spaced will allow more conversations within a given geographical area of the building.

Newer available wireless telephones can work as local PBX extensions while in range of an authorized wireless LAN system but become cellular or personal communications service (PCS) phones on commercial networks when they go out of range of the WLAN. The PBXs monitor the presence of the phone on the WLAN and associate the extension number to the 10-digit public number of the mobile service employed. This permits calls to the individual's PBX DID number to reach the intended receiver wherever he or she may be.

Some wireless telephones can have the same telephone number as a desk phone of the user; others require separate phone numbers and the use of forwarding or call transfer arrangements.

If wireless telephony is, or will be, a major part of the owner's communications plan, then the designer should select a telephone system with the ability to support these features.

7.5.5 Telephone cable plant and support structure

A complete system for telephone facilities in a building includes provisions for the entrance cables, the main terminal and equipment room, the riser cable system, the distribution cable system for each floor, the cable distribution terminals, and the station cabling. Refer to EIA/TIA standards in 7.22 for proper design of cabling and pathway regardless of the specific tenants or type of telephone equipment being proposed.

7.5.5.1 Service entrance cables

Service entrance cables are the telephone company's cables that cross the owner's property and enter the building. The type and location of the service depends upon telephone company distribution facilities, local practices, and codes. Telephone companies normally prefer underground cables. In most localities, the owner's contractor will need to provide the conduits for the service. Some areas may permit direct buried service. In this case, the owner's contractor will provide the necessary trench work. Some areas require a utility easement for buried service.

The number of telephone lines, including provisions for future, will determine the size and number of entrance conduits required. For most systems, a 10 cm (4 in) conduit for every 13 935 m² (150 000 ft²) of usable floor space with a minimum of two conduits is recommended. Good practice is to install at least one spare conduit.

Most current installations now also need provisions for fiber-optic cables as part of the service to the building. These cables are smaller than traditional twisted pair copper telephone cables. Install fiber cables in smaller, dedicated conduits or in inner duct (protective tubes) within larger ducts.

Include a means of bonding and grounding cable inside the building. At the openings for cable entrances, seal around the installed conduit to avoid penetration of the water barrier by water and gas, and to avoid service interruption from flooding or equipment damage from dampness.

7.5.5.2 Communications equipment room

The building's communications equipment room (CER) is the heart of the building's communications system. This room will be the main demarcation point between the telephone company central office and the facility's telephone system. The entrance cable usually runs directly to this main terminal room.

Use conduit from the service entrance to the main terminal. Conduit simplifies future additions and protects the service cable. For some types of cable, codes require metal conduit.

Communications staff need ready access to the terminal room at all times. Locate the room as close as possible to the center of the riser-cable distribution facilities. The room should be well lighted, cooled, ventilated, and equipped with electric outlets. The room requires adequate floor support for heavy terminal equipment. This room should be used only for communication equipment, and it should have some sort of access control. More and more health care facilities install CCTV cameras in their IT spaces to better monitor the actions of various vendors who enter the space.

The main terminal room [here, *communications equipment room*, known in other standards as the *main distribution frame* (MDF)] will contain the utility demarcation point. Telephone utilities will route their cables from the central office through protective devices to terminations on special jacks called the *network interface*. These jacks form the boundary between the utility and the premises distribution system. The utility normally installs and owns the cable terminals and cable protectors (surge protection). Surge protection for data and communications cables may be required within the premises in addition to the utility surge protection. The CER may also contain utility-owned switching and transmission equipment. It contains terminals for the building (or campus) owner-provided distribution cables.

For large installations, locate floor-type main terminals in the CER. The CER needs to be large enough to meet the original telephone service needs and to provide for later installation of additional terminals for growth. Depending upon communication requirements, batteries may have to be installed in or near the CER.

In many buildings involving large, sophisticated installations, large amounts of floor area are necessary to accommodate the complex switching equipment associated with PBX or Centrex telephone services. For early planning purposes, a PBX and main distribution

frame require the larger of a 2.4 m to 3.7 m (8 ft to 12 ft) space or 0.2% of the gross floor area to be served (including expected future growth). Carefully design the room to accommodate the required PBX and Centrex services. PBX equipment can require as little as a 20 A, single-phase, dedicated circuit or as much as an 80 A, three-phase connection. Provide this power from the life safety system if it is used for emergency communications, or from the critical system if not. The room should be as clean as possible and located in an area not subject to dampness or flood.

Smaller buildings may use wall-type main terminals. Each of these terminals provides connections for the desired number of pairs of cable for voice and data equipment.

The CER may contain switching equipment or services, in which case the room's environment and electrical services should accommodate the PBX or servers.

7.5.5.3 Riser systems

The riser system is the backbone of the building's telephone network. It allows facilities to bring cables from the main terminal room to the various floors of the building.

The riser cables should route through riser conduits or sleeves depending upon the relative location of riser closets. Local codes may determine the appropriate protection based on fire protection or other considerations.

Telephone cable used for risers is generally multi-pair #24 AWG copper wire with an overall sheath. Such cabling has nominal pair counts of 50, 100, 200, 300, 400, and 600 pairs. Size the riser cable to serve the worst-case scenario for growth and change. Usually hospitals require fewer telephones per floor area than office buildings. Medical office buildings (MOBs) (or floors within a hospital) may require more devices since telephone sets may appear in each exam, conference, and office space. Generally three pairs of riser cable for each 13.9 m² (150 ft²) of hospital gross floor area will handle telephone requirements. So, for example, a closet serving 1858 m² (20 000 ft²) would require a 400-pair riser cable. The riser count will be considerably smaller if the facility uses VoIP telephone systems, as all the VoIP phones will connect to Ethernet switches rather than copper telephone pairs. Even with VoIP phone systems, however, some copper telephone distribution should be installed to support miscellaneous services that cannot currently be supported over VoIP transport.

7.5.5.4 Apparatus closets

The risers will bring signals from the CER to a set of telecommunications rooms (formerly called *intermediate distribution frames*, or IDFs). Most facilities use 4-pair cable from the station terminals in the telephone closets and terminated in a standard wall jack for horizontal telephone distribution. Because of the impending convergence to VoIP telephones, new buildings and remodeled areas should always be equipped with uniform cable plants, of the type required for LANs. Terminate those horizontal cables in TRs on rack-mounted panels of 4-pair modular jacks (RJ-45). Use suitable cross-connect cables to connect to telephone riser cables. These cables will have RJ-45 plugs on one end and connectors matching the terminals on the other. In some cases, organizations may wish to

segregate cables intended for voice and data, and use different colored jacks or icons to identify the cable usage at the outlet. Both voice and data cables, as well as TV distribution, may terminate in common “multimedia” outlet plates that will accommodate any type of connector.

Begin by referring to TIA/EIA-568 to size the TRs and cable connections. However, size the TRs to house all electronic signaling systems in the room to support the inevitable convergence of all electronic transport systems to IP. This concept allows the planning of comprehensive spaces for all systems, easy future interconnections, and better economies of backup power and HVAC support for all systems. Many hospital staff fear the notion of putting these services into a single room, thinking that the persons who service these other systems are not on staff of the hospital, and that these people therefore constitute a security threat. However, the many ways to mitigate this potential risk allow the more effective co-location design of these spaces.

TRs also need to be sized to provide wall space (measured horizontally) to support terminals, riser cable, and miscellaneous equipment. Plan about 1.1 m (3.5 ft) of clear wall for closets serving up to 929 m² (10 000 ft²) and 1.8 m (6 ft) of clear wall for rooms serving up to 1858 m² (20 000 ft²).

7.5.5.5 Satellite closets

Some facilities may be able to use satellite closets (smaller TRs). However, facilities will greatly enhance their ability to provide for future needs if the design uses facilities that conform to the EIA/TIA standards for TRs.

Satellite closets (or cabinets) usually do not contain electronic and power equipment. Their primary use is to provide cable-terminating facilities; that is, connecting blocks for station wiring. Existing facilities often demand satellite closets because of the inadequate space of a single apparatus closet to meet increasing needs, or to better serve the physical layout and shape of the building. Closets need a minimum of 61 cm (2 ft) of wall for each 371.6 m² (4000 ft²) of area served, up to the size of a TR (see 7.5.5.4).

7.5.6 Public telephones

Most health care facilities will need one or more public telephones, located conveniently near major paths of travel and where members of the public will congregate in larger numbers. The widespread adoption of personal cellular phones may well make such facilities obsolete. Few telephone utility companies offer pay phone services that are free to the owner. Many nonutility providers will share proceeds in some ways.

While telephone companies may install premanufactured telephone booths at suitable locations, built-in booths with a wide variety of designs, finishes, and colors can often better enhance the appearance of the building. Most phone providers are not prepared to work with the building designers to provide facilities that will harmonize with the interior, so this will become the responsibility of the architect.

Locate public telephones where they will be readily accessible to the general public. There is no reliable rule for determining the most suitable number of public telephones a building will need. The Americans with Disabilities Act (ADA) requires public telephones to be accessible, and it includes height restrictions and clearances around the telephone to permit maneuvering of wheeled, personal assistance vehicles.

7.6 Intercom systems

7.6.1 Introduction

Intercom systems provide direct station-to-station verbal communication within the health care facility. In addition, loud-speaking intercom stations allow these systems to function as voice-paging systems.

7.6.2 Design criteria for intercom systems

7.6.2.1 General

Studies show that a loud-speaking internal call via an intercom system takes an average of 30 s to complete, while an internal telephone call takes an average of 3 min to complete. Moreover, using the telephone handset to make an internal call will block incoming external calls, even though voice lines may be available, since a number of telephones will always be busy on internal calls. It is impractical to use the same telephone instrument to consult with someone else within the facility while using the telephone for an external call. People communicate with brevity and precision when they are aware that others may overhear what is being said. The quick and simple operation of an intercom system as a stand-alone system or as part of the telephone system stimulates frequent use. However, various kinds of wireless handheld devices, not to mention audiovisual nurse-call systems may quickly make these kinds of systems obsolete for most applications.

7.6.2.2 System selection

Many factors affect the type and size of an intercom system, including the facility's size, the traffic capacity required, and whether the system will be localized by department, consist of one large hospital-wide intercom system, or combined telephone intercom systems with stations located throughout the facility.

7.6.2.3 Local intercom systems

Localized intercom systems can provide paging and hands-free answer-back voice communications within a few strategic locations. These systems can work for areas with a central control point for the department, such as a reception desk. Provide a master station with the ability to call and receive calls from any station in the system at the reception desk. Provide staff stations that call and receive calls from a limited number of master stations, elsewhere. If needed, use ceiling speakers driven by the intercom system to provide local paging from the master station. The master station can call each staff station, and each staff station can call the master station, but staff stations cannot call each other.

Local intercom systems were traditionally installed in radiology departments, laboratory, laundry, dietary offices, loading docks, surgery suites, and physical therapy departments.

7.6.2.4 Hospital-wide (multiple master) intercom systems

A health care facility may need its staff stations to be able to do more than simply call one or more master stations. In such cases, an all-master intercom system will work better than a set of local systems described in 7.6.2.3. This system consists of master stations with the capability of calling any other station in the system and conversing hands free at both stations. If needed, the designer can add staff stations connected to a dedicated master station to the system.

7.6.3 System types and selection

7.6.3.1 Multiple master intercom systems

Older facilities may still have hardwired systems, but most new systems are microprocessor-controlled. Some of the possible functions of these newer systems include:

- a) *Restricted access.* Any station can be restricted to operate a limited number of functions, such as paging and group calls, and/or be restricted to call only certain other stations. Within this second restriction, groups of stations may be restricted from calling other groups of stations.
- b) *Audio program distribution.* Stations can select from multiple programs such as radio, weather reports, and taped educational programs. Calls interrupt the audio program.
- c) *Camp-on-busy.* If the called station is engaged, the caller receives a busy signal, and the call remains camped on the desired party number for up to 120 s. As soon as the called station becomes free, the call is automatically set up with normal call tone.
- d) *Automatic recall.* Called station engaged—low-priority call. During camp-on-busy, the caller can request an automatic recall to free his own station for other calls while waiting for the first station to become free. The first call is then established as soon as both stations are free.
- e) *Break-in.* Called station engaged—high-priority call. During camp-on-busy, the caller (A) can break in on the engaged station (B) if the call is urgent. The new call will warn both parties in the original conversation (B and C) by tone. B and C will both overhear the break-in call. (A) can withdraw at any time, leaving (B) and (C) in conversation. (C) can also withdraw, leaving (A) and (B) in conversation.
- f) *Break-in immunity.* Stations with break-in immunity cannot be broken in on.
- g) *Automatic transfer. Number transfer.* A station can transfer incoming calls to any other station so for cases where the subscriber temporarily relocates. Multiple numbers can transfer to the same station. This feature can be used for two main purposes:

- 1) *Secretarial transfer.* Persons who do not wish to be disturbed for a period, or who are not present, can ask a colleague or a secretary to take their calls. During a meeting a secretary can take calls for all members.
- 2) *Follow-me (call forwarding).* Persons who visit other offices can route their calls to any present location. During a meeting, all members can route their calls to the meeting room.
- h) *Conference.* Additional stations can be interconnected for conferencing.
- i) *Group call.* Announcement to a group of stations. A station can call a predetermined group of stations. A group call has priority over other calls. Several groups can be formed in the system (standard up to 10), and each station can be a member of several different groups.
- j) *All call.* Group call to all stations—emergency call. This function can be used for paging people.
- k) *Single-digit and reduced-digit dialing.* This feature allows single-digit or reduced-digit dialing of the most-called stations or of any frequently used feature, such as paging system access.
- l) *Public address (PA) access.* Announcements via PA system. The system can be linked to a PA system for giving one-way messages.
- m) *Page reply.* A paged person can answer the page from any intercom station in the system and be connected directly with the person that originated the page.
- n) *Stored-voice message.* The exchange may connect to a stored-voice message system for voice mail on the intercom system. This system allows callers to leave individual recorded messages both on their own and on other stations to be retrieved when the called party returns.
- o) *Other functions.* For special needs, vendors can usually provide any required functions. Standard features cover most needs, and are, of course, less expensive to incorporate.

7.6.4 Design considerations for intercom systems

- a) *Station locations.* Master and staff intercom stations can be either desk- or wall-mounted. Wall-mounted stations offer the advantage of freeing up desk space, but can create feedback problems if located too closely. Exterior stations should be of weatherproof construction.
- b) *Station handsets.* Areas with high ambient noise may require handsets, which also provide improved privacy. Use handsets sparingly, as they defeat the primary advantage of an intercom system to provide quick, hands-free communications.
- c) *Station grouping in a multiple master intercom system.* Determine paging systems groups during design.
- d) *Station identification.* In a multiple master intercom system with stations installed throughout the facility, a master index of station extension numbers will be required. An easy solution to this need is to have identical intercom station and telephone extension number in the same room. This would save printing two separate in-house telephone and intercom directories or memorizing two sets of numbers.

- e) *Central controller.* Install the central controller in a communications closet. If staff will use the intercom system to provide emergency communications, connect it to the life safety electrical system; otherwise, connect it to the critical electrical system.

7.7 Nurse-call and code systems

7.7.1 Introduction

Nurse-call systems provide a way for patients to signal staff that they need help. Nurse-call systems can also provide staff-to-staff communication. Today's nurse-call systems can operate over the voice/data cabling infrastructure, can be wireless (limited), and can interface with other building communication systems. The power of this integration allows information exchange between nurse-call and other voice and data systems in the hospital. This ability to integrate enables more efficient communication, frees up staff time for other tasks, and reduces medical errors.

Code alarms are the highest level of emergency call in a hospital. When a cardiac arrest or other emergency occurs, the system alerts the person responsible for the delivery of the crash cart to the point of need and notifies the resuscitation team as to the room or area that initiated the alarm. Different hospitals may call this alarm level different things, such as *code blue*, *code 199*, *code 99*, *Doctor Heart*, *crash unit*, etc.

7.7.2 Design criteria for nurse-call and code systems

7.7.2.1 Nurse-call system codes and standards

Health facility regulations require nurse-call systems in hospitals, nursing homes, and psychiatric care facilities. Usually these requirements are minimum standards and the facility's own requirements will dictate the type of system needed and the location of the different components. Regulations do not generally require nurse-call systems in medical and dental offices, medical clinics, and residential care facilities, but even these facilities may need some kind of signal system for more efficient operation. The U.S. Department of Labor Occupational Safety and Health Administration (OSHA) requires that all nurse-call equipment be certified by a nationally recognized testing laboratory (NRTL). One industry standard is UL 1069, which covers the manufacture of nurse-call equipment. Other applicable standards include the NEMA Installation Guide for Nurse Call Systems and NEMA SB 10.

7.7.2.2 Design criteria for code systems

Hospital regulations require a code alarm system. Typically, code buttons (or other initiation devices) are located in intensive care and coronary care patient rooms, emergency rooms, recovery rooms, labor and birthing rooms, surgery suites, and other areas required by the hospital. Annunciators should be located at the central control center so the telephone operator can announce the code alarm either via the PA system, by radio paging, or both. Hospitals also commonly locate redundant annunciators at adjacent

nurses' stations and the anesthesia office. In some hospitals the staff members may want the code alarms from the patient's room to go to the local nurses' station. This arrangement allows local staff to verify that the call is not a false alarm before initiating the call to the code team.

7.7.2.3 Types of nurse-call systems

Nurse-call systems are primarily divided into two basic groups: visual systems and audiovisual systems. A building may use both types of systems. Visual systems use light and tone signals to communicate calls, and audiovisual systems add station-to-station voice communication. Visual systems tend to work best for radiation and therapy departments where voice communication is not needed. Audiovisual systems work best for inpatient units and other areas where voice-to-voice communication is necessary. Networking multiple local systems into one overall system can provide centralized reporting and the ability to answer calls from multiple locations.

Psychiatric nurse-call systems operate as basic nurse-call systems (visual only or audiovisual), but with the added feature of psychiatric grade room devices that, depending on local codes, may have on/off control using keyed switches.

7.7.2.4 Programming specific system requirements

Before beginning the design of the nurse-call system, the designer should confer with staff members to find out how the particular department will operate and to determine their specific communications requirements. The nursing, IT, communications, biomedical engineering, facilities, and whichever department will maintain the system should also be included in the conference to assist with the planning of integration with other communication, data, and medical equipment systems. Many health care facilities will have standardized on a particular nurse-call manufacturer. If so, be sure to consult the manufacturer as well.

7.7.2.4.1 End-user programming

End-user programming involves meeting with the nursing staff or clinic staff to determine and document the operational requirements that are needed by staff for the nurse-call system serving their patient care area. The engineer will meet with different departments to determine their specific needs. However, the add-on features and integration issues will vary depending on how the staff operates day to day and on what other departments with whom they interface outside of their own. For instance, nursing staff in an emergency department where the pace of activity is fast and hectic may place a priority on communicating with doctors and other staff as quickly as possible and may like the option of integrating with wireless or cellular phones. Nursing staff on a patient floor may not need the quickness of wireless phones, but may prefer pocket pagers where more information can be sent as to the specific patient's needs so they can prioritize patient requests. The key is to remember that one size does not fit every department. In order to better facilitate the conferencing, the engineer should have a thorough understanding of the capabilities of the nurse-call systems.

An engineer needs to answer several basic questions to design, including:

- a) *Type of system.* How large is the department and what is the level of acuity of the patients it serves? Will a visual system satisfy the requirements or would an audiovisual system be a better choice?
- b) *Lines of communication and methodology.* Besides patient/nurse communication, who else does staff in the care area need to talk to and where will they be? Which rooms inside the patient care area need to communicate with each other? Can communication by telephone suffice or would a nurse-call system work better? Can the nurse-call system be integrated with the telephone system so they operate seamlessly together? Can the nurse-call system take the place of a local or networked intercom system?
- c) *Call response.* What nurse stations will answer what calls? Are these stations staffed 24/7/365 or only during specific hours? In a hospital, do “swing rooms” need to connect to different nurses’ stations at different times depending on the staffing changes?
- d) *Nurse assist.* In a hospital or psychiatric care facility, which areas require nurse assist or other emergency calls and who will need to receive the calls? Where will they be?
- e) *Redundancy.* In a hospital, do adjacent nursing stations provide backup help in an emergency or when the primary nurses’ station is left unattended? Can incoming calls automatically forward to a nurses’ location or transmitted to the nurse via a pocket paging or wireless telephone system?

Nurse-call systems offer many add-on features including:

- 1) *Staff tracking.* This system uses infrared (IR) sensors located in each room and in corridors to detect badges carried by staff. The system allows someone to determine the precise physical location of each person carrying a badge. The system can automatically cancel a pending patient call and light the corridor light outside the room when a nurse walks into the room. One of the key benefits of this system is the ability to locate or page a particular staff member without having to do an all-call page, thus creating a quieter atmosphere for the patients and family members. Another variation of this system is to use different colored push-button lights, called *staff presence stations*, at the entrance to each space. With this system, the staff should press the appropriate buttons when entering or leaving a space to notify the system what kind of person is in that room. Staff presence stations are considerably less costly than the use of IR badges and sensors, but provides much less data and with much less reliability than the IR systems.
- 2) *Room status systems.* Similar to a manual staff location system, this system consists of colored push buttons placed in each selected room to indicate the state of each room. These push buttons activate a corresponding colored lamp in the corridor dome light and/or annunciate at a central location. One color generally indicates the room is ready for use, another indicates the caregiver is in the room, and a third indicates the room needs cleaning. Some emergency departments and clinics find these systems to be effective.

- 3) *Wireless telephone integration.* Wireless telephones can integrate to the nurse-call system to allow voice communication from the patient to the caregiver, rather than to a charge nurse confined to the unit's nurses' station.
- 4) *Dedicated nurse-call pocket pagers.* Pocket pagers integrated with the nurse-call system allow the system to send text messages to individual nurses to indicate the specific needs of a patient. These pagers can be dedicated to the nurse-call system or integrated with the hospital's pager service. In the latter case, be sure to evaluate throughput time if the pagers will also be used for code calls; some commercial paging services can take up to 90 s to transmit a page.
- 5) *Equipment locator system.* This system is similar to the staff tracking system in that it uses IR badges and sensors, but the badges are affixed to equipment, and software within the nurse-call system can portray what room the particular equipment is located.
- 6) *Equipment alarm annunciation.* Most nurse-call systems have the ability to monitor a set of dry contacts that are part of medical equipment. This feature allows staff to know if a piece of medical equipment is in alarm and where it is. Staff can then address the issue. Most systems use the ANSI HL7 communications protocol and interface. As nurse-call system technology evolves, there will be a greater ability to transfer data to and from information systems, especially as IP based systems evolve.
- 7) *Nurse-call control via integrated bed controls.* Some hospital beds have controls in the sides of the bed with nurse-call buttons and entertainment controls. These beds require a connector plug allowing a physical and electrical connection from the nurse-call system to the bed.
- 8) *Staff scheduling software.* Several nurse-call manufacturers offer software packages that work with the nurse-call system to allow assignment of patients and staff to individual patient rooms. Some such packages can work on a computer or on the nurse-call system.
- 9) *Networking.* Many nurse-call systems need to serve different areas and floors through networking. This arrangement allows intercommunication between departments as well as centralized monitoring and reporting functions.

7.7.2.4.2 Systems integration programming

The power of nurse-call systems can go well beyond the equipment itself. Integration with other non nurse-call systems can leverage the ability of the caregiving staff. Integration/interface requirements will vary by system and brand. Such integration allows a comprehensive facility-wide data and communication system. As various kinds of systems evolve to IP, they will be easier and easier to interface. Nurse-call systems can integrate with the following among others:

- a) *Telephony systems.* The audio communication portion of the nurse-call system can integrate with the facility's telephony or PBX system. This interconnection allows someone to dial a telephone extension from the nurse-call system. This integration can include both hard-wired and wireless phone sets.
- b) *Database systems integration.* Nurse-call systems can interface with database systems such as patient registration, in order to allow all of the systems to form a

single common database, sharing all critical patient information, rather than having to have many separately stored data sets. This kind of interface may require a specialized integrator to determine the specific needs for the systems that requiring integration.

Other systems that can interface to the nurse-call system include the following:

- 1) Pocket pager systems
- 2) Fire alarm system (for alarm annunciation of patient rooms)
- 3) Patient tracking systems
- 4) Patient wandering systems
- 5) Paging systems
- 6) Intercom systems
- 7) Patient entertainment systems
- 8) Bed controls
- 9) Time and attendance systems
- 10) Equipment alarm monitoring systems

7.7.2.4.3 Other requirements

In addition to national codes and NFPA 99, consult local codes to determine specific device requirements. The NEC, Article 517, provides the requirement that nurse-call system equipment is to be connected to the critical branch of the health care facility's emergency power system. The ADA contains some provisions regulating placement of certain wall and ceiling mounted devices.

7.7.3 System types

7.7.3.1 Visual nurse-call systems

Visual systems provide audible signaling and visual annunciation of patient calls. Most systems have at least two call priority levels: normal and emergency. Visual systems work well where patients may be left unattended and may need to call for help, but they do not need voice communication to the staff. These systems may include the following kinds of stations:

- a) *Patient bed station.* A patient originates a call by pushing a button on a cord. These calls continuously illuminate the white section of the corridor dome light and any associated zone lights. They will illuminate the patient call light and sound a slow tone at all duty stations. They will illuminate the patient's room and bed numbers, and sound a slow tone at the master station. Staff can only cancel the call at the originating station.
- b) *Toilet emergency station.* A patient originates an emergency call by pulling a cord. These calls will flash the white or red section of the corridor dome light and the white or red section of any associated zone lights. They flash the patient call light and sound a fast tone at all duty stations, and they flash the patient's room

and bed numbers and sound a fast tone at the master station annunciator. Staff can only cancel the call at the originating station.

- c) *Duty station.* These stations provide audible and visual annunciation of calls placed from any other station in the system, but do not indicate the room number originating the call. Duty stations are usually located in clean and soiled utility rooms, medication rooms, and other areas in which staff members are likely to be when not at the nurses' station.
- d) *Master station annunciator.* When a call is placed on the system, the room and bed number flash or steadily illuminate, depending on the priority level of the call. The station also generates a call tone with a distinct tone and rate for normal and emergency calls.

7.7.3.2 Audiovisual nurse-call systems

Audiovisual nurse-call systems provide audible signaling, patient-to-staff voice communication, and staff-to-staff voice communication. An audiovisual system works well on nursing floors where direct voice communication, unencumbered by number dialing, enhances caregiving and staff efficiency.

Audiovisual systems can provide multiple levels of calls and can be programmed for patient specific needs. These systems can also integrate with other systems as previously discussed. The size and type of the facility will determine the overall system architecture and number of systems. These systems can be networked as discussed earlier.

7.7.3.3 Code system variations

- a) *Nurse-call system.* Most nurse-call systems can include a code call function, programmed so that the code calls annunciate on both the nurse-call annunciation system as well as the central control center. Nurse-call systems can supervise the individual code station for electrical shorts or opens in the wiring or burnt out or missing lamps in the corridor dome lights. A supervised code system assures that every code station will operate when required (or at least, that staff will know immediately which stations will not operate properly).
- b) *Telephone system.* A code call system can be set up as a separate direct line to the central operator via the hospital telephone system. With this type of installation, any telephone set in the facility can initiate the code alarm. If the phone system has direct access paging, the caller can directly access the PA system, thus bypassing the telephone operator. Code call pages should have priority over all other paging calls.
- c) *Radio paging.* Code call alarms can be transmitted to the resuscitation team members via the radio-paging system, provided the system has the capability of grouping paging calls together so the proper people are notified with just one call from the telephone operator. Microprocessor-controlled nurse-call systems can be interconnected with the radio-paging system to automatically initiate code calls to the code team members whenever someone initiates a code call.

7.7.4 Typical system components

7.7.4.1 Patient bed station

A patient can originate a call on the system by pushing a button on a pillow speaker or cord set. Most systems can vary the type of call a patient can make, either by a manual selector switch at the patient station or by programming at the master station annunciator. Some typical kinds of patient calls are as follows:

- a) Normal calls typically illuminate the white section of the corridor dome light and white section of any associated zone dome lights; illuminate the patient call light and sound a tone at all duty stations; and display the patient's room number and bed number and sound a slow tone at the master station annunciator. Staff can cancel these calls, after answering them, at the master station.
- b) Personal attention calls perform the same functions as normal calls. They differ from normal calls in that staff can only cancel them at the patient location. They may cause a different tone at the master station.
- c) Priority calls flash the corridor dome lights and associated zone lights; flash the patient call light and sound a fast tone at all duty stations; and display the patient's room and bed numbers, and sound a fast tone at the master station annunciator. Staff can only cancel these calls at the patient bed station. Staff can answer the call from the master station.

As an option, the patient station can have a privacy switch that will prevent conversation within the room from being monitored at the master station. This switch does not interfere with the placement of a call to the master station, and the master station can still speak to the bed station. This option can create the hazard that it gets inadvertently activated, or else someone activates it and forgets it so that the patients can become confused when staff do not answer their calls. Some systems only allow this feature to be controlled at the master station so the patient cannot inadvertently place his or her station into privacy.

7.7.4.2 Patient station cord set

Several different cord sets are available for the patient's use to place a call. Pillow speakers are very common because they combine nurse-call features with television and lighting controls. An option on many patient stations is to mute the television or radio audio and transfer the nurse-call audio to the pillow speaker when the nurse communicates with the patient station. This is a desirable feature since it keeps the patient and nurse from having to compete with the television audio in order to communicate. For facilities that do not need television controls, a standard call button and cord set can suffice. Some patients will be unable to operate buttons, and they will require pressure-pad cord sets.

7.7.4.3 Built-in bed controls

The nurse-call system can be interfaced to built-in bed rail controls that allow the patient to place a call, turn a TV set off and on, change the TV channel, and regulate the TV volume. The bed rail speaker can also carry two-way voice communication. These features require an outlet box behind the bed for the multipin receptacle to allow

connection from bed to nurse-call system. Additional backbox space and termination provisions need to be included at the patient station to terminate the wiring from the multipin receptacle.

7.7.4.4 Toilet emergency station

These stations usually flash the white section of the corridor dome lights and associated zone dome lights, sound a unique tone at all duty stations, illuminate the station's call-placed light emitting diode (LED), display the room number and call priority, and sound a rapid tone at the master station. Voice communications to the master station may be possible via the associated patient bed station. Staff can only cancel toilet emergency calls at the calling station. These stations consist of a pull cord located in toilet, shower, tub, and hydrotherapy areas. They allow a patient who falls to reach the cord and pull it, when they are unable to get off the floor unassisted. Some of these stations are UL 1069 listed as water-resistant and can be exposed to water spray in a shower area.

7.7.4.5 Staff station

These stations allow the caller to place calls and carry on two-way voice communication to the master station. Staff station calls annunciate at the master station as a different priority level than other calls. Staff stations should be located in offices, staff lounges, and other areas that need intercom capabilities to the nurses' station.

7.7.4.6 Duty stations

Duty stations combine the call features of the staff station with an alerting function from the rest of the system. The duty station provides audible and visual annunciation of calls placed from other stations in a particular area of the nursing unit or the entire nursing unit. Normal and emergency calls have distinct signals. Duty stations should be located in clean and soiled utility rooms, medication rooms, and other areas staff members are likely to be when not at the nurses' station.

7.7.4.7 Master station annunciator

The master station annunciator calls or receives calls from patient stations, toilet emergency stations, nurse assist stations, code blue stations, staff stations, duty stations, and other master stations. When a call is placed on the system, the master station displays the room (bed) number along with a priority name, letter, or word. When the system has more than one call, the system automatically sequences them in order of importance and time of placement. Staff answer a call by lifting the station handset and either pressing a touch point on the master station or pressing the push-to-talk button. Two-way voice communication then begins and may continue through the handset or the speaker/microphone in the master station. If staff do not answer the calls immediately, the tone signal will repeat.

Selective station monitoring or paging of several or all stations simultaneously can be accomplished from the master station. When the system is programmed, patient stations should be grouped separately from staff and duty stations so that staff can be paged

separately from patient areas. Master stations from the same system or other systems can be connected together to provide intercom capabilities between them. The assignment of stations to zones for paging or monitoring is totally flexible and can be programmed on-site. See Figure 7-5.

7.7.4.8 Nurse assist button

These wall-mounted push-button stations should be located in ICUs, CCUs, birthing suites and labor delivery recovery postpartum (LDRPs) rooms, surgeries, recovery rooms, and other hospital areas in which the staff may need to request additional assistance from within the unit. These calls annunciate differently than a standard patient or toilet emergency station call. Most nurse-call systems provide at least nine distinct levels of call. Nurse assist calls annunciate at the unit's nurses' station and other locations from which help can be expected.

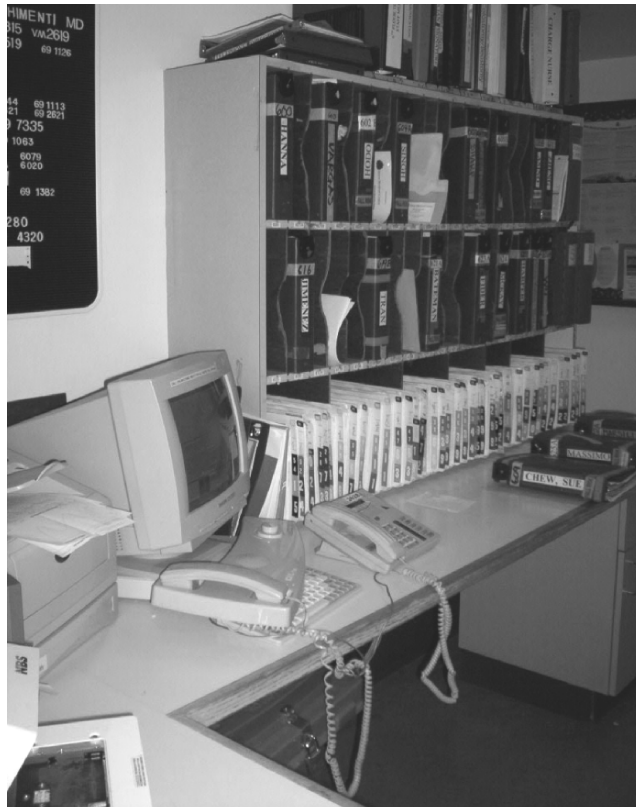


Figure 7-5—Master station annunciator

7.7.4.9 Code button

See 7.6.2 for design criteria. These stations may be part of the nurse-call system to initiate the highest level of call within the hospital to signal the resuscitation team that a patient is in cardiac or respiratory arrest.

7.7.4.10 Dome lights

Locate dome lights in the corridor above the door of the space containing the calling station or patient's bed in recovery and holding areas. These lights indicate which room, or bed, initiated a call and the level of that call. Dome lights can be multi-sectioned (maximum of six) with different colors to indicate different types of calls from each room. For example, a six-section, six-color dome light can indicate the following calls from each room, as shown in Table 7-1.

These colors may vary depending upon the scheme established in the facility. The same dome-light color scheme should be utilized throughout the facility.

7.7.4.11 Zone dome lights

Similar in appearance to dome lights, these devices should be located at corridor intersections to indicate the areas or zone that the call is coming from.

Table 7-1—Dome lights

Call type	Priority level	Dome-light indication
Code blue	1	Flashing blue
Nurse assist	2	Flashing white, steady green
Toilet emergency	3	Flashing red
Patient—Priority	4	Flashing white
Patient—Personal attention	5	Steady white
Patient—Normal call	6	Steady white
Stat service	—	Flashing green, orange, and yellow
Nurse service	—	Flashing green
LPN service		Flashing orange
Aide service	—	Flashing yellow
Nurse present	—	Steady green
LPN service		Steady orange
Aide present	—	Steady yellow

7.7.4.12 Equipment cabinets

Centralized nurse-call equipment should be located on the floor of the areas it serves. These cabinets should be located in a secured low-voltage or communications room. These cabinets can be rather numerous and large, so the engineer needs to coordinate with architectural for adequate space and location. See Figure 7-6.



Figure 7-6—Equipment cabinets

7.7.5 Nurse-call system options

Most nurse-call systems offer several other optional features. The designer should carefully select from among the various options so as to prevent wasting money, but also to provide the features the staff will need to care for their patients. Some optional features include:

- a) *Nurse service.* This feature, standard on most microprocessor-controlled nurse-call systems, allows the nurse at the nurses' station to answer a patient's call and, if the call cannot be satisfied from the nurses' station (i.e., the patient requests a glass of water) the nurse can send a call to a nurse or aide. Pushing the nurse service button will flash the green section of the corridor dome light and flash the

green section of any associated zone dome lights. Pushing the LPN service button will flash the orange section of the corridor dome light and flash the orange section of any associated zone dome lights. Pushing the aide service button will flash the yellow section of the corridor dome light and flash the yellow section of any associated zone dome lights. If staff continue to be unable to answer the call so that the call does not get reset, the system will automatically initiate another patient call. This feature allows the staff member answering calls to remain at the nurses' station while the patient's needs are being satisfied by others.

- b) *Staff locator.* This feature uses buttons or IR receivers in each room to provide information to the system as to the whereabouts of various staff members (or categories of staff). A switch on the master station annunciator will illuminate the room numbers with staff. The nurse at the nurses' station can then locate the closest staff member that can respond to a nurse call from an adjacent room and direct the nurse to it. Some nurse-call systems allow the nurse to answer the call from the patient station. Other systems provide an interface to the telephone system to permit the staff member to use the patient's telephone to answer a call from another patient. This feature is convenient for finding someone, but it also means staff members have to check in and out of each room; they may have to interrupt service to one patient in favor of another, and patients trying to rest may be disturbed by calls from the nurses' station.
- c) *Nurse follower.* During night and off-peak hours the nurse at the nurses' station may transfer calls to another location. This feature, combined with staff location, allows call-in tones to be sent only to rooms with staff members are registered.
- d) *Pocket page interface.* A nurse-call system can interface with a pocket page system so that calls from patients appear on the pager of the appropriate staff member. This mode of operation is most useful during low staff periods (e.g., nighttime or lunchtime). In the semiautomatic mode of operation, a ward clerk or secretary answers the patient call and then determines whether or not to send the call over the pocket page system. In this mode, the calls can be screened, and the screener only sends calls requiring a nurse response. Finally, the manual mode of operation allows an operator to locate a particular nurse by manually dialing his or her pager number. This approach reduces the noise pollution in a hospital that is generated by constant overhead audio paging.
- e) *Call transfer.* In some units there may be a requirement for nurse calls to be transmitted to different nurses' stations at different times. For example, there may be swing rooms that can be a part of two adjacent nursing units depending upon the number of beds required in each unit. Calls from these rooms should be transferred from one nurses' station to another on an individual room basis. Entire groups of rooms may also be transferred between two nurses' stations. Call transfer may be accomplished several different ways depending upon the sophistication of the nurse-call system. A microprocessor-controlled system can be programmed from the master station to assign patient rooms to a particular nurses' station on an individual room basis.

7.7.6 Centralized nurse-call system

Some hospitals or nursing homes may want to have all patient calls for the entire facility answered at a central location, either on a full-time or nighttime basis. When the nurse-call systems for each nursing unit are interconnected with the other units, the calls from several systems may be answered at one location. This feature is useful at night when the number of patient calls is reduced and calls from several systems can be handled by one person. The staff locator feature provides a large benefit in these systems so the person answering calls can locate the staff members closest to the room initiating the call and direct them to the correct room.

7.7.7 Psychiatric nurse-call system

The nurse-call system for psychiatric patient facilities serves a different role than those installed in a general-care nursing area. In a psychiatric unit the nurse-call system usually serves primarily as an alarm system for staff to request additional assistance. The secondary purpose is to allow patient calls.

- a) *Room entrance station.* In a basic psychiatric nurse-call system, each patient room has a room entrance station located in the corridor outside the room. These stations have one or more keyed switches used to activate or deactivate the patient station and nurse assist station within the room. When these switches are in the off or deactivate position, the patient cannot initiate nuisance calls on the system. Room entrance stations can also signal the nurse at the nurses' station that a staff member is about to enter the patient's room. The nurse at the nurses' station can then monitor the conversation within the room and send assistance if required.
- b) *Nurse assist.* Some systems, originally developed for prisons, may satisfy the nurse assist requirements. These systems use a receiver in each room and an initiation device that staff carry with them at all times. If a staff member requires help, he or she initiates an alarm by actuating the initiation device. The receiver picks up the signal and the nurses' station sounds the alarm indicating the room location. This system has advantages over a standard psychiatric nurse-call system in that staff members always carry the initiation device with them.

7.7.8 Medical and dental offices and clinics

Variations of a visual or lower scaled audiovisual nurse-call system can be appropriate for clinics and offices. Some examples include the following:

- a) *Room status system.* Multi-section, colored dome lights located above the corridor door into each exam room with corresponding switches in each room. One illuminated color may signal that the patient is ready to see the doctor. Another color may indicate the room is vacant and needs to be prepared for the next patient and/or another color may be used to signal the room has been prepared and is available for the next patient. A central annunciator may be located at the reception desk to indicate the status of each exam room. Systems can indicate where the doctor's "next patient" is located by flashing the appropriate dome light and can track patient and staff flow throughout the office or clinic.

- b) *Doctor and dentist offices.* Different-colored lights may be used to provide rapid, discrete interoffice communication between the doctor and his or her staff. Messages will vary between offices, but some typical messages are “doctor’s next patient has arrived,” “doctor is wanted on the telephone,” “doctor would like to see his assistant or laboratory technician,” “hygienist wants doctor to check patient.”

7.7.9 Assisted-living facilities

Residents in assisted-living facilities may need to summon assistance if they experience a fall or other emergency. A visual nurse-call or lower scaled audiovisual nurse-call system should be installed with emergency stations in the bathroom and at a central location in the living area. A central annunciator can be located at the lobby reception desk or other continuously monitored location. One limitation of utilizing a conventional visual nurse-call system in an assisted living facility is that the residents are usually mobile (not confined to a bed) and may not be next to a station when they fall and need help.

Wireless systems solve this problem by having each resident carry an alarm device. Receivers located in each living unit and in common areas provide facility-wide coverage. Optional features of these types of systems include interconnection with the telephone system to enable direct voice communication to the resident, and/or a computerized database to automatically provide the resident’s name, doctor, and other pertinent information at the central monitoring location. At this writing, many wireless systems cannot give specific room of call annunciation for the patient call.

7.7.10 Design considerations for nurse-call and code systems

After the engineer has talked with the facility staff and determined the type of nurse-call system that best meets the hospital’s needs, he or she designs the final system.

- a) *Patient bed stations.* Mount these stations in the wall behind the patient bed, in a patient headwall unit, or in the patient’s bedside cabinet. Locate the station to allow the call cord to be draped to the patient bed.
- b) *Toilet emergency stations.* Position these stations so they can be activated by a patient seated on the toilet and/or by a patient who may have fallen forward on the floor. In combination toilet/shower rooms, one station may be sufficient provided it meets the location requirements described in item a) and the cord is long enough to drape into the shower to a maximum of 15 cm (6 in) above the floor.
- c) *Staff and duty stations.* Sometimes rooms such as staff lounges and utility rooms serve more than one nursing unit. If so, provide two or more duty or staff stations, each connected to a different unit’s nurse-call system. Identify each station’s nursing unit.
- d) *Master station annunciator.* These stations can either be wall-mounted or desk-mounted. Wall-mounting these stations frees up valuable desk space, if wall space is conveniently accessible. Many master stations should be desk-mounted to allow flexibility in their location. Room numbers on the master station should match the final room numbers assigned to each room by the facility.

- e) *Psychiatric patient stations.* These stations, installed in ambulatory patient rooms, should be tamper-proof for the patients' safety. Call cords should not be located in patient bedrooms, and toilets should use tamper-proof push buttons in lieu of pull cords.
- f) *Central equipment and power supplies.* Connect nurse-call systems to the critical branch of the emergency distribution system in hospitals or to essential emergency power systems in other health care facilities. Coordinate ventilation, wall space, and wall depth required for these cabinets.
- g) *Code stations.* Locate code stations on the wall in highly visible locations so they are easily located in a medical emergency.

7.8 Radio communication systems

7.8.1 Introduction

In general, the term *radio* refers to the process of transmitting signals through the air (sometimes referred to as *ether*), without the use of wires. In the early days of radio technology, it was referred to as *wireless*. Currently (and in this chapter) the term *wireless* is used to categorize systems that use low-power radio signals to convey information over relatively short distances (up to 100 m or so), generally within buildings or campuses. In this subclause, the term *radio* is used to discuss wireless systems that are intended to transmit information over longer distances, including hundreds of kilometers or more.

Most modern health care facilities use a wide variety of radio systems. Uses include but are not limited to:

- a) *Radio paging* (see 7.9.4) Health care operations may employ privately owned radio-paging systems for internal or local vicinity coverage, and almost always use pager services subscribed from commercial carriers. Such subscription services may provide local vicinity, national or worldwide areas of coverage.
- b) *Cellular services.* The services generally referred to as cellular may include true cellular telephone systems, PCS systems, or specialized land mobile radio (SLMR) systems. All of these systems operate over a range, and allow the user to dial and receive wireless telephone calls over the world's public switched telephone network (PSTN). Normally, the user buys suitable portable units and subscribes to service providers to obtain a phone number and dial tone. Some very large private campuses may operate their own micro-cells (the transmitter/receiver stations that provide these services). Several new technologies have recently emerged that allow the same user appliance to be a WLAN-PBX phone when in range of the home facility (see 7.5.4.12), but automatically become a cellular or PCS telephone when not.
- c) *Mobile/portable radios.* Health care departments needing quick communication either inside the facility or within a reasonable range outside (typically up to about 30 mi) often use *land mobile radio* (LMR) technology. Typical user departments are security, engineering, housekeeping, motor pool, and its/telecommunications maintenance groups. LMR systems may consist of simple base stations that communicate with a small group of portable or mobile radios, conventional

repeater systems that may include one or many channels, or participation in a major city, county, or state trunking radio system.

- d) *Entertainment radio or TV systems.* TV distribution is covered in 7.19. In some cases, it may be desirable to make receipt of AM and FM broadcast signals available inside health care facilities.

7.8.2 Privately operated radio transmitting and receiving systems

Many health facilities own LMR voice and/or data and paging systems. Only qualified engineers should attempt design of a radio system. A typical system consists of mobile or portable two-way radios or receivers distributed to users, companion base station receivers and transmitters, control-point consoles, and antennas. Most systems require the owner to obtain an operating license from the FCC. The vendor can often handle licensing details, but public law holds the user responsible for proper operation and licensing. Facilities with these systems therefore need to have a common license filing point, and a staff member who is at least familiar with license requirements, renewal dates, and system layout. Licenses include fixed transmitter locations, heights, frequencies and output power, mobile and portable unit quantities, and areas of authorized operation. Some radio antenna towers also require coordination and approval from the Federal Aviation Administration (FAA) and may require marking paint and/or regulation lighting. There are statutory fines for improper use of radio equipment.

Proper operation of radio equipment requires a suitable environment for the equipment. If a health care facility ever needs to depend on the performance of a radio system in a life-threatening situation (either in normal operations or emergencies/disasters) it should operate. Proper backup power, grounding, lightning protection devices, mechanical security, maintenance cycles, and antenna survivability (for ice and wind) are all important reliability factors that are often overlooked. Major radio systems manufacturers publish standards that should be applied.

7.8.2.1 Operational requirements and licensing procedure

In order to operate a radio system, the system owner/user should obtain a license for the system from the FCC and be assigned call letters to identify the station. An important part of planning a radio-paging system involves conforming to the FCC requirements regarding radio system control, and obtaining the station license. The following material discusses both the FCC requirements and licensing.

A copy of the appropriate part of the FCC Rules and Regulations should be available at each control point (see CFR 47 Part 90 [B4]). A copy of the applicable FCC Rules and Regulations should be kept on site. The FCC defines a control point as an operating position under the control and supervision of the licensee where the person immediately responsible for the operation of the transmitter is stationed and where monitoring facilities are located. Owners should obtain authority from the FCC for each control point. Every system should have at least one control point.

A dispatch point is any point from which messages may be transmitted under supervision from a control point. Dispatch points may be installed without authorization. Each control point should have the following facilities:

- a) A visual indication of a “transmitter-on” condition—either a light or a meter
- b) Facilities to permit the operator to turn the transmitter on and off
- c) Equipment to permit the operator at the control point to monitor all transmission by dispatch points under his or her supervision
- d) Facilities to permit the operator at the control point to take transmitter control away from dispatch points (priority or supervisory control)

Any operator should be able to monitor the channel to see if it is clear before transmitting.

These regulations determine, to a great extent, what equipment the facility should have in any given system. For example, a special requirement of the FCC license is to monitor the channel prior to transmitting. This means that the system should have either a receiver/monitor or a method of indicating detection of the carrier transmission by others on the same frequency, or both. As a practical matter, health care facilities with automatic paging terminals typically use the terminal itself as the control point. Most modern paging terminals provide full status displays and allow manual interruption of operation if required. Facilities cannot start “on-the-air” until the station license is granted.

7.8.2.2 Transmitters

This subclause also applies, in most cases, to receivers in two-way radio systems.

Transmitters are generally located as close to the antenna as possible to reduce signal losses in the cabling between the transmitter and the antenna. Equally important is to locate them to provide for easy service access, security, and temperature control. Systems using radiating coaxial cable for the antenna system may benefit from a central transmitter location to provide equal cable runs to all parts of the building.

A wide range of transmitter configurations is available based on particular supplier requirements, range of coverage, type of antenna, and method of signal coverage within the building(s) and hospital complex. Transmitters frequently mount inside of a 48 cm (19 in) standard rack cabinet with a secured door. Some transmitter designs allow for the mounting of the transmitter chassis into standard EIA 48.7 cm (19 in) relay racks. Most transmitters and related equipment are heavy and require proper installation. Refer to current seismic standards for critical systems when designing the anchorage and support for the equipment. Transmitters generally contain the following modules: a power supply (connected to the building emergency power system or dedicated battery pack), the transmitter and receiver(s), and control console interface.

While primary power requirements vary depending upon transmitter power, generally one 117 Vac, 60 Hz, 20 A circuit is adequate. Connect the transmitters to the life safety branch of the emergency system. Provide UPS power where a continuous operation is critical. Properly ground the transmitter equipment. Requirement for such spaces is expected to increase in the future, as more dependence develops for wireless technologies.

7.8.2.3 Antennas

The following are considerations in choosing antenna type and location.

Quarter wavelength ground plane and single dipole antennas are better for applications where broad, circular coverage is needed. Due to the construction of the antennas, they need a free area with a radius of about 3 m (10 ft) around the antenna for the ground plane elements at the place of installation. The multiple dipole and collinear antennas provide more energy towards the horizon, so they are not as good for campuses.

If possible, locate antennas above nearby steel or concrete structures and above other antennas that lie within a radius of wavelength. If the antenna will mount on a roof, for example, and there are no obstacles nearby, mount it on a steel pipe at least 3 m (10 ft) high in order to avoid lobe lift, which will decrease the field strength at ground level. Mount antenna(s) a minimum of 3 m (10 ft) above the ground or roof. The horizontal distance between ground plane antennas and nearby building sides should be at least 15.2 m (50 ft) to prevent both reflection and permanent-wave patterns.

In a large building made of reinforced concrete, the signal from the antenna may be so strongly attenuated in one or more parts of the building that reception there becomes unsatisfactory. To improve reception in a single location, install an additional transmitter (or multiple, additional transmitters) connected to an internally located antenna at the place suffering the weak signal.

Provide lightning protection for all antennas. If a radio antenna suffers a direct hit from lightning, no built-in protection will save it, nor possibly its transmission line and base station, from substantial damage. The 100 000 A current and tremendous surge voltage from a direct lightning hit will destroy an antenna used in normal radio installations. Antenna designs with lightning protection actually minimize damage from nearby lightning strikes as well as damage and static that can be caused by various other electrostatic charges in the air. DC grounded elements within the antennas themselves provide this important feature. Multiple dipole and collinear antenna designs that incorporate dc grounded elements best serve this function.

To a certain degree, all sorts of materials attenuate radio waves, but metallic objects (such as steel- reinforced buildings) attenuate them more. Obviously, then, the roof above the structure is a bad place to put an antenna for this system, as the radio waves might have to pass through several screening floors before reaching the receiver.

When radio waves reach a surface, some of them will pass or be absorbed, while others will be reflected. When the reflected radiation mixes with the direct radiation, interference will occur. This interference will amplify the signal at some places but weaken and perhaps extinguish it at other places. A special risk of dead zones is present at elevators or stairwells, or between thick pillars. Eliminate dead zones by change of antenna location or type.

Reradiating systems can also boost weak paging signals in portions of the facility where the primary transmitter provides ineffective service. These systems support cellular and

two-way radio communications in larger health care facilities. In many cases, they can also carry paging signals. These systems are custom engineered for each facility and are beyond the scope of this recommended practice.

7.8.2.4 Internal reradiating systems (IRS)

Systems described in this subclause are commonly known by several names including *in-building systems*, *BDAs*, *leaky coax*, or *distributed antenna systems* (DAS). The FCC refers to such systems in Part 15 of its regulations as *tunnel radio systems*, to reflect where the technology first developed (i.e., in railroad and highway tunnels where it was desirable to reradiate various types of radio signals that would otherwise be shielded from penetration).

Today, there is increasing use of IRS technology for the following two reasons:

- a) Buildings are being constructed using low-emission (Low-E) glass to reduce transmissibility of heat through windows, and thus conserve energy. Most Low-E glass causes serious attenuation (due to reflection) of radio frequencies. The higher the RF, the more the Low-E glass will attenuate it.
- b) Frequencies commonly used by cellular and public safety services (around 800 MHz) and PCS services (1.9 GHz) are often severely attenuated, but demand for these systems continues to grow. Many communities are developing ordinances to require complete coverage inside new buildings for the radio systems used by their emergency first responders. Additionally, the popular use of digital cellular and PCS “telephones” with data communications capabilities for support of PDAs suggests the need for signal enhancement for these services.

The right combination of outdoor signal source, antennas, bi-directional amplifiers, filters, and an indoor distribution system can meet the need for such signal enhancement. The internal distribution system will consist of passive components, radiating cables (leaky coax), distributed antennas, and in some cases, fiber optics.

The largest cost of an IRS is the labor to install the inside distribution components. Radiating cables and/or distributed antennas should be placed to obtain the necessary internal coverage. Most owners will need 100% coverage. FCC regulations also require that radiating from the system be contained within the building or structure in which it is installed. This means that both engineering and installation practices should carefully consider the radiated power provided by each element of the system.

Engineers should design healthcare IRS installations as a general utility that someday will support all radio services the owner of the structure may wish to support. Today’s most used radio bands are shown in Table 7-2:

Table 7-2—Radio bands

VHF – Hi	150 MHz to 174 MHz
UHF	450 MHz to 470 MHz (up to 512 MHz in some areas)
760 MHz to 930 MHz	Public safety, cellular, radio paging
1.9 GHz	Personal communications service (PCS)

Simple systems can support any one or a part of one of these ranges. Systems to support multiple bands require special engineering. Radiating cable (leaky coax) will cover the entire range, depending on the electronics used in the active portions of the system. However, radiating cable is very expensive to install correctly in existing structures. It should be kept away from other metallic objects—a distance of 2 in or more in most cases—and if metallic objects are placed next to it in the future, its performance will degrade.

On the other hand, a distributed antenna system requires antennas that cover the entire desired range without creating reflections or *standing waves*. The inherent difficulties of broadband antenna design make this a difficult challenge.

In many cases, a carefully selected combination of radiating cables and distributed antennas may be the best solution. In such designs, the antennas should be isolated by taps or attenuators so that values of reflected waves are kept small. This separation will permit addition of antennas serving other wavelengths in the future.

It is generally found that amplifiers and band filters required to complete an IRS for the bands listed in Table 7-2 will only support one of these bands of frequencies. In fact, the range of frequencies between 760 MHz and 930 MHz, if supported for all services, will generally require at least four separate amplifier sets. For very large systems (areas of 100 000 ft² to 250 000 ft² or greater), single-mode fiber-optic cables may carry signals, in analog form, from a master site (headend) to remote distribution nodes. In most systems, each electronic band component will require a pair of fiber-optic strands. In smaller systems, the distribution area can be connected directly to the headend with coaxial cable.

7.9 Paging systems

7.9.1 Introduction

The purpose of the paging system is to transmit messages to persons who do not have a fixed location within the facility. These systems generally augment the telephone system, in that they notify persons who are not at a fixed telephone number to contact another person inside or outside the facility. These systems also allow hospital administration or

emergency responders to make general emergency announcements. In order to be effective, these systems should reach most locations where these people are likely to be.

Many hospitals are attempting to minimize or eliminate the use of overhead paging systems because the high levels of noise they create can make hospitals more stressful and impede the healing process. The primary alternative to the traditional overhead paging system is the wireless telephone systems, which allow staff to contact the person who is not at a hard-wired telephone directly. Another option is to provide voice-quality speakers as part of the telephone system, and to distribute them appropriately, so as to allow these speakers to be used for emergency overhead paging purposes.

7.9.2 System types

Overhead paging systems can increase the efficiency of communications in most health care facilities. There are three types of systems:

- a) *Voice-paging system.* Voice-paging or PA systems broadcast general audio announcements. Voice-paging systems use transducers, electronics, and cable plant to reproduce local audio signals over large floor areas. Voice-paging systems serve as a general PA system for a less specific audience and usually support a broader range of messages than radio-paging systems. Besides voice signals, paging systems may transmit background music, sound masking noise, security tones, or recorded fire alarm system announcements. The voice-paging system may be interconnected with the building telephone, intercom, or visual annunciator systems as part of an overall building communication system. Voice-paging systems may be required for issuing instructions in response to emergency conditions including code blue alarms.

A voice-paging system can become a distraction that outweighs the advantages of its use. This may result from poor design or from abuse. General voice paging should be directed toward specific audiences with content suitable to concise messages.

The policy directing the use of a voice-paging system should impact the system design. Multiple zoning can insulate parts of a facility from constant announcements. In hospitals, for example, separate zones (or the exclusion of voice-paging speakers) are appropriate for surgery, delivery, recovery, ICU, and other patient rooms.

- b) *Radio-paging system.* Radio system paging transmits voice or digital messages over a RF channel and is better where cost is not an obstacle. Messages can consist of coded signals, one-way, or two-way voice transmission. Installation costs are low, the system requires little or no space, and it creates minimal disturbance. Radio paging is effective in many areas where visual or voice paging is not practical; for example, it often covers rest rooms, utility spaces, and nearby outdoor areas with its radio signal. However, equipment is costly and maintenance costs can be high since pocket-carried receivers are subject to damage. Radio paging can be tied into the telephone system so that paging can be initiated by staff members other than the telephone operator. See 7.5.4.3.

- c) *Flashing annunciator paging.* This system provides a silent, visual, coded message by repeatedly lighting numbers on annunciators located throughout a facility. These systems rarely suit health care facilities because of the excessive number of annunciators required before the coverage provided can compare to other types of paging.

7.9.3 Voice-paging systems

7.9.3.1 Design criteria for voice-paging systems

7.9.3.1.1 General

Systems with building-wide voice paging should provide it throughout the facility for general and emergency announcements. Most health care facilities find paging disruptive. Hence, planning should include efforts to minimize use of the paging by shifting communication to other less disruptive systems such as telephone, intercom, radio paging, and wireless telephones. Once a paging system is in place, it can include background music. The PA system consists of loudspeakers, local volume controls, amplifiers, wiring, and termination hardware. The PA system should interface with the telephone system to permit initiating pages from operators' consoles. Provide a microphone for operators to use in the event of a telephone system failure.

Audio components (amplifiers, equalizers, mixers, etc.) are all solid-state devices. Performance is not measured by broadband or hi-fi principles, but rather in terms of reliability, control of signal sources, and correct distribution and syllabic articulation of voice. The system need not reproduce the entire audible spectrum for satisfactory results, and quite often compromises with performance are required to keep these systems affordable.

7.9.3.1.2 Priority

Paging system inputs may be manual (microphones at operators) or automatic (CD, tone generator). In both small and large voice-paging systems, the relative signal priority determines the control requirements. A paging system with background music and one paging microphone location needs to automatically mute the background music when the operator activates the microphone. When a system uses several paging sources or a paging source and an emergency signal, the engineer should design a priority system to accommodate each source's level of importance.

Paging systems can also include controls to change the volume to suit varying work conditions, changing personnel, background noise, etc. Also, system design can allow controls based upon different input signals. In a paging system with background music for instance, the system may allow a listener to vary the volume of background music, but ensure that emergency paging messages will play at full volume. The various volume levels should be consistent with each signal's priority.

7.9.3.1.3 Zoning

In large installations, and in small installations where specific activities vary from area to area, the PA system should be zoned. Each zone may require local volume and paging controls. Priority controls for both source selection and volume are designed to accommodate both zone paging and local sources. In some installations, local pages have priority, and in others, general pages have priority.

7.9.3.1.4 Talk-back

Single-zoned systems may include the ability for the persons near the speaker to talk back to the originator of the page, either by push-button control or by automatic means. Talk-back complicates the electronics of a paging system, especially when it is part of a multizoned system with several signal sources. For these kinds of systems, alternate ways of listener response (telephone, intercom, etc.) usually provide better solutions. Talk-back from speakers in large rooms is usually ineffective unless the person is close to a speaker. Public areas should not have talk-back.

7.9.3.1.5 Distribution

In music and paging systems, engineers have several options for distributing audio signals. The simplest design involves one set of audio lines run to each speaker zone with background music and paging levels set at the main amplifier. When an area requires local control, the audio lines may run to a local volume control equipped with a bypass relay (priority relay). The relay coil connects to a priority control pair to bypass the volume control for paging announcements.

7.9.3.1.6 Muting

A voice-paging system with two sources, including one with priority, can accomplish the required signal level changes two ways. First, priority signal may simply play at a higher volume than other signals. This method works best where the nonpriority signal is at a low volume so the priority signal need not be too loud. Second, initiating priority signals can mute the nonpriority signal either by relay contacts or solid-state devices. The same circuit may drive the priority relay at local volume controls. Most health care paging systems use the second method. Some components have automatic circuitry that mutes a signal input when they detect an audio signal from a different input or inputs. Automatic electronic muting often eliminates an objectionable pop caused by relay contact closures in other systems.

7.9.3.1.7 Volume

The required audio volume determines electronic component ratings. The system should be louder than the ambient noise. Sound with a signal-to-noise ratio of at least 10 dB with an appropriate frequency response and distortion below 5% generally provides audible signals. Room acoustics will affect the volume delivered. Small rooms with low ceilings consisting of acoustic tile are usually not a problem. Rooms with acoustically hard surfaces (plaster walls and ceiling, and tile floor, for example) have a high reverberation

time that will contribute to poor intelligibility. To accommodate variations in acoustics and ambient sound levels, provide an audio sound level to average ambient noise level range of 20 dB to 30 dB, and an overall audio signal distortion of less than 2%.

7.9.3.1.8 Frequency response

Many paging systems, especially those using a telephone system as the audio source, do not require frequency shaping electronics because the electronics and speaker system will present the full range of telephone or microphone frequencies to the listener. If particular rooms present acoustical problems or where music or a natural sounding voice page is important, use an equalizer.

7.9.3.1.9 Compression

Audio signal volume varies from one source to another (i.e., from one person to another). Different paging announcers may produce a difference in voice levels greater than 20 dB depending on their voices and how they use the microphone or telephone. Variations in signal levels of 20 dB are annoying to many listeners. Using audio signal compressors may help to reduce sound level variations. These devices commonly control microphone and telephone/intercom/paging interface inputs because the volume of these sources varies the most. Prerecorded music sources, radio receivers, tone generators and noise generators usually produce a consistent signal/level or have their own compressors (i.e., automatic gain control). Systems using mostly or only trained operators have no need of compression.

7.9.3.1.10 Source

The quality of the input source will determine the maximum quality for the overall system. Most microphones work with acceptable quality, but the location of the device will also influence the quality of the signal. Placing the microphone several inches from the announcer's mouth helps reduce problems of room noise and reverberations. Telephone handsets and headsets with an interface to the paging system provide both efficient operator access and close microphone use for noisy environments. When an operator should address a microphone from more than 30 cm (12 in) away, noise and room echo will be the likely result.

7.9.3.1.11 Interfacing

Telephone, intercom, and tone generating systems may connect to the voice-paging system. In such designs, define the priority and zoning of each system. A telephone or intercom system may use several interconnecting lines to provide both general and zone paging. Some systems use telephone paging interface units to decode a touch-tone and select a paging zone. The drawback of such units is that the operator should dial the paging system, wait for a paging system tone, and press the zone code before making a page, which takes longer than simply dialing a paging number.

7.9.3.1.12 Coverage

Generally, voice-paging systems distribute speakers to provide even coverage of direct sound at the proper frequencies and at sufficient volume to be heard above the ambient noise. High-volume distributed systems (usually horn-type speakers) generally work better in noisy areas. Most applications involve low-level, closely spaced, recessed, ceiling speakers. Even the best recessed ceiling speakers have a narrow, high-frequency, dispersion angle. With 2.7 m (9 ft) high ceilings, speaker spacing of 3.7 m to 4.9 m (12 ft to 16 ft) centers is typical. This spacing may be increased somewhat for higher ceilings and in narrow corridors. The closer the speakers are, the more even the sound volume and quality will be.

7.9.3.1.13 Equipment

Locate voice-paging equipment in the main control room with access to cooling. Speaker wiring requires one pair of conductors for a single-zoned page-only system, two pairs for a single-zoned music-page priority system, and many pairs for a multizoned multiple-page priority system. Priority logic pairs will often be #22 AWG, and audio signal pairs will be anywhere from #20 AWG to #14 AWG. Loudspeakers should have multiple tap matching transformers for setting individual speaker volume levels. The installers should balance the system at the completion of installation to provide adequate volume throughout all departments.

7.9.3.1.14 Installation

Nearly all sound-system components on the market today exhibit low-noise, low-distortion, flat frequency response, and high continuous power ratings. Individual component ratings rarely limit the performance of sound systems.

Solid-state audio components are available for specific input and output levels, so cascading components (for example, a mixer, an equalizer, and a power amplifier) require that the output level of each unit match the input level of the next unit. A mismatch of audio signal levels will degrade the overall system signal-to-noise ratio or reduce its maximum output.

Systems generally transmit audio signals at three levels: microphone level, line level (for lines between various pieces of equipment), and high level (the output of the power amplifiers used to distribute audio frequency energy to speakers). The microphone and line level signals are susceptible to pickup of hum, noise, and cross talk from higher level lines and power cables. Keep microphone level lines separate from other audio lines or power cables, and bundle each type of audio line separately in each equipment rack. Microphone and line level cables perform better when using an overall metallic shield within the cable jacket.

When an audio system includes an equalizer, the installer should measure and correct the frequency response of the system to match the desired response curve. Improper system response may cause a loss of speech intelligibility or make the system sound unnatural.

Proper use of a voice-paging system is as important as its initial installation. People familiar with the equipment should instruct operating personnel in the system's use. Often this instruction is specified as part of the system installation.

7.9.3.1.15 Reliability

Including backup inputs (a second microphone or a microphone as backup to a telephone system) and backup electronics (amplifiers, etc.) can greatly increase overall system reliability. Many components permit battery-powered operation that permits operation during loss of power, but powering the system from an emergency source will do so much more cost-effectively.

7.9.4 Radio-paging systems

7.9.4.1 Introduction

Radio-paging systems transmit alerts and, in most cases, messages from fixed locations over a RF channel to portable paging receivers. Radio-paging systems used in a health care setting can provide tone alerts, tone alerts followed by voice messages, numeric messages, or alphanumeric messages. These pages rapidly notify critical staff and deliver detailed information to pagers equipped with text displays. Basic radio-paging systems consist of a paging terminal that generates the paging information, an associated radio transmitter, an antenna system, and the pagers carried by facility staff. More elaborate systems could include networked paging message entry terminals, multiple paging transmitters, and complex methods of distributing paging signals within dense hospital structures.

7.9.4.2 Design criteria for radio-paging systems

When designing a radio-paging system, the engineer should consider the number of active radio pager users, the average system call rate, the desired grade of service, the average input waiting time, and the maximum message storage time. In addition, the following functional factors should be considered to define radio-paging system performance: number of active radio pager users, average system call rate, desired grade of service, average input waiting time, and maximum message storage time.

7.9.4.2.1 System input or encoder

On-site and off-campus paging systems often connect to one or more of the telephone, intercom, staff register, nurse-call, and code blue systems. The majority of new systems use alphanumeric paging, delivering text messages from networked paging workstations, or more commonly, from office PCs running software designed to deliver text messages to a remote paging terminal.

Telephone interconnected and networked systems provide almost unlimited access to the paging system. Interconnection with external hospital systems such as staff in/out register systems, intercom systems, and nurse-call systems is unique to each paging equipment supplier.

A paging terminal may be any kind of device, manual or automatic, that can create a paging message. Many paging terminals incorporate various combinations of manual and automatic paging, and most modern high capacity paging terminals support multiple pager types. The following is a typical list of paging terminal access methods:

- a) *RS-232 or IP-network connected automatic paging terminals.* These terminals allow connection to local or remotely located workstations where the paging information is created from internal databases. After looking up the correct pager alerting data from the stored databases, the automatic paging terminal will initiate a paging transmission.
- b) *Manual desktop or flush-mounted keyboard console.* These devices are often appropriate at the telephone operator position, although parallel units may be located at several sites throughout the facility.
- c) *Telephones.* Pages can originate from telephones that use dial or DTMF, and that are either dedicated or part of the facility's telephone system. Dial-up access to paging terminals using DTMF or touch-tone telephones remains a common access method.
- d) *Automatic alarm stations.* Any contact opening or closing device can connect to the system to initiate an emergency or routine radio page message. Common signals of this type include elevator stoppage, security door openings, boiler temperature limit switches, chiller failure, oxygen low pressure, etc.

7.9.4.2.2 System type

On-site pagers for use with campus paging systems, like the systems that control them, come in many different types. Systems vary by frequency band (VHF low band, VHF high band, UHF, and 900 MHz); type of decoding (two-tone or five-tone analog and digital); and type of message capability (tone, voice, LEDs, LCDs, digital display, and alphanumeric display).

7.9.4.2.3 Frequency selection and FCC licensing

For on-site systems, the frequency is largely a matter of which available paging frequencies will work best for the facility and which is the least crowded. For on-site paging systems, carefully designed systems on the same frequency can operate without harmful interference with each other, even when only a very few miles apart. In the Public Safety Radio Service channel pool, the VHF low band and UHF bands are the least crowded. The FCC has set aside one-way paging frequencies for which all hospitals and other emergency medical service (EMS) providers are eligible. The paging-only frequencies available to this class require preprocessing by a *frequency coordinator* prior to submittal to the FCC. Multiple frequency coordinators can perform this service for applicants.³

The FCC has also allocated the industrial/business channel pool frequencies for paging systems operated by commercial or non-profit entities. These frequencies include VHF high-band frequencies and UHF frequencies for paging only. The paging-only frequencies

³ See: <http://wireless.fcc.gov/publicsafety/coord.html> for additional information.

in the Industrial/Business Radio Service may be coordinated by multiple frequency coordinators, including the Industrial Telecommunications Association (ITA) and the Personal Communications Industries Association (PCIA), prior to submittal to the FCC. The FCC has also authorized paging frequencies in the 900 MHz range for which all hospitals are eligible. Prior to a hospital submitting to the FCC, multiple frequency coordinators can coordinate frequencies in this range including the ITA and PCIA.

The VHF low-band frequencies and UHF frequencies are generally much less congested than the VHF high-band frequencies. Therefore, these frequencies are less likely to have problems in sharing the frequency. However, hospitals should not use VHF low-band frequencies, if possible, because few manufacturers produce equipment in these frequencies, and designing effective antenna systems for these frequencies can be difficult.

The FCC does not coordinate or provide any engineering of all of the frequency assignments and will generally authorize whatever the certified frequency coordinator requests. Because of this problem, before installing a system, engineers should deploy frequency monitoring equipment to monitor the frequency band selected. If hospitals in the area have formed a frequency coordinating committee, that organization can help determine the best frequency. Note also that certain frequencies have limits to the licensable transmitter power output. These limitations can impact the overall paging system design. On-site radio-paging systems, however, particularly for tone-only or display messages, require less power than voice or wide area paging, and the lower power levels on these channels may be entirely adequate.

With the exception of large systems operating on certain 900 MHz channels, paging channels are not generally available on an exclusive basis. This means that channels are shared and interference between users should be resolved. In some cases, paging terminals may need “lock-out” receivers that monitor the paging channel and prevent transmissions if the channel is already in use. This feature adds delay to the speed of alerting, so a better solution is to avoid the use of lock-out receivers by limiting coverage of areas beyond the health care facility.

Only persons holding an FCC commercial license or equivalent FCC-approved certificate may service and adjust radio-paging transmitters.

7.9.4.2.4 Type of encoding

Again, the gradual shift from two-tone and five-tone to digital encoding has paralleled the growth of radio and electronic technology. Most equipment installed today is either two-tone and voice or digital numeric/alphanumeric encoding. Digital encoding is extremely fast; that is, approximately 1.5 s for the transmission of a battery saver preamble and alerting signal, and approximately 0.33 s for transmission of the alerting signal vs. as much as 5 s for two-tone systems. In a low traffic, small paging system, the latter would be no problem. But with today’s larger systems, high-traffic loading dictates that transmission time be as short as possible. Digital encoding also permits simple tone alerts, numeric messaging (such as a phone number to return a call to), and alphanumeric display paging messages. These too can transmit in a total of 2 s or less. Voice messages generally

require at least 5 s to 10 s, depending upon the operator. Traffic capabilities in digital display systems can be up to ten or more times that of voice systems. Digital encoding, because of high-speed multiple transmissions and built-in error checking techniques, reduces *falsing* (where a pager receives a message designated for someone else or pager receives a false alert tone where no message was transmitted).

7.9.4.2.5 Message type

Radio-paging messages may consist of alerting tone(s), LED or LCD signals, voice, vibrations, digital numeric display, and alphanumeric display (providing up to several hundreds of characters per message). Engineers should select alerting methods based on how the paging system will be used, the number of pagers, the expected message traffic, and the budget.

Tone-only pagers have become more difficult to obtain as the cost of full-featured alphanumeric pagers has dropped. Formerly, tone-only paging was a good choice for staff members who needed to receive a minimum number of messages where the response was predetermined by the alert received. For example, one tone would mean “call your office,” and another tone might mean “return to your workstation.” A change in the tone may signify the level or urgency. More sophisticated tone-only pagers have multiple addresses; that is, one address number for individual calls and one for a group call, and display signals to visually indicate which address number has been called.

Tone and voice pagers provide unique message content. Although most paging messages contain number information such as “call extension 386,” some emergency messages may be difficult to transmit without the added impact of voice. For this reason, voice paging remains popular where priority alerting is required, particularly if the caller needs to use a dial-in telephone to send the page.

Display pagers, particularly those with alphanumeric messaging capabilities, can provide surprising amounts of information, and all display pagers on the market today have large message memory capacity. These units generate an audible alert (or a silent alert), followed by display of a detailed numeric or text message on an LCD display. This method provides high message accuracy and confidence during busy times, and eliminates the need to call the operator for verification. Night shift staff commonly use vibration alert pagers to avoid excess noise. Alphanumeric paging is the most common form of paging in health care facilities.

7.9.4.2.6 Pager batteries and chargers

Pagers can use either disposable or rechargeable batteries. Most new pagers use disposable alkaline batteries rather than rechargeable batteries. Facilities using rechargeable batteries need to provide space and facilities for recharging, while facilities using disposable batteries need to implement battery management policies, including recharging and/or proper disposal.

7.9.4.3 Design considerations for radio-paging systems

7.9.4.3.1 Encoder location

Telephones, intercom stations, or automatic alarm station type encoders tied to the paging terminal may be located almost anywhere in a facility. However, FCC regulations require that every radio-paging system have one control point from which the entire system is controlled and where FCC representatives can contact staff who can promptly disable the system in the event of harmful interference. This control point is most commonly located at or immediately adjacent to the telephone operator's position or at the emergency department. This location is generally the focal point for radio paging and other types of message functions and is the recommended site for the designated control point.

The designated control point may be a workstation connected to a remotely located paging terminal. If telephone operators offer manual paging service, systems should include an encoder device (typically a keypad or telephone desk set), a microphone with hand or foot switch (if voice messages are to be provided), a small loudspeaker with volume control (part of a frequency monitoring system to allow cooperation in the use of the FCC assigned frequency), and an "in-use" or "busy" signaling indicator (illuminates when other encoders or input devices are using the system).

7.9.4.3.2 Paging terminal configuration and location

The paging terminal of a radio-paging system contains the control circuitry of the system. Paging terminal equipment includes a computer/central processor unit; message storage capability; pager address databases and other special circuits and related software systems. Also connecting to the paging terminal may be inputs from internal TCP/IP networks, telephone systems, or intercom systems, as well as an output to the system transmitter.

The location of the paging terminal in a facility is largely a matter of convenience, but clean, air-conditioned spaces that may be key-lock secured are better, as is proximity to facility telephone and network systems.

Paging terminals commonly mount in a 48 cm (19 in) rack- or wall-mounted cabinet. Paging terminals generally use computer bus technology providing control of sequencing and prioritization of connected encoders, automatic alarm devices, intercom stations, telephones if the system is interconnected, speech storage circuitry, display message control, automatic system supervision and diagnostic circuitry, and interface of staff registration and message management systems. All automated paging terminals include an automatic station identifier (ASI) that eliminates the need for the telephone operator to transmit the station call letters periodically as required by the FCC. An ASI may transmit either a voice message or Morse code, the latter being more common in new systems. The ASI makes the identification at prescribed intervals, but it will not interrupt a transmission.

Where continuous operation of the paging system is critical to the functioning of the hospital, designs can provide for redundant and/or hot standby paging terminal configurations.

Paging systems generally require little power, usually a 120 V ac, 60 Hz, 20 A circuit. Engineers should also provide backup power to the paging, served by the life safety branch of the emergency system. Provide UPS power where continuous operation is critical. Paging terminals require relatively clean operating environments with temperature and humidity regulation.

Radio-paging systems with either multiple dispatch points or interconnection with the hospital's telephone system will generally include a monitoring circuit with output to the control point. This design allows the telephone operator to meet the FCC requirement of monitoring all voice-paging transmissions and to be able to interrupt such transmissions for priority page messages or to prevent illegal transmissions.

7.9.4.3.3 Transmitter location and configuration

Designs should locate transmitters as close to the antenna as possible to reduce signal losses in the cabling. However, engineers should also consider locating them to allow for easy service access, security, and temperature control. Systems using radiating coaxial cable for the antenna system may warrant selection of a relatively central transmitter location to provide equal cable runs to all parts of the building.

Many transmitter configurations are available based on particular supplier requirements, range of coverage, type of antenna, and method of signal coverage within the building(s) and campus. Transmitters normally mount in a 48 cm (19 in) standard rack cabinet with a secured door. Some transmitter designs allow for mounting the transmitter chassis into standard EIA 48.7 cm (19 in) relay racks. All paging transmitters and related equipment is heavy and requires proper support. Pay attention to meeting all current seismic standards. Transmitters generally contain a power supply, the transmitter itself, and in many cases, an automatic lock-out receiver. This receiver provides a signal to the paging terminal to inhibit paging transmissions when it detects a carrier signal from another transmitter on the same frequency. This assures compliance with the FCC requirement to cooperate in the use of the assigned frequency.

Power requirements for transmitters are similar to those for paging terminals.

Improved "coverage" of an on-site system is obtained by some suppliers by using multiple transmitters on a single paging channel. These transmitters can operate in simulcast mode, in which multiple transmitters operate simultaneously. This technique requires specialized design beyond the scope of this document. The transmitters can also operate in sequence, with each transmitter sequentially sending. Such transmissions generally do not result in repetitive pages from a specific pager since special software in the pager eliminates duplicate pages of the same message. Sequential transmission can accomplish several things. It lowers total radiated power (which reduces interference with other possible users on the same frequency and reduces the possibility of interference with sensitive or unshielded biomedical electronic equipment); provides more even signal coverage within the building(s); improves coverage of a multiple building complex; and provides better coverage of below-grade floors. Internal re-radiating systems (see 7.8.2.4) can also improve coverage.

7.9.4.3.4 Antenna systems selection

The conditions governing the installation of an on-site paging system antenna are quite different from those applying to a mobile radio system. The main objective is not to cover as large a geographic area as possible but to ensure full and uniform coverage within the defined paging area.

Ideally, radio-paging signals disperse uniformly in all directions and decrease linearly at increasing distance from the antenna. In practice, however, screening and reflection attenuate the signals, so that antenna radiation is not uniform. In addition, signal strength is at its lowest directly below the location of most antennas, further complicating the possibilities for locating the antennas.

On-site paging receivers are generally best suited to receive vertically polarized radiation. Many things affect the choice of transmitter antenna, such as the size and shape of the area to be covered, the construction of the building where the paging is to be performed, etc. For these reasons, there are several different types of antennas in use, including:

- a) Ground plane
- b) Dipole and multiple dipole designs (may be omni-directional or directional)
- c) Collinear antennas (may be omni-directional or directional)
- d) Radiating coaxial cable systems

The antenna height should always be as low as possible to cover only the minimum area, thereby reducing the risk of interference with other installations.

Well-designed paging systems also include two additional items to protect against interference to other radio services located both within and nearby the health care facility; these are a RF isolator and band-pass filter on the transmitter output. The isolator provides protection against the generation of intermodulation distortion in the transmitter (and the consequent interference to other wireless systems). The band-pass filter reduces any harmonic or spurious output from the transmitter.

7.9.4.3.5 Requirements and licensing procedure

Operators of paging systems with voice capabilities should identify themselves with station call letters every 15 min in Industrial/Business Radio Service and every 30 min in the Public Safety Radio Service {FCC 90.425(a) [B4]} unless licensed in the Public Safety Radio Service under the provisions of Sec. 9020(a)(2)(v) [per FCC 90.425(d)(6)]. However, if the station makes no transmissions over a 30 min period, it should identify itself at the end of the next transmission. Stations need not go on the air solely for identification. The FCC will accept Morse code station identification.

When changing the radio-paging system, the FCC may require the facility to change its license. Some such modifications are substantial and require frequency coordination as well as issuance of a modified license. (Generally substantial modifications are changes to the installation or license that are technical in nature or would otherwise modify performance of the paging system.) Other modifications are minor, such as licensee

mailing addresses, and require only notification of the FCC to initiate issuance of a modified license.

7.10 Physician and staff register systems

7.10.1 Introduction

Physician and staff register systems are information systems used to locate specific doctors or other staff persons, provide telephone and pager numbers to the operators and others, verify the availability of needed specialties, and provide meeting reminders. Some systems provide printed patient lists. Messages received before the physician or staff has arrived are stored and then displayed to the intended recipient upon arrival.

7.10.2 Design criteria for physician and staff register systems

7.10.2.1 General

Codes do not currently require staff register systems. More and more of these systems are now integrating with other systems, and the trend is to not install stand-alone systems. Hospitals (and occasionally their medical staffs) purchase these systems for many reasons. Doctors want a means of letting staff know they are there, as well as a means to find out which other physicians are in-house. By having a staff registry system to locate various doctors, annoying voice paging is reduced. Some health care organizations have lost costly legal actions due to the inability to locate or verify the presence of a particular specialist who was actually in-house at the time of critical need.

The number of functions to be accomplished by a register system depends on several factors:

- a) *Message traffic.* Some modern register systems are actually “options” provided as part of a computerized telephone answering system. Facility size creates problems in locating staff members for both emergency and routine messages. The bigger the facility, the more likely it is that people are going to be away from the “assigned” workstation. For example, few facilities can afford to equip every staff member, plus the roster of outside physicians, with pocket pagers. Overhead loud-speaker paging can become almost continuous background noise pollution for both patients and staff. The display of staff location information on video monitors throughout the hospital in key locations can greatly reduce these problems. Health care organizations with register systems generally agree that these systems reduce overhead paging by at least 80%. The balance of the paging represents information of an emergency or general nature not suitable for register system use. Monitors for this system can also display, via special symbols, the location of a particular member, their pocket pager number, and the presence and urgency of waiting messages.
- b) *Number of hospitals in proximity.* In larger metropolitan areas, where physicians often see patients in several hospitals, the location problem for routine, urgent, and emergency messages becomes critical. “Where did Dr. Davis go when he left City General? Did he go to Einstein or St. Anthony’s?” Microprocessor-based

register systems can store and display this information quickly and easily. The physician leaving a facility has several destination choices to pick from when he leaves. The system stores this information and allows its retrieval by a telephone operator in seconds.

- c) *Specialization.* If 80 doctors are in the hospital and a particular specialist is needed in the emergency room, the question becomes, “Is there a neurosurgeon in the house?” If so, what is the name of the neurosurgeon and where is he? With a well-designed register system, these questions can be answered quickly, and the proper person can be located.
- d) *In-house staff location.* In teaching hospitals, the in-house staff should often solve the problem of locating and assembling the best team of physicians. A staff registry system, identifying who is in the hospital and who is on call, can greatly facilitate this process. Some hospitals have display monitors that list outside physicians currently in-house and staff members separately to simplify this process.
- e) *Incentive to use.* The overriding need for input devices is simplicity. If entry/exit stations are difficult to operate, they will not be used. At entry/exit stations, directions and function labels should be simple, clear, concise, and familiar. Displays should be very readable. The entry/exit procedure should be quick and easy to remember. Engineers should ensure that the physicians are directly involved in the selection of the system to maximize the chances that they will actually use it.

7.10.3 System types and selection

7.10.3.1 General

In its simplest form, lighted annunciator registries, with toggle switches by the names, have been used for at least 70 years. Computer-based systems are mostly replacing these older systems, but they can still be found in existing facilities.

The development of microprocessors, personal computers, and mainframe computers has allowed for the expansion of the registering in and out concept to extremely sophisticated systems. A single system can serve thousands of physicians and staff members with special functions for message management, voice synthesis, internal and external destination information, location of staff by title or specialty, radio paging, telephone interconnection, multiple video monitor display or staff registration information, displays of code blue or disaster alerts, staff profiles [listing telephone number(s), pocket pager number, date/time last in hospital], system diagnostics, message printers that may include a list of the doctor’s patients and those of his group, logging printers, etc.

7.10.3.2 Lighted annunciator panels

Lighted annunciator panels consist of a minimum of two panels, one usually in front of the telephone operator position and the other at the doctor’s entrance point. Both panels have a switch opposite each backlit name slot. A staff member or doctor indicates their presence by turning on the switch opposite their name. This in turn lights the appropriate

name in each panel. Many of these systems have a light flashing circuit activated at the telephone operator position that advises the entering or exiting physician of a message waiting. Often, a private telephone or two-station intercom system is provided to obtain messages from the operator.

This installation requires a pair of wires for each name to be annunciated. Therefore, a panel for 50 persons requires a minimum of 100 wires and 200 terminations. The disadvantage of lighted annunciator panels appears when more names should be added and/or the system should be expanded to add or relocate entry/exit stations. For example, adding one doctor's name (assuming space is available on the panel) requires moving every name in the alphabet beyond the initial letter in the name to be added. When changes occur, this can be a time-consuming process, multiplied by the number of panels in the system. Adding stations requires more wire, conduit space, and multiple terminations. Moving a station is the biggest problem because of the electrical conduit and cabling, all of which may have to be replaced or extended via a large junction box with terminal strips. Large systems require a cable bundle with a diameter as large as 15 cm (6 in). Lighted annunciator panels are simple to use and reliable. However, they do not offer the users much incentive to register in and out, and it is expensive to display the data in more than a limited number of locations in rather close proximity. Relocating a medium-sized (200 name) panel, with its corresponding raceway, wire, and labor needs, can be as costly as an entire modern microprocessor-based system.

7.10.3.3 Keypad or coded button-operated register systems

This type of system began replacing annunciator panel systems 40 years ago. The stations became much smaller since they eliminate the annunciator panels at both the entry/exit station and the switchboard.

To use this system, the staff member enters an assigned multi-digit registration number in the keypad. The entered digits display via LEDs in a display window for verification. The staff member then pushes an *in* or *out* button (sometimes within the keypad and sometimes separate) to complete the registration. If a message is waiting, a *message* light will illuminate, and the user can call the operator with the provided handset. A *message cancel* button is sometimes provided. Due to wiring simplicity, facilities can install multiple entry/exit stations at various entrances and other key locations.

7.10.3.4 Voice systems

A number of voice systems are on the market, all of which are quite similar in their functions. With these systems, a staff member registers into the system from either a dial or touch-tone type telephone. First, the staff member dials a multi-digit system access number; a connection tone indicates access. Then the staff member enters his or her assigned number into the system. The voice synthesizer in the system responds by repeating the digits dialed and then saying the words *in* or *out*, depending upon the current status of the staff member. The staff member then dials, for example, the number four to register in (GHI) or six (MNO) to register out. Messages stored in the system can be tagged with the extension number of internal departments trying to reach the registering staff member. Depending upon various option selections, these "extension calling"

messages may be entered either from the operator position or from any telephone within the hospital. Special number codes are utilized to accomplish these functions. Voice synthesizers can include a number of canned messages, such as “call lab,” “call office,” and “call records.” Video display monitors may be added wherever desired in the hospital to display staff members’ names, pocket pager numbers, location in the hospital, alternate covering physician number, specialty codes, and message insertion and retrieval from outside telephones. Some suppliers offer an option for dedicated telephone “terminals” that do not require the initial dialing of an access number to use the system.

Components of these systems include the following:

- a) A telephone operator 12-button keypad with video monitor
- b) Video display monitors throughout the hospital
- c) A microprocessor controller
- d) Entry/exit stations that might consist of dedicated telephones, network telephones, and/or hospital telephones
- e) FCC approved telephone interconnect device
- f) System cabling (generally two twisted pairs)
- g) Message printer option

7.10.3.5 Microcomputer system

Microcomputer-controlled registry systems are now available from many suppliers. These systems provide all of the functional capability of the other systems plus new and useful functions relating to management of the message-processing function at the telephone operator position and related record keeping and staff services. These systems require engineers to customize the functions, instructions, user terminology, nomenclature and vocabulary, display formats, message content, and many other variables. Better systems allow the hospital user to retain most of this flexibility. In this case, suppliers provide in-service training in system operation, set-up modification, and testing.

A printer for messages received at registration, and a logging printer with its system data activity printing capability for legal records, free the telephone operators from the enormous chore of logging all page and message information. Some systems can display special alert messages on all video monitors, such as disaster alerts and code blue information. Messages for staff members may be personal (“Your garage called: your car is ready”), departmental (“Department/Pediatrics meets 9:00 a.m., Nov. 14, Conference Room A”), or general (“CME Program, June 4, routine, doctor’s dining room”).

Physician information available to the main telephone operator position in regard to each physician can vary from the pager number and several telephone numbers, to a full profile of demographic data including office addresses, backup doctor, mode of payment accepted, whether board-certified, etc.

7.10.4 Design considerations for physician and staff register systems

- a) *Entry/exit stations.* Locate entry/exit stations at major physician entrances including video monitors listing in-house doctors. Entry/exit station users should have a practical, useful, and compelling incentive to use the station. Well-designed systems provide personal, general, departmental, and emergency messages.
- b) *Central control equipment.* Control cabinets and power supplies need the same type of environment as other communication control equipment. Locate operator consoles by the telephone operator. Well-designed systems use off-the-shelf video and RF monitors or both.
- c) *Cable plant.* These systems normally require no more than two twisted pairs of #22 AWG or pencil-sized shielded cable for connection of entry/exit stations to the computer, and coaxial cable for the monitors. Provide battery backup for the central processing unit (CPU) where momentary power losses are common.
- d) *Software considerations.* These systems require programming to provide simple user-friendly displays and instructions. For a staff registration system, personal comfort in operating the system requires this programming. If any portion seems awkward, staff members will avoid it. Start-up of the system requires input of all the roster data plus the pre-established message content and other user variables. The system supplier should teach the operating personnel not only how to run the system, but also how to change all the variables and modify the database.

7.11 Dictation systems

7.11.1 Introduction

Dictation systems record and store voice signals (dictation) for transcription. Medical staff use these systems to produce patients' medical records and for administrative functions. The effectiveness of a dictation system will depend on both the flexibility of the system and on the way the staff uses the system. Simple systems, effective training programs, and operator assistance help improve performance. Prerecorded instructions, available each time a system is used, will be useful where staff may work at several facilities and might need a reminder of operating codes each time they relocate.

7.11.2 Design criteria for dictation systems

7.11.2.1 General

Federal and state laws require health care facilities to maintain a medical record for every individual who is evaluated or treated. Individuals write more slowly than they speak and memory retention decreases over time; consequently, producing medical records from dictation systems, which use contemporary spoken records, is more efficient and more accurate than producing them from handwritten staff notes.

Select systems based on performance, measured by turn-around time of important dictation, ease of use, dependability, and overall throughput.

Two trends affect the way dictation works in hospitals:

- a) Voice recognition software continues to develop. Speed and accuracy are increasing. The greatest successes have come in areas like emergency and radiology, where many standard reports can be set up as forms and input limited to discrete windows of information. Implementation of voice recognition faces a special challenge of understanding accents. As the use of voice recognition grows, the need for transcription will become more of an editing function.
- b) Many dictation systems now make use of the desktop PC or the telephone to record reports in digital format. Dictation, review, and editing are handled on the local PC. Once dictation is complete, the caretaker sends the finished report to a central file server or digital recorder. Locate the dictation recorder or file server in the TR or data center for ease of connection to the telephone lines and to provide the proper environment.

7.11.2.2 System capacity

An effective dictation system eliminates bottlenecks. The system capacity should be determined by a survey of the dictating load, taking into consideration the number of persons dictating, amount of dictation, and dictating habits. All systems should allow dictation positions and recording machines to be economically added as system usage expands. While two systems may perform the same amount of dictation, systems where dictation cannot be scheduled will make more recording capacity necessary.

7.11.2.3 Recording machines

Dictation systems record dictation voices using cassettes, microcassettes, loop, and digital recording devices. Newer systems use the desktop PC, equipped with an application that captures dictation as a digital file and forwards the file to the central recorder through the hospital's network. The details of the recording devices are less critical than in the past due to increased effectiveness of digital management systems. Portable dictation stations often add flexibility to the overall system, so the central equipment should have an effective means of reading (and handling) digital files or cassette tapes generated by portable devices.

7.11.2.4 Record keeping

Most dictation systems used in health care facilities are computer-based equipment. These computer-based systems keep records for each dictation. The information may include location of priority dictation; length of dictation recorded with system totals; production history of each transcriptionist; doctors' code, patients' code; and length and type of each dictation. The particular information recorded varies from system to system and can be tailored to each installation. In high-volume installations, this record-keeping capability is necessary.

7.11.2.5 Transcription

Transcription controls include recorder transport functions and controls for tone, speed, and intercom (for speaking with the supervisor). Transcriptionists' terminals typically contain a word processing system.

7.11.2.6 Dictation station comfort

Good dictation stations make it easy for an author to record, review, and edit his notes. Each dictation station (or telephone handset) should have controls (or codes) for rewinding, fast forwarding, quick reviewing, full playback, editing, and signaling the operator. Automatic start/stop controls make the system more efficient by eliminating pauses in the dictation. Comfort can affect the efficiency of dictation systems. User-friendly terminals include features like signal muting during fast forward and reverse, automatic gain control, and clear indication of system functions.

7.11.3 System types and selection

- a) *Digital dictation systems.* Most dictation systems supplied to health care facilities provide close integration of record keeping and transcription control. Any dictation piece can be accessed in any order. It can be identified by the doctor's name, dictation type (priority), patient number, time entered, etc.
- b) *Portable.* A small dictation system may consist of portable machines and tape players. The dictation author carries recorded tapes to the transcriptionist.
- c) *Central system—independent.* A central dictation system allows dictation at any time at various points convenient to the medical staff. Dictation and relevant data transmits to a central location for storage until staff can transcribe it. An independent system requires a separate cable plant and dedicated dictating sets. These sets are similar to desk phones, with push buttons to record, playback, rewind, etc. Dedicated dictation sets are designed specifically for their task and will be labeled accordingly. These labels can help reduce training time and improve ease of use [over telephone system access; see item d)].
- d) *Central system—telephone access.* Used with telephone systems, central dictation systems receive dictation via the telephone system through telephone instruments. Central recording connects to the telephone system via a trunk line. The author can record, listen to playback, etc. A person should learn these dictation codes to effectively use the telephone instrument. Interconnection to the telephone system has the advantage of greater system flexibility and wider system access [than dedicated dictation sets; see item c)]. Telephone system interconnection can allow off-site access.

7.11.4 Design considerations for dictation systems

- a) *Dictation stations.* Locate stations for convenience and so staff wishing to dictate can do so with access to all relevant source material. Common areas needing dictation stations include charting areas at nursing stations, operating and delivery suites, control areas, radiology reading rooms, and pathology analysis areas.

- b) *Portable recorders.* Portable recorders should be compatible with central system transcription machines.
- c) *Wiring.* When the recording machines and supervisors' console are in separate rooms, cables should connect them. When the dictation system operates through the telephone system, provide a cable path from the console and recorders to the telephone switch.
- d) *Power source.* Although not directly tied to patient safety, dictation systems are necessary for efficient facility operation. Many facilities protect the dictation system by a UPS system to reduce the economic impact of short power fluctuations, which could interrupt dictation in progress. UPS sizes for this application typically vary from 1.5 kVA to 3 kVA.

7.12 Patient physiological monitoring systems

7.12.1 Introduction

A patient-monitoring system provides numeric and waveform displays of one or more physiological parameters at the bedside and at a remote location. These systems make it possible to provide continual monitoring of several patients from a central location for surveillance and recording, increasing the quality and quantity of the information and thus improving the caregiver's ability to deliver appropriate care. Many hospitals install fetal monitors. Some of these systems include telemetry for ambulatory patients.

Patient-monitoring systems consist of bedside monitors, a central station, optional remote monitors, patient computer systems, and the interconnection hardware. Bedside monitors acquire, process, and display patient parameters, such as the electrocardiogram (ECG); pulse rate; respiration waveform and rate; blood pressure waveform(s) with systolic, diastolic, and mean values; temperature; and oxygen saturation. They provide alarms for out-of-bounds parameter values and may provide data storage and vital sign trend analysis. There are a variety of input signals from these systems, such as the small, millivolt level ECG obtained through skin electrodes and the transduced blood pressure (from a strain gauge excited by the monitor). The monitor may also accept manually entered data obtained intermittently from other sources (e.g., cardiac output). The bedside instrumentation may be a single device, but frequently is a collection of devices. The monitor may be modular with some parameter modules inserted into the mainframe as needed. The signal conditioning input device may be a separate, smaller unit connected to the monitor with an umbilical cable, permitting it to be located close to the patient or on the bed, with only one cable from the bed to the monitor.

The central station provides remote waveform displays, digital values (e.g., heart rate) and alarms for several patients. Continuous waveform recording onto a paper strip can be initiated manually and certain alarm conditions will automatically start short recordings of ECG and other parameters. Many systems incorporate special- or general-purpose computer systems for signal analysis, display, and report generation. These additional displays and printers may be located at the central station while the computers may be remotely located. Signal transmission in currently marketed systems is often digital.

The interconnection cabling can be a multiconductor for analog or digital signals or coaxial for data or display. It connects the bedside instrumentation with the central station display, the central-station special-purpose computer, or a network, depending upon the complexity of the system. All of the elements of the system interconnect, often by more than one signal cable and a separate power cable. The system may connect to additional central stations, to special-purpose computers (e.g., for arrhythmia analysis of the ECG), to remote displays, or to a patient data management network.

7.12.2 Design criteria for patient physiological monitoring systems

7.12.2.1 General

Patient physiological monitoring systems include connection by cable or wireless system to a central station and perhaps to additional instrumentation. Local bedside patient monitors without connection to a central station may occur anywhere in the hospital, such as the emergency department, recovery room (PACU), delivery room, ORs, short stay surgery, and neonatal intensive care unit (NICU). The bedside instrumentation may be connected at the bedside to recorders or to other devices.

7.12.2.2 Telemetry systems

Hospitals frequently use telemetry system for ambulatory patients. These systems include portable transmitters carried by each patient and ceiling-mounted antennas located throughout the area. A receiver at the nurses' station processes the signal and displays the patient's heart rate. If the hospital considers wireless telemetry, the system supplier will generally make on-site field strength measurements to ensure adequate signal coverage. Each installation requires individual design based on its peculiar construction, placement of walls, and location of electrical equipment.

7.12.2.3 Computers

Special-purpose computers often make up part of patient-monitoring systems. Arrhythmia monitoring systems store a patient's heart rate on a hard disk and continually update and analyze this information to detect abnormal changes. Future upgrades or replacement systems in larger or more sophisticated institutions will include signal processing and interconnection to other systems. Just as with other systems, ensure that these systems have adequate cooling, emergency power, separation of circuits from sources of electrical noise, and grounding.

7.12.3 Design considerations for patient physiological monitoring systems

7.12.3.1 General

Obtain requirements for physical space, power, and cooling requirements from the system supplier for each specific installation. In addition, obtain interconnection requirements for the patient-monitoring system, including sizes and types of raceways, cables, and terminating junction boxes at the bed locations and central station. For most applications,

a 2-gang-deep outlet box at each patient bed location with a single-gang cover plate should be adequate.

Although modern digital systems require less power and cabling, they may have more components and interconnections. Access to junction boxes and the various components of the monitoring system is important for installation and maintenance. Hospital power systems are noisy, and engineers should ensure separate circuits for the monitoring system.

7.12.3.2 Location of equipment

Bedside monitors can be located on small tables, on mobile instrument carts for freedom of movement to any desired location, or on wall-mount brackets to keep the bedside area as free of equipment as possible.

Locate patient-monitoring central stations at the nurses' stations of the units. The central monitors and recorders are usually located on or above the counter within easy view for continual monitoring. Larger systems with several monitors may be built into custom casework.

Remote monitors may be wall- or ceiling-mounted at any strategic location in the room or in medical staff flow patterns, such as hallways, where facility staff desire to have patient monitoring. These additional monitors allow observation of the patient parameters while staff members are away from the central station.

7.12.3.3 Space requirements

Provide a countertop or other suitable structure to support the equipment at the central station. Provide adequate space from the rear of the instruments to the back of the enclosure for ventilation and cable access. A minimum of 15 cm (6 in) should be sufficient. The structure should consist of a surface above and behind the monitoring equipment for protection of the cables and equipment. The system supplier may offer custom-built enclosures. Provide space for the system control equipment and arrhythmia monitoring computer either at the central station or in a separate equipment closet, potentially the IT closet, for the area served. For larger systems (34-bed unit) provide 7.4 m² (80 ft²) of wall space with plywood backing and cooling capacity of 10 000 Btu/h.

7.12.3.4 Installation requirements

Depending on the specific-system requirements, install a 1.9 cm to 3.2 cm (0.75 in to 1.25 in) raceway from the monitor outlet at each patient bed location to the system control equipment location. If the control equipment is in a separate equipment closet or room, provide additional raceways from the control equipment to the central monitor station. Patient-monitoring cables may also run in a cable tray system. To avoid electrical interference, locate the cables at least 30.5 cm (1 ft) away from power lines, air-conditioning units, diathermy units, elevators, etc. For retrofit installations, surface-mounted raceways may be used for the interconnecting cabling. If the facility uses

wall-mounted brackets to support bedside monitors, the walls require adequate backing to support the load.

7.12.3.5 Power requirements

Each patient bed location should have a hospital grade emergency power receptacle located within 91.4 cm (3 ft) of the monitoring equipment. In critical care areas, the receptacle for the patient-monitoring equipment should connect to the critical branch emergency circuit dedicated to the bed location. Depending on the size of the system, four to ten emergency duplex receptacles connected to the critical branch of the emergency power system should be provided for the control equipment. Computerized arrhythmia systems may require uninterruptible power for the central control equipment. Provide several emergency receptacles at the central station sufficient for the number of monitors and recorders to be installed at this location.

7.13 Picture archiving and communication system

7.13.1 Introduction

In recent years PACS have rapidly replaced traditional film-based imaging systems. PACS rely on standard computer hardware and networks, as follows:

- a) PACS management software runs on standard network file servers.
- b) Short-term image storage relies on redundant files servers (RAID arrays).
- c) Long-term and archive storage relies on high capacity optical disc or magnetic tape “juke” boxes.
- d) Radiologists’ reading stations are based on standard workstations.
- e) Review workstations frequently are simply high capacity PCs with high-resolution monitors.
- f) Virtually all PACS use standard networking protocols—frequently connecting through the hospital’s network.
- g) Virtually all imaging equipment complies with current DICOM radiology communication standards and connects with standard Ethernet ports.

PACS implementation places an extremely heavy burden on the hospital network. File sizes normally run 20 000 to 100 000 times larger than the normal data files. PACS studies normally travel through the network 5 or 6 times between initial capture to final archival storage, and the radiologist typically views two to three comparative studies during the reading process.

As a result, engineers should take special care in designing the structured infrastructure systems and network to support PACS.

7.13.2 Design considerations

Consider the following during design of PACS:

- a) PACS design requires careful coordination between the medical equipment planner, communication systems planner, and system vendor to assure that network capacity and configuration will support PACS operation.
- b) Provide IT outlets adjacent to all imaging modalities and PACS equipment.
- c) Design the network to ensure that network switches and segments are configured to handle the PACS traffic without slowing delivery of other data.
- d) Prior to configuring the PACS and network, the medical equipment planner and clinical staff should develop a PACS workflow plan indicating how studies will be captured, reviewed and certified, read by radiologists, distributed to clinicians, and archived.
- e) The PACS workflow plan should include activity within the hospital and remote facilities.
- f) PACS workflow should also address issues such as:
 - 1) Patients arriving with film records: Will the films be scanned into the system or read on view boxes?
 - 2) Release of information: Will films be printed, images sent on CD ROM, or Web access provided?
 - 3) Will physicians have Web access to studies?
 - 4) How will existing film records be handled: All films scanned or individual studies scanned as former patients are readmitted?
 - 5) Will PACS be implemented in existing facilities 6 to 12 months in advance of the move in order for an adequate database of comparative studies to be built up on the system?

7.14 Emergency medical service communications

7.14.1 Introduction

EMS is a system of trained personnel, transportation equipment, and communications equipment that provides pre-hospital medical care to patients at locations remote from the health care facility and during transport to the hospital. Emergency transportation includes ambulances, helicopters, and fixed-wing aircraft. The communications equipment supporting this team should provide continuous voice communications, allowing medical control to remain with emergency department medical staff, and may include the capability to provide cardiac telemetering between the patient's site and the hospital emergency department. The facility may also use this communications equipment to coordinate the hospital's participation in regional emergencies. State or regional authorities usually set criteria for the design, operation, and control of EMS communication systems. Engineers should carefully coordinate any design to ensure that they are integrated into regional communications and response plans.

A wide variety of radio communications options are available to support EMS communications requirements. The majority of systems fall within the VHF and UHF frequency ranges, with many systems in urban centers making use of multi-agency regional or statewide 800 MHz trunked radio systems. In many EMS communications

systems, cellular telephones provide ambulance to hospital communications capabilities. In some cases, cellular telephones have become the primary communications tool, with traditional EMS radio systems being relegated to auxiliary use. These cellular telephone based systems may be designed to support cardiac telemetry as well as voice communications. Following the 9/11 attacks, New York hospitals lost the local telephone utility service for an extended period. The cellular phones they had set aside for emergency use were on a network that was overloaded and unavailable. They were only able to communicate following the event by using cellular phones that employees had brought and that were on other networks. Having cellular phones on several networks would be a prudent measure to ensure reliability of communications during a crisis.

7.14.2 Design criteria for EMS communications

Whenever a health care facility is equipped for emergency care, the engineer should investigate his or her responsibilities in the design and installation of EMS communications equipment. It requires close coordination with operational staff, regional EMS communications planning groups, and the equipment supplier.

7.14.3 Design considerations for EMS communications

7.14.3.1 General

Engineers have many options for radio communications systems to provide EMS communications, and the equipment locations and power requirements can vary widely from facility to facility. The engineer should carefully investigate the system requirements for each design and ensure the reliability of the power supply to this important system.

7.14.3.2 Emergency department communications center

Hospital emergency departments will have defined work areas containing radio and telephone communications equipment and where emergency department staff may receive radio and cellular telephone calls. Design considerations for this space relate primarily to management of ambient noise, installation of suitable protected power, provisions for a variety of communications resources (radios and telephone systems, as well as computers that may be used to provide bed status or the status of regional EMS facilities), and provision for suitable routing of cables between radios or dispatch consoles and remotely located equipment spaces.

EMS base station radio equipment will most likely consist of a desktop remote control console connected to remotely located radio equipment, and may also include relatively compact desktop radios with attached power supplies. Traditional radio telemetry systems designed to support the transmission of telemetry from ambulances to the emergency department often include a console containing the radio control equipment, as well as equipment to display the physiological monitoring signals. Newer radio telemetry system designs include the capability to receive cardiac telemetry from cellular telephones and to display that telemetry data for emergency department interpretation and recording.

7.14.3.3 Radio equipment room

Remotely located, base station radio equipment typically resides in the highest suitable location within the facility. This location will most often be telecommunications equipment rooms, elevator penthouses, or similar mechanical spaces located on or near the top floor of the facility. The associated antennas then mount on an outside parapet or specialized antenna mount, with cables run into the radio equipment spaces. In all such designs, pay attention to ensuring that the technical spaces are reasonably clean environments with adequate heating and cooling to maintain equipment temperatures within manufacturer specifications. All equipment within these spaces needs emergency power that is suitably grounded, and all cabling leaving the room needs to have adequate lightning protection.

7.14.3.4 Raceway for antenna cabling

EMS antennas normally mount on the roof of the health care facility. The engineer should provide a raceway and cable entry ports between the externally mounted antenna and base station radio(s). The engineer should verify the maximum length of these cables for the system installed. All antennas need to be bonded to the structure ground system.

7.14.4 Hospital emergency operations centers

Many health care facilities have elected to establish Emergency Operations Centers (EOCs) within their facilities. The EOCs are most often located within or immediately adjacent to the emergency department, based on the required interaction between the EOC and emergency department functions. EOC rooms typically have a wide variety of technical systems including multiple telephones, ring-down lines to local public safety answering points (PSAPs), multiple two-way radios, multiple desktop PC workstations, and spaces suitable for managing both the health care facility and external EMS operations during a crisis. Planning for these spaces requires design of adequate UPS and generator backed power, development of workspace with adequate task lighting and audio isolation from adjacent work areas, and planning for a large number of cable raceways for the required radio equipment. In many cases, they will have multiple radios in a wide variety of frequency ranges, with the express goal of providing comprehensive linkages within the facility, with other participants in the EMS operations environment, and with local public safety authorities.

Typically, these spaces are conference rooms with provisions for multiple workstations that include telephone, computer, and miscellaneous radio communications devices. The radio facilities that are needed in such a space may include LMR or similar radios operating on channels authorized by local fire, EMS, law enforcement, hospital coordination, transportation departments, and/or amateur radio emergency services. Such an ad hoc assembly of seldom-used and randomly installed radio systems can be a major source of mutual interference if the whole facility is ever called on to activate simultaneously. Major interference can exist between radios operating on closely spaced frequencies, and between radios and computers and telephones. A technically competent coordinator or consultant should be used to produce a plan to mitigate such interference.

Proper planning for such a facility may involve placing all of the intended radio devices in a common radio room near the necessary outdoor antennas and equipping them with remote-control adaptors that can operate over standard telecommunications cables to control console units in the EOC space. Radios may be operated from common backed-up power supplies or batteries, and all antenna cables should pass through a common grounded bulkhead with lightning protection devices. Antennas for radios in the same band of frequencies should be distributed in the available antenna space to provide as much separation as possible. This configuration will permit the radios to operate with much less mutual interference. Removing the radios themselves from the room in which the telephones and computers are located will help to eliminate interference between them. Consoles with headset capabilities will also reduce the room noise level that would otherwise be experienced with multiple radio loudspeakers in a room.

7.15 Clocks

7.15.1 Introduction

Health care facilities require clocks to provide accurate and reliable time indication for legal records, medical procedures, and efficient and safe operation of health care facilities. Clock systems with automatic hourly and 12-hour time supervision and regulation features provide accurate and reliable synchronized time indication. Individual non-self-regulating (non-system) type clocks will usually provide reliable individual time indication. Hospitals may use clocks that are powered from the building power distribution system or that use batteries. Clock systems can also provide control signals for time-of-day control of building systems, such as heating, ventilating, and air-conditioning (HVAC) and exterior lighting. In this mode, the clock control unit takes the place of numerous individual time clocks. Clock systems also work together with time and attendance systems to assure synchronization of these devices.

7.15.2 Design criteria for clocks

7.15.2.1 Clock locations

Provide clocks in lobbies, waiting rooms, cafeterias, staff lounges, offices, central control centers, and other locations specified by any relevant regulations and where desired by the owner. In nurses' stations, recovery rooms, scrub sinks, birthing rooms, emergency treatment rooms, intensive care rooms, coronary care rooms, ORs, and nurseries use clocks with a sweep second hand readout or digital direct read display to facilitate timing of pulse or other physiological indicators. Some regulations require elapsed time clocks in emergency, surgery, and delivery suites, depending on staff requirements.

7.15.2.2 Individual clocks

Individual non-self-regulating (non-system) type clocks will usually furnish reliable individual time indication. However, these clocks have the inherent disadvantage of not synchronizing with the other facility clocks so the facility staff will have to manually reset them at least twice a year for daylight savings time changes. These clocks can derive

power from batteries or from the building power system. The costs of battery-operated clocks are low, they are mobile, relatively accurate, and have long battery life, making them a popular choice. The obvious trade-off is that facility staff have to replace the batteries periodically. These clocks are also not as rugged as institutional clocks and do not hold up as well under cleaning.

7.15.2.3 Elapsed-time clocks

Elapsed time clocks measure the time between manual activation and manual deactivation, making them useful for measuring the duration of time-sensitive events. These clocks may be sweep-hand type or digital displays. If the readout is large enough [2.5 cm (1 in) is acceptable; 5 cm (2 in) is recommended], digital direct-read displays are better than analog dial clocks in the operating and delivery rooms. Digital direct-read clocks use two types of displays: LED and LCD. LCD displays are legible from an angle view, but can only be manufactured up to 5 cm (2 in). LED clocks can be manufactured to virtually any size [5 cm to 10 cm (2 in to 4 in) is typical], but they are hard to read from an angle. Time clocks should have the capability of immediate automatic time correction in the event of power interruption. Elapsed-time clocks start and stop when a user activates them, with settings for start, stop, and reset from zero or resumption. These clocks should have both count-down and count-up capability with an audible signal at the end of count down.

7.15.2.4 Clock system—wired

There are three types of direct-wired systems: minute-impulse, synchronous, and binary coded decimal (BCD). Minute-impulse systems are obsolete. Wired synchronous systems require three conductors from the master controller to all of the secondary clocks, with the clocks wired in parallel. The three conductors are for clock power, correction, and common. System voltage is either 120 V, 60 Hz or 24 V, 60 Hz. BCD systems transmit digital signals to synchronize digital clocks and computer systems via an RS-232 port connection.

7.15.2.5 Clock system—carrier current

This system requires connection only to a suitable 120 V, 60 Hz electric circuit, usually the nearest unswitched duplex receptacle circuit. These systems provide automatic individual self-correction by carrier current transmitted over the building secondary electrical distribution system. The costs of carrier frequency signal generator equipment make these systems economical only for medium to large facilities and remodels. Sometimes the clock system carrier current can interfere with other systems.

7.15.2.6 Clock system—wireless

Wireless clocks are available in two forms, as follows.

7.15.2.6.1 Independent clocks

Known as *atomic clocks*, independent clocks slave directly to radio signals from the National Bureau of Standards radio station WWVB at Boulder, Colorado. They are usually battery-powered and may not be suitable in some critical health care room functions. Additionally, the 60 kHz WWVB signals have an extremely long wavelength and therefore do not penetrate many building structures well.

7.15.2.6.2 Radio repeating systems

Proprietary in-building radio repeating systems carrying precise time pulses derived from a central Global Positioning Satellite (GPS) receiver. Such systems take the timing pulses that are part of the GPS system and convert them to proprietary digital signals. They then propagate the signals through the building by a system of repeater units. Engineering for such systems generally should be done by manufacturer's representatives, and repeaters usually require FCC licensing.

7.15.3 Design considerations for clocks

7.15.3.1 Size and mounting

Clocks are available in a wide variety of sizes, face styles, enclosure styles, and mounting methods. Most facilities mount clocks on the wall in a semi-flush or surface-mounted configuration. In either case, the clock comes with a flush outlet box to support the clock and to accommodate a concealed attachment plug and receptacle to allow quick disconnection of the clock wiring. The plug and receptacle are three-wire grounding type for carrier current systems, but 4-wire grounding type plugs and receptacles for direct-wired system clocks. Engineers should determine clock sizes by maximum viewing distances and relations to architectural designs. Table 7-3 lists minimum recommended sizes.

Table 7-3—Clock sizes

Viewing distance m (ft)	Clock diameter cm (in)
30 (100)	30 (12)
46 (150)	38 (15)

7.15.3.2 Clock system control unit

The clock system control unit contains the time base for the clock system. The time base is usually a quartz crystal oscillator, which is either synchronized with the 60 Hz power line or is a completely independent, temperature-compensated oscillator. The signal from the oscillator drives either a master synchronous motor or a microprocessor-based computer.

Mechanical-motor-type units are no longer manufactured but are still occasionally found in many existing hospitals. For these systems, the motor regulates the system control signals. The microprocessor-based units generate control signals using solid-state counting and signal generation circuits.

The main function of the master control unit is correction of secondary clocks that otherwise display the incorrect time due to power failure or changing to or from daylight savings time. Synchronous wired and carrier-frequency-type systems provide up to 59 min slow and 55 s fast correction at the end of each hour, and fully correct the clocks within 12 h.

Design the master time control unit with a standby feature to ensure retention of the master time during power outages. This device may be either a spring motor or an internal battery capable of retaining the master time for a minimum of 12 h.

7.15.3.3 Cable plant

The synchronizing signals originate at the master control unit and travel to the clocks either by direct (dedicated) wiring or by carrier current signals over the 120 V, 60 Hz building secondary electrical distribution system. If a facility selects a carrier current system, the engineer should investigate possible interference with medical instruments and monitors caused by the high-frequency carrier current signal. Medical instruments may also backfeed a frequency on the power distribution system, causing the clocks to malfunction.

7.16 Fire alarm system

7.16.1 Introduction

Fire alarm systems for health care facilities ideally should provide early detection; accurate location of the alarm origin; fire department notification; and automatic control of the HVAC systems, elevators, and other building systems necessary to make the building safer for its occupants.

The prerequisite to designing the fire alarm systems for health care facilities is to understand the unique hazards presented by these buildings, as well as the unique ways their staff respond to fires. As is repeated in many places in this book, the engineer setting out to design or to work on a particular system should work with the building owner to fully understand these issues. And because fire alarm systems are highly regulated, usually by both federal, state, and local authorities having jurisdiction (AHJs), the engineer should synthesize the demands of these regulations and regulators together with the plans of the facility owner whose staff will be responding to a fire.

The obvious feature that distinguishes health care facilities from other types of buildings is that many of the occupants are incapable of leaving the building, or, indeed, of undertaking any kind of self-preservation. As a result, in buildings that house numbers of such patients, the normal strategy for dealing with a fire—evacuating the building—

should be abandoned in favor of a strategy of fighting the fire in place and containing any possible spread. Because of this need, the systems and fire protection elements of the architecture and other building systems should support the ability to detect the fire quickly, and then to contain it to as small an area as possible so as to protect the other vulnerable building occupants.

Finally, the engineer thinking about a health facility would do well to understand the hazards that are particular to health care facilities and that are different from other types of buildings. Most health care facilities contain all of the “normal” potential sources of ignition—waste paper, soiled linen, etc. In addition, because health care facilities contain many kinds of occupancies (kitchen, laundry, laboratory with hoods, paint and engineering shops, offices), they should include fire alarm systems for these areas carefully tailored to the needs of these areas in a way that is blended with the overall needs of the occupants of the facility. However, health care facilities also contain unique hazards due to the procedures that occur within. As an example, the Joint Commission, formerly the Joint Commission on Accreditation of Healthcare Facilities (JCAHO), has reported a recent trend of fires in ORs due to ignition of cloth drapes by cauterizing tools.

The fire protection systems, including operational improvements, have resulted in steadily falling numbers of fires and fire deaths for the last decade. However, the total amount of property damage caused by fires has remained relatively constant over the same period of time (see Aherns [B1]). Within health care institutions, 1999 (the most recent year for which data are available) saw only 5900 fires in health care institutions and only three deaths (of a national total of 523 600 fires with 3041 deaths). Within health care facilities, 2500 fires, 111 injuries, and all of the deaths occurred within nursing homes. Another 3000 fires occurred in hospitals, causing the most damage (\$8.5 million) of fires in any kind of health care occupancy, as well as causing 117 injuries. The lessons from these data are probably that the nursing homes, due to the weakened health status of the occupants and relative lack of expertise in firefighting of staff, should have fire alarm systems that detect products of combustion very quickly, and that isolate the fire to as small an area as possible for as long as possible. Within a hospital, there are so many different types of unusual hazards that the relative number of incidents to square footage is high. And again because of the weakened health of the occupants, the number of injuries per fire is relatively higher than that of other building types.

One other feature of health care facilities that makes the design of parts of fire alarm systems difficult is the frequency of renovations and changes within a facility. In most facilities, the architecture remains fairly static over long periods of time.

7.16.2 Design criteria for fire alarm systems

Fire alarm systems are required by life safety regulations. The engineer should meet with the local fire marshal to determine the legal fire alarm requirements. Although beyond the scope of this recommended practice, building codes require compartmentalization, fireproofing, and sprinklering as essential to adequate fire protection in health care facilities. The electrical engineer is not charged with the responsibility for designing architectural, structural, and fire suppression systems, but the engineer should integrate the fire alarm system design with the overall fire protection plan.

In addition to the building codes enforced by the various building authorities, other standards may be enforced by organizations such as the Centers for Medicare and Medicaid Services (CMS) or the Joint Commission. Some of the basic standards referred to by these organizations in the area of fire protection are National Fire Protection Association (NFPA), Underwriters' Laboratories (UL), and Factory Mutual (FM). UL and FM standards are equipment testing standards that are used to determine if equipment meets the functional and operational requirements of the appropriate NFPA standards and to determine that the equipment does not present a safety hazard if properly installed and maintained.

The following standards provide appropriate guidelines for the application, installation, maintenance, and use of fire-protective signal systems:

- NFPA 72
- NFPA 90A
- NFPA 101
- ASME A17.1
- CABO/ANSI A117.1

In addition to codes, the following factors should be considered when designing fire alarm systems:

- a) A high percentage of patients in acute care hospitals are not ambulatory. Almost all patients will require staff assistance for relocation or evacuation.
- b) Most hospital patients are in a weakened condition, and many have some cardio-pulmonary deficiency. Therefore, the effect of smoke inhalation can be devastating in terms of loss of life.
- c) Panic or stress resulting from a poor fire management plan can cause shock, heart attack, and stroke—particularly in the critical patient.
- d) Heat from the fire or even the absence of environmental systems can jeopardize the sick patient's life. Extremes of temperature are particularly threatening to the critically ill or postoperative patient.
- e) Ambulatory patients may be sedated and may not be able to evacuate or relocate themselves.
- f) The high incidence of plastics, volatile liquids, and other combustibles in a hospital present a unique hazard—that of supporting combustion and often producing toxic gases.
- g) At any given time, a significant percentage of patients cannot be relocated or evacuated, because they are undergoing surgery or some other invasive procedure. For example, a 300-bed hospital can have as many as 30 such patients during a typical morning.
- h) The presence of data processing, biomedical, radiological, and other electrical and electronic equipment presents a two-fold problem. First, these items, because of their high use of electricity and combustibles, increase the chances of fire. Second, when a fire starts, the loss of critical, sophisticated, and expensive equipment can be a major financial loss.

- i) About half of all hospital fires begin in service areas such as kitchens, general storage, maintenance areas, etc. Fires in patient care areas are most likely to occur in patient rooms.
- j) Finally, the ADA contains requirements for device location and alarm intensity (audible and visual).

7.16.3 System architecture

Many other texts cover the basics of fire detection and alarm systems comprehensively. (See, for example, Volume 6 of the American Society of Healthcare Engineering (ASHE) Management and Compliance Series, Fire Alarm Systems [B2]). Most systems available today are microprocessor-based systems consisting of a number of distributed control panels. Each control panel can operate independently of the others, but the system of panels is linked so as to allow centralized control and reporting.

Multiplex systems use microprocessor technology to poll various groupings of initiation circuits. Instead of requiring a set of conductors for each alarm initiation circuit as in older systems, a multiplex system requires a single set of conductors to a remote data gathering panel, which, in turn, serves a number of its own alarm initiation circuits regardless of the number of circuits or risers in the data gathering panel zone(s). In addition to reducing the number of conductors required, a multiplex system also simplifies the method of wiring. Instead of requiring, for the purpose of supervision, that all the wiring for a single zone be installed in one continuous loop without any parallel branching, a multiplex system can be installed using parallel branching at any convenient location. This is made possible because NFPA codes only permit the use of active multiplex systems that report continually the status of each device on a zone within prescribed time intervals, eliminating the need for the conventional method of continuous supervision (NFPA 72).

Because many initiating devices in a multiplex system share a common transmission path and each device transmits its status sequentially, it is not always possible for a change of status indication to be received immediately at the control panel. Codes permit a delay from the time a fire is sensed by an initiating device until it is displayed at the control panel. Since requirements can vary with each application, the acceptability of the system delay time should be determined before a particular system is specified or accepted.

Codes now permit fire alarm systems to be combined with other systems not related to fire emergencies. These include security, building management, and combination communications/fire alarm systems. When these systems are used, fire alarm signals should be clearly recognizable and should take precedence over any other signal. The non fire alarm functions of the system cannot degrade the integrity of the fire alarm functions. Circuits and components that are common to fire alarm and non fire alarm functions should be installed and supervised in accordance with fire alarm system standards. Combination systems should be listed by an NRTL for fire alarm use. When combination systems can meet these requirements, significant cost savings can be realized when the systems are installed. Because of the importance of the fire alarm system for life safety and property protection, combination systems should be installed and serviced by trained fire alarm personnel. However, some health care facilities choose to forego the potential

cost advantages of a combination system, thinking that combining the fire alarm system will mean that the system will be down whenever it is down for some other reason, such as updating the building automation system.

7.16.4 Design considerations for fire alarm systems

7.16.4.1 General

Both manual and automatic fire alarm initiation should be used in health care facilities. The complete system should consist of ceiling or spot-type smoke detectors, duct-type smoke detectors, manual stations, and sprinkler water flow switches. Use heat detectors selectively in place of smoke detectors where conditions may tend to cause a false alarm from smoke detectors.

7.16.4.2 Smoke detectors

In terms of sensitivity and number of devices, the smoke detector is the first line of defense in a health care facility. Ceiling detectors should be provided in corridors and spaced no more than 9.1 m (30 ft) apart or more than 4.6 m (15 ft) from any wall. Various building and NFPA codes govern spacing at doors and dead ends. Corridor detectors serve two purposes. They control the operation of cross-corridor smoke doors, and they provide hospital-wide coverage, detecting smoke from adjacent spaces. Since fire and health codes ensure that no area will be far from a corridor, all spaces are near a detector. In addition to corridors, smoke detectors should be used in high fire risk areas where false alarms are not likely, in areas requiring very early detection such as medical records, electrical rooms, and computer rooms, and in areas without sprinkler heads. Most health care facilities will contain fire sprinkler systems, but sometimes sprinklering areas such as ICUs, electrical rooms, or radiology rooms may be unwise, as an accidental discharge may jeopardize patient safety or expensive equipment. In these areas, the engineer should consider using a smoke detector operated pre-action sprinkler system. Similarly, provisions in ASME A17.1 require that power to elevator equipment should be disconnected before the application of water to an elevator equipment room. In this case again, a smoke- or heat-detector-operated pre-action sprinkler system should be used.

Some codes permit or require smoke detectors and other initiation devices in various areas, including in patient rooms, at smoke barrier doors, and at horizontal exits to be used in lieu of corridor detectors on patient sleeping room floors. When door closers are required, smoke detectors can be provided as a part of a combination holder/closer.

Suppliers of photoelectric-type and ionization-type smoke detectors have long debated the advantages and disadvantages of their detectors for health care facilities. Accepted wisdom has been that hot, invisible products of combustion are detected faster by ionization detectors, and cold, visible smoke from a slow, smoldering fire is detected better by photoelectric detectors. Photoelectric-detector suppliers argue that fires likely to occur in hospitals are of the slow, smoldering type. They also contend that photoelectric detectors are best in large buildings where smoke cools when it should travel great distances before detection. It is accepted in the industry that false alarms from ionization detectors are more likely to occur from cooking fumes, ozone produced by electrical

arcing, steam, and engine exhaust. UL 268-2006 [B8] now requires all detectors to pass the same fire tests including the slow, smoldering fire test originally used only to test photoelectric detectors. This has improved the performance of the ionization detectors, but for some models it has made the detector even more sensitive and subject to more false alarms. Suppliers of ionization detectors argue that quick-burning fires are more dangerous and do not produce the visible products of combustion needed for photoelectric-detector operation, making their ionization detector the logical choice. Combination photoelectric/ionization detectors are available. The specifier should make the choice based on the above factors, local and state requirements, and the requirements of the particular facility. Detectors selected for use in health care facilities should be listed under UL 268-2006.

Detectors now available are usually addressable and contain various other intelligent features. Such features include the ability to verify an alarm before initiating an alert, and changing the sensitivity of the device so as to adjust for dust or other environmental influences. These features serve to save the health care facility considerable operational costs in terms of fees resulting from too frequent false alarms. Another intelligent feature embodied in many detectors now available is a self-test feature, which allows the system to test the individual detectors in a way that satisfies the quarterly (but not the yearly) testing requirements of the JCAHO, and thus saves tremendous staff time, while at the same time ensuring much better system reliability.

7.16.4.3 Door closers

The use of closers on patient room doors is a controversial issue. The BOCA Basic/National Building Code [B3] now allows their use in order to meet the requirements for detectors in the patient room, though the issue continues to be debated. The use of closers almost demands that holders be provided, because nurses cannot function with all patient room doors closed at all times. If closers are required, detector control of closers can be handled in a number of ways, as follows:

- a) The smoke detector can be installed as an integral part of the holder/closer. This location permits detection of smoke in both the room and the corridor, but its position makes for poor detection in either case.
- b) A smoke detector can be installed in the patient room. If a fire starts in the room, the door closes and a general fire alarm is initiated, but without annunciation (usually at the nurses' station or over the door) the location of the fire cannot be quickly determined and the patient can be asphyxiated before the fire is discovered. This represents a sacrifice of the patient to impede smoke spread to the corridor. Individual annunciation of each patient room is an alternative and can be provided by addressable-type devices.
- c) Holders can be operated from corridor smoke detectors by zone or by individual detectors. Another alternative is to close all patient doors in the building for any general alarm. However, if all doors are closed, a problem with evacuation and relocation of patients is also created.

Because all of the preceding methods are unsatisfactory, door closers are not recommended for patient rooms, unless in a jurisdiction requiring them under the BOCA

Basic/National Building Code [B3]. Patient room detectors offer an additional measure of protection at increased cost. Corridor detectors, fire-rated trash cans, noncombustible mattresses and fixtures, and vigilant supervision by the nursing staff may provide adequate protection against the patient room fire.

7.16.4.4 Heat detectors

Heat detectors should only be used in lieu of smoke detectors in places likely to provide false alarms due to the normal occurrence of combustion products. The designer should keep in mind that sprinkler heads operate only a little slower than heat detectors and, in addition to extinguishment, provide alarm initiation and general location annunciation through flow switches. The only advantage added by the heat detector is that it can provide better annunciation. Heat detectors, flame detectors, and other special detectors are not used extensively in fully sprinklered facilities.

7.16.4.5 Sprinkler system water flow switch

In a fully sprinklered facility, the next line of protection is provided by sprinkler water flow switches. The importance of flow switches comes from the fact that virtually every space in the building has a heat-actuated sprinkler head. The only difficulty in using the sprinkler system to initiate an alarm is in providing accurate location annunciation. For several reasons, sprinkler zones may not always coincide with fire alarm or building zones and smoke and fire compartments. Often, sprinkler systems are hydraulically calculated by the fire protection contractor, and zoning becomes a matter of optimum water flow and lowest cost, rather than building geography. If sprinkler zones and other zones do not coincide, the engineer should ensure that

- a) The sprinkler zone on the annunciator coincides with locations of the heads monitored by the flow switch—not the location of the flow switch itself. Sometimes, the sprinkler flow switch and the sprinkler heads it monitors are not located in the same area.
- b) The limits of the sprinkler zone are properly identified. In all cases, coordination is required among subcontractors to ensure the proper location of annunciation for alarms initiated by the sprinkler system.

7.16.4.6 Duct detectors and fan shutdown

Air-conditioning and ventilating systems can potentially transmit smoke, toxic gases, and fire from one building compartment to the other. They may also provide oxygen to sustain combustion. For this reason, many codes require duct smoke detectors to be installed in HVAC ducts to automatically initiate the exhaust of smoke-laden air or to shut down air-handling equipment and to provide an additional measure of detection. These detectors should also be tied into the fire alarm system to initiate a general alarm. A large amount of smoke is generally required to activate a duct detector, because the smoke-filled air entering the duct from the fire area is mixed with, and diluted by, large volumes of clean air entering the duct from other areas. To provide appropriate warning, then, duct detectors should be used in addition to an area smoke-detection system, never in lieu of it. Duct detectors should be installed in the return duct at a location before the return air is

exhausted from the building or mixed with outside air. Duct detectors in the main supply duct should be installed downstream from the last filter (to detect smoke from a filter fire) and upstream from humidifiers (to prevent false alarms). Some local or state authorities require additional detectors in the duct system to detect smoke before it is diluted. Additional supply duct detectors provide little or no additional protection and are not recommended. Additional detectors in the return ducts can provide additional protection when installed at dampers or other strategic locations to detect smoke near the source before the air is diluted by air from collateral ducts. Although providing an additional measure of protection, the additional detectors are not usually worth the additional investment—particularly in a fully sprinklered building or in a building with area smoke detectors mounted on 9.1 m (30 ft) centers in the corridors. Most codes dealing with duct detectors in the duct system (not at air units) are not specific and only imply intent. Therefore, local interpretations vary widely.

Duct-mounted detectors can cause considerable trouble for the hospital operating engineer. The detectors frequently do not work well due to dirty sampling tubes, inadequate airflow (low-flow detectors are now available), or other reasons. Contractors often install them so that they are inconvenient to access for service and testing. And even when they are relatively easy to access, they still require getting into a ceiling space in order to test and maintain them. Duct-mounted detectors are not as effective at detecting smoke in a room as would be an area detector installed in the ceiling of the same space. Finally, one installed duct-mounted detector requires more initial capital as well as more ongoing maintenance money per unit than one installed ceiling-mounted area smoke detector. So the engineer designing a system should seriously consider the use of more of the latter and the fewest possible of the former, consistent with the requirements of relevant codes.

All detectors (both duct and area) in a system should shut down all fans and close all dampers in the affected zone. That is, facility-wide fan system shutdown is not recommended. HVAC systems not only provide heating and cooling, which are especially important to critical patients, but also humidification and proper air balance, which are crucial to infection control. Moreover, parts of the facility not directly affected by the fire should continue to function normally as patients are relocated and efforts are made to control the fire. The simplest and a reliable mechanism for this purpose is a pneumatic/electric valve used to close pneumatic smoke dampers. The control panel includes wiring and modules to initiate control functions, and this shuts down the fans and closes the smoke dampers. When the fans shut down, they de-energize the pneumatic electric (PE) valve and the dampers close. If the dampers are electric, wiring should be provided from the fan to each damper.

7.16.4.7 Smoke evacuation systems

Smoke evacuation systems are becoming increasingly popular in commercial and institutional buildings. These systems use return and exhaust fans to evacuate smoke-filled air with the outside air dampers fully open to provide makeup air. Such systems are not usually appropriate for health care facilities (unless required by state or local codes) for the following reasons:

- a) Patients may be subjected to sudden, significant changes in temperature from the outside air. As mentioned earlier, the lives of critically ill patients may depend upon favorable environmental conditions.
- b) Extremely cold, outside air can freeze coils in the duct system—especially cooling coils, unless the cooling coils utilize a glycol mixture.
- c) Smoke evacuation systems tend to complicate the HVAC control system.
- d) Additional generator capacity may be required to serve the fan loads.

Such a system may be required for several reasons. Some jurisdictions require these kinds of systems for health care facilities. Some health care buildings may be built in high-rise structures that have very different needs for fire detection and alarm than do lower buildings. Some MOBs may also be in high-rises, and may function quite well with smoke evacuation systems. The designer should post warnings where these systems are used, about subjecting patients to cold outside air and the potential for freezing the coils should be included on the smoke evacuation control panel.

7.16.4.8 Manual pull station

Manual pull stations provide the final measure of protection in a fire detection system. In addition to those placed at exits and in corridors as required by codes, manual stations should be provided at all nurses' stations. Usually, the nurse will see fire or smoke in the patient care area or become aware through a call over the nurse-call system. Since the staff should assist patient evacuation, there is no time to walk to an exit door in order to initiate an alarm.

In addition to exits and nurses' stations, pull stations should be installed so that horizontal travel distance to a pull station is never more than 61 m (200 ft). Break-glass stations (stations with a glass restraining rod), double-action stations, or covers over stations may be used in public areas as a deterrent to false alarms. Recent requirements for the handicapped prohibit mounting manual stations out of the reach of children.

7.16.4.9 Alarm signals

When a fire activates the detection system, it will initiate alarms, both audible and visual. Visual systems consist of flashing "fire" lights (CABO/ANSI A117.1). The ADA contains minimum performance requirements for these devices. One issue engineers should be aware of and that has not been adequately determined is the potential need for visual devices in exam rooms in MOBs (because in MOBs, the patients are reasonably capable of self-preservation, at least compared to patients in hospital beds). The ADA requires that in public areas, disabled persons be provided with equivalent warning signals. Therefore, if there are audible signals in a corridor that can be heard in the exam rooms, then the facility would be required to provide visual alarm devices in the exam rooms. There is no published case law on this issue, but this interpretation is certainly a possible one, and the engineer should work with the owner of a facility and with the owner's lawyers to determine how to design the system for them.

Audible alarm signals can be chimes, bells, or electronically generated sounds such as the slow whoop. The slow whoop is not recommended for health care facilities because it can frighten patients. Since the fire alarm signal is primarily used to initiate a planned response by the staff, the alarm should be heard in all parts of the building, including mechanical rooms. The requirement might mean the use of different types of audible signal devices in different locations (for example, chimes in nurses' stations, horns in mechanical rooms). However, some authorities require the alarm sound to be the same throughout the system. The engineer should also consider that horns in mechanical areas adjacent to patient care areas may alarm patients unnecessarily.

Some older buildings may still contain coded type annunciation systems. In these systems, various devices or groups of devices within a zone were assigned a single "code." Then, when a device initiated, it would generate an audible coded signal unique to its zone, allowing the facility staff to determine the location of the incident so that they could respond quickly. Coded systems require more maintenance, especially as the springs inside the coders wear out and are not replaceable.

Presignal, zoned voice alarm, and other systems that do not provide facility-wide general alarm signals are not recommended for health care facilities. These systems may be considered for the campus-type facility where there is no chance of a fire spreading from building to building. Facility-wide alarm signals may also be undesirable in the extremely large facility where the number of occupants makes the building-wide evacuation or relocation of patients, visitors, and staff undesirable or the sheer number of automatic devices makes the incidence of false alarms high. The decision to go with something less than a facility-wide general alarm is one that should be taken up with inspection authorities and accreditation agencies.

Presignal systems are no longer common, but voice alarm systems that automatically direct prerecorded messages to selective parts of the building are becoming increasingly popular—especially in high-rise buildings. Most building codes require voice alarm systems for high-rise business and residential occupancies, but do not require them for high-rise institutional occupancies. The voice alarm is intended to relocate or evacuate occupants of a large building one, two, or three floors at a time—thus avoiding a panic situation in crowded stairwells. In order to facilitate fast response by a fire brigade, a software-coded voice-splicing system can be utilized. The system will automatically provide discreet location information via the system speakers (i.e., "Dr. Firestone: Respond to the fourth floor, east wing"). A voice alarm system also assumes that the building's occupants can respond to voice instructions under their own power, which is not true for health care facilities. Since patients must rely on staff help to relocate or evacuate, voice alarm systems are not always recommended for health care facilities that have an adequately trained staff and a well-maintained paging system. If the paging system is used to broadcast instructions during a fire situation the engineer should verify that paging speakers are located in all areas of the facility.

7.16.4.10 Elevator control

Standards for elevator installations in multistory buildings may require that the elevator controller be interlocked with the fire alarm system to provide elevator recall. Although

these standards intend for the elevator to be controlled by elevator lobby smoke detectors, many authorities require elevator recall to be initiated by any general fire alarm. As stated before, health care facility fires are unique in many ways. The fire brigade attempts to control the fire while relocating patients to safe areas of the hospital. Although a fire may be burning in one wing of the hospital, operation of the hospital must continue in other areas. Elevators can be very useful in relocating patients and dealing with other emergencies. So the automatic controlling of elevators from the fire alarm control panel on any general fire alarm is not recommended, but may be required by code.

Requirements for a vertical fire alarm zone, incorporating all of the upper (second floor and above) floor lobby smoke detectors for a particular elevator bank are frequently encountered. With all lobby detectors on a single initiating circuit, elevator recall can be indicated on the fire alarm annunciator. However, the floor of the fire would not be known unless adjacent smoke detectors sense the fire and make the proper annunciation. Therefore, the vertical zone is not recommended unless other detectors connected to the floor zone are installed in the vicinity of the elevator lobby to provide floor annunciation. An alternative to the vertical zone would be to use lobby detectors with auxiliary relay contacts and to place each lobby detector on the same zone with other detectors on that floor. Each lobby detector's auxiliary relay contact would be used for elevator recall. These contacts are connected in parallel with two wires connected to the elevator bank control circuit.

Elevator control systems should be designed so that smoke detected on any upper floor will cause the elevator control circuit to go into the recall mode. All elevators in the elevator bank return to the ground floor and cease operation with the doors open. The elevators can only be returned to operation by means of a fireman's key. If an elevator is on an upper floor when the sequence begins, its door closes and will not be permitted to open until the elevator reaches the ground floor. The car will also stop on the second floor if a first floor lobby detector senses smoke. The system will stop the car on the third floor if the first and second floor lobby detectors sense smoke, and so forth.

7.16.4.11 Emergency communication systems

Emergency communications systems can be useful in high-rise health care facilities. These systems usually consist of a central control station, usually located on the ground floor, portable telephones, and strategically located telephone jacks for firemen's use in stairways, at exit doors, at sprinkler system valves, and at hose connections. In addition, a corridor and lobby paging system is used for transmitting "live" or prerecorded messages to the building occupants. These systems are generally required by building codes for high-rise residential and business occupancies. Although they are not always adopted for institutional occupancies, state authorities frequently require them. These systems can be a valuable tool for firefighters if the firefighters desire to use them and are properly trained in their operation.

In some jurisdictions, the purpose or requirement, if applicable, for "fire-phone" jack systems can be met through use of the fire department's radio system, if it can be shown that it has adequate coverage in all portions of a building. This may require use of a radio

signal augmentation system as covered in 7.8.2.4. Some local jurisdictions, in fact, require such an augmentation system in new buildings.

7.16.4.12 Annunciation

A zoned, back-lit, graphic, or video display terminal (VDT) annunciator should be installed where it can be monitored 24/7. This location will usually be the telephone operator location, a security office, and engineer's office, or the emergency department nurses' station. This location should have access to a telephone and a paging microphone. Duct detectors for each fan system, each manual station, and each sprinkler water flow switch should be separately zoned and annunciated by a separate light on the annunciator. Smoke detectors should have a light for each building zone as a minimum. Graphic annunciators are preferred if the graphics are prepared with sufficient detail and areas of the facility are properly labeled. Graphic annunciators can be confusing if sufficient detail is not included or if the person doing the monitoring is unfamiliar with the facility layout. Graphic annunciators tend to be more expensive than backlit annunciators and are difficult and expensive to modify when expanding the facility or changing the fire alarm system. If zones are properly labeled, backlit annunciators are adequate for most health care facilities.

Note that many local fire fighting organizations will require that a building contain an annunciator panel in an obvious location near the fire fighters' entrance to the building. The fire fighters will use this panel in the event of a fire to quickly assess the situation they are facing. The engineer should work closely with the fire fighters to determine and to satisfy their annunciation requirements.

7.16.4.13 System integrity

Applicable codes address protection and supervision requirements, so they will not be discussed in this recommended practice in detail. It should suffice to say that all alarm-initiating and alarm-indicating circuits must be supervised to detect a single ground or open fault in the circuit wiring that would interfere with normal operation. Most hardwired fire alarm systems used today utilize single-loop circuits (previously known as *Class B circuits*) that may not be capable of initiating or sounding an alarm when the initiating or indicating circuit is in a "trouble" condition. Double-loop circuits (previously known as *Class A circuits*) are designed to deliver alarms even with a single grounded or open conductor and are therefore recommended. This is generally accomplished by using special zone modules in the control panel and looping the circuit conductors back to the control panel instead of ending the circuit with an end-of-line resistor after the last device.

Health care facilities generally have a large number of area type smoke detectors on ceilings—especially in corridors. Single-loop initiating circuits go into trouble (from an open circuit) when a smoke detector is removed and may not be able to initiate a fire alarm signal. This is of particular significance if initiating circuits combine several types of devices, such as smoke detectors, pull stations, and flow switches. In a large hospital, there is high probability that at any given time a detector will be out for repair or a circuit will be in a trouble alarm.

7.16.4.14 Power supply

Fire codes require that all fire alarm systems have a primary power supply and a trouble signal power supply (usually taken from a different phase of the power system from the primary power supply using two single-pole circuit breakers). If systems automatically notify the fire department, provide a secondary power supply sized to operate under normal load for 60 h. Codes for health care facilities require the fire alarm system to be connected to the life safety branch of the emergency system, which is supplied by the primary and secondary power sources. When this is done, batteries are not generally required. Since there is some controversy concerning the need for batteries with generators, the designer should check with the AHJ. If batteries are required, they must have 4 h capacity.

7.17 Security systems

7.17.1 Introduction

Security concerns in health care facilities have dramatically increased in recent years. Security systems affect daily operations as well as design and should be coordinated with work and traffic flow, visitor access, egress requirements, and hardware. Security systems consist of electrical and electronic devices that provide access control, infant abduction prevention, monitoring, and intrusion detection. These systems supplement passive physical and staff monitoring provisions. Access control systems restrict passage through doors serving controlled spaces to authorized people. Intrusion devices monitor the security of property within the facility in areas with a high risk of theft. Delayed egress devices and alarms protect from staff leaving through unmonitored exits. Current codes do not require security systems, but health care facilities may want them to protect the personal safety of staff, patients, and the public, and to reduce property loss.

7.17.2 Design criteria for security systems

The following subsystems work together to provide hospital facility electrical and electronic security:

- a) *Access control system.* As a minimum, this system should protect building perimeter entries, pharmacy entries, ICU suites, OR suites, pediatric suites, medical records areas, equipment storage rooms, clean supply rooms, medication supply rooms, IT equipment rooms, and other high-traffic or high-value spaces not open to the general public during the day or at night when staff is reduced. When possible, provide access control systems for telecommunication closets to address concerns raised by HIPAA regulations and to assure discipline between the various departments sharing the closets. These systems require presentation of one or more credentials to a reading device before a person can pass through a doorway. These credentials can be plastic cards containing information that can be read on magnetic stripe or proximity technology; *smart cards* that can accept data from the system; keypads; or biometric devices including eye or fingerprint sensors. For added security, the system can require multiple credentials. The system controls electrical door hardware, including electric locks and strikes,

magnetic locks, and electric latch retraction devices. These systems often require interlocks with automatic door operators, the fire alarm system, delayed egress panic device override, or infant abduction systems. For increased security, door contact switches can monitor unauthorized entry or a propped open door. This device requires a “request-to-exit” device along with the door switch to allow egress from the secure side of the door without sending an alarm.

The access control system can connect to a video surveillance system to direct a camera view toward a door when credentials are presented or when the door switch activates.

Advanced access control systems have interfaces to human resources databases, IT department network security provisions, elevator control, map-based graphics, integrated CCTV, and partitionable databases.

- b) *Infant/child abduction system.* Hospitals use these systems when they perceive the danger of a potential *abduction*. The system consists of devices attached to the children that transmit a radio signal to transceivers in the protected area and at portals to the area. If the device is removed from the child, fails to transmit its presence, or is near an exit portal, the system can sound alarms to alert staff and security personnel, stop elevators, and close and lock exits. The system can also direct CCTV cameras to preset views.
- c) *Patient wandering system.* These systems help keep patients who may be disoriented or lost within a protected area. It uses devices and operates identically to the infant/child abduction system described in item b).
- d) *Asset tracking system.* This system monitors the location of radio signal sensitive tags attached to valuable portable medical equipment. Radio transceivers located throughout the facility can locate an asset and generate an alarm when the equipment moves to an unauthorized area.
- e) *Intrusion-detection system.* This equipment can be useful for pharmacy dispensing areas, drug vaults, narcotic cabinets, radiology, silver recovery, bulk storage rooms, gas storage rooms, cashiers, emergency exits, and medical records. The protection devices can be any number and kind of security sensor. The sensors deactivate when the protected area is occupied so they do not constantly signal the presence of authorized staff in the area. Such devices may include switches on doors, relay contacts of motion detectors, capacitance detectors, photoelectric beams, or pressure mats. Intrusion detectors include:
 - 1) A remote, key-operated activation/deactivation switch or access control system credential reader installed outside protected areas adjacent to the room entrance door frame.
 - 2) An integral capability for the attachment of wiring for remote alarm and intrusion indication equipment (visual or audio) to provide annunciation at a security office or central control center.

Where security systems affect personnel safety or protect valuable items or information, the engineer should specify a supervised security system. The electronics of these systems indicate trouble when shorts or open wires develop.

- f) *Metal-detection system.* These systems prevent inadvertent or premeditated loss of valuable hardware, instrumentation, movable equipment, etc., which may be

intermixed with soiled linen or with refuse that is being removed from a facility. They use metal detection, x-ray, or other systems at all loading (discharge) platforms to screen all carts or material-handling equipment leaving the facility.

- g) *Video surveillance system.* Video surveillance systems monitor and control access points to facilities including all areas where cash is handled, the pharmacy, the emergency room, and other sensitive areas. Security guards monitoring television systems may have an opportunity to locate or identify intruders and prevent violent or destructive activities. Locate cameras in high-traffic areas such as main lobbies where door switches are useless. Video surveillance cameras are also valuable in waiting areas, cashiers' counters, at loading docks, near doors with access control and intercom, around the building perimeter, and in parking areas. Video surveillance systems usually provide remote control of camera position, preset camera views initiated by sensor or a security system output contact, guard tour sequencing, multiple camera screens, and digital recording.
- h) *Security command post.* Monitors, control equipment, and recorders should be located at the security command post. Provide at least two monitors and one digital recorder for every nine cameras. Multiplexers permit user selected sequential and split camera display. Available split screen modes should include dividing the screen one, four, nine, and sixteen ways, with any camera or sequence of cameras displayed in any picture segment. The second monitor for each nine cameras should be usable for similar split screen display, spot monitoring, and recording playback. Pop-up display and temporary continuous recording should occur automatically whenever a monitored door opens.

7.17.3 Security sensor devices

A security sensor is any detection device ranging from a simple door switch to a sophisticated solid-state motion detector. Examples of security sensors are as follows:

- a) *Mechanical switches.* These switches, generally with spring-loaded levers or plungers, operate when a door, window, or cabinet cover opens.
- b) *Magnetic switches.* These switches supervise the position of movable openings, such as doors and windows. A magnet on the movable portion operates a switch on the fixed or frame portion to activate the alarm system.
- c) *Balanced magnetic switches.* These switches use a bias magnet inside the switch housing on the fixed frame together with a standard magnet on the movable portion of an opening. They will respond to an excessive magnetic field imposed on them, as well as to a reduced field. They are most difficult to compromise with an external magnet, and are therefore more tamper-proof than standard magnetic switches.
- d) *Foil (tape) and screens.* Foil is a thin strip of low ductility tin-lead material adhered to a glass surface to detect breakage. Cracking or breaking the glass interrupts the circuit current flowing through the foil. Screens are grids built with wooden dowels containing a groove in which a fine hard-drawn copper wire is embedded. The grids form an electrical barrier over openings. If a wooden dowel is broken, the wire breaks, interrupting the circuit current in the same manner as foil.

- e) *Pressure mats.* When stepped upon, these devices close an electrical contact, activating the alarm system. These devices make an excellent intrusion-detection device since they can be concealed under carpeting or scatter rugs. They are stable, reliable devices and, when used properly, have an extremely low false-alarm rate. They have single-pole, single-throw (SPST) switching action, providing only a cross (short) on the protection circuit.
- f) *Beams.* These devices project a beam of light (usually IR or solid state) to a constantly energized photocell. When the beam is interrupted, it de-energizes the receiver and activates an alarm.
- g) *Audio detection.* Sensitive microphones may sit in an area to detect sounds of intrusion. Sounds they pick up are amplified and operate an alarm relay if they are loud enough and are repetitive beyond a preset count. Audio detection operates best in quiet areas, such as vaults.
- h) *Ultrasonic.* This system fills an area with high-pitched sound waves (above human hearing) and detects the disturbance of the sound pattern when motion occurs in the area.
- i) *IR body-heat detection.* This motion detection system is basically optical since the detector “sees” a moving human source of IR energy [37 °C (98 °F)] against a background at room temperature [usually around 22 °C (72 °F)].

7.18 Facility monitoring

7.18.1 Introduction

Health care facilities contain complex systems critical to patient care that must be monitored. Current codes require many of the following monitoring systems.

7.18.2 Medical gas alarms

NFPA 99 requires hospitals to monitor the operation and condition of the source of supply, the reserve (if any), and the pressure in the main line of their nonflammable medical gas distribution systems.

The gases covered by this standard include, but are not limited to, oxygen, nitrous oxide, medical compressed air, carbon dioxide, helium, nitrogen, and mixtures of such gases. The alarm system is required to detect two classes of system problems: abnormal line pressures (high or low) and low gas supply.

Alarm equipment, including panels and actuating switches, normally comes as part of the medical gas distribution system. The engineer should closely coordinate his or her work with the supplier of the gas distribution equipment. The engineer’s areas of responsibility normally include the following:

- a) Alarm system ac power
- b) Alarm panel locations
- c) Interconnecting alarm signal wiring

The NEC requires the ac power source for the gas alarm system to be the life safety branch of the hospital electrical system.

NFPA 99 requires all medical gas alarm systems to include two master alarm signal panels, which will display alarms related to the source of gas supply for the entire system. One master panel must be located in the office or principal working area of the individual responsible for the maintenance of the medical gas system (the maintenance supervisor or hospital engineer). Locate the second panel to ensure continuous surveillance, at the telephone switchboard, the security office, or at another suitable location. The intent of these requirements is to ensure continuous, responsible surveillance of the medical gas system, since the life of the hospital's patients depends on continuous delivery of the medical gases.

In larger hospitals, where medical gases are distributed to widely separated areas, NFPA 99 requires area alarm panels. NFPA 99 specifically lists the following areas where medical gas may be supplied and where area alarm systems must likewise be installed:

- 1) Anesthetizing locations
- 2) Vital life support areas
- 3) Critical care areas
- 4) Intensive care areas
- 5) Post-anesthesia recovery
- 6) Coronary care units
- 7) Operating and delivery rooms

Install area alarm panels at the nurses' station or other suitable location near the point of use that will provide responsible surveillance.

The engineer should make provisions for the signal wiring between the alarm panels and the actuating (pressure sensing) switches. The gas distribution engineer will determine the switch locations. The electrical engineer will need to provide support and protection for the signal wiring in the form of raceways and cable trays.

7.18.3 Refrigeration alarms

7.18.3.1 Introduction

Hospitals frequently contain refrigeration equipment such as blood bank refrigeration, donor organ refrigeration, pharmacy refrigeration, laboratory refrigeration, kitchen refrigeration, kitchen freezer, and/or morgue refrigeration. JCAHO now requires monitoring of any refrigerator containing patient medications, including refrigerators containing breast milk. The alarms provide an indication of loss of power and indications for improper internal temperatures.

7.18.3.2 Design considerations for refrigeration alarms

Obtain alarm equipment locations and power requirements from the medical equipment planner and from the refrigeration equipment supplier. Each type of refrigeration equipment normally comes with its own alarm system. The master monitor station and its associated temperature sensor normally mount inside the refrigeration enclosure, while remote monitors are normally located where continuous surveillance is available. The engineer should provide raceway for the multiconductor cable between the master and remote monitor stations. The NEC requires that power for these alarm systems be derived from a life safety circuit.

7.18.4 Emergency generator monitoring

NFPA 99 requires an emergency generator monitoring system. Locate it at a 24/7 manned station.

7.18.5 Energy monitoring and control systems

7.18.5.1 Introduction

Energy monitoring and control systems (EMCSs) may be used as part of an energy conservation program. Such systems, in addition to saving energy, may

- Protect and limit damage to equipment.
- Allow malfunctions to be corrected with minimal service interruption.
- Operate equipment only when necessary, thus extending equipment life.
- Cut down on the number of operating personnel required.
- Improve maintenance management.
- Combine with other systems to perform other related functions, such as fire alarm annunciation, security, life safety, and other real-time event-initiated functions.

Various levels of control are available as follows:

- a) *Basic local controls.* These are equipment control systems supplied/recommended by the equipment system supplier. These systems turn equipment on or off depending on sensor-activated (temperature, humidity, pressure) messages. A larger, more sophisticated EMCS should incorporate local controls into its system.
- b) *Single building system.* A microcomputer controls the independent local controls of several pieces of equipment in one building. In the event of a failure of the microcomputer, the local controls operate the equipment.
- c) *Distributed processing control systems.* These systems employ a minicomputer that controls numerous limited-area systems or the single building system, or both. Mass storage of information is used to keep records and to support a sophisticated software system. In the event of minicomputer failure, the basic local controls will operate the equipment.

7.18.5.2 Design considerations for energy monitoring and control systems

Refer to IEEE Std 241™ (*IEEE Gray Book™*) for the design of EMCSSs.

7.19 Television systems

7.19.1 Introduction

Television systems transport video and audio content from a single head-end location to multiple locations. The consumer market has become the driver in terms of what technology systems people expect to see in health care facilities.

Health care facilities are looking for new ways to provide patients with information and entertainment at the bedside to make their hospital stay more comfortable. This is a growing trend as it can aid in a facility's goal to create a healing environment. The television system not only provides services to the patient, but it can also gather and share information between departments.

Content considerations for television systems include the following:

- a) Entertainment and educational programming
- b) Interdepartmental communications
- c) Patient monitoring
- d) Video surveillance systems

Design considerations for cable television systems include the following:

- 1) Space planning
- 2) Cable plant
- 3) Satellite receiving stations
- 4) Master antenna
- 5) Amplifiers
- 6) Computer-directed programming
- 7) Servers
- 8) Video displays and recorders
- 9) Broadcasting spaces

7.19.2 Content considerations for television systems

7.19.3 General

Rapid changes are taking place throughout the entire field of television that affect its use in health care facilities. A vast number of new program services are becoming available, not only to the general public but to special groups at technical facilities. These services include cable satellite earth stations, microwave interconnections, and improved videotape and hard drive distribution. Compressed digital formats including standard definition

(SDTB) and high definition (HDTV) are replacing traditional analog based distribution. Viewing is shifting to new program sources and to pay TV.

7.19.3.1 Entertainment and education programming

Any modern healthcare facility will incorporate a television or patient entertainment system. Basic entertainment may consist of the following:

- a) Master antenna feed from off-air channels
- b) Local cable company feed
- c) Portable DVD or video cassette player

Enhancing this system may include the following:

- 1) On demand programming and services
- 2) Digital TV
- 3) E-mail and high-speed Internet access
- 4) Feature films
- 5) Digital music
- 6) Gaming
- 7) Educational health programming

7.19.3.2 Interdepartmental communications

7.19.3.2.1 Medical staff education

The health care facility's size and teaching requirements will determine the need and criteria for educational television. Pictures of surgical procedures have long been an important educational tool among surgeons. In recent years, live television has been a feature of national or regional meetings in which a large audience, usually situated in a hotel lecture room or other meeting hall, can watch a surgical procedure taking place at a remote hospital. Modern television techniques such as split-screen, instant replay, slow motion, and added animation enhance the educational value of these showings. With the advent of lower priced equipment, surgical television is beginning to take a more prominent place as an intramural or institutional educational instrument. With standard equipment, operative procedures can be transmitted live or shown as digital recorded media in the hospital auditorium, classroom, and at department meetings. Cineradiography, which is done during surgical procedures, can be shown in conjunction with the operative film. Digital media of such procedures combines views of the operation, the pathologic section, intraoperative x-rays, and noncommittant commentary of the surgeon and his or her team, and consultants to comprise a record unsurpassed by any other medium. Appropriately edited, this type of audio/video record may form the basis of a teaching library, which is especially valuable in instances of rare or unusual cases as well as medicolegal situations.

7.19.3.2.2 Pathology consultation

A two-way audio/video system between the frozen-section laboratory and the OR can enable the surgeon to communicate directly with the pathologist. This system permits examination of a microscopic slide during consultation by video with the pathologist without leaving the operating table. It also provides the pathologist a view of the pathologic lesion in situ without entry into the OR. A television camera may mount in or on the surgical light for this purpose. A camera over the cutting table can enable the surgeon to direct the pathologist or technician as to precisely how to section a specimen, if necessary, without leaving the OR. In general, two-way audio/video between OR and the frozen-section lab should eliminate the need to bring the pathologist into the OR. Simply viewing the video screens in the OR should permit the surgeon to supervise the sectioning of a specimen and to peer into the microscope without leaving the OR.

7.19.3.2.3 Radiology consultation

As an aid to diagnosis, an audio/video hook-up between the OR and the x-ray department permits x-rays to be viewed on the television screen in the OR. This method provides several distinct advantages over the older practice of locating the films, carrying them into the OR, and sorting out the most appropriate films to mount on the view box. It also reduces annoyances such as not getting a good view from the operating table, mounting the wrong films, possibly contaminating clean objects by inadvertent contact and misplacing films in transit between the OR and the x-ray department. Where fluoroscopy x-ray equipment containing a video camera is employed in surgical procedures, the x-ray image may be displayed on a monitor in the radiology department for interpretation.

7.19.3.2.4 Patient monitoring

- a) *Intensive care unit (ICU).* Hospital regulations require that each ICU patient be visible from a nursing station. Some designs, however, can meet this regulation and still not provide the caregivers with a clinically useful view of the patient. Although one can argue that a televised view of the patient provides very little useful information, many nurses feel more comfortable supplementing their direct observation with CCTV. Compared to the physiological monitors, the video picture of the patient is a reminder that the patient is a human being. When a unit uses such a system, it will perform better if the general room illumination is adjustable with a dimmer control switch.
- b) *Radiation therapy.* Some radiation therapy procedures require the use of heavy shielding between the patient and the equipment operator. At the same time, the technician conducting the procedure needs to be able to position the patient precisely with respect to the radiation beam, and to ensure that the patient does not move during the exposure. This problem is often resolved with a color CCTV system, installed to give the equipment operator a clear view of the patient and the beam reference marks. The video camera needs a zoom lens and resolution adequate to allow precise determination of the patient's position. Install the video cable between the camera and the monitor to preserve the shielding performance of the radiation shielding.

7.19.4 Design considerations for television systems

7.19.4.1 Space planning

Plan space for these systems early in the design stages of a new building. Head-end equipment consists of RF modulators, demodulators, processors, combiners, and audio/video servers that could require a substantial amount of space. When planning for an equipment space, always provide a future growth space. The space will also require adequate power, HVAC, phone outlets, and network connectivity. In large buildings, equipment in telecommunication rooms may be necessary to amplify the signal longer distances.

7.19.4.2 Cable plant

The backbone of a television system is the limit for what service can be provided at the end-user locations. Pay careful attention to the content that will be delivered. Provide connectivity for future systems that may be installed at a later date. A multicable design concept is recommended for the television distribution system. At a minimum, provide one RG-6 cable, two Category 6 cables, and possibly one multimode fiber cable at each monitor location from the headend.

Technologies are now emerging that treat traditional broadcast and/or on-demand programming as server-based digital information, and deliver program content to viewing locations over LAN structured cabling. Such systems can negate the requirement for coaxial cable distribution systems in new facilities.

When designing a television coaxial distribution system, the more bandwidth provided, the more the system will be able to expand in the future. Today's coaxial systems should have a minimum bandwidth of 1 GHz. Another beneficial design feature is to allow return pathway in a system. Cable and passive components such as splitters and taps should allow return path. Several configurations of different sized coaxial cables can meet a design goal. Three typical cable sizes are half-inch coax (used primarily for long runs between buildings), RG-11 (typically used for a trunk cable within a building), and RG-6 (used for drops to TV outlets). Signal level at a tap should be maintained at 3 dBmV to 5 dBmV minimum up to 15 dBmV maximum. As the attenuation level increases, the higher channels will begin to drop off.

7.19.4.3 Satellite receiving station

A facility can install a satellite receiving station either at ground level or on the building roof with a clear view of the satellite arc. These stations require cable trays or ducts from the central control head-end to the roof and to a convenient outside location at ground level. If the satellite dish mounts on the roof, the design should include structural reinforcement of the roof to support the weight of the dish.

7.19.4.4 Master antennae

The engineer should make a list of signals to be received and design accordingly. The frequencies and their signal strength will determine the type of antenna required. A particular facility may require several antennas to cover all required frequencies.

- a) *Location and orientation.* Use a signal strength survey to determine the exact location and orientation of antennas.
- b) *Lightning protection.* Follow requirements for lightning protection given in the NEC, Article 810, and in NFPA 780. Where a facility elects to provide lightning protection, use grounded surge arresters.

7.19.4.5 Amplifiers

Use preamplifiers and amplifiers as follows:

- a) *Preamplifiers.* Use preamplifiers when incoming signals are too weak to be accepted by the amplifier.
- b) *Amplifiers.* Use amplifiers for signal amplification to overcome distribution system losses and provide suitable output. A broadband amplifier may be suitable if it can cover all incoming channels and maintain adequate signal level inputs to the distribution system; otherwise, use single channel amplifiers for each input.

7.19.4.6 Computer-directed programming

This system provides a central control panel where one can direct programming to each television display in the health care facility. In addition, the system can keep track of time used and provide a printout for billing information. Patients can be billed for full-length movies and patient education programs. Computer-directed programming should be purchased when it is cost-effective. As designs mature and the system costs decrease, this system will pay for itself from manpower savings and new revenue from movies and patient education.

7.19.4.7 Servers

Servers connected to the network could offer an enhanced television system. The servers can provide on-demand programming and services, digital TV, e-mail and high-speed Internet access, featured films, digital music, gaming, and interactive educational services.

7.19.4.8 Video displays and recorders

- a) *Video displays.* Use plasma or LCD displays only for broadcast systems and other non high-resolution, color/contrast critical applications. For hospital surgery and other high-resolution applications, cathode ray tube (CRT) displays are required.
- b) *Television projection systems.* Use television projection systems for large group viewing. These systems accept signals from a connected closed-circuit system including rebroadcast of external media (cable TV, satellite, or MATV) or locally originated material.

- c) *Recommended display sizes.* Display sizes depend on the type of content and viewing distance from screen. The height of the screen limits how far away a viewer can stand before experiencing eyestrain and fatigue. Standard definition video is six times the height of the screen for comfortable viewing distance. High definition video and computer images are four times the height of the screen for viewing distances. These recommendations apply to both 4:3 and 16:9 aspect ratios.
- d) *Recording equipment.* Use digital video storage devices where instant playbacks are desired, for further studies or for permanent records. These systems allow for instantaneous access of material for review and editing. They are IP based systems and would support a centralized information server as well as other types of distribution.

7.19.4.9 CCTV camera selection

Newer cameras are small, compact units with a minimum number of circuits contained in a self-contained, one package system. Give special consideration of the camera location and the subject matter. In a medical suite needing high definition medical imagery, provide a high definition/high resolution camera with varying capabilities. In other areas such as security or studio productions, a standard definition camera would suffice.

7.19.4.10 Camera mounting

- a) *Indoor.* Use an air-cooled housing where temperatures exceed those of camera specifications. In studios, the heat from the stage lighting makes air conditioning necessary. Use explosion-proof housings for viewing hazardous areas. Use remotely controlled pan and tilt mounts when cameras view more than one area. Use standard tripods on cameras for portable use.
- b) *Outdoor.* Always use a weatherproof housing. Never face cameras toward the sun at any time of the day. Avoid picking up reflections from glass or water, if possible.

7.19.4.11 Subject viewing

Locate a camera so that desired areas, objects, or subjects receive the maximum benefits from available lighting.

- a) *Lens selection.* Choose a lens that fits the scene. A fixed lens limits the field of view to one scene. Lens turrets have the advantage of handling three or four lenses with varying focal lengths (normal view, wide angle, and varying degrees of telephoto). A zoom lens permits varying the focal length without loss of subject viewing during the change.
- b) *Operation.* Cameras that are easily accessible may be controlled manually. The more expensive remote control should be provided where local operation is not feasible. Remote control should be located and coordinated with other operating devices involved in the application being viewed on an adjacent monitor.

- c) *Video switching.* Provide video switching where more than one camera should be viewed on a monitor.

7.19.4.12 Subject lighting

Distinguishable details depend on scene contrasts, camera resolution, and monitor revolving powers. Consider ultra-low lux cameras for outside security applications to avoid overlighting the area solely for the camera. Consider the use of IR lighting and cameras for certain security uses.

- a) *Required lighting levels.* Use the same light levels needed by the human eye for clear visibility. Minimum lighting incident on the scene should be at least 20 fc (215 lx).
- b) *Additional lighting.* Plan lighting so that a minimum number of “hot spots” are seen from camera locations. Evenly illuminate the complete scene for viewing.
- c) *Automatic iris.* A lens with an automatic iris helps in outdoor situations to control the amount of light focused on the camera’s internal imager. The automatic iris adjusts the amount of light admitted into the camera to allow it to handle illumination increases from 10 fc to 10 000 fc (107 lx to 107 600 lx). Indoor cameras frequently employ internal liquid crystal shutters that are part of camera’s imager. These shutters act as an electronic version of the mechanical automatic iris mentioned previously. However, these only offer lighting control for the camera’s imager over a relatively narrow range of scene illumination, and this makes them more suitable for use with indoor cameras.

7.19.4.13 Monitor selection

Monitors should have the same resolution and type of interlace as cameras. Locate monitors for minimum light reflections on faces. Avoid vertical mountings. Use circularly polarized faceplates to reduce glare where ambient lighting is high.

7.19.4.14 Studio

If a hospital will have a studio for local origination, arrange it for efficiency and storage considerations. The studio should be large enough to show a patient in bed. The design should consider acoustical criteria for noise levels and reverberation delays. Lighting should include track lights and some floor pedestals, which will flexibly provide key, fill, and backlighting for various sets. Provide selective dimming on certain circuits. These rooms will need special cooling.

7.19.4.15 Chapel

If a facility includes a camera in the chapel and intends to use it several times a week, it should be permanently mounted with a remotely controlled pan, tilt, and zoom lens on the camera. If the facility will use the camera only once per week, it should be easily detachable from its wall mounting so that it can be used the rest of the week in other places.

7.19.4.16 Operating room

In recent years, the camera on a floor-standing boom and the hand-held camera have disappeared. Current installations include a television camera mounted on an extension arm attached to the stem of the surgical light and outfitted with sterilizable detachable handles. Some manufacturers of surgical lights provide a model with a television camera mounted in the center pod of the light.

Another approach for surgical suites of any size is a portable unit consisting of a console that contains a video recorder and a viewing screen, on which is mounted an adjustable boom to hold the television camera. The camera should be remotely controllable for pan, tilt, and zoom.

7.20 Sound reinforcement systems

7.20.1 Introduction

Sound reinforcement systems provide sound pickup, sound playback, processing, amplification, and reproduction of an original acoustic source within the room or space. Such systems increase the intensity, clarity, and coverage of an original acoustic sound source. Frequently, sound reinforcement systems also need to reproduce prerecorded sounds associated with audio and video recordings, computer-based playback systems, slides with audio, and motion picture projection. Sound reinforcement systems may use one or many discrete audio channels to properly recreate the original audio sound field for the listener.

7.20.2 Design criteria for sound reinforcement systems

A room with unintelligible sound will need a sound reinforcement system. The sound system should maintain an adequate direct sound-to-reverberant field ratio (for clarity), and it should improve the signal-to-noise ratio (i.e., increase volume above the room's ambient noise level). A good sound system should provide natural sound that is clear and non-fatiguing for the listener and that seems to originate at the acoustic source.

Sound reinforcement systems are often required in auditoriums, theaters, meeting rooms, lecture rooms, and chapels. In certain cases, a sizeable space such as a cafeteria or large lobby might have several different uses, resulting in the need for a sound system that is readily user reconfigurable for that space.

7.20.3 Design considerations for sound reinforcement systems

Sound reinforcement systems consist of one or more microphones, one or more prerecorded media playback devices, an audio mixer/controller, signal processing electronics, audio power amplifier(s), and one or more loudspeakers. The proper operation of a sound system depends primarily on the location and the choice of microphones and loudspeakers employed within the reinforced space.

7.20.3.1 Room acoustics

Small auditoriums and lecture rooms designed with acoustics suitable for the natural propagation of live speech often do not require sound systems except to reproduce recorded material. Highly reverberant small to medium-sized rooms and larger rooms will employ a sound system to improve intelligibility. Most gathering spaces benefit from a reinforcement system that aids the occasional quiet talker and helps lecturers to be heard over noisy audience members. The usefulness of any sound reinforcement system, and whether it is needed, depends primarily on the characteristics of the space where the system is installed.

Room surfaces vary in the amount of sound energy they absorb. Hard surfaces, such as concrete, plaster and tile, reflect most of the sound energy that reaches them. Soft surfaces, such as carpet, acoustic tile, and batt insulation behind a porous fabric cover, absorb a large portion of the sound energy they receive. Sound energy in rooms with mostly hard surfaces will dissipate more slowly than sound energy in rooms with soft, acoustically absorbent surfaces. Thus, rooms with low sound absorption have longer reverberation times.

Where sound reinforcement should be applied in an acoustically difficult room, i.e., one with an excessive reverberation time or a high ambient noise level, the system will need a higher level of performance. To maintain adequate speech intelligibility in such rooms, use loudspeakers employing an enhanced ability to focus sound accurately at listeners but away from walls and ceilings. Precisely controlling the placement of sound in reverberant rooms minimizes the amount of sound energy “spill” that adds undesirably to the room’s reverberant energy field. Using high-directivity loudspeakers, in line with their greater size, will usually increase the overall cost of the sound system. Therefore, the cost of acoustical treatment used to tame a difficult room should be weighed against the cost of the sound system components employed.

7.20.3.2 Loudspeaker location

Sound waves in air travel at about 344 m/s (1130 ft/s). When an amplified sound reaches a listener within approximately 30 ms of the original sound, and both sounds are similar in intensity, the sounds will appear to blend and reinforce one another. When the time interval is greater than 30 ms, the sounds will tend to separate and be heard more as separate sounds or echoes as the time interval is increased. Therefore, the best location for a central loudspeaker cluster is often directly above the acoustic source (lecturer, etc.) such that the sound paths from the acoustic source to the listener and from the loudspeaker cluster to the listener differ by less than 9.1 m (30 ft). This condition should exist for every listening location in the room.

7.20.3.3 Centralized, precedence, and distributed loudspeaker systems

- a) *Centralized sound system.* A centralized sound system reproduces sound at only one location. Centralized systems are used in spaces where sound may be directed (line of sight) to the audience. Sound levels usually vary with distance from the central loudspeaker(s) location.

- b) *Precedence system.* A precedence system typically utilizes a centralized system at the front of the room, plus a secondary loudspeaker system and electronics to cover the rear portion of the room. A precedence system allows coverage of a larger area than that usually permitted by a centralized system alone.
- c) *Distributed sound system.* A distributed sound system reproduces sound from multiple sources, usually from ceiling mounted loudspeakers that face down into the listening environment. Distributed systems work best in spaces with low ceilings or where the “front” of the room may change. Distributed loudspeaker systems work because the myriad of interference patterns generated by the many loudspeakers usually employed sum to form a coherent sound field. Distributed sound systems can produce very uniform sound levels throughout a covered room.

7.20.3.4 Volume

Sound reinforcement systems should be able to generate enough volume to provide a satisfactory signal-to-noise ratio at each listener location plus some margin for signal peaks. The “signal” in this case is direct loudspeaker sound, and the “noise” is ambient room noise caused by people, machinery, and other sources. Choose amplifier power and loudspeaker power ratings to provide nearly the desired volume level.

Equip the sound system with volume-limiting devices that limit maximum system sound pressure levels. Properly adjusted, these devices also serve to protect the sound system loudspeakers from accelerated wear and damage due to excessive power resulting from high sound levels, whether purposeful or accidental.

7.20.3.5 Audio mixers and controllers

Sound system control devices provide for the selection and routing of specific sound sources as required by the user. Audio mixers usually incorporate sound control facilities in addition to other hardware that permits individual sound sources to be blended in varying proportions as required to maintain uniform sound levels. Other audio mixer controls may allow modification of the frequency characteristics of the respective sources for functional or artistic purposes.

The type of mixer used in a sound system usually depends on the number of sources to be controlled, required features, and its intended use. A simple installation such as a lecture room with one microphone might use a simple manual mixer about the size of a paperback book with very few user controls other than volume. A manual mixer might require slight adjustments to accommodate the vocal styles and characteristics of different lecturers, but generally it could remain at the same volume setting for all similar uses.

When several microphones are employed, such as for a panel discussion in an auditorium, the relative level of each microphone can be preset using the manual mixer. However, the sound system’s overall acoustical gain should be low enough to prevent acoustical feedback from occurring due to loudspeaker energy reaching the large number of open microphones.

In general, manual mixers should be adjusted differently for each event, so this type of mixer's controls should be readily accessible to the sound system operator in the reinforced space. The controls for automatic mixers may or may not require adjustment for each event depending on the type of event and the differences in signal sources. Provide controls for projector and auxiliary inputs at the mixer location, and near the stage or other accessible location within the reinforced space.

7.20.3.6 Equipment

- a) *Loudspeakers.* Many loudspeaker types are available for centralized and distributed sound systems. Each type of loudspeaker is suited to a specific application or range of applications. When improperly applied, a loudspeaker may perform poorly. In large rooms where long throws are required, a large cone driver (speaker/transducer) in a horn or utility enclosure is used for low frequencies and a compression driver and horn (or several horns) are used to reproduce high frequencies.
- b) *Microphones.* Cardioid, supercardioid, and hypercardioid (directional) microphones and omnidirectional microphones are all used in sound reinforcement systems. Directional microphones are preferred by many performers and production groups for the freedom from acoustical feedback that they provide. Not to be left out, omnidirectional microphones can have a smoother off-axis frequency response than directional microphones, and they can be easier to equalize in permanent sound system installations. They are a good choice for many lecture and auditorium sound reinforcement systems where there is sufficient gain before feedback. Dynamic (nonpowered) microphones are often preferred since they are often more durable than other microphone types such as condenser microphones. Plus, they simplify system installation and use by not requiring a source of phantom (microphone) power to operate (as may be obtained from a professional mixing console). Lavalier (chest worn) microphones were originally developed for television broadcast use. They are not suited for live sound reinforcement applications except in sound reinforcement systems possessing unusually high gain-before-feedback margins.
- c) *Power amplifiers.* Loudspeakers can only perform properly when driven by audio power amplifiers having compatible electrical characteristics. A power amplifier should provide sufficient audio power to allow the connected loudspeaker(s) to reach the designer's intended sound pressure level. The output impedance characteristics of the power amplifier and loudspeaker load should be compatible. The total loudspeaker load on a given power amplifier channel should not exceed the power amplifier's capabilities, or amplifier overload and possible sound distortion and/or loss of sound can occur.
- d) *Hearing assistance systems.* In the U.S., the ADA as well as some local governing bodies require that sound systems serving the public beyond a specific size include facilities to assist persons with hearing impairments to hear the program or event. RF based and IR based systems are the types most commonly employed in the U.S., although induction (magnetic loop) systems are also available. The equipment used typically includes a fixed or portable radio transmitter for RF systems, and an IR signal modulator/emitter(s) for IR systems. The transmitter or

emitter obtains a copy of the same audio signal that is heard over the sound system loudspeakers. A quantity of user-carried pocket or neck-worn receivers with earphones is normally kept on hand for loan to system users. The ADA requires that the quantity of receivers on hand be at least equal to 4% of the room's occupancy, although local governing bodies may have other requirements that differ. RF based systems are the simplest to install since the RF signal easily passes through objects and people to allow proper reception throughout the room. RF system signals travel easily through walls and ceilings to other locations, so these systems should not be used where program confidentiality is an issue. IR based systems require the user's receiver to be within direct line of site of the emitter in most instances for proper reception. Walls and, usually, glass panes block IR signals from passing to adjacent rooms and the outdoors. This makes IR systems a better choice for confidential uses. IR systems are subject to interference from direct sunlight and some lighting systems, making them suitable for indoor use only. RF based systems are subject to interference from other transmitters that are on or near the system's primary RF. Sound quality can be good to very good for both system types.

- e) *Cables.* Wiring for a sound reinforcement system involves separate cables to each microphone input, cables to projector and auxiliary inputs, cabling to and from a control console (mixer) when required, and wiring to loudspeakers. Due to their higher current-carrying requirements, loudspeaker cables should be sized according to the intended loudspeaker load. Ideally, loudspeaker cables should be sized to keep power losses in the cable to less than one-half decibel (12.5%). Cables for source devices such as microphones, CD players, and the like need only be #22 AWG with an overall foil or copper braid shield. Multiple paired cables with conductors as large as #12 AWG or #10 AWG may be required to deliver audio to a large loudspeaker cluster.

7.21 Disaster alarm systems

7.21.1 Introduction

A disaster alarm system alerts the central control center as to the status of disasters, either natural or man-made. Coordinate signals with local civil defense and disaster area authorities.

7.21.2 Design considerations for disaster alarm systems

- a) *Actuating devices.* Actuation can be local or remote. Data can be furnished directly or via telephone, radio, or microwave channels. The number of channels and their coding should meet the requirements of civil defense and local disaster area authorities. Signals are originated by remote control from the offices of civil authorities or by local push buttons. Each coded channel requires a signal-canceling button with a pilot light.

- b) *Annunciator*. The annunciator needs to be located at the central control center. Annunciator panels should have a circuit supervisory feature to indicate alarm, operational faults, trouble buzzers, silencing switches, and pilot lights. Test buttons are necessary to verify readiness of equipment and for use in training drills.

7.22 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

Guidelines for Design and Construction of Health Care Facilities.⁴

Americans with Disabilities Act (ADA).⁵

ANSI HL7, Health Level Seven: An Application Protocol for Electronic Data Exchange in Healthcare Environments.⁶

ASME A17.1, Safety Code for Elevators and Escalators.⁷

BICSI Telecommunications Distribution Methods Manual (TDMM).⁸

CABO/ANSI A117.1, Accessible and Usable Buildings and Facilities.

IEEE Std 241, IEEE Recommended Practice for Electric Power Systems in Commercial Buildings (*IEEE Gray Book*).^{9, 10}

⁴ The current edition of the Guidelines is available from the American Institute of Architects Academy of Architecture for Health, 1735 New York Avenue, N.W. Washington, DC 20006 (http://www.aia.org/aah_gd_hospcons).

⁵ Additional information can be found at <http://www.usdoj.gov/crt/ada/adahom1.htm>.

⁶ ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

⁷ ASME publications are available from the American Society of Mechanical Engineers, 3 Park Avenue, New York, NY 10016-5990, USA (<http://www.asme.org/>).

⁸ BICSI publications are available at <http://www.bicsi.org/> or from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

⁹ IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

¹⁰ The IEEE standards or products referred to in this clause are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

IEEE Std 802.3AF, IEEE Standard for Information Technology—Telecommunications and Information Exchange Between Systems—Local and Metropolitan Area Networks—Specific Requirements—Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications—Data Terminal Equipment (DTE) Power Via Media Dependent Interface (MDI) (superseded by IEEE Std 802.3-2005).

NEMA Installation Guide for Nurse Call Systems.¹¹

NEMA SB 10, Audio Standard for Nurse-call Systems.

NFPA 70, National Electrical Code® (NEC®).¹²

NFPA 72, National Fire Alarm Code®.

NFPA 90A, Standard for the Installation of Air-Conditioning and Ventilating Systems.

NFPA 99, Standard for Health Care Facilities.

NFPA 101, Life Safety Code® Handbook.

NFPA 780, Standard for the Installation of Lighting Protection Systems.

TIA/EIA-568, Commercial Building Telecommunications Cabling Standard.¹³

TIA/EIA-569A, Commercial Building Standard for Telecommunications Pathways and Spaces.

TIA/EIA-606A, Administration Standard for the Commercial Telecommunications Infrastructure.

TIA/EIA-607, Commercial Building Grounding and Bonding Requirements for Telecommunications.

UL 1069, Hospital Signaling and Nurse Call Equipment.¹⁴

¹¹NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

¹²NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA (<http://www.nfpa.org/>).

¹³TIA/EIA standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

¹⁴UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

7.23 Bibliography

[B1] Aherns, Marty, “The U.S. Fire Problem Overview Report: Leading Causes and Other Patterns and Trends,” National Fire Protection Association, June 2003, pp. 6–11.

[B2] American Society of Healthcare Engineering (ASHE), Management and Compliance Series, Fire Alarm Systems, Volume 6.¹⁵

[B3] BOCA Basic/National Building Code.¹⁶

[B4] Code of Federal Regulations Title 47 Part 90, Volume V, FCC Rules and Regulations.¹⁷

[B5] IEEE Std 802.3-2005, IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications (supersedes IEEE Std 802.3AF).

[B6] IEEE 802.11, Wireless LAN (WLAN) standards.

[B7] IEEE 802.11-2005, Local and Metropolitan Area Networks—Specific Requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.

[B8] UL 268-2006, Smoke Detectors for Fire Alarm Signaling Systems.

¹⁵Additional information can be found at http://www.ashe.org/ashe_app/index.jsp.

¹⁶BOCA publications are available from the Building Officials and Code Administrators International, Inc., 4051 W. Flossmoor Rd., Country Club Hills, IL 60478 or from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

¹⁷CFR publications are available from the Superintendent of Documents, U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20013-7082, USA (<http://www.access.gpo.gov/>).

Chapter 8

Medical equipment and instrumentation

8.1 Overview

The single most important causative factor in the changes that occur in the diagnosis and treatment of diseases, and therefore, in the design, construction, and renovation of health care facilities, is changes to technology, expressed in different kinds of medical equipment and instrumentation. Decisions related to medical equipment come from architects, from biomedical staff, from various users groups, from administration, often in isolation; the innocent engineers often find these things thrust upon them, and they should be the coordinators of the various electrical requirements and implications. Therefore, the engineer should have a general grasp of the various kinds of equipment, should have some understanding of the forces driving evolution in the kinds of devices, and should understand how the equipment impacts the balance of the facility electrical systems.

Because this field is changing so rapidly, this chapter cannot be the definitive description of medical equipment. Rather, the goal of the chapter will be threefold. The first section of the chapter will describe certain general trends that are affecting the evolution of medical equipment. The second section describes electrical considerations that the electrical engineer should take into account in every installation of equipment, regardless of its use. Finally, the third section will describe some of the more important kinds of equipment that engineers will encounter in various kinds of healthcare settings.

8.2 Definitions

For the purposes of this chapter, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms* [B5]¹ should be referenced for terms not defined in this clause.

8.2.1 dc offset: Found when the ac voltage waveform is elevated aboveground by some constant voltage.

8.2.2 failures: Periods when the voltage drops to near zero for a prolonged period. Failures can be either momentary or outages. The duration of the voltage drop distinguishes between outages and momentary failures.

8.2.3 glitch: When either a dc offset or a failure causes the reversal on 1s and 0s in computer memory or data path. A glitch is the result of a condition rather than a condition. As computers run faster and faster, the occurrences of glitches become more frequent. However, most software systems now include error-checking routines to minimize the effect of glitches.

¹The numbers in brackets correspond to those of the bibliography in 8.7.

8.2.4 sag: The cycle-to-cycle decrease in the voltage. Sags occur at steady-state time intervals.

8.2.5 spike: An impulse that is imposed on the waveform. These usually have a duration of less than 100 μ s.

8.2.6 surge: The cycle-to-cycle rise in voltage. Surges also occur at steady-state time intervals.

8.3 Trends in medical equipment evolution

Technology advances are changing the world of medical equipment faster than almost any other sphere of medical science. This chapter cannot possibly represent the entire spectrum of available medical devices nor can it hope to be completely current with technological developments. Rather, the intent of this subclause is to describe some of the trends driving changes to medical equipment that will manifest themselves in new developments to the typical kinds of equipment described in 8.5.

8.3.1 Digital convergence

The rapid development of computing power and methods has created huge improvements in most medical technologies. Conventional x-rays, combined with computer techniques, have led to computed tomography (CT) scans and other kinds of imaging. Developments in networks are creating new storage systems and allowing intelligence to be embedded into the diagnostic tools available to doctors, to allow them to make ever more effective decisions. Wireless and other communications technologies (see Chapter 7) allow remote monitoring of patients and simultaneous consultation by multiple experts in different locations. Continued advances in computing power and memory have resulted in increased density of power per area, together with falling costs. These factors have made it ever more possible to embed more and more computing power into ever more processes, and with ever more effectiveness. This trend should continue, resulting in more and more improved devices.

One of the primary areas where digital technology is advancing is in the area of digital patient records. Such records will ideally capture all of the data related to the patient and will prevent such things as one doctor prescribing a medication that will interfere with another that the patient is already taking (to take a simple example). The pervasiveness of computing power in so many facets of the health care delivery process is rapidly transforming the electrical distribution systems in health care facilities to be more and more like those in data centers.

8.3.2 Regulations

Medical devices are regulated by numerous agencies. The U.S. Food and Drug Administration (FDA) should approve any new medical technology before it can be implemented. Similar agencies in Europe and other countries play similar roles for their countries.

One of the driving factors in the eventual deployment of any new technology is reimbursement. Because a large portion of the U.S. population is currently covered by Medicare programs, decisions by this agency to reimburse a new technology will dramatically affect its eventual deployment throughout the U.S. health care sector, with market effects that can encourage the adoption of the new technologies in other areas. Reimbursement by private insurance companies plays similar roles.

The Joint Commission, formerly the Joint Commission on Accreditation of Healthcare Organizations (JCAHO), does not exercise jurisdiction over the devices themselves, but do work to assure that the devices are being used in a safe and effective way.

8.3.3 Wireless applications

The rapid advances in wireless applications have allowed rapid deployment of devices that can be attached, worn, or carried by patients. Examples of this kind of advance is in the change from hard-wired monitoring devices to wireless telemetry systems that allow a patient to be mobile and to be monitored wherever the patient is in a health care facility. Much of the equipment within a hospital can now transmit signals wirelessly into the patient's electronic medical records. Continued advances in wireless networks (within the constraints imposed by security issues) will make more and more technologies and therapies available on an outpatient basis as well.

8.3.4 Micro- and nano-technologies

In addition to becoming wireless, technologies are becoming smaller. This change is leading to the rise in implantable devices. These devices are inserted into the body of the patient and can deliver therapy over a long period of time and/or monitor the condition of the patient and wirelessly transmit vital signs to caretakers. Futurists predict a huge surge in the use of implantable devices throughout the general population in the next few years, together with continued development and dispersion of monitoring systems.

8.4 General electrical considerations for medical equipment

8.4.1 General

Medical equipment may require hot water, cold water, and/or drain connections. It may also require other utilities such as compressed air, natural gas, steam, exhaust, special vents, and electrical service. Electrical issues resulting from the use of different kinds of medical equipment include the following:

- a) Patient and staff safety
- b) Voltage (special voltages)
- c) Capacity (amperes)
- d) Hertz (frequency)
- e) Reliability of service
- f) Control

- g) HVAC
- h) Special construction or systems needed to provide for proper and useful operation [such as radio frequency interference (RFI) shielding, electromagnetic interference (EMI) shielding, special communication systems, etc.]

8.4.2 Patient and staff safety

Some knowledge of electrical safety considerations may be helpful when designing hospital installations. Patient safety is viewed in terms of the small amount of 60 Hz currents that, if allowed to flow through the heart, could induce fibrillation (see Bruner [B2]; Lehnert [B7]). This is the same condition that can occur when a person comes close to electrocution by touching a high-voltage power line. In the broad sense, patient safety also includes protection from erroneous data due to electrical noise. The lack of information due to noise conditions or the generation of erroneous data can make diagnosis difficult or impossible under critical conditions and potentially puts the patient into jeopardy. EMI has been reported as causing defibrillators, pacemakers, and ventilators to malfunction (see *Health Devices* [B4]; Leeds, Okhtar, Damato [B6]). It can also add noise that will either obscure data or make it difficult to interpret. High-density currents flowing through electrode or transducer sites may also injure the patient by causing serious burns.

One other kind of consideration frequently overlooked in designing equipment installations is the placement of the power and other cords. Very often, the cords should be draped in a certain direction because of the relative locations of the equipment and the various outlets or other interconnected equipment, and the cords may interfere with staff access to the patients or ability to perform the required procedure. This kind of problem usually results from the lack of coordination between the user of the equipment, the equipment planners and purchasers, the engineers and architects who lay out equipment and outlets, and the contractors who try to install it. Even when thought through, the time lag between the initial design of a particular installation and the eventual ordering of the equipment may result in changes to available models of equipment that change the assumptions made about the location of cords and controls on equipment, thus rendering even the best planning wasted. The only way to deal with these kinds of problems is for all of the team members to understand the needs of the clinical users of the equipment and to take them into account as they perform their parts of the complicated construction dance.

8.4.2.1 Microshock hazard

Several conditions could arise to affect the flow of 60 Hz leakage currents as a function of poor input isolation of the measuring equipment or poor grounding of the primary circuits. A fault in the ground line will allow leakage current to flow through the path indicated. One such path encompasses electrodes or transducers placed inside the heart. If the input circuits of the instruments involved are adequately isolated, the current that flows can be kept to a very low value under the worst possible case—full line voltage being the direct source, for example. The exact distribution of 60 Hz currents that will cause fibrillation with a high degree of predictability has not been determined. However, the results of various experiments have resulted in an upper limit of 20 μA , 60 Hz being considered as

the threshold for fibrillation. UL 544,² CSA C22.2, and ANSI/AAMI ES1 all require a 20 μA limitation for input circuit isolation for the condition of the direct application of 120 V.

These standards also require that the chassis leakage current be held to 100 μA or less. This limitation essentially eliminates a shock being felt by personnel caring for the patient and is a reasonable compromise between safety and the extra cost of providing unnecessarily low chassis leakage currents.

8.4.2.2 60 Hz noise

Stray currents coupled to the body generate common-mode voltages that must be accommodated by the measuring instruments. Such devices must be able to effectively attenuate these signals by 100 dB or more. Levels of 10 V may exist on the body and yet should not interfere with measurements of signals in the millivolt region.

Sixty hertz electromagnetic signals generate differential voltages. Since these signals are differential and in the pass band of much of the measuring equipment, they need to be eliminated or reduced at their source. The patient environment should be one that will restrict the electromagnetic field to low levels. There will typically be an unavoidable area in the electrode system used for measuring heart rate and any signals picked up by this loop will be amplified as a normal signal.

Select a site for the equipment not directly adjacent to the emergency generator power plant, main power service entrance, diathermy machines, and units containing large motors. These locations will commonly produce extremely large amounts of EMI and the problem of obtaining high-quality data rises exponentially with closer distances to such sources. Keep high-current feeder lines away from patient areas.

EMI drops off rapidly with distance from the source (it varies by the square of the distance). So mounting most kinds of power equipment at least 5 ft away from any electronic equipment that may be susceptible will ameliorate the noise sufficiently. Where this distance does not suffice, more distance or a system of shielding may be required.

8.4.2.3 Burns

High-density currents flowing through electrode sites can generate burns. The usual source of the energy involved is the electrosurgery equipment. Poor contact of the return electrode of the electrosurgical unit may cause the currents to seek an easier path to ground. This route might be through other electrode sites.

8.4.3 Voltage considerations

Some modern equipment requires that the utilities be within a particular operating range for the equipment to function properly. Electrical needs will include both the quality of power provided and criteria for the characteristics of the power supply system. Since

²Information on references can be found in 8.6.

much of modern medical equipment is computer-based or computer-controlled, the presence of electrical disturbances can affect equipment operation. The ability to function is based on the following characteristics of the power supply built into the equipment:

- a) Noise filtering
- b) Stored energy
- c) Energy surge absorption ability
- d) Voltage regulation characteristics

One final consideration is what the equipment does to the power supply voltage waveform and to the current waveform. Current technology sometimes chops the power supply voltage waveform to regulate the power to the equipment. This produces a nonsinusoidal waveform on the power supply system. Whenever the power supply waveform is nonsinusoidal, the waveform can be divided into its fundamental frequency and the harmonic frequencies of the fundamental. These harmonics appear as current and impact the total system through heating losses, and possible resonance when connected to capacitive loads on the power supply line. Resonance can cause very high voltages on the supply line.

Certain kinds of equipment involve very high momentary currents periodically and otherwise relatively small continuous currents. The engineer should carefully verify voltage requirements for this equipment and carefully check the voltage drop across the system to assure proper system operation.

Much medical equipment is designed to operate satisfactorily down to 90 V. But some areas now face potential brownout conditions. Further, codes require hospitals to routinely test their emergency generators. Depending upon how carefully such systems are energized when testing, the testing may create transients on the line that can reach levels of 200 V and more for durations of several milliseconds. The equipment should be able to survive such transients or be protected through external filters to allow operation without damage or loss of data.

8.4.4 Capacity considerations

Likewise, for equipment that requires a large-ampacity, short-duration power input, the impedance of the power supply system becomes important.

8.4.5 Frequency considerations

In today's "wireless" environment, engineers should assume that electromagnetic signals are ubiquitous throughout the health care facility. EMI may be caused by signals coupled to the patient from power lines and high-frequency generators such as radio and TV stations. This noise covers the spectrum from a few hertz to several gigahertz. Electrosurgical units, FM, AM, and TV transmitters, telemetry units, electronic ballasts, radar and communication equipment, computer systems, and electrosurgical units place noises on the power line that may be sinusoidal, pulse, and impulse, as well as other types. The voltages can range from a few microvolts per meter to volts per meter for noise transmitted through the air.

Measuring equipment should be designed to handle the various transmitted interferences. This ability to filter out noise requires extensive detail in the design of input filters, shielding, and the bypassing of nonlinear elements. Chassis leakage current limitations prevent discriminating against arbitrary amounts of line interference by the use of power line filters. Filter sections tied to ground are generally not usable because they quickly cause the chassis leakage currents to exceed 100 μA . Series inductive elements in conjunction with stray capacitances are the methods employed to attenuate the effects of line noise. Even with the best filtering systems included within the equipment, however, electrical engineers will do well to design distribution systems that reasonably separate circuits and feeders serving patient care areas from those serving noise-producing equipment such as elevators, computers, pumps, and the like.

8.4.6 Reliability of service considerations

Obviously, different pieces of medical equipment serve different clinical needs, and the importance of these clinical functions also varies. In addition, some equipment, such as nuclear cameras, perform tasks that can take many minutes to complete. For this equipment, a power glitch can result in the loss of lots of already acquired data so that the procedure must be repeated, thus, be started over, backing up the queue of patients waiting for later procedures. The needs of continuity of service to the equipment can be driven by both safety and economic needs.

In addition, most medical equipment operates in medical office and other kinds of outpatient settings many of which do not have emergency generators. Finally, even if a certain piece of equipment is served by some kind of emergency or uninterrupted power, if the balance of the space has no power (lights, ventilation, power, etc.), then using that piece of equipment will be impossible notwithstanding it has power.

8.4.7 HVAC considerations

Although medical equipment generally resides in a fairly benign environment, it may be used in a wide variety of situations. Thus, the equipment will better serve potential needs if it is able to operate in the following typical environments:

- a) Temperature: 15 °C to 45 °C (59 °F to 113 °F)
- b) Shock: 30 G
- c) Vibration: 15 G to 30 G
- d) Condensation: none
- e) Humidity: 45 °C (113 °F), 90% relative humidity

Some areas of the country occasionally face brownout conditions. Much equipment is designed to operate satisfactorily down to 90 V. Further, many hospitals routinely test their emergency generators. Depending upon how carefully such systems are energized when testing, transients may be placed upon the line that can reach levels of 200 V and more for durations of several milliseconds. The equipment involved is expected to survive such transients without any damage or permanent loss of data.

Although much of the electronic equipment used will be capable of operating over wide temperature extremes, it will be better to design the environment such that temperature variations from day to night can be minimized. This will reduce the probability of condensation forming that may interfere with the operation of some units. Also, any corrosive problems due to moisture buildup will be minimized.

8.4.7.1 Humidity

One danger to proper operation of sensitive electronic and monitoring equipment is the presence of static electricity. This is because integrated circuits can be damaged or destroyed by static voltages as low as 400 V. Walking across a rug can generate static electricity in the range of 10 000 V. One of the driving factors for the accumulation of static electricity is the humidity in the vicinity. Humidity lower than about 35% greatly increases the probabilities for damaging static electricity (see “Avoid Static Damage to Your PC” [B1]).

8.5 Description of certain kinds of medical equipment

8.5.1 General patient equipment

Management of patients has been significantly aided by measurement, monitoring, and data acquisition systems. These devices are located in intensive care, critical care, coronary care and progressive care units, surgical suites, intensive care units (ICUs), and general care areas.

Health care providers can provide proper patient care only if they have sufficient information about heart and lung performance, the medication provided, and any notes made by the nursing staff. There are myriad other observations and actions to be taken with all types of patients. This subclause covers that class of equipment generally known as patient monitoring equipment and the type of equipment usually found in coronary care units (CCUs), progressive care units, operating rooms (ORs), and ICUs.

This equipment collects and displays information on heart and lung performance. The equipment measures and displays heart rates; systolic, diastolic, and mean pressures; cardiac outputs; respiratory waveforms; and rates and temperatures.

Alarms may be provided at the bedside instruments for parameters deviating below or above certain set points. Additionally, computers can be programmed to analyze *cardiac arrhythmias*, the term given to significant random abnormalities of the heart waveform. Trends of events can be stored and recalled for later observation. The parameters are typically the same as for the CCUs but it is more likely that measurements will be made from transducers or electrodes placed inside the heart chambers. Because of patient status, equipment in such areas typically contains additional controls, features, precision, and accuracy.

As various patients regain their strength, many are allowed considerable freedom in their daily activities, but they still require close monitoring. Such units may employ telemetry

systems, using individually carried monitoring equipment that wirelessly transmits information to the monitoring station.

In the general sense, all patient monitoring equipment works the same way. A transducer, either on the surface of or inside the body, picks up the signal of interest. These signals range from a few microvolts to several millivolts, depending upon the parameter of interest. Bandwidths range from dc to approximately 100 Hz. The output of the transducer is converted to an electrical signal that undergoes certain processing that depends upon the end purpose of the data. Typically, the equipment will use filters to remove as much noise and patient-induced artifact as possible. Finally, the equipment will contain some kind of processing for indicating deviations from either high or low alarm settings, waveform presentation, and analog-to-digital conversion for the computer data management systems.

Patients are relatively large sized, complicated, electrical sources. The measuring instruments connected to them should be able to provide acceptable information in the presence of large amounts of electrical noise and deliberately induced signals that have been applied for other reasons. Examples of large noise sources are electrosurgery, defibrillation, and pacemakers. The spectrum covers amplitudes from a few microamperes to several amperes, frequencies from a few cycles per second to many megahertz, and voltages ranging to a few kilovolts. The patient is a convenient pickup for 60 Hz and electromagnetic signals. Patient and electrode impedances are complex resistive-capacitive combinations that make the generation of unwanted signals an easy matter.

8.5.1.1 Defibrillators

Defibrillators apply large energies, ranging up to 400 J, for the purpose of converting a fibrillating heart to normal sinus rhythm. A fibrillating heart beats in a random manner, such that the net blood flow is close to zero. Normal sinus rhythm is the rhythm of a heart that is pumping adequately. The defibrillation pulse can have durations ranging from about 3 ms to 30 ms, and the voltages reaching electrodes attached to the patient can range as high as a few kilovolts, differential or common mode. Thus, adequate protection should be afforded to the monitors connected to the patients. The monitor's output may be disturbed by the large amount of energy applied, but the monitor should recover quickly and not be damaged.

8.5.1.2 Pacemakers

Pacemakers apply currents of a typically rectangular shape to the heart for the purpose of compensation for a chronic abnormality. Electrodes are embedded inside the heart and stimulated by means of pulses ranging from a fraction of a milliamperes to a few milliamperes, and with durations ranging from a few tenths of a millisecond to 2 ms. Equipment used in determining and displaying heart rate is used to display these pulses in order to determine if the heart has responded properly to the stimulus, but at the same time, must not count these pulses in case the patient's heart should fail to function. Alarm circuits should be able to discriminate between the absence of a heartbeat and the presence of the artificial stimulus. Since the artificial stimulus is orders of magnitude greater than the few millivolts of electrocardiograph signal, the design task is formidable. Typically,

some compromise will be reached and information is provided to the user with respect to the care that will be exercised when pacemakers are involved.

8.5.1.3 Electrosurgical devices

Electrosurgical devices are cutting tools employing large magnitudes of high-frequency current. Kilovolts, amperes, and megahertz signals are involved. The equipment tied to the patient should not be damaged by such signals and, in the case of surgery, useful data is expected in the presence of these large disturbances.

8.5.2 Commonly encountered patient room equipment

8.5.2.1 General

For an intensive care area, nearly all of the equipment will be bedside mounted and may have signals routed to a central station. Patient rooms may be equipped in an infinite number of ways, and the engineer should carefully coordinate all of the electrical needs for all of the equipment in the rooms. Different kinds of rooms are likely to require different setups, and the engineer should work with the users and the design team to properly define and coordinate the requirements. The balance of this subclause describes some commonly encountered patient room equipment and the electrical considerations related to it.

8.5.2.2 Bedside

For beds where blood pressures will be directly monitored, include transducer mounting poles, etc.

8.5.2.3 Central station

Central station consoles can range from simple tables on which the equipment sits, to a custom-built enclosure. Regardless of the central station console chosen, the following minimum features need to be provided:

- a) AC power connectors approximately every 25.4 cm (10 in) along the console's length
- b) Cable protecting conduits from central station console to central station junction box
- c) A horizontal surface for mounting monitoring equipment (for special consoles, consult the supplier during planning stages)
- d) A surface above and behind the monitoring equipment, to protect the equipment
- e) Access to rear of monitoring equipment at the central station location without the need to move equipment
- f) Adequate ventilation (cooling) for the monitoring instruments

8.5.2.4 Remote areas

Recent trends in equipping intensive care facilities indicate that remote displays at strategic locations, based upon the medical staff flow patterns, are desirable. It allows observation of the entire unit while staff members are away from the central station. Whenever displays in these areas are considered, adequate mounting facilities and power and signal distribution, which are the responsibilities of the hospital, should be considered as well. Note that memory oscilloscopes normally require coaxial cables for signal interconnection to the central station.

8.5.2.5 Telemetry system

If the hospital considers telemetry, it may be necessary for the manufacturer to make on-site field strength measurements to ensure adequate signal coverage. Because each hospital has specific details of construction, such as placement of walls, location of electrical equipment, etc., that can affect telemetry signal reception, each installation should be treated on an individual basis.

8.5.2.6 Computers

Hospitals using computer systems should make adequate signal and power arrangements during the initial stages of planning. Recommendations for computer installations vary with specific situations. Consult the equipment supplier as soon as possible in the planning stages of these installations. Computer system installations normally require special signal junction boxes and larger than normal diameter or additional conduits (refer to Chapter 7). In addition, power requirements for computer-based systems are generally higher, and provisions for increased power capacity should be incorporated into the hospital ac supply lines to the proposed computer/patient monitoring areas.

8.5.2.7 Beds

Most hospitals now use some kind of electrified beds. The beds often require outlets that are not the conventional 120 V, 20 A. Some beds have control devices mounted on the bed rails. These control devices, or *side-coms*, often require specialized plugs in the headwalls, allowing the beds to connect to the television, nurse-call, over-bed lights, and other systems.

8.5.2.8 Headwall mounted equipment

Use of a wall mount, ceiling mount, or shelf to mount the bedside modules keeps the area immediately adjacent to the bed free from monitoring equipment, an important consideration when patients are in need of constant attention. The mounting brackets can be installed when the cables are being installed or at the same time as the central station, remote, and bedside junction boxes are being installed. Steel or plywood plates should be included in the wall sufficient to distribute equipment support forces over a large section of the wall as required by specific construction. In an arrangement using two wall mounts, the mounting holes between units should be 35.56 cm (14 in) apart, center-to-center. When not mounted directly on the wall surface, the bracket(s) should be mounted on a

suitably large, 1.91 cm (0.75 in) thick plywood sheet prior to wall mounting to make it easier to properly space and align brackets. Typically, two half-modules, shelf, and bracket weigh approximately 13.6 kg (30 lb), so appropriate fasteners should be used.

8.5.3 Neonatal area equipment

8.5.3.1 Incubator

Most incubators have two functions: reverse isolation and heat balance. Some are designed only to maintain the infant's temperature (e.g., radiant warmers). It is important for nursery personnel to bear in mind that the isolation function of the usual incubator is only to protect the infant from airborne infections, because his inspired air has been filtered. An infected infant in such an incubator discharges his unfiltered expired air into the nursery, and other infants are not isolated from him unless they are also in an isolation-type incubator. Incubators that have been carefully checked and that are free from fire and electrical hazards should be available for any infant who needs supplemental heat. There should always be a standby heat incubator or radiant warmer and bassinet for unexpected deliveries or problems. Additional humidity or an oxygen-enriched environment can either be provided by the incubator or, when radiant warmers are used, delivered to the infant by means of a hood. The *isolette* normally contains a small blower, air filtration system, a heating rod device, and a water port for humidity control. The *incubator* contains a small blower, an air filtration system, a heating rod device, and a water port for humidity control.

8.5.3.2 Patient monitor

The typical patient monitor used in the neonatal nursery (or similar unit in an ICU or CCU unit) will provide measurements for the following parameters:

- a) The electrocardiogram (ECG or EKG) is a graphic recording or display of the time-variant voltages produced by the myocardium during the cardiac cycle. The P, QRS, and T waves reflect the rhythmic electrical depolarization and repolarization of the myocardium associated with the contractions of the atria and ventricles. The ECG is used clinically in diagnosing various diseases and conditions associated with the heart. It also serves as a timing reference for other measurements.
- b) Respiration. Breaths/min in the range of 0 to 80.
- c) Blood pressure. Utilizing a pressure transducer, a carrier amplifier, and a display utilizing two meters showing the systolic and diastolic pressure in mmHg.
- d) Temperature is recorded from the skin, the rectum, and the ambient area. Normal temperature ranges are as follows:
 - 1) Oral (mouth): 37 °C (98.6 °F)
 - 2) Rectal: Usually 1° higher than the oral reading
 - 3) Skin temperature: 21 °C (70 °F)
- e) Electrical parameters
 - 1) Voltage: 120 V

- 2) Frequency: 60 Hz
- 3) Watts: 100 W to 200 W
- f) Sources of electrical problems
 - 1) RFI
 - 2) Patient electrodes (chest, ear, and nose clips); there can be 12 electrodes
 - 3) Stylus wears out; driven by servomotor
 - 4) Voltage fluctuations from outside sources
 - 5) Incorrect grounding
- g) Design and installation recommendations
 - 1) Locate receptacles and patient input outlets as close to patient as possible.
 - 2) Emergency power is essential (an alternate source with adequate capacity should be provided from an independent branch for emergency use and routine maintenance).
 - 3) Electrical circuits for bedside (or crib and incubator) patient monitors and central station monitors to be on same phase leg.
 - 4) All receptacles should be hospital grade or equivalent.

8.5.4 Surgical suite

The surgical suite, whether in a small community hospital or in a major general or teaching hospital, is usually the most complicated in the facility in regard to electrical systems, equipment, patient safety considerations, and of course, in communications. OR equipment may be centrally located, analogous to a central station, or it could be mounted near the anesthesiologist or close to the OR table. The instruments may be in racks, consoles, or individually stacked on bench tops.

8.5.5 Catheterization

8.5.5.1 General

Catheterization is the process of collecting data from inside the heart chambers for the purpose of determining the details of heart performance and whether surgery can be effective in correcting deficiencies with blood flow or other heart abnormalities. A catheter is a small tube that is guided into the blood vessels through tiny incisions in the groin area or upper arm.

Catheterization is a type of x-ray that is done to image blood vessels in various parts of the body, including the heart, brain, and kidneys, so as to determine whether the vessels are diseased, narrowed, enlarged, or blocked altogether. After passing a catheter through an artery leading to the body area of interest, a contrast material is injected to highlight the vessels when x-rays are taken. The x-ray tube generates x-rays that pass through the body part being imaged. The body attenuates the x-rays at different levels, so that the differences in attenuation can be picked up by a TV signal.

Today, many catheter studies have been replaced by less invasive methods, such as CT angiography and magnetic resonance (MR) angiography, that do not require that a catheter be inserted. Catheterization is still widely used in patients who may undergo surgery, angioplasty, or stent (small cylindrical support) placement.

8.5.5.2 Surgical use

Surgeons sometimes use catheterization to plan an operation or to decide on the best surgical procedure. Using catheter angiography as an aid to see inside blood vessels, surgeons can repair diseased vessels from within using tiny instruments and inserting a stent to keep the vessel open. Advances in the design and use of catheters allow physicians to perform very complex therapeutic procedures from within the blood vessel.

8.5.5.3 Electrical requirements

Electrical requirements for catheterization and angiography equipment are similar to those for conventional x-ray equipment. However, because of the extreme invasiveness of the procedures, other considerations enter into the design of electrical spaces containing this equipment. First, the procedures cannot be interrupted without serious hazard to the patient. Thus, power to these units must be on the critical branch of the electrical distribution system. Many facilities use small UPS systems for this equipment to ensure continuity of service during an outage. Many manufacturers recommend “equipotential grounding systems” for their cath/angio rooms.

8.5.6 Dialysis

The introduction of maintenance dialysis for the treatment of renal disease with uremia is generally acknowledged as one of the most important advances in medical treatment in the last 25 years. This procedure is used to prolong the life of thousands of patients awaiting kidney transplants, and it also extends the active life of the kidney patient.

Electrical engineers designing electrical systems within dialysis suites should design then with patient safety as the foremost consideration, and then considering feeding the equipment utilized. The area is always suspect to moisture from patient waste, the dialysate fluid, and other fluids with a salt base. All electrical equipment shall be grounded.

All receptacles should be ground-fault interrupter (GFI) type and hospital grade or equivalent. Serve the dialysis machine from its own independent circuit in order to provide the highest probability that a nuisance trip on another piece of equipment will not interrupt the patient treatment. Due to the length of time a dialysis patient spends on the machine, consider electric supply system outage frequency and to the need for emergency power.

8.5.7 Diagnostic imaging

8.5.7.1 General

Imaging equipment refers to a wide range of diagnostic and exploratory systems. What began as a simple process using film and x-ray radiation exposures is now a real-time, computer-based industry. Medical facilities use imaging equipment in many ways, ranging from simple x-ray films that locate broken bones to computer-aided tomography (CAT) units that provide digitally enhanced section views through the patient.

While the number of different kinds of imaging equipment has changed, so too has the practice of imaging. Some hospitals, usually built a long time ago, sometimes feature large, centralized diagnostic imaging departments. More and more health care facilities find it more effective to locate various imaging equipment throughout the facility, where most easily accessed by the patients and staff who need a particular modality. Thus, the electrical challenges that engineers once faced in one centralized location are now found scattered throughout practically every area of a medical facility. Due to this scattering of units, the once simple solutions to x-ray unit power distribution may no longer be as economically feasible. Power distribution to this equipment requires detailed study in each instant of not only the specific equipment, but also the specific electrical power distribution system.

8.5.7.2 X-rays and their production

The fundamental imaging technique is radiography, or x-ray. A *radiograph* is a visible photographic record—an x-ray picture—produced by the passage of x-rays through an object or body and then recorded on a special film. In medicine, it enables the radiologist to study the inner structures of the human body as an aid to diagnosis. How a radiograph is produced—what physical and chemical reactions take place—is the subject of this subclause.

The first question that naturally arises is: What are x-rays, and how do they behave? They have two aspects of behavior—as rays and as particles. A ray can be defined as a beam of light or radiant energy. (Energy simply means the capacity for performing work.) Light or radiant energy travels as a wave motion and hence one measurable characteristic is its wavelength.

To understand the concept of waves and wavelength, think of the disturbance created in a quiet pond when a pebble is tossed into it. As the pebble strikes the water, some of its energy produces waves that travel outward in ever-widening circles. Although the water is in motion, it does not travel forward progressively. This can be seen by the motion of a floating chip of wood or of a leaf that rises and falls with the waves but does not progress from its original location. The energy of the waves proceeds outward from the center. The wavelength of the water waves is the distance from crest-to-crest or trough-to-trough. In any system of waves, the distance between two successive corresponding locations in the moving energy pattern is the *wavelength*.

Light, radio waves, x-rays, and so forth are energy waves of electric and magnetic influence. They are appropriately called electromagnetic waves and travel at tremendous speed—about 3×10^8 m/s (186 000 mi/s). All these forms of electromagnetic radiation are grouped according to their wavelengths in what is called the *electromagnetic spectrum*. The following examples will provide some comparison of waves and wavelength.

The length of 60 Hz ac waves is about the distance as from coast to coast of the U.S. The wavelength of short radio waves is about 2 m. Medical x-rays—only about 1/10 000 the wavelength of visible light—have a wavelength of about one billionth of an inch. The useful range in medical radiography comprises wavelengths approximately 0.01 nm to 0.05 nm.³ See Figure 8-1.



Courtesy of Siemens Medical Solutions USA, Inc.

Figure 8-1— Axiom x-ray system

As mentioned earlier, x-rays also act as if they consisted of small, separate bundles of energy called *quanta* (singular: quantum) or photons. Under certain circumstances the action of a beam of x-rays can be better understood if it is considered not as a succession of waves, but rather as a shower of particles. This does not imply that a beam of radiation changes erratically from particles to waves and back again. Instead, the aspect that is most apparent depends upon the way the radiation is being used or on the method being used to detect or record it.

³The wavelength of visible light at the center of the visible spectrum is about 5.5×10^{-5} cm, while the x-rays used for radiograph—those in the center of the medical x-ray spectrum—have a wavelength of approximately 5.5×10^{-9} cm. Therefore, the wavelength of the x-rays is only about 1/10 000 that of visible light.

The two natures of x-rays are inseparable. For instance, to know the energy in a single quantum (i.e., in one of the small separate bundles of energy), it is necessary to know the wavelength of the radiation. But wavelength is a wave characteristic and must be determined from a consideration of the wavelike nature of radiation.

The experimental facts that prove radiation to be both wavelike and particle-like are well established. Radiation has a dual nature, not in the sense that it behaves unpredictably, but in the sense that one aspect will predominate under one set of circumstances, the other aspect under another.

Fundamentally, x-rays obey all the laws of light, but among their special properties certain ones are of interest to the x-ray technician, as follows:

- a) Their extremely short wavelength enables them to penetrate materials that absorb or reflect visible light.
- b) They cause certain substances to fluoresce; that is, to emit radiation in the longer wavelengths, i.e., visible and ultraviolet radiation.
- c) They affect photographic film, producing a record made visible by development.
- d) They cause biologic changes (somatic and genetic); a fact that permits their use in therapy but also necessitates caution in using x-radiation.

These special properties have application in medical and industrial radiography, therapy, and research.

8.5.7.3 X-ray tube

X-rays arise when fast-moving electrons (minute particles, each bearing a negative electrical charge) collide with matter in any form. The most efficient means of generating x-rays is an x-ray tube. This is an electronic device that is considerably larger but actually less intricate than the electronic tubes in a radio. In an x-ray tube, x-rays are produced by directing a stream of electrons at high velocity against a metal target. In striking the atoms of the target, the electrons are stopped. Most of their energy is transformed into heat, but a small proportion (about 1%) is transformed into x-rays.

The simplest form of x-ray tube is a sealed glass envelope (from which the air has been pumped) containing two important parts: the anode and the cathode. The anode is usually formed of copper and extends from one end of the tube to the center. A block of tungsten about 1/2 in square is set in the anode face at the center of the tube. This is called the *target*. Tungsten has been found to be the most efficient target material for two reasons: first, its high melting point withstands the extreme heat to which it is subjected, and second, it has a high atomic number, making it a more efficient producer of x-radiation than materials of lower atomic number. The small area of the target that the electrons strike is called the *focal spot*; it is the source of the x-rays. There are two types of anode—the stationary and the rotating—more will be said about them presently.

The cathode contains a tungsten wire (filament) wound in the form of a spiral about 1/8 in diameter and 1/2 in long; it is set in a cup-shaped holder (called the *focusing cup*) an inch

or so away from the anode. The support for the focusing cup extends outside the tube so that appropriate electrical connections can be made.

The cathode filament is heated to a glow (incandescence) in just the same way as the filament is in an ordinary light bulb. However, the filament is not heated to produce light, but rather to act as a source of electrons that are emitted from the hot wire. The cathode is so designed and located within the tube that the electrons form a stream, beamed in the right direction, and of the exact size and shape to produce the desired focal spot on the target of the anode.

When a very high potential (thousands of volts) is applied to these two x-ray tube components (the cathode and the anode), the available electrons are attracted to the anode in such a manner that they strike the focal spot with tremendous force. The higher the potential (voltage), the greater the speed of these electrons. This results in x-rays that are of shorter wavelength and greater penetrating power and intensity.

As has been mentioned, the focal spot is the area of the target that is bombarded by the electrons from the cathode. The shape and size of the focusing cup of the cathode, the length and diameter of the coil (filament), and the dimensions of the focusing cup in which the coil rests all determine the size and shape of the focal spot.

Heat and x-rays are generated by the impact of the electrons. Only a small part (about 1%) of the energy resulting from this impact is emitted from the focal spot in the form of x-rays. Most of the energy is wasted by heating the target. This heat should be conducted away from the focal spot as efficiently as possible. Otherwise, the metal would melt and the tube would be destroyed. Tube manufacturers use a variety of methods for carrying the heat away from the focal spot. The simplest method is to back up the target with a good heat-conducting metal, such as copper, and to extend the copper outside the glass bulb to a fin radiator. In some tubes, water or oil is pumped through internal holes in the copper so as to dissipate the heat more effectively.

The size of the focal spot has a very important effect upon the quality of the x-ray image. The smaller the focal spot, the better the detail of the image. But because a large spot can tolerate more heat than a small one, some method of obtaining a practical size of focal spot that would provide good image detail had to be found. These methods are: utilizing the line-focus principle and rotating the anode.

The line-focus principle refers to the fact that the electron stream is focused in a narrow rectangle on the anode target. The target face is made at an angle of about 20° to the cathode. When the rectangular focal spot is viewed from below—in the position of the film—it appears more nearly a small square. Thus, the effective area of the focal spot is only a fraction of its actual area. By using the x-rays that emerge at this angle, radiographic definition is improved while the heat capacity of the anode is increased because the electron stream is spread over a greater area.⁴

⁴In designating tube size, manufacturers use a dimension that is the effective focus size. That is, a so-called 1.0 mm tube has a projected focus of 1 mm by 1 mm.

To increase further the capacity of the anode to withstand heat, the rotating-anode tube was developed. As the name implies, the disk-shaped anode rotates on an axis through the center of the tube during the period of operation. The filament is so arranged as to direct the electron stream against the beveled area of the tungsten disk. Thus, the position of the focal spot (the area of the target the electrons strike) remains fixed in space while the circular anode rotates rapidly during the exposure, continually providing a cooler surface for reception of electron stream. In this way the heat is distributed over the area of a broad ring, and for the same exposure conditions, the focal spot area can be made one-sixth or less that required in stationary-anode tubes.

Some tubes contain two separate filaments and focusing cups that provide focal spots of different size and capacity.

Manufacturers furnish charts with all types of x-ray tubes to indicate the limits of safe operation—the maximum factors of kilovoltage, milliamperage, and time that can safely be used for a single exposure. Some manufacturers also give cooling charts that indicate how rapidly exposures may be repeated. Thus, a tube can always be operated within its rated capacity.

8.5.7.4 Operation of the x-ray tube

The electrical apparatus that permits the control and operation of the tube consists of a number of basic components, as follows:

- a) A high-voltage transformer
- b) An autotransformer
- c) A rectifier
- d) A power supply for the filament of the x-ray tube
- e) A choke coil to adjust the current supply to the filament

The circuits involving the x-ray tube, rectifier, and high-voltage transformer are arranged so that high-positive voltage is applied at the anode end of the tube, with the high-negative voltage applied at the cathode. The electrons from the hot cathode filament are negative charges and thus are attracted with great force to the positive anode. This high voltage is usually expressed in terms of peak kilovolts ($1 \text{ kV} = 1000 \text{ V}$).

Voltage has nothing to do with the manner of electrons that compose the stream flowing from cathode to anode; voltage controls the speed of each electron, which in turn has very important effects upon the x-rays produced at the focal spot.

The temperature (the degree of incandescence) of the cathode filament controls the number of electrons generated. This control is accomplished by adjusting the filament current through its own low-voltage electric circuit. The hotter the filament, the more electrons that are emitted and become available to form the electron stream—that is, the x-ray tube current. In the x-ray tube the number of electrons flowing per second is measured in milliamperes ($1 \text{ mA} = 0.001 \text{ A}$). The quantity of x-rays produced at a particular kilovoltage depends upon this number. For example, when the number of electrons per

second doubles, the current (milliamperage) doubles, and the x-rays produced double in number. Note that setting the x-ray machine for a specific milliamperage actually means adjusting the filament temperature to yield the current flow (milliamperage) indicated.

One way to think about what takes place inside an x-ray tube is as a conveyer system at a sand pit. Suppose that above one end of the conveyer belt there is a hopper full of sand that runs out the bottom through an adjustable opening onto the moving belt. Assume that the grains of sand are the electrons. The number of grains available to be carried away each second by the belt depends on the size of the outlet opening of the hopper, which can be compared to the degree of incandescence of the cathode filament. The moving belt will carry away all of the sand just as the kilovoltage will move all of the electrons available at the filament that comprise the electron stream.

Now, suppose the belt speeds up (the kilovoltage increases). The number of grains of sand (electrons) traveling per second remains unchanged. Only so many get through the opening (the cathode incandescence) regardless of the belt speed (kilovoltage). Those that are available just travel faster. Again, suppose that the hopper hole is opened wider (filament incandescence is increased). More grains of sand (electrons) per second fall on the belt. The belt carries a bigger load—more grains per second (greater milliamperage)—but the belt speed (kilovoltage) is the same. As the effects of milliamperage and kilovoltage are discussed in the following subclauses, it may be helpful to refer again to this “conveyer” discussion. This should help to explain how these two factors affect the x-ray beam.

8.5.7.5 X-ray beam and image formation

Most diagrams of the x-ray tube show x-rays as forming a neat triangular pattern as they are produced at the focal spot. This serves a good purpose in emphasizing the action of x-radiation outside the tube. However, the radiation does not behave in that way. Actually, x-rays are like visible light in that they radiate from the source in straight lines in all directions unless they are stopped by an absorber. For that reason, the x-ray tube is enclosed in a metal housing that stops most of the x-radiation; only the useful rays are permitted to have the tube through a window or port. These useful rays are called the *primary beam*. That pencil of radiation at the geometric center of the primary beam is called the *central ray*.

A high voltage is applied to the x-ray tube in order to produce x-rays. The electrical apparatus is such that the kilovoltage can be changed over a rather wide range, usually 30 kV to 100 kV or more. When the lower range of kilovoltages is used, the x-rays have a longer wavelength and are easily absorbed. They are termed *soft* x-rays. Radiation produced in the higher kilovoltage range has greater energy and a shorter wavelength. Such x-rays are much more penetrating and are called *hard*. It should be understood that the x-ray beam consists of rays of different wavelengths and penetrating power.

8.5.7.6 X-ray absorption

The key attribute of x-rays is that they are able to penetrate matter. Not all the x-rays that enter an object penetrate it. Some are absorbed. Those that do get through form the image,

or shadow, as it is frequently called. The extent to which x-rays are absorbed by a material depends on the following three factors:

- a) The wavelength of the x-rays
- b) The composition of the object in the path of the x-ray beam
- c) The thickness and density of the object

The long wavelength x-rays—i.e., those produced at lower kilovoltages—are easily absorbed. The shorter wavelength x-rays—i.e., those produced in the higher kilovoltage range—penetrate materials more readily.

The composition of an object has a bearing on x-ray absorption depending on the atomic number of the material. For example, a sheet of aluminum, being of lower atomic number (and therefore consisting of a lower number of particles) than copper, absorbs a lesser amount of x-rays than does a sheet of copper of the same area and weight. Lead (of still greater atomic number) is a great absorber of x-rays. For this reason manufacturers use lead in the tube housing and for protective devices, for instance, in the walls of the x-ray room and in the special gloves and aprons used during fluoroscopy.

The relation of x-ray absorption to thickness is simple; a thick piece of any material absorbs more x-radiation than a thin piece of the same material. The density of a material has a similar effect. For instance, an inch of water will absorb more x-rays than an inch of ice.

Of course, applying x-rays to bodies must take into account the fact that the body is a complex structure made up not only of different thicknesses but of different materials. Because different materials absorb x-rays in different degrees, they absorb different amounts of x-rays. For example, bone absorbs more x-rays than flesh does; and flesh, more than air (in the lungs, for instance). Furthermore, diseased structures often absorb x-rays differently than do normal flesh and bones. The age of a patient also has a bearing on absorption. For example, in the elderly, the bones have less calcium content and hence less x-ray absorption than do the bones of younger people.

Subject contrast is the relationship among x-ray intensities in different parts of the image. Subject contrast depends upon the nature of the subject, the radiation quality used, and the intensity and distribution of the scattered radiation, but it is independent of time, milliamperage, and distance, and of the characteristics or treatment of the film used.

8.5.7.7 Factors affecting images

An x-ray image can be affected by three factors: milliamperage, distance, and kilovoltage.

- a) *Effect of milliamperage.* Increasing the milliamperage increases the quantity of x-rays, and decreasing the milliamperage decreases the quantity. All the x-ray intensities of this leg pattern, or the brightness of the image, will increase as the amount (quantity) of x-radiation from the focal spot increases. Therefore, this brightness can be readily controlled by changing the milliamperage. However, it should be understood that the various x-ray intensities will continue to bear the same relation to each other.

- b) *Effect of distance*
 - 1) Again, the x-ray intensities of the pattern can be altered uniformly by an entirely different, nonelectrical means—by moving the tube from or toward the object. In other words, the distance of the tube from the object has an effect on the intensity of the image. Thus, as the distance from the object to the source of radiation is decreased, the x-ray intensity at the object increases; as the distance is increased, the radiation intensity at the object decreases. This all results from the fact that both x-rays and light travel in diverging straight lines.
 - 2) A change in distance is very similar to a change in milliamperage in its effect upon the overall intensity of the image. The amount by which the overall image intensity is changed when milliamperage or distance is changed is a matter of simple arithmetic.
- c) *Effect of kilovoltage*
 - 1) A change in kilovoltage causes a number of effects. The first to be considered here is the fact that a change in kilovoltage results in a change in the penetrating power of the x-rays. Another fundamental rule of all x-ray technique is that increasing kilovoltage reduces subject contrast; decreasing kilovoltage increases subject contrast.
 - 2) A second effect of increase in kilovoltage is that not only are new, more penetrating x-rays produced, but so are more of the less penetrating rays, which were also produced at the lower kilovoltage. This occurs with no change in tube current.
 - 3) The combination of these two effects of increase in kilovoltage is to modify the pattern so that a pronounced increase in overall intensity of the pattern would have been noted, in addition to the differences in intensity having been leveled out.
- d) *Summary.* From the discussion thus far, the following conclusions can be drawn: Overall intensity of the image can be controlled by the three factors: milliamperage, distance, and kilovoltage. When milliamperage or distance is used as a factor for control of intensity, subject contrast is not affected. However, when kilovoltage is used as a control of intensity, a change of subject contrast always occurs in conjunction with the change in intensity.

8.5.7.8 Heel effect

The previous discussion assumed that the intensity of radiation over the entire area covered by the primary beam is constant. Actually, there is a variation in intensity due to the angle at which the x-rays emit from the focal spot. This is called the *heel effect*. The following is a description of this effect and the way in which it may be used to advantage.

This so-called heel effect is the variation in intensity of the x-ray output with the angle of x-ray emission from the focal spot. The intensity of the beam diminishes fairly rapidly from the central ray toward the anode side and increases slightly toward the cathode side. This phenomenon can be made good use of in obtaining balanced densities in radiographs of heavier parts of the body. To do so, arrange the patient relative to the tube so that the

long axis of the tube is parallel to that of the body part, with the anode toward the more easily penetrated area. For example, in radiography of the thoracic vertebrae, the neck should receive the less intense rays from the anode portion of the beam, while the heavier chest area should be exposed by the more intense rays from the cathode portion of the beam.

The heel effect is less noticeable in closely coned projections where the x-ray beam is fairly restricted. Where a long area, such as the thoracic vertebrae, will be included, it is important.

8.5.7.9 Geometry of image formation

The purpose of radiography is to obtain as accurate an image as possible. Two factors that contribute to this accuracy are the sharpness and size of the shadow. A demonstration that can be made with light bulbs will make clear how these factors are applied in radiography.

Get a small, clear lamp, such as is used in a night-light. Set it up about 3 ft from a wall, turn it on, and place your hand an inch or two from the wall. Notice that the shadow produced by this small light source is nearly the same size as your hand, and that the edges are quite sharp. Now move your hand away from the wall—toward the light—and watch how the shadow grows larger and fuzzier along the edges. Next, substitute a large, frosted bulb and notice that the edge of the shadow is a little fuzzy even when your hand is close to the wall. The fuzziness is caused by the larger light source. Again, move your hand toward the lamp and see how the shadow enlarges and the fuzziness increases.

So it is with x-rays. The smaller the source of radiation (focal spot) and the nearer the object is to the recording plane (film), the sharper and more accurate the image. Conversely, the larger the source of radiation and the farther the object is from the recording plane, the greater the fuzziness and magnification. In addition, not only the shadow of the edge of the object but all of the shadows of the structures within it are involved in radiography, because x-rays penetrate the object whereas light does not. The same laws apply to the shadows of the internal structures as apply to the edges. If one of these structures is farther away from the recording plane than another, the structure farther away will be magnified more, which will result in unequal magnification. This variation from the actual proportions of the object is known as *distortion*. (Distortion and magnification are not necessarily bad things. Sometimes this is deliberately done in order to permit diagnosis of an otherwise obscured part.)

All the foregoing may be summed up in five rules for accurate image formation:

- a) The x-rays should proceed from as small a focal spot as other considerations will allow.
- b) The distance between the tube and the object to be examined should always be as great as is practical. At maximum distances, radiographic definition is improved and the image is more nearly the actual size of the object.
- c) The film should be as close as possible to the object being radiographed.
- d) Generally speaking, the central ray should be as nearly perpendicular to the film as possible to record adjacent structures in their true spatial relationships.
- e) As far as is practical, the plane of interest should be parallel to the film.

8.5.7.10 Scattered radiation

The previous explanations assumed that when x-rays strike an object, some rays pass through and some are absorbed. In other words, these explanations have implied that all of the rays that come out of the object have come straight from the focal spot (primary beam) and have traveled through the part to form a well-defined, clear-cut image, and that all of the rays that did not penetrate were absorbed and could be forgotten. Actually, some of the radiation is scattered in all directions by the atoms of the object struck, very much as light is dispersed by a fog. The secondary rays thus produced are known as *scattered radiation* or *scattered x-rays*.

Because of this scattering, the object is a source of photographically effective but unwanted radiation. It is unwanted because it does not contribute to the information of the useful image. On the contrary, it produces an overall exposure superimposed on the useful image. The effect of this overlying uniform intensity is to reduce contrast, and hence, to decrease the visibility of gradations in the image when viewed on the fluoroscope or recorded on film.

Other sources of scattered radiation are materials beyond the image plane—the tabletop, for instance. Radiation arising from such sources may be scattered back to the image.

8.5.7.11 Recurring scattered radiation

Obviously, scattered radiation should be minimized. Backscatter is readily controlled by placing a sheet of lead immediately behind the film. Another important way to reduce scattered radiation is to confine the primary beam to a size and shape that will just cover the region to be x-rayed. This is done by attaching to the x-ray tube a cone or aperture diaphragm.

X-ray cones are metal tubes of various shapes and sizes—some provide circular fields and others, rectangular. Aperture diaphragms consist of sheets of lead with circular, rectangular, or square openings. When these are properly used, the part of the object not x-rayed does not contribute appreciably to scattered radiation, and the machine will generate an improved image. The size of the area that a cone will encompass at a certain distance indicates the extent to which scatter occurs. Some manufacturers specify the projected diameter of their cones at given focus-film distances. For cones that do not carry this information, it can also be determined with test films and the results then marked on the cones.

Another way to determine the projected field is to use Equation (8.1):

$$(A \times B)/C = X \quad (8.1)$$

where

- A is the distance from focal spot to film plane
- B is the aperture of diaphragm or diameter of cone
- C is the distance from focal spot to diaphragm or lower rim of cone
- X is the diameter of projected field at film plane

As an example, the focus-film distance A is 36 in; the diameter of the cone B is 4 in; the distance from the focal spot to the lower edge of cone C is 12 in. What amount of film X would be encompassed by the x-ray beam? Using Equation (8.1), we have:

$$(36 \times 4)/12 = 12 \text{ in, diameter of projected field}$$

Of course, the smallest cone that will provide adequate coverage should always be used, and care should be exercised in centering the tube so that cutoff of the image will not occur.

Thick, heavy parts of the body, such as the abdomen, produce a much higher proportion of scattered radiation than does a thin part, such as the hand. Therefore, when radiographing the heavier body parts, technicians use an additional means of controlling scattered radiation called a *grid*. This apparatus is composed of alternating strips of lead and radio-transparent material, such as wood or aluminum, so arranged that when the focal spot is centered over the grid, the plane of each lead strip is in line with the primary beam. The lead strips absorb a considerable amount of the oblique scattered radiation (that is, the rays not traveling in the direction of the primary beam). The radio-transparent strips allow most of the primary rays to pass through to the film.

The relation of the depth to the width of the radio-transparent strips represents the grid ratio. To illustrate, if the depth of the transparent strip is eight times its width, the grid ratio is eight to one (8:1); if the depth is six times the width, the ratio is 6:1, etc. The greater the ratio, the more efficiently will the grid absorb scattered radiation.

When a stationary grid is used, the shadows of the lead strips are superimposed on the useful image. This can be tolerated when a grid with very thin, uniformly spaced strips is used. The very fine lines are not objectionable in the image. To eliminate the grid pattern, however, it is merely necessary to move the grid at right angles to the strips during the exposure; in this way the grid lines are blurred and not distinguishable. A device comprising a grid and the mechanism for moving it is called a *Potter-Bucky diaphragm*, or sometimes simply a Bucky. The grid absorbs a large part of the secondary radiation and even some of the primary radiation. It is obvious, therefore, that the exposure needs to be increased to compensate for this loss. The necessary increase in exposure should be determined by trial with the particular equipment. It depends on the grid ratio; the more efficient the grid in absorbing scattered radiation, the greater the exposure increase needs to be. As a guide for experimenting, a factor of three is suggested.

Regardless of the efficiency of the grid in removing scattered radiation, a cone diaphragm should always be used with the Bucky to restrict the primary beam properly. Here again, it is well to realize that with this combination, care should be exercised in aligning the tube so that image cutoff will not occur.

8.5.7.12 X-ray filters

Filters are thin sheets of metal (generally aluminum) inserted at the tube portal to absorb the longer wavelength rays that do not contribute to the image. This is a safety device for protection of the patient.

8.5.7.13 X-ray generating apparatus

As has been mentioned, the principal devices, aside from the x-ray tube, are an autotransformer, a high-voltage transformer, a rectifier circuit and valve tubes (when necessary), and a low-voltage transformer for the filament of the x-ray tube.

- a) *Transformer.* A transformer is a device used to transfer ac electrical energy from one circuit to another and from one voltage level to another. In the simplest form it consists of two coils of insulated wire wound on an iron core without having any electrical connection between them. The coil connected to the source of power is called the *primary winding*, the other, *the secondary winding*. Voltage is induced in the secondary when energy is applied to the primary. The voltages in the two coils are directly proportional to the number of turns of wire in each, assuming a theoretical 100% efficiency. For example, if the primary has relatively few turns, say 100, and the secondary has many, say 100 000, the voltage in the secondary is 1000 times higher than that in the primary. Since the voltage is increased, this type of transformer is called a *step-up transformer*. At the same time, the current in the coils is decreased in the same proportion as the voltage is increased. In the example given, the current in the secondary is only 1/1000 of that in the primary. A transformer of this type is used to supply the high voltage to the x-ray tube.
- b) *Action of ac.* Voltage can be described in the form of a graph that represents the action of an imaginary voltmeter—if such a very fast-acting one could be built—connected to the transformer terminals. When 60-cycle ac is used, the needle of the voltmeter would move from zero to a maximum (peak or crest) and back to zero again in 1/120 s. It would immediately start off in the opposite or inverse direction, reach a peak, and return to zero in another 1/120 s. This action is called a *full cycle* and requires 1/60 s. Sixty of these cycles are accomplished in 1 s, hence, the term *60 Hz ac*. For x-ray purposes, the tube voltage is almost always expressed in terms of the peak or crest value (which is abbreviated krp). The x-ray tube receives a series of voltage pulses, one for each useful peak, and therefore produces x-rays in pulses or bursts.
- c) *Autotransformer.* The usual line voltage supplied for x-ray equipment is 220 V ac. X-ray techniques, however, require a wide variety of kilovoltages. Therefore, the line voltage is adjusted by a special type of transformer—an autotransformer—so that the primary of the high-voltage transformer has a variable and predetermined supply. The result then is that the high voltage to the x-ray tube can be preselected at the autotransformer before the x-ray exposure is actually made. The device is called an autotransformer because the primary and secondary are combined in one winding.
- d) *Low-voltage transformer for filament.* Some means needs to be furnished not only to light the filament of the x-ray tube but to control the degree of incandescence. The requirements for this are a few amperes at 4 V to 12 V that are provided by a step-down or low-voltage transformer. The secondary winding of the step-down transformer is heavily insulated from the primary and the iron core so that the high voltage to the x-ray tube cannot get back into the supply lines of the x-ray machine.

e) Tracing the generator circuit

- 1) There are a number of auxiliary devices that go to complete the x-ray generating apparatus, such as meters, fuses, and circuit breakers. Tracing the circuit will help to make clear the action of the various parts of the apparatus. Fuses are placed in the incoming line as in all electrical apparatus. The current passes through the switch to the autotransformer. A line voltage compensator at 3 A can be adjusted so that the correct input voltage is applied to the autotransformer. A prereading (ac) voltmeter in the autotransformer circuit indicates the voltage applied to the primary of the high-voltage transformer by means of the variable control. A circuit breaker acts when the high-voltage transformer is overloaded. A switch with automatic timer is closed to make the x-ray exposure. The high-voltage x-ray tube current is indicated by the milliamperage (mA).
- 2) The low-voltage transformer for the filament of the x-ray tube is supplied from a fixed position on the autotransformer. An ammeter permits the proper setting of the filament voltage control for the transformer. The secondary of the filament transformer is connected directly to the tube filament in the cathode of the x-ray tube. The terminals of the secondary of the high-voltage transformer are connected in various ways to the x-ray tube, depending on the rectification method.
- 3) Modern equipment is so constructed that all parts exposed to high voltage are especially insulated. This includes the high-voltage transformer, the rectifier system, valve tube and x-ray tube filament transformers, cables, and the x-ray tube.

f) Radiography equipment—power distribution and grounding

- 1) System capacity (voltage sags)
- 2) System impedance. The constraining factor for most radiographic equipment is the impedance of the supply system, not the current capacity. Radiographic units do not draw their normal discharge current for long periods. However, when they fire, they need to have the voltage and current available in order to properly excite the x-ray tube. A power supply impedance that is too high will have an I^2R loss (heating loss) in the system, which will reduce the voltage available during firing the tube.

g) High-speed CT scanner

- 1) Power distribution and grounding
 - i) Transients and duration acceptable
 - ii) Supply line variations
 - iii) Emergency power
- 2) Power conditioning
- 3) Air conditioning

h) Conventional CT scanner

- 1) Power distribution and grounding
 - i) Transients and duration acceptable

- ii) Supply line variations
 - iii) Emergency power
- 2) Power conditioning
- 3) Air-conditioning needs (minimal)
- i) *MRI scanner*
 - 1) Power distribution and grounding
 - i) Transients and duration acceptable
 - ii) Supply line variations
 - iii) Emergency power
 - 2) Power conditioning (sometime supplied with system)

8.5.7.14 Power requirements

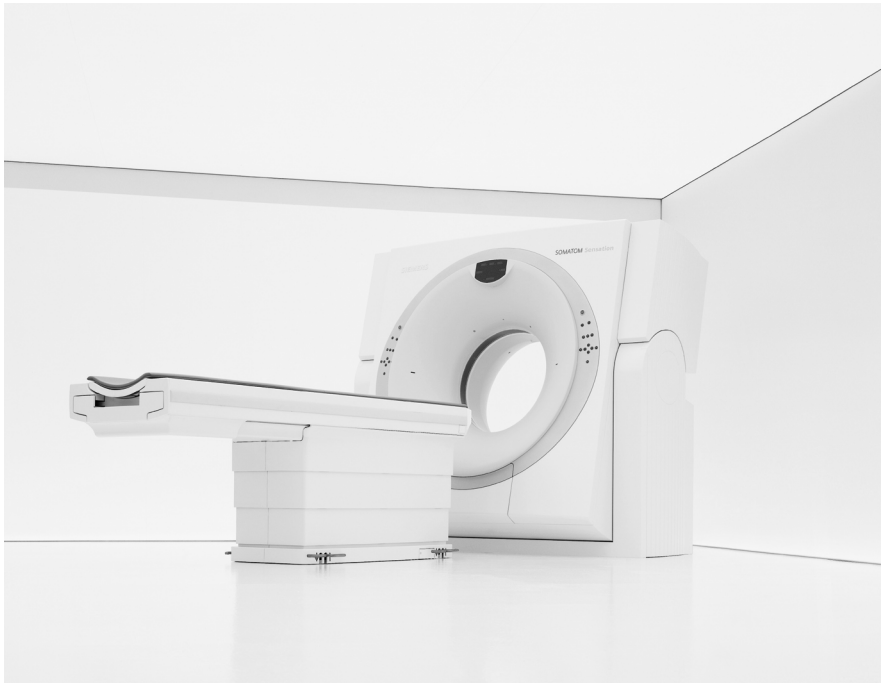
X-ray machines produce momentary high-power factor loads of 20 kVA to 160 kVA. The momentary load usually has a duration of less than 2 s, but 6 s or 7 s exposures are not uncommon. In order to perform properly, x-ray machines operate within a certain voltage range, which is sometimes called the *absolute line voltage span*. Within this range, voltage regulation cannot exceed a certain value (usually in the 3% to 10% range). A typical 95 kVA (480 V nominal) unit will have a steady-state voltage requirement of from 360 V to 507 V. During the x-ray exposure, the voltage should not dip more than 6%, and under no circumstances may it dip below 360 V. Some x-ray machines have undervoltage relays that will automatically cut them off if voltage swings outside of the prescribed tolerance. In other instances, the x-ray unit may remain online, but yield exposures of poor quality.

X-ray manufacturers normally specify minimum feeder sizes for given increments of feeder length. They will also specify minimum transformer sizes and minimum circuit impedance. Because of the high power factor (usually about 95%), x-ray machines do not create great voltage drops across inductive reactances the same way as transformer and generator windings. However, the resistance of the supply circuit will bear heavily on the total voltage drop. Because of the high power factor, x-ray generator loads create heavy real power requirements on standby generators. Because of the high real power requirements for x-ray machines, x-ray exposures can cause slowing of standby generators, reducing the frequency of the supply, especially where the emergency generators are relatively small. Reduced frequency of power supply can be a problem for x-ray generators, because some units operate on a resonance principle. Sophisticated x-ray machines, such as computed axial (or computer-aided) tomography (CAT, or simply, CT) scanners and special procedures equipment with microprocessors, can require surge suppressors or other power conditioners. However, the designer should always consult the vendor before applying a power conditioner.

8.5.7.15 Computerized axial tomography

X-rays have been used as the foundation for a wide range of different applications to create different ways to view different parts of the body, greatly reducing the need for invasive procedures to simply view a part of the body. One of the primary modalities now

using x-ray technology is the computerized axial tomography (CAT, or CT) scan. This process uses digital processing to generate a three-dimensional image of the internals of an object from a large series of two-dimensional x-ray images taken around a single axis of rotation. The CT machine uses an x-ray source that rotates around the object, with x-ray sensors positioned on the opposite side of the circle from the source. The machine takes many data scans progressively as the object is gradually passed through the gantry. Conventional CT machines use a small x-ray tube, rotated behind a circular shroud. Electron beam tomography uses a far larger tube, with a hollow cross section and rotates only the electron current. This machine has a data sweep of only 220° . See Figure 8-2.



Courtesy of Siemens Medical Solutions USA, Inc.

Figure 8-2—CT scanner

CT provides a diagnostic tool and a guide for interventional procedures. Sometimes, the process includes injection of contrast materials (such as barium, administered orally or rectally) or intravenous iodinated contrast substances to highlight structures such as vessels or intestines that otherwise would be difficult to delineate from their surroundings. Modern multi-detector CT systems can complete a scan of the chest in less time than it takes for a single breath (useful if the patient cannot hold her breath) and display the computed images in a few seconds. Improvements in CT technology have meant that the overall radiation dose has decreased, scan times have decreased, and the ability to recalculate images (for example, to look at the same location from a different angle) has increased over time. Still, the radiation dose from CT scans is several times higher than the conventional x-ray.

Newer, spiral CT machines can process continually changing cross sections as the gantry, holding the patient, smoothly and slowly slides throughout the x-ray circle. The computers associated with these machines generate three-dimensional volumetric information that can be viewed from multiple different perspectives on attached CT workstation monitors.

CT and other computer-assisted imaging devices may operate in one plane (thus, single-plane machines) or in two planes simultaneously (bi-plane machines). The bi-plane machines require more vertical space, but have no other implications for electrical systems.

8.5.7.16 Electrical impedance tomography

Electrical impedance tomography (EIT) is a medical imaging technique in which an image of the conductivity or permittivity of part of the body is inferred from surface electrical measurements. Typically, conducting electrodes are attached to the skin of the subject and small alternating currents applied to some or all of the electrodes. The resulting electrical potentials are measured, and the process repeated for numerous different configurations of applied current. This technique may be used for monitoring of lung function, detection of cancer in the skin and breast, and location of epileptic foci. All of these applications are, at the time of this writing, experimental.

8.5.7.17 Ultrasound

Ultrasonography, or ultrasound techniques, are used primarily in gastroenterology, cardiology, gynecology, obstetrics, urology, and endocrinology to perform diagnosis or therapeutic procedures. These techniques are used primarily for imaging, though the imaging may facilitate interventions such as biopsies or drainage of collected fluids. Ultrasound, or sonography, uses high frequency sound waves to see inside the body. A device that acts like a microphone and speaker is placed in contact with the body using ultrasound gel to transmit the sound. As the sound waves pass through the body, echoes are produced, and bounce back to the transducer. These echoes can help doctors determine the location of a structure or abnormality, as well as information about its make up. Ultrasound is a painless way to examine internal organs such as the heart, liver, blood vessels, breast, kidney, or gall bladder, and is most commonly known for its ability to examine fetuses in the mother's womb. Ultrasound scanning is currently considered to be a safe, non-invasive, accurate, and cost-effective investigation of the fetus. It has progressively become a crucial obstetric tool and plays an important role in the care of many pregnant women. Ultrasound machines require no special electrical systems. See Figure 8-3.

8.5.7.18 Mammography

Mammography is a type of imaging that uses a low-powered x-ray to provide pictures of breast tissue. In general, normal functioning tissue and abnormal cancerous tissue only differ slightly in their attenuation, or x-ray stopping power. However, cancerous tissues can be separated from normal tissue if the breast contains an abundance of fat. Cancerous cells, and some benign tumors, also contain very small areas of calcium deposits that may also be detected. Radiologists tend to look for these visually, but may use computer-

assisted software to detect these deposits (see computer-aided detection). Mammography is usually used in breast cancer screenings and is able to detect 85% to 90% of breast cancers in women over the age of 50.



Courtesy of Siemens Medical Solutions USA, Inc.

Figure 8-3—Ultrasound

8.5.7.19 Scintimammography

Scintimammography is primarily used in breast cancer screenings to detect abnormal tracer uptake in areas that may be tumors. It is most useful in women with dense breast tissue and little fat or for those whose mammogram was not diagnostic. Following injection of a radioactive tracer into the blood stream, the tracer is absorbed by any cancerous cells in the breast tissue or surrounding lymph nodes. A new gamma camera is used to detect the tracer localized in abnormal cancer cells. Because the machine is

designed for dedicated breast imaging, it is more comfortable and allows better uptake measurements than general nuclear medicine gamma cameras.

8.5.7.20 Magnetic resonance imaging

Magnetic resonance imaging (MRI) is a method of creating images of the inside of opaque organs in living organisms. MRI developed from the study of nuclear magnetic resonance, so the actual name for the medical technology is *nuclear magnetic resonance imaging* (NMRI) or NMR.

The process works by using a large, powerful electromagnet to align the atomic nuclei of tissue molecules. Then the system applies radio frequency (RF) pulses in a plane perpendicular to the magnetic field lines so as to cause some of the hydrogen nuclei to gradually change alignment from their upright positions. The frequency of the radio wave pulses operates according to the *Larmor equation*. The machine applies magnetic field gradients in the three-dimensional planes to allow encoding of the position of the atoms. Then their new alignment can be measured and recorded by coils wrapped around the patient. Then when the RF turns off, the nuclei go back to their original configuration. A computer then applies an inverse Fourier analysis for the data to obtain the image. This process allows an observer to see tissue with quite detailed anatomical features, and the images are of sufficient quality to allow clinicians to distinguish between pathologic tissues (such as a brain tumor) from normal tissue.

Compared to x-ray techniques, the MRI techniques appear to be harmless to the patients. However, because the process uses very strong electromagnets, the presence of ferromagnetic materials in the patient or near the magnet can lead to serious problems. Interaction of the magnetic and RF fields with such objects can lead to mechanical or thermal injury, or to failure of implanted devices. This problem will likely grow far more acute in the future, as the use of implants continues to grow sharply.

Electrical considerations for MRIs include the large loads such systems impose on power distribution systems. Again, these systems, especially the magnets, will require the use of a UPS to keep the magnet energized, as well as putting the equipment on a source of backup power. Perhaps the most difficult challenge the MRIs present is the need to keep ferromagnetic materials (including electrical distribution equipment) out of the area near to the magnet. Manufacturers will normally provide information on the detailed requirements for their specific equipment, and the electrical engineer should be scrupulous in following these directives. See Figure 8-4.



Courtesy of Siemens Medical Solutions USA, Inc.

Figure 8-4—MRI

Because of its versatility, the quality of its images, and its relative safety, the MRI procedure has been applied to more and more spin-off processes and techniques. Magnetic resonance spectroscopy (MRS) is a technique that combines the spatially addressable nature of MIR with spectroscopic information from NMR, allowing clinicians to study a particular region within an organism without providing information about the chemical or physical nature of the region. Functional MRI (fMRI) measures signal changes in the brain that are due to changing neural activity. Diffusion MRI measures the diffusion of water molecules in biological tissues. This technique, still experimental as of this writing, is intended for use in patients who have experience ischemic stroke or other brain injury, to study the connections within the brain. Finally, in interventional MRI, the images produced by an MRI scanner guide a minimally invasive procedure interactively. This use obviously requires the use of special instrumentation due to the need for non-ferrous objects near to the magnet. Each of these variations of the MRI has electrical requirements similar to that for the more conventional MRI used for purely diagnostic imaging.

8.5.7.21 Picture archiving and communication systems

Many imaging devices now produce digital, not film images. Picture archiving and communication systems (PACS) are computer networks dedicated to the storage, retrieval, distribution, and presentation of images. Full PACS store images from various modalities, including ultrasonography, radiography, MRI, positron emission tomography (PET), CT, and radiography. PACS replaces hard-copy based means of managing medical images, such as file archives. It expands on the possibilities of such conventional systems by providing capabilities of off-site viewing and reporting (distance education, tele-diagnosis).

A typical PACS network consists of a central server, which stores a database containing the images. This server is connected to one or more clients via a local-area or wide-area network, which provide and/or use the images. For backwards compatibility, most imaging departments or practices use a field digitizer.

Because PACS are basically computer networks, the equipment for this system will be housed in some kind of data room. Electrical engineering for spaces containing PACS equipment will be similar to that of any other IT type of room. See Figure 8-5.



Courtesy of Siemens Medical Solutions USA, Inc.

Figure 8-5—Cosmos PACS

8.5.8 Nuclear medicine

Nuclear medicine is the branch of medicine that uses unsealed radioactive substances in diagnosis and therapy. It may also be referred to as *radionuclide imaging* or *nuclear scintigraphy*. Nuclear medicine diagnostic tests are usually provided by a dedicated department within a hospital that will include facilities for the safe storage, handling, preparation, and disposal of nuclear material. A nuclear medicine study involves the introduction of a radionuclide into the body via injection in liquid or aggregate form, inhalation in gaseous form, or injection of a radionuclide that has undergone microencapsulation. Most diagnostic radionuclides emit gamma rays, while the cell-damaging properties of beta particles are used in therapeutic applications.

8.5.8.1 Gamma camera

The gamma camera is a system of detectors, photo-sensors, and computers used to detect the radiation emitted from radionuclides inside the body. Gamma cameras consist of a gamma-ray detector, such as a single large sodium iodide scintillation crystal, coupled with an imaging subsystem such as an array of photomultiplier tubes and associated

electronics. Gamma cameras use lead collimators to form an image of the radionuclide distribution in the body on the gamma-ray detector. The gamma camera's photomultipliers will detect the x and y position of each gamma-ray event, and the computer will use the coordinates to build an image. Since each radionuclide has a unique gamma-ray emission energy spectrum, and since the energy of a gamma ray is detected in a gamma camera by the brightness of the scintillation associated with an event, gamma cameras use energy windows to limit the imaging process to gamma-ray events of particular energies. A gamma camera may rotate, allowing the construction of an image of a "slice" through the patient at a particular position, using a process called *single photon emission computed tomography*.

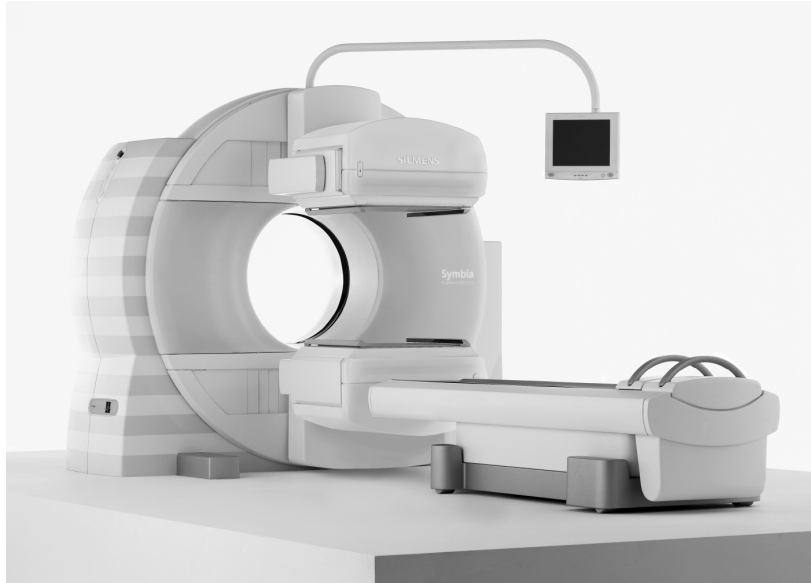
The power consumption of gamma cameras is not too large. However, the images take a long time to generate, so that if power to the camera is lost, entire lengthy procedures must be repeated, at great cost and inconvenience to both the patient and to the caregiver. Thus, most gamma cameras have UPS systems installed upstream.

8.5.8.2 Positron emission tomography

PET is a nuclear medical imaging technique that produces a three-dimensional image or map of functional processes in the body.

The process involves the injection (usually into the bloodstream) of a short-lived radioactive tracer isotope that decays by emitting a positron, chemically combined with a metabolically active molecule. During a waiting period, the metabolically active molecule (usually a sugar) becomes concentrated in tissues of interest, upon which the patient enters the imaging scanner. The short-lived isotope decays and emits a positron. After traveling up to a few millimeters, the positron annihilated by an electron, producing a pair of gamma ray photons moving in opposite directions. The scanner detects the photons when they reach a scintillator material in the scanning device, creating a burst of light that is detected by photomultiplier tubes. The technique depends on simultaneous or coincident detection of the pair of photons; the scanner ignores photons that do not arrive in pairs (i.e., within a few nanoseconds). By measuring where the gamma rays end, their origin in the body can be plotted, allowing the chemical uptake or activity of the body part to be determined. The scanner then uses the pair-detection events to map the density of the isotope in the body, in the form of slice images separated by about 5 mm. The resulting map shows the tissues in which the molecular probe has become concentrated and is read by a nuclear medicine physician or radiologist, to interpret the result in terms of the patient's diagnosis and treatment. Clinicians are increasingly reading PET scans alongside CT scans, the combination giving both anatomic and metabolic information (what the structure is, and what it is doing). PET occurs most often in clinical oncology (medical imaging of tumors and the search for metastases) and in human brain and heart research. See Figure 8-6.

PET uses isotopes with short half-lives, such as Carbon-11, Nitrogen-13, Oxygen-15, and Fluorine-18 (with half-lives of 20 min, 10 min, and 110 min, respectively). Due to their short half-lives, the isotopes must be produced in a cyclotron at or near the site of the PET scanner. Then the clinician will incorporate these substances into compounds normally used by the body such as glucose, water, or ammonia, for injection into the body.



Courtesy of Siemens Medical Solutions USA, Inc.

Figure 8-6—PET Scan

PET scanning is invasive, in that it injects radioactive material into the subject. The total dose of radiation is small, usually around 7 mSv. (Average annual background radiation is about 2 mSv to 7 mSv; chest x-ray radiation is about 0.02 mSv; chest CT scan is about 8 mSv). Because of the injection of radioactive material, any one participant cannot undergo too many such scans. Further, the dose to the operators is another limiting factor in the operation of a PET facility. Finally, due to the high costs of cyclotrons needed to produce the short-lived radioisotopes for PET scanning, few hospitals use such devices. The U.S. Medicare system currently does reimburse PET scans for certain specific conditions, such as the staging of particular cancers. Reimbursement now drives the majority of PET installations, which are located primarily in major U.S. cities and particularly in retirement states such as Florida.

The most significant trend in PET today is the combination of PET and CT scanners into a single unit, providing registered images of the patient in both modalities. This arrangement provides a significant aid in interpreting PET data, since anatomical structures are not clear in the PET image. However, although a CT scan is taken in just a few seconds (minimizing the effects of patient movement, breathing, heartbeat, and bowel action), the PET scan takes about 30 min, so that the registration of the two images is not precise. See Figure 8-7.



Courtesy of Siemens Medical Solutions USA, Inc.

Figure 8-7—PET scan in use

8.5.9 Single photon emission computed tomography

Single photon emission computed tomography (SPECT) uses radioactive tracers and a scanner to record data that a computer uses to construct two- or three-dimensional images of active brain regions. SPECT tracers are more limited than PET scanners in the kinds of brain activity they have the ability to monitor. The tracers of SPECT are longer lasting than those of PET, which allows for different, longer lasting brain functions to be examined, but this also requires more time for the SPECT to be completed. SPECT is often chosen over PET simply as a cost issue, for it uses less equipment and fewer staff.

8.5.10 Physical therapy

8.5.10.1 General

The physical therapy department is usually the prime element of the rehabilitation wing of a hospital. The department provides for patients who have suffered injury to their motor system, or who have had a major or minor stroke affecting use of arms or legs, requiring the re-education of affected muscles or systems. The department also retrains patients in speech therapy for those patients who have had damage in that communication sense.

8.5.10.2 Partial immersion baths

a) *Whirlpool bath*

- 1) This bath is given in a metal tub filled with water that is kept in constant agitation. It thus provides both water temperature control plus the mechanical effects of water in motion. The water is kept in agitation by an ejector, a turbine, or compressed air. The bath provides heat, gentle massage, debridement (the excision of contused and devitalized tissue from the surface of the wound), relief from pain, and muscle relaxation. It also permits active or assistive exercise of the part that is immersed in the tub.
- 2) The tub's temperature is maintained by a thermostat. Typical temperature settings are 32 °C to 38 °C (90 °F to 100 °F) for the entire body, 38 °C to 39 °C (100 °F to 102 °F) for the legs, and 40 °C (105 °F) for the upper extremities. Often, temperature settings of 43 °C to 46 °C (110 °F to 115 °F) are used for therapeutic effects. When the patient has impaired circulation, temperature should not exceed 40 °C (105 °F). Treatment usually is of 20 min duration.
- 3) Whirlpool baths are employed in the treatment of chronic traumatic disorders, inflammatory conditions, joint stiffness, pain, adhesions, neuritis, tenosynovitis, sprains, strains, and painful stumps following amputations. Adding a small amount of sodium sulfathiazole to the water hastens the healing of infections. The bath may be used preceding, or instead of, massage or other mechanical applications to injured extremities.

b) *Contrast baths*

- 1) Contrast baths involve sudden, alternate immersions of upper or lower extremities in hot and then cold water. They increase circulation because of the contraction and relaxation of the blood vessels as a result of the alternating temperature extremes. One bath container is filled with water at a temperature of 38 °C to 43 °C (100 °F to 110 °F), and the other holds water of 10 °C to 18 °C (50 °F to 65 °F).
- 2) The body part being treated is immersed in the baths in a definite, systematic manner. While authorities differ slightly on the actual length of time a limb should be immersed in each tub, there is still fair general agreement. A typical contact sequence might be as follows:
Hot for 4 min to 10 min, cold for 1 min to 2 min
Hot for 4 min, cold for 1 min
Hot for 4 min, cold for 1 min
Hot for 4 min, cold for 1 min
Hot for 5 min
- 3) Treatment always begins and ends with immersion in hot water.
- 4) Contrast baths are therapeutically effective for headaches, arthritis, fractures, peripheral vascular disease, and as a precedent to massage and exercise in cases of sprains and contusions. When treating patients with peripheral vascular disease, care should be taken to avoid great extremes of temperature.

In addition to items a) and b), health care facilities use a variety of other partial immersion or localized baths. Some of these include: the hot full wet pack, in which the patient is wrapped from neck to feet in a sheet that has been immersed in water of about 27 °C to 32 °C (80 °F to 90 °F) and wrung out; cold, hot, or neutral baths for the extremities, which vary by temperature; douches and showers, in which streams of water at controlled pressure and temperature are directed at the surface of the body; ablutions, or sponge baths; leg, foot, arm, and hand baths, which require immersion of the involved body part in small baths of controlled temperature; half-baths, in which the patient sits, the water level being at about the level of the navel; affusions, where the water is poured on the patient from a basin or a pitcher at approximately 16 °C to 27 °C (60 °F to 80 °F) of temperature; sitz baths, in which the torso, but not the extremities, is immersed in water; Hauffe baths, which provide a constantly increasing water temperature; and a number of other kinds. The particular form of a bath employed depends upon the disorder being treated, the body part or parts involved, the patient's physical condition, and the purposes of the hydrotherapy.

8.5.10.3 Full immersion baths

Hubbard tank. The Hubbard tank is a full-body therapeutic pool with a water temperature of 37 °C to 40 °C (98 °F to 104 °F). The water is usually agitated and aerated, providing both heat and gentle massage. The patient lies on a canvas plinth and is lifted to and from the pool by means of electrically driven overhead cranes. Some tanks have a grating on the floor that permits the able patient to stand. Partial weight bearing and ambulation can be initiated in the pool, which may be prescribed when gait exercises are indicated, but the stress of weight is contraindicated.

The Hubbard tank is useful where the patient's disease or disability is manifest in many joints, such as in chronic arthritis, or in burn cases when debridement and active exercise are desirable.

Exercise in water is indicated for the following conditions: spastic paralysis, as in paraplegia; marked muscle weakness with the possibility of increasing strength through voluntary motion, such as in partial peripheral nerve lesions (for example, polyneuritis); poliomyelitis; following amputation when muscle strengthening and stretching of contractures in the involved extremity are indicated; chronic arthritis; following joint injuries; for mobilization in the aftercare of plastic and joint operations and tendon transplants; after abdominal fascial transplants; in certain cases of cerebral palsy; extensive skin burns; muscular incoordination; some neurological disorders; and disorders requiring metabolic stimulation.

Water activities are contraindicated for cases of acute joint inflammation or other acute infections, febrile disease, acute neuritis, active pulmonary tuberculosis, and the acute stage of poliomyelitis.

Other types. Other types of full immersion hot baths include: full-body hot baths, with water temperature at 36 °C to 41 °C (96 °F to 105 °F), used for brief periods of time in treating chronic, rheumatic joint manifestations, and for the relief of muscle spasm and colic; chemical baths, usually involving the introduction of carbon dioxide gas into the

water for therapy with patients suffering from chronic heart disease; oxygen baths, which pump oxygen into water of about 32 °C to 35 °C (90 °F to 95 °F), used for hypertensive and advanced cardiac disease cases; brine or salt baths, using sodium chloride, primarily for treatment in cases of osteomyelitis, fractures, dislocations, arthritis, myositis, fibrositis, gout, and chronic sciatica; foam baths; and sponge baths.

8.5.10.4 Electrical design recommendations

- a) Locate receptacles as close to units as possible. Provide rough-in as per manufacturer's recommendation.
- b) All circuits to be ground-fault protected.
- c) Ground all equipment and adjacent metallic surfaces.
- d) For all large tanks and spas, furnish and install outlet in ceiling for patient lift.

8.5.11 Neurophysiological department

8.5.11.1 General

The neurophysiological department deals in the areas of brain disorders and in such diverse activities and states of the nervous system as waking, sleeping, dreaming, consciousness, speech, learning, and memory. The electroencephalogram (EEG) is the primary tool utilized by the neurophysiologist and surgeon. The electrical activity of the brain is used to determine brain death in accident cases, and in certain circumstances, can be used as an electrical parameter check in organ transplants.

8.5.11.2 EEG measurements

Electroencephalography measures the electrical activity of the brain. Since clinical EEG measurements are obtained from electrodes placed on the surface of the scalp, these waveforms represent a very gross type of summation of potentials that originate from an extremely large number of neurons in the vicinity of the electrodes.

The electrical patterns obtained from the scalp are the result of the graded potentials on the dendrites or neurons in the cerebral cortex and other parts of the brain, as they are influenced by the firing of other neurons that impinge on these dendrites.

EEG potentials have random-appearing waveforms with peak-to-peak amplitudes ranging from less than 10 μV to over 100 μV . Required bandwidth for adequately handling the EEG signal is from below 1 Hz to over 100 Hz.

For clinical measurements, surface or subdermal needle electrodes are used. The ground reference electrode is often a metal clip on the earlobe. A suitable electrolyte paste or jelly is used in conjunction with the electrodes to enhance coupling of the ionic potentials to the input of the measuring device. To reduce interference and minimize the effect of electrode movement, the resistance of the path through the scalp between electrodes should be kept as low as possible. Generally this resistance ranges from a few thousand ohms to nearly 100 k Ω , depending on the type of electrodes used.

Placement of electrodes on the scalp is commonly dictated by the requirements of the measurement to be made. In clinical practice, a standard pattern called the *10 to 20 electrode placement system*, is generally used. This system, devised by a committee of the International Federation of Societies for Electroencephalography, is so named because electrode spacing is based on intervals of 10% to 20% of the distance between specified points on the scale.

In addition to the electrodes, the measurement of the EEG requires a readout or recording device and sufficient amplification to drive the readout device from the millivolt-level signals obtained from the electrodes. Most clinical electroencephalographs provide the capability of simultaneous recording EEG signals from several regions of the brain. For each signal, a complete channel of instrumentation is required. Thus, electroencephalographs having as many as 16 channels are available.

Because of the low-level input signals, the electroencephalograph should have high-quality differential amplifiers with good common-mode rejection. The differential preamplifier is generally followed by a power amplifier to drive the pen mechanism for each channel. In nearly all clinical instruments, the amplifiers are ac coupled with low-frequency cutoff below 1 Hz and a bandwidth extending to somewhere between 50 Hz and 100 Hz. Stable dc amplifiers can be used, but possible variations in the dc electrode potentials are often bothersome. Most modern electroencephalographs include adjustable upper- and lower-frequency limits to allow the operator to select a bandwidth suitable for the conditions of the measurement. In addition, some instruments include a fixed 60 Hz rejection filter to reduce power line interference.

In order to reduce the effect of electrode resistance changes, the input impedance of the EEG amplifier should be as high as possible. For this reason, most modern electroencephalographs have input impedances greater than 10 M Ω .

Perhaps the most distinguishing feature of an electroencephalograph is the rather elaborate lead selector panel, which in most cases permits any two electrodes to be connected to any channel of the instrument. Either a bank of rotary switches or a panel of push buttons is used. The switch panel also permits one of several calibration signals to be applied to any desired channel for calibration of the entire instrument. The calibration signal is usually an offset of a known number of microvolts, which, because of capacitive coupling, results in a step followed by an exponential return to baseline.

The readout in a clinical electroencephalograph is a multichannel pen recorder with a pen for each channel. The standard chart speed is 30 mm/s, but most electroencephalographs also provide a speed of 60 mm/s for improved detail of higher frequency signals. Some have a third speed of 15 mm/s to conserve paper during setup time. An oscilloscope readout for the EEG is also possible, but it does not provide a permanent record. In some cases, particularly in research applications, the oscilloscope is used in conjunction with the pen recorder to edit the signal until a particular feature or characteristic of the waveform is observed. In this way, only the portions of interest are recorded. Many electroencephalographs also have provisions for interfacing with an analog tape recorder to permit recording and playback of the EEG signal.

8.5.11.3 Typical electrical considerations for EEG machines

- a) Voltage: 120 V, possibly protected by power conditioner
- b) Frequency: 60 Hz
- c) Amperes: One dedicated 20 A circuit
- d) RFI
- e) Patient lead connections
- f) Multichannel pen recorder with chart speed of 30 mm/s
- g) Interconnections to VDT or analog-type recorder
- h) May need to equip fluorescent fixtures in the immediate area with RFI filters and low-leakage ballasts
- i) May need shielding in walls of room housing the equipment

8.5.11.4 Magnetoencephalography

Magnetoencephalography (MEG) is similar to EEG, but magnetic fields are measured instead of electric fields.

8.5.12 Pulmonary function laboratory

8.5.12.1 General

The practice of rhythmically inflating the lungs by artificial means has been found to be of great value in the treatment of respiratory failure, the causes of which can be induced by many conditions and/or injuries. Since it is not practical to do this by hand for any length of time, there are machines that have been designed for the purpose. This does not include machines that exert negative pressure externally on the chest, as they are not used much these days. Only intermittent positive pressure machines will be described. The enormous number of such machines available indicates that none suit every possible purpose. There are even fewer that are satisfactory for the special problems presented by infants or for adults with small chest cavities.

8.5.12.2 Equipment

a) *Ventilator*

An ICU ventilator should be able to ventilate any patient from birth to adult size and should be able to work equally well in the presence of normal lungs or highly abnormal ones. Humidification is essential, but apparatus dead space should be kept to a minimum. The dead space in some humidifiers is far too large for use with infants. It should also be remembered that water overload in infants is a real hazard. Accurate control of inspired oxygen concentration is important, because there is evidence to suggest that high oxygen concentrations, combined with pressure on the lungs, may contribute to death from *ventilator lung* (a condition characterized by decreasing compliance of the lungs, visible as increasing opacity

on x-rays, associated with small translucent areas; an air bronchogram-microscopy will show hyaline membranes in the alveoli).

Since ICUs tend to be places of stress for both patients and nursing staff, it is helpful if a ventilator is fairly quiet in operation—on the other hand, an alteration in noise may serve as an alarm to warn of machine failure. Ease of sterilization is important, as patients on ventilators are very susceptible to infection.

To summarize, some desirable features of a ventilator for use in this type of unit are as follows:

- 1) Ability to deliver accurately a tidal volume of 15 ml to 1000 ml
- 2) Ability to deliver this volume against high resistance and/or low compliance
- 3) Ability to deliver low flow rates
- 4) Rate control from 15/min to 40/min
- 5) Accurate control of inspired oxygen concentration
- 6) A variable inspiratory-expiratory ratio (I:E ratio)
- 7) Good humidification for all tidal volumes
- 8) Ease of sterilization
- 9) Quietness of operation
- 10) Ability to apply a variable expiratory resistance

The type or types of machine chosen for an individual unit depend on personal preference and also on the conditions treated. Some units may prefer to have all of one type—this certainly ensures that the staff becomes familiar with its operation. It is preferable to have two or three different types, to cope with various problems. A greater variety could become unwieldy.

b) *Monitoring of ventilation*

It is essential to have some method of ensuring adequate ventilation of the patient at all times. For this purpose several devices are used. Most machines incorporate a pressure manometer that reads airway pressure at the mouth or at the machine; this is connected to the patient by a wide-bore tubing of low resistance. Due to resistance in the airways, the pressure in the alveoli may be very different from that at the mouth. Many machines have a blow-off valve preset at, for example, 70 mmHg, to protect the lungs from excessive pressure.

8.5.13 Oncology

8.5.13.1 General

The oncology departments of health care facilities use many of the diagnostic and treatment equipment described in other parts of this chapter. However, unique to this treatment protocol is the linear particle accelerator.

8.5.13.2 Linear accelerator

The linear accelerator (LINAC) is an electrical device for the acceleration of subatomic particles. It may be used to produce x-rays, by accelerating electrons into a target window, or for the production of high-energy particles so that the results of particle collisions may

be studied, usually with a bubble chamber or other device. A LINAC consists of the following elements:

- a) Particle source.
- b) High voltage source for the initial injection of particles.
- c) Hollow pipe vacuum chamber. The length of the chamber will vary with the application.
- d) Within the chamber, electrically isolated electrodes whose length varies with the distance along the pipe.
- e) One or more sources of RF energy, used to energize the cylindrical electrodes.
- f) As the particle bunch passes through the tube, it is unaffected (the tube acts as a Faraday cage) while the frequency of the driving signal and the spacing of the gaps between electrodes is designed so that the maximum voltage differential appears as the particle crosses the gap. This change accelerates the particle, imparting energy to it in the form of increased velocity.
- g) LINACS used for medical applications accelerate electrons using a complex bending magnet and a 6 million to 30 million electron-volt potential to treat both benign and malignant disease. The reliability, flexibility, and accuracy of the radiation beam produced have largely supplanted cobalt therapy as a treatment tool. In addition, the device can simply be powered off when not in use.

Use of a LINAC is usually preceded by a simulation. The simulator is an x-ray machine used to mark the area of the body that will be treated. This process may involve the planting of a probe to help better visualize the area that is to be treated. This simulation is done to limit the amount of radiation to the normal tissue. During the simulation, the clinicians may construct a head hold or alpha cradle. These devices ensure that the patient remains positioned precisely the same way during each treatment. See Figure 8-8.

The LINAC procedure may also use blocks to better concentrate the radiation at the tumor. The blocks are used to reshape the standard rectangular radiation field to a custom shaped contour for a specific patient for radiation treatment. The therapeutic irradiating field passes through the open area of the block in a shape specific to the prescription for that patient.

There are many diagnostic uses for radiation, but radiation therapy is also an important part of the radiological world. Radiation therapy is a relatively common form of treatment for cancer and is becoming more and more successful each year. The reason for this is that radiation therapy machines can more tightly control the radiation beam, directing it just at abnormal tumor and limiting the exposure to surrounding normal tissues. This type of therapy has further been refined through the usage of 3-D imaging technology and computerized treatment planning to better identify and target the cancerous tissue.

Radiation therapy destroys the cancer cells' ability to reproduce, allowing the body to then naturally rid itself of these cells. Radiation therapy can be performed two different ways. The first, external beam radiation therapy, uses radiation generated through a machine outside of the patient's body and targeted at the abnormal tissue. The second, brachytherapy, gives the radiation to the patient through radioactive sources that are placed into the body through a catheter or as implanted seeds.



Courtesy of Siemens Medical Solutions USA, Inc.

Figure 8-8—Oncor linear accelerator

For prostate and larynx cancer, radiation therapy may be the sole approach taken to fight the disease. In other cases, such as breast cancer and bladder cancer, chemotherapy and/or surgery often accompany the radiation therapy. Combination types of treatment are more and more common for many types of cancers.

Simulators require electrical systems similar to those for other x-ray equipment. LINACS typically require a large power source, but few other special considerations. The spaces housing LINACS require significant amounts of shielding to limit the diffusion of the radiation, and the rooms are enclosed in several feet of concrete, designed by nuclear physicist. The patients treated in these areas are under tremendous stress, and the machines themselves have a fearsome aspect. The design team for these installations usually work to minimize the anxiety that the spaces can create, and to make them as non-threatening as possible.

8.5.13.3 Gamma knife

A gamma knife (or *cyber knife*) is a special multi-source machine that focuses a high intensity of radiation on a small area. The devices, using technology originally designed for cruise missiles, can track and destroy brain tumors without breaking the skin. The cyber knife uses six different joints that can move the radiation source (a small linear

accelerator) with great flexibility. The precision of this technology allows surgeons to point several beams of radiation at a tumor. Surgeons begin by scanning the tumorous portion of the brain and program the scan into the device. If the patient moves even slightly, the robot reads the computer-stored map and keeps the beams focused on the tumor. These devices are used as local therapy, especially for brain tumors. They are investigational and not part of the routine array of cancer treatments as of this writing.

8.6 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ANSI/AAMI ES1, Safe Current Limits for Electromedical Apparatus.⁵

CSA C22.2, No. 125-M, Electromedical Equipment.⁶

NFPA 70, National Electrical Code® (NEC®).⁷

NFPA 99, Standard for Health Care Facilities.

UL 544, Medical and Dental Equipment.⁸

8.7 Bibliography

Additional information may be found in the following sources:

[B1] “Avoid Static Damage to Your PC”; available at <http://www.pcworld.com/article/id,82184-page,1/article.html>.

[B2] Bruner, J. M. R., “Hazards of Electrical Apparatus,” *Anesthesiology*, no. 2, March–April 1967.

[B3] FIPS Pub 94-1983, Guideline on Electrical Power for ADP Installations.⁹

[B4] *Health Devices*, vol. 5, no. 8, pp. 194–195, June 1976.

⁵ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

⁶CSA publications are available from the Canadian Standards Association (Standards Sales), 178 Rexdale Blvd., Etobicoke, Ontario, Canada M9W 1R3 (<http://www.csa.ca/>).

⁷NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA (<http://www.nfpa.org/>).

⁸UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

⁹FIPS Pub 94-1983 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (<http://global.ihs.com/>).

[B5] IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition. New York: Institute of Electrical and Electronics Engineers, Inc.¹⁰

[B6] Leeds, C. J., Okhtar, M., and Damato, A. N., "Fluoroscope-Generated Electromagnetic Interference in an External Demand Pacemaker," *Circulation*, vol. 55, no. 3, March 1977.

[B7] Lehnert, B. E., "A hazard of magnetic interference with normal cycling of the Boums Infant Ventilator," *Respiratory Care*, vol. 21, no. 7, pp. 576–578, July 1976.

[B8] Starmer, C. F., Whalen, R. E., and McIntosh, H. D., *American Journal of Cardiology*, vol. 14, pp. 537–546, October 1964.

¹⁰IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

Chapter 9

Health care renovations

9.1 Overview

The one constant in a hospital is change—change in personnel, change in patient demographics, change in technology, change in treatment methods, and change in space demands. Unfortunately, most codes and the design standards written for health care professionals often neglect the upgrade and renovation of existing facilities that are necessary to meet these changing needs. This neglect stems in part from a number of factors that seriously complicate renovation projects and that often render the projects works more of art than of science. A functioning hospital is a facility that is extremely sensitive to disruptions of any sort. Renovations are therefore especially tricky, as they often disrupt not only the immediate area but also other areas.

These renovation difficulties are usually exacerbated by changing code requirements. Indeed, recognizing the growing need for direction, codes are beginning to specifically address renovation in a number of instances. Several model building codes contain provisions for bringing the entire facility up to current codes in the event of renovation above a certain percentage of facility floor space. NFPA 99¹ includes sections dealing with both new and renovated buildings. Other codes provide installation guidelines for performing certain portions of a renovation. Engineers should in all cases familiarize themselves with the codes that pertain to the particular renovation, noting carefully the provisions therein for renovation projects. See Figure 9-1.

Despite their inherent difficulties, renovation projects are becoming more and more common, and, therefore, are more and more deserving of specific attention. Recent reports show that hospitals now overwhelmingly choose renovation projects over new construction for modernizing their facilities or for providing new services.

Moreover, during recent years, many hospital infrastructures have been neglected as hospitals have spent their resources expanding their facilities. Many of these facilities now contain utility systems that have reached their limits in terms of both age and capacity. *Health Facilities Management* [B2]² reports that hospital buildings and equipment are aging faster than those of other industries. They report that the average age of hospitals' physical plants are more than 40% older than the average age of Standard & Poor's industrial firms' physical plants. Moreover, rural hospitals average 24% older than the average age for all hospitals and 70% older than the typical Standard & Poor's industrial firm.

This infrastructure neglect has involved:

- Additional connections/increases in demand with no concurrent addition to system capacity.

¹Information on references can be found in 9.11.

²The numbers in brackets correspond to those of the bibliography in 9.12.

- Deferral of needed maintenance.
- Successive remodeling/revisions to areas and systems without the benefit of a comprehensive facility design.
- Failure to replace outdated systems.
- A tendency to minimize capital costs at the expense of increased operating costs.

Hospital industry experts predict that hospitals will begin to be forced to upgrade and modernize their infrastructures whether or not they continue to grow. Indeed, a small proposed expansion often precipitates a comprehensive upgrade of one or more systems.



Figure 9-1—Existing conditions

This chapter seeks to deal as comprehensively as possible with the issues involved in the renovation process for health care facilities. As renovations come in infinite shapes and sizes, no such treatment can cover every case. The authors have assumed a good working knowledge of the proper design for health care facilities and have here tried to formulate a set of guidelines that will assist the engineer engaged in a renovation to ask the questions that are appropriate for such an endeavor.

In general, the challenges facing the electrical engineer doing a renovation are three: (1) what's there; (2) how to do the renovation, given what's there; and (3) how to do the renovation while minimizing the disruptions to the rest of the facility and the patients trying to heal in those spaces.

9.2 Coordination

9.2.1 Coordination with users

In addition to the more detailed technical issues discussed in the following subclauses, a renovation project requires, most of all, coordination. The most important people in this process are the users of the space to be renovated, of the adjacent spaces, and/or of otherwise affected spaces.

One user especially concerned with renovation projects is the hospital engineer. This individual is responsible for the continued proper operation and maintenance of the system after it is placed into operation, and the engineer designing a renovation will do well to coordinate with the hospital engineer. Indeed, in designing a renovation project, the electrical engineer should become something of a spokesperson for the hospital engineer; i.e., the engineer's mission is partly to educate all parties, thus resulting in an intelligent allocation of resources.

9.2.2 Coordination with other trades

Equally as important as coordination with the user is coordination of the electrical work with the other building trades. Such coordination can take many forms. Many older buildings, designed using air induction unit ventilating systems, suffer from a lack of above-ceiling space. Column spacing may be irregular, and various structures will further constrict above-ceiling space. The building may include *choke points*, or situations such as deep beams around the shafts in the core, which render a particular design approach impracticable or impossible.

Construction crews inevitably encounter situations in which the ducts conflict with the cable tray, which conflicts with the sprinkler piping, which conflicts with the electrical feeders, and so on. Similarly, the other trades will have risers of their own that must be relocated or built around. Therefore, any renovation design should be carefully coordinated with the designers of the other trades to eliminate or to deal with all such areas of conflict. Compromises are often necessary and may include reduced ceiling heights, surface-mounted luminaries, or the rerouting of lines. Each proposed compromise should be carefully considered in terms of cost, future flexibility, integrity of design, aesthetics, and code compliance. The engineer should therefore communicate the implications of each such accommodation to all involved parties during the design of the project.

Similarly, work between the trades should be sequenced so as to minimize disruptions and to maximize ease of installation. This work sequence needs to be carefully considered during the design phase of a project to minimize delays and rework. Such care will, in turn, result in a better job at a lower cost and/or earlier completion.

9.2.3 Coordination with code officials

The third major group that ought to be consulted in a renovation project is the various code officials that have jurisdiction over the project. When a specific project requires, for

instance, implementation of a system in phases, the inspectors and codes administrators should become part of the design process to ensure that all of the various phases can be accomplished safely, and with as little difficulty as possible. Some renovations and upgrades are performed largely to meet updated codes and to placate the various inspectors, and thus their input is essential. Often, one set of codes will force things on a project that are forbidden by another set of codes.

Some particular installations may not be able to meet the letter of the code as a result of existing conditions. A good example of this problem is the need to locate electrical equipment under existing waste risers that cannot be moved. In such a situation, the officials may allow drip pans to be built under and around the pipes to protect the equipment. In all such situations where the letter of the code cannot be met, it is crucial to work with the senior code authorities to define an installation that is safe, that meets the needs of the owner, and that meets the intent of the codes. Design professionals need to recognize that such compromises and judgments make them particularly vulnerable to liability claims should something go wrong. Clear, written confirmations from the owner and from code officials are imperative. Finally, the design should, if possible, incorporate provisions that allow full compliance at a later time.

In such regulatory compliance cases, the engineer and owners should carefully study the facility for overall safety and reliability of service to patients. A comprehensive plan should be carefully formulated, so that individual renovation projects, as they occur, may be designed in accordance with the general plan of overall facility code compliance. Each step in this procedure should be carefully coordinated with the authorities having jurisdiction (AHJs), for each installation will necessarily be a compromise approach. If properly planned and implemented, the sum of the compromises should provide a system of overall reliability and safety, and one that largely complies with the letter, as well as the spirit, of applicable codes and standards.

9.2.4 Existing conditions—Uncertainty

First among the many challenges facing the electrical engineer undertaking a health care renovation is the uncertainty regarding the existing conditions. Depending upon the age of the facility being renovated, record documents may be difficult to find. Even when these documents are available, most hospital engineers will attest to their being of suspect accuracy. And, even where the record documents were accurate at the completion of the project, staff likely will have made small changes here and there inside the building that, over time, can mean substantial deviations from whatever the documents originally showed. Finally, even where the drawings might be accurate and the spaces relatively unchanged, the fact that much of the electrical system hides behind the walls makes determining the exact physical location of various system elements virtually impossible in many situations.

Obviously, any health care renovation project should begin with substantial efforts to determine the existing conditions of the space to be renovated. Such investigation will take the form of visiting the project, studying the existing drawings, interviewing users of the space and facility operations staff, and testing the existing systems to determine how they are performing.

One approach to some of these problems that is often found extremely useful is the early demolition of the space to be renovated. The early demolition will uncover unexpected difficulties and will allow the design to incorporate the solutions into the final plans. Such an approach can be especially useful, as even the most careful design cannot account for all of the peculiarities of a given area nor for all of the conduits that pass through the proposed renovation space. Early demolition will ultimately save headaches, money, and often time. The problem with such an approach, of course, is the increased disruption and the loss of revenue from the additional time the space is not useful.

9.2.5 Existing conditions—Inappropriate

A second significant issue faced by the engineer attempting to renovate an existing health care facility is that the existing space may not support the proposed renovation. The building structure often severely limits the above-ceiling space, making coordination with the other trades especially difficult and especially important. There may be few options for routing new, needed feeders. The routing of conduits and feeders through existing spaces can be extremely difficult. The engineer should be careful in such cases to consider the types of conduits specified, as electrical metallic tubing (EMT) with set-screw fittings may be much more practical to install than intermediate metallic conduit (IMC) or rigid conduit that requires threaded connections. Frequently, abandoned chases, chimneys, or laundry chutes can be convenient avenues to spaces requiring renovation. More often, however, the feeders should be routed through occupied spaces; all options should be carefully investigated, discussed with all of the interested parties, and designed with sensitivity to their requirements.

The existing distribution equipment may be old and in need of replacement. It may have insufficient capacity. It may not be able to accept new breakers or switches. The system may not contain adequate spares/spaces or may not have sufficient capacity to accept additional loading. In such cases, not only the branch circuit wiring but also the distribution system itself must be renovated. If the power source is upgraded, the available fault current may be increased beyond the short-circuit rating of the equipment.

A third area of coordination with existing systems is the specification of medical equipment. Very often, the existing electrical system will contain only 240 V three-phase power, or 120/240 V single-phase power. In such cases, the engineer should coordinate the specification of any equipment outside of the electrical division specification with the available electrical characteristics. Similarly, older systems can be noisy (i.e., prone to spikes and surges as a result of a motor starting or of x-ray loads), overloaded, divided incorrectly in terms of the essential loads, or poorly grounded, all of which should be considered in the specification of other equipment. Such requirements and the condition of existing equipment need to be discussed among all users, vendors, and other designers.

Finally, many older systems do not lend themselves to renovation based upon current codes. The most notable example of such a situation is that of a hospital with only one grouping of essential loads (or one grouping per area), i.e., those areas not served by life safety, critical, and equipment branches. Older hospitals tend to have been provided with one emergency panelboard that now serves a variety of loads, both essential and non-essential. Very often, trying to correct such an installation in a particular area being

renovated to comply in all respects with current codes is virtually impossible without a full-scale upgrading of the entire system—a solution that can be extremely costly, inconvenient, and often, of marginal value. Indeed, such an upgrade can often be more disruptive than helpful in advancing overall system reliability. A similar problem is how much of the existing system to upgrade—just within the area of the project, or upstream into the overall distribution system. The answer to this question will have obvious implications for the safety of the patients and for the cost of the project.

In the end, it is critical that designs are carefully thought out and well integrated with the balance of the existing system, rather than being just another patch in a quilt of overlapping, disjointed designs.

9.2.6 Disruptions to existing systems

Assuming that the electrical engineer can determine what is existing in the area of a proposed renovation, and can develop a plan to renovate the area and the supporting systems appropriately, the actual implementation of those plans will likely lead to significant disruptions of the balance of the facility. Such interruptions may be caused by the following:

- a) Temporarily (or accidentally) shutting down existing services
- b) The need to relocate personnel; by the disruption of traffic flows
- c) The affecting of sterile environments; by noise and vibration
- d) The need to haul debris out of the affected space or new materials into the project site

A common design practice from the past, for instance, was the subfeeding of several panels from the same riser (see Figure 9-2). Such a situation inevitably causes problems when a shutdown of one floor results in the shutdown of other floors. Similarly, risers through floors, both of power and of communications systems, should be accounted for in the design of a project, and either built around or relocated. The engineer should carefully locate all such risers affecting other areas and coordinate their final disposition with both the architect and the various owners' parties. Often, feeders for a particular renovation project will need to run through other occupied spaces, perhaps even patient care areas.

Obviously, the electrical engineer involved in designing the renovation of a space should carefully define the disruptions that will occur and work with the contractor and the caregivers to ensure that the facility can continue to operate and care for the patients at all times during the construction process. All such work should be coordinated in detail with the users of those spaces to minimize disruptions, and with the other trades (for cutting and patching, for instance). Much work may be performed after hours to minimize disruptions. Note, however, that requiring a contractor to perform such work outside normal business hours in order to accommodate users will inevitably result in overtime premiums. The operational benefits of such work should be carefully evaluated in light of these costs, and the options should be reviewed with all parties.

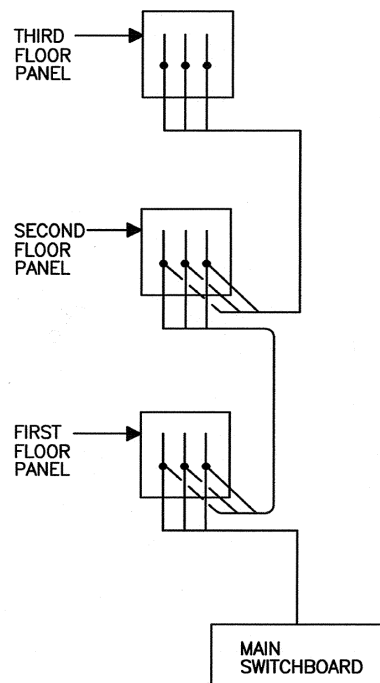


Figure 9-2—Subfeeding of several panels from the same riser

A critical issue with renovation projects has to do with the sequence of operations between various systems. When an existing system is modified or expanded, or where a renovation or expansion provides a new system that must interface with an existing system, the electrical engineer should determine how the old system will react to changes in the new system and how the new system will react to changes in the old system. Details of these systems should be carefully considered and detailed, in order to allow proper operation of the facility. Commissioning, recommended as good practice for most projects, is of crucial importance in these circumstances.

9.3 Loads and energy management

Current trends in hospital equipment, and in its power consumption, are moving in two opposite directions—while hospitals are using more and more equipment, thus increasing demands of the electrical system, technology is allowing for equipment to accomplish the same tasks with less and less power. Today's chillers, for instance, use fewer kilowatts per ton than those chillers of 10 years ago. The net overall affect of a renovation, though, tends to be an increase in electrical loads. Accordingly, a hospital addition will clearly add load to the electrical system, and a hospital renovation will impose a new use profile onto the existing electrical system. The decision of whether to add on, rework, or simply reuse should be carefully considered in terms of its impact on the balance of the existing system.

The engineer planning a modification to an existing electrical system needs to carefully evaluate the system configuration of the essential systems, and whether it has the three separate essential system branches required by the National Electrical Code[®] (NEC[®]) (NFPA 70). If not, the engineer should determine the following:

- a) Whether such a division should be imposed on the system
- b) The types of loads
- c) How the loads will cycle on and off, and how that use profile will affect the balance of the system

In addition, the engineer should assess the current-carrying capacity of elements to be reused, all the way to the service entrance switchboard, and should obtain actual field-measured loading information for these devices over a time sufficient to allow a reasonable approximation of the existing loads (the NEC requires one year of load readings). With this information, the engineer can define the steps necessary to graft the proposed system onto the existing system without significant disruption.

9.4 Electrical power distribution system

9.4.1 Essential distribution system

When renovating a hospital the engineer should determine if the existing essential electrical distribution system meets the requirements of the currently enforced edition of the NFPA codes (the NEC, NFPA 99, and NFPA 101), as discussed previously. If the system is deficient, and the renovations affect a significant portion of the building, plans for system upgrade should be formulated. If, however, the renovation affects only a small portion of the facility, the AHJs may be willing to issue a variance for the design.

One approach to the renovation of an essential system that utilizes only one emergency branch is, in some ways, less complicated than renovating a multiple-branch system. The most widely adopted codes (the NEC and NFPA 99) require that a minimum of two branches be added (note that for essential systems with a load of only 150 kVA, only one switch is required). The addition of branches to the existing system can help to facilitate construction phasing. If the existing distribution and branch circuit panelboards on the load side of the existing distribution equipment are properly subdivided, the existing distribution feeders can be rerouted and served from the new automatic transfer switches (ATSS), creating the three distinct branches. However, if the load-side distribution and branch circuit panels serve a conglomeration of loads from each type of essential system load, three branches, consisting of transfer mechanisms and distribution apparatus, should be added. In essence, this approach provides an additional, properly designed infrastructure for the eventual support of the entire facility. This approach allows the future transfer of loads from the existing system to the new system as renovation projects occur.

Renovating essential systems with multiple branches, each serving a variety of essential system loads, potentially makes the construction phasing of the project much more complicated. The most effective solution in most cases is to create three entirely new

branches and to phase the renovations as previously described. Alternatively, the existing branches could be designated to each serve a different one of the essential system loads. Then as renovations proceed, the loads for those renovations can be strictly divided among the various branches until all of the facility loads are properly divided.

9.4.2 Area renovation

Presumably, the engineer undertaking the renovation of a particular area will be working in accordance with a cohesive system renovation/expansion vision as previously discussed. However, in some cases such an approach may not be possible, and existing system infrastructure may not allow proper division of loads. In this event, the renovation design can reuse existing system components, relying on upstream modifications to provide suitable reliability of service to the renovated project. Alternatively, essential loads for the area to be renovated may be properly divided onto a set of panels that, in turn, are served from the one branch of the existing system, relying on future system renovations to properly reconnect these loads. Such an approach should only be used, though, as a last resort and after careful consultation with appropriate authorities.

9.5 Emergency power systems

Of critical importance to the proper operation of a health care facility is its standby generation system. Chapter 5 should be consulted for guidelines for the proper design of such a system. However, several modifications may be made relatively easily to an existing system to enhance overall plant reliability and to respond to new demands imposed by proposed load additions/modifications. A frequently encountered problem is the need for additional capacity in the generator plant. Past studies done by the American Hospital Association indicate that overloading the generator is one of the principal reasons for failure of the emergency power system during an emergency. A system currently employing two or more generators is already using some sort of paralleling, lead-lag, or other load-sharing scheme, and should be relatively easy to modify. A one-generator system, though, may be more difficult to modify. This problem too can be attacked from a number of different directions.

The simplest approach to solving generator loading problems is the replacement of the existing generator with a larger unit. This approach, though, is limited in that it may force replacement of the distribution equipment that was presumably sized to service the smaller generator. Moreover, reliance upon a single generator is never as reliable as serving the same system from two or more units. Finally, such replacement of an existing generator will be tantamount to discarding the balance of the older generator's remaining useful life. Accordingly, addition of a second generator to the existing plant is usually the preferred approach.

A simple and relatively low-cost method for adding this additional generator is to add a single engine-generator set and associated transfer switch(es) remote from the existing generator(s), but near to the end-use loads and dedicated to serving those loads. Locating the new generator close to the new loads will reduce initial costs by eliminating load feeders. However, fueling the new generator from the existing bulk storage fuel tank could

be expensive and/or difficult, depending on the site layout. Second, the remote generator makes maintenance, operation, and testing more time-consuming than for a centrally located common plant. A third disadvantage is the lack of redundancy that could be realized when paralleling or interconnecting two or more generator sets. Finally, the building cost for the new generator space (if the generator is located indoors), the noise, the exhaust, the accessibility to the unit, and the unit's heat rejection should be all be considered before selecting this option.

A second approach to adding a generator onto an existing plant is to introduce it in a primary-secondary set-up. For example, if the existing system uses a 350 kW generator to serve 300 kW of essential loads (see Figure 9-3), and if plans call for the addition of 100 kW of essential load, the existing generator could be supplemented by a 500 kW unit and transfer mechanism (see Figure 9-4). In this approach, the 500 kW generator normally carries all of the load, with the older 350 kW unit acting as a standby. Then, should the 500 kW generator fail, the standby unit will come online, shed 100 kW of load, and carry the balance. Such an approach should also involve a redistribution of the essential loads so that all critical/life safety loads are not “dumped” when the smaller generator dumps a portion of the load. This scheme offers a comparable cost to the replacement of an older generator by a larger generator; dramatically improves system reliability; offers capacity for future expansion; and uses, rather than discards, the investment in the existing generator.

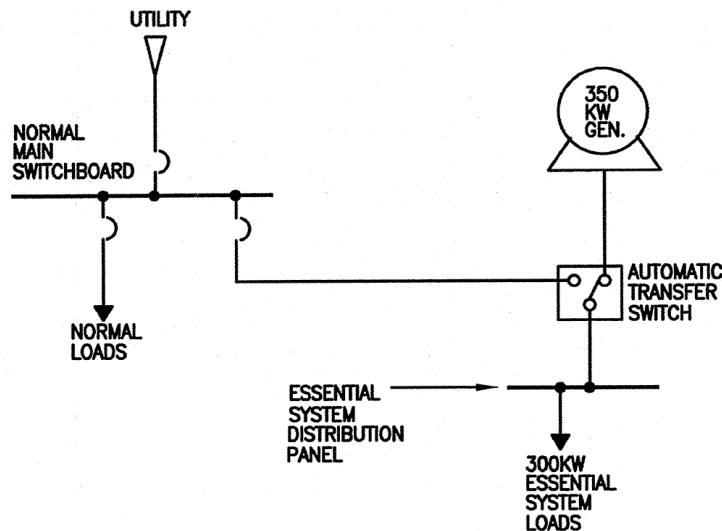


Figure 9-3—Hypothetical system before renovation

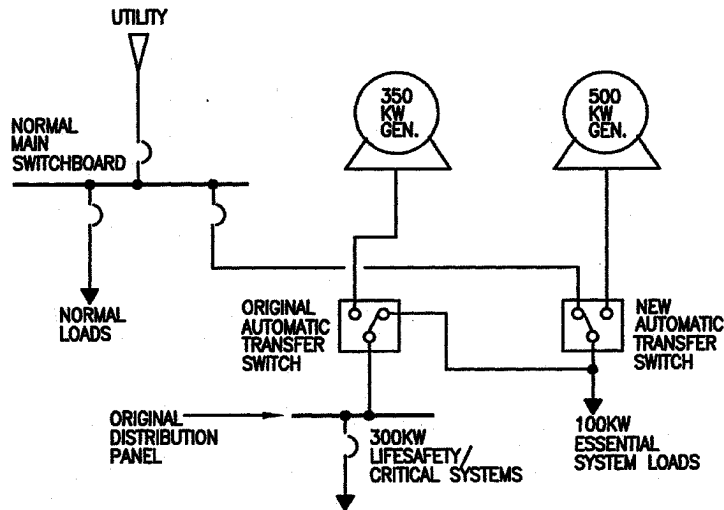


Figure 9-4—Hypothetical system after renovation

A final approach to adding a generator, and one virtually necessitated by a system of three or more generators, is to add a new generator and parallel it with the existing generator system. This arrangement provides the ultimate in reliability for essential system loads. In this scheme, some lower priority loads can be shed to balance load on the remaining generator(s). The disadvantages of paralleling generators are the cost of the system; the physical limitations of generator room expansion; the ability of the fuel, cooling, and exhaust systems to handle the additional generator; and the new short-circuit duty on the switchboard that may impact the overcurrent devices.

9.6 Planning for patient care

9.6.1 Safety and reliability

For a health care facility, the twin issues of personnel safety and system reliability are inextricably wound together, as very often a patient's life might depend upon the reliability of the building electrical system. Changes in current codes, such as the division of essential loads, largely represent a response to these concerns. Any construction involved in the renovation of a health care facility should be performed in strict accordance with all current codes to ensure a facility without inherent risks to its future occupants. Similarly, the designer should take care to correct any safety defects that may be uncovered in the course of the renovation.

One obvious safety issue in the renovation of an existing facility is the age of the various system components. For instance, older conductors represent a potential hazard both to individuals contacting them and to those depending upon them for continued operation of utilization equipment. The engineer needs to examine the existing site to determine if

existing switchgear, panelboards, and/or feeders may be reused by splicing into existing conductors; however, it is a practice that should be avoided. Similarly, component capacities and coordination characteristics should be verified for proper operation of the proposed system. Feeders and large branch circuit conductors should be tested, and connections should be checked with temperature detectors. Where large nonlinear loads are being added to existing systems, the neutral conductors may not be of sufficient size.

The prudent engineer will also spend time examining the site for other electrical hazards. Some such hazards include the following:

- a) Branch circuit neutral wire shared by circuits from two panels
- b) Circuit breakers that are double-lugged
- c) Bare neutral feeder conductors
- d) Missing junction-box covers
- e) Poor splices
- f) Wires not properly protected by overcurrent devices
- g) Medium-voltage cables glowing with corona halos

This list is not intended to be exhaustive; it merely reflects some of the more interesting situations experienced by the authors of this chapter. All such problems should be identified and corrected as quickly as possible.

9.6.2 Grounding

9.6.2.1 Introduction

The engineer should also carefully examine the existing grounding system. Elements to be checked (depending upon the particular renovation) include the system ground, the emergency generator neutral, the ground-bus bond between critical and normal branch circuit panels, and whether branch circuits serving patient care areas contain a green grounding conductor. A properly grounded system is important not only to patient and staff safety, but also to effective operation of today's electronic equipment.

9.6.2.2 System grounding

To determine if the system ground at the main switchboard is adequate, the designer should test the impedance of the ground path using a method equivalent to the *Biddle test* (see IEEE Std 142™, *IEEE Green Book*™). The impedance of the ground path should not exceed 10 3/4; 5 3/4 or less are preferable for larger systems. If the impedance exceeds 10 3/4, additional ground rods may have to be driven to lower the impedance. Similarly, secondary grounds for transformers serving areas to be renovated should be checked, as should continuity of grounding conductors and bonding jumpers from the grounding electrode to the last existing panel to be reused.

9.6.2.3 Area renovation

When renovating patient care areas, the engineer should determine if the receptacles and fixed electrical equipment serving the area are grounded by an insulated copper conductor in a metallic conduit. In older installations, the raceway was commonly used as the bonding connection. Affected branch circuits should be rewired from the panel with a circuit containing an equipment grounding conductor. The engineer should also verify that the ground bus of the critical branch circuit panel and the ground bus of the normal branch circuit panel are properly bonded together with an insulated copper conductor #10 AWG or larger, as now required by the NEC.

9.6.2.4 Impact of changes on integrity of system

Obviously, any modification to an existing electrical system will have repercussions that extend far beyond the area being renovated. In particular, the engineer should check the time-current characteristics of devices to be added against those of existing devices. This crucial element of renovation design is often overlooked, but should be carefully considered so as not to compromise system selection coordination. Similarly, addition of motor loads to an existing system may put short-circuited currents onto a system incapable of withstanding these stresses. Transformer replacement will affect the maximum available fault currents to portions of the system. Other electrical characteristics, such as loads cycling on and off, loads generating harmonics that disrupt other devices elsewhere on the system, and transformer inrushes, all may result in further changes in the final system design. Accordingly the engineer needs to consider carefully the impact the loads and system design will impose upon the existing system and take the necessary steps to mitigate those effects. The engineer should conduct a complete short-circuit and protective device coordination analysis to determine required protective device upgrades and system withstand capabilities.

9.6.2.5 Operating room electrical systems

Operating rooms (ORs) are areas of much concern in the renovation process as a result of several factors. First, the overriding concern is for the patient's safety during the treatment. Second, the declining use of flammable anesthetics and changing code regulations regarding isolated power in ORs continue to cause much confusion. Finally, ORs are not immune to the proliferation of technology, and specifically, to technology that requires an outlet. A perfect example of this sort is the addition of a three-phase laser to an existing OR now served by a single-phase isolation system.

Chapter 4 describes the reasons that an isolated power system (IPS) may be desired in ORs. Generally speaking, if a particular OR already contains an IPS, any addition to that room's electrical system should derive from that IPS. If the existing system is at capacity, a second system, complete with its own alarms, can be added to accommodate the new requirements. The second system could serve several rooms, as in the case of a three-phase system serving lasers in two or three rooms. In this case, each room served should have remote annunciators located in each room, and all devices should be carefully labeled in the room to indicate the correct panel. On balance then, using IPSs in ORs that

are to be renovated is strongly recommended, and maintaining the use of isolated power in a room already containing an IPS is even more strongly recommended.

A final question often encountered in the renovation of an operating room or suite is that of receptacles to be used. At one time, ORs were equipped with NEMA locking-type receptacles under the theory that if a careless person were to trip over a cord, it should stay plugged in. Less and less equipment is now being made (or purchased) with plugs to fit these receptacles. Straight-blade receptacles are becoming more and more prevalent under the theory that the clumsy person is better off unplugging the cord, rather than ripping the device out of the patient. The engineer planning an OR renovation should be careful to coordinate the receptacle type with the needs of the staff.

9.7 Lighting

Properly lighting a hospital renovation project poses several unique challenges. The original lighting design relied on older technologies and on older standards that used footcandles as the sole design criterion to achieve its lighted environment. The aesthetic sought was probably the institutional look seen in so many older hospitals, rather than today's more home-like approach. Applying current technologies and current methods for design of lighting and its control, however, can be especially difficult as a result of the physical limitations noted earlier. Proper amounts of daylight may be difficult to achieve through existing window openings. Most of the principles of good lighting for hospitals found in Chapter 6 can be achieved through careful coordination with the users, the architect, and the other trades.

The patient room is central to a hospital, and its design serves to highlight some of the creativity that should be used in renovation design. A patient room may be occupied by various people performing various sorts of tasks as described in Chapter 6. Older designs did not necessarily cater to all of these needs, but instead tried to achieve a certain footcandle level. In attempting to achieve the lighting required for all of the required functions, the engineer should incorporate the design principles and new technologies of Chapter 6 while adapting to the existing conditions. In patient rooms the problems of space above the ceiling are minimal, as most of the task-specific lighting for the space can be mounted on the walls (i.e., over-bed lights and night-lights), or may be table lamps specific for visitors, or may be located so that they are in some far away corner (such as down-lights for visitors), so as not to interfere with the other trades. Such a combination of methods and fixtures not only provides task-specific light for each of the individual room functions, but also does so in a manner that avoids some of the potential coordination problems.

Of course, the engineer should take care not to “over-engineer” the space (i.e., to not provide such a profusion of varied lights and switches that operation becomes similar to operating a 747 airplane).

Another portion of the hospital with challenges unique to renovation are laboratories. In the past, laboratories were planned by the architect and lighted to the proper footcandle level by the engineer. Newer technologies and methods emphasizing the proper lighting at

the task surface can both hinder and help the engineer. The new technologies include the use of lamps with proper color rendering indices and color temperatures making the visual tasks required in the laboratory easier to achieve. However, the physical limitations of the space, as well as the fume hood and other ductwork of the mechanical engineer, can make the proper arrangement of luminaires installed overhead within the ceiling extremely difficult to achieve. In such cases, the laboratory arrangements may be rearranged to best accommodate both the preceding conditions as well as the user's traffic and use patterns. Permanently installed or portable task lighting may be used to provide the higher levels required for certain tasks. Again, each of these options should be carefully coordinated with the various parties to the project.

Another lighting application that causes problems in renovations is the corridors and the nurses' stations. Corridors typically have the worst space congestion above the ceiling, making wall sconce, linear surface-mounted sources, or down-lights in soffits especially useful. Figure 9-5 illustrates one potential solution. The space above ceilings in corridors, and over and around the nurses' stations, is usually filled with equipment, making lighting particularly difficult. In addition, nurses' stations are being equipped more and more with video display terminals (VDTs) and with monitoring screens that increase the lighting and glare problems associated with these areas. Dropped areas at the perimeters of the stations afford good opportunities for fixture placement, as well as help to emphasize the nurses' station as a separate space within the larger space. Efficient use of task and under-counter lighting may also be useful in these spaces.

In each of the cases mentioned, the engineer should first carefully assess the lighting requirements of the space to be renovated, and then the existing conditions that will affect the lighting design. Then the engineer should design the lighting system in accordance with the principles in Chapter 6, while coordinating carefully with the architect, the other trades, and the staff to ensure the proper installation.

9.8 Communication and signal systems

9.8.1 Fire alarm systems

Fire alarm systems seem to cause more problems in the renovation of a health care facility than any other system. They are crucial to the safety of building occupants, yet they seem to have an aura of mystery surrounding them. The fire alarm system is also highly integrated into the building as a whole.

Fire alarm technology and codes have both changed significantly and quickly, so that older buildings now tend to have some sort of combination of systems of different vintages somehow rigged together into a single precarious system. Maintenance is inevitably laborious and expensive, and failures of these systems are common.

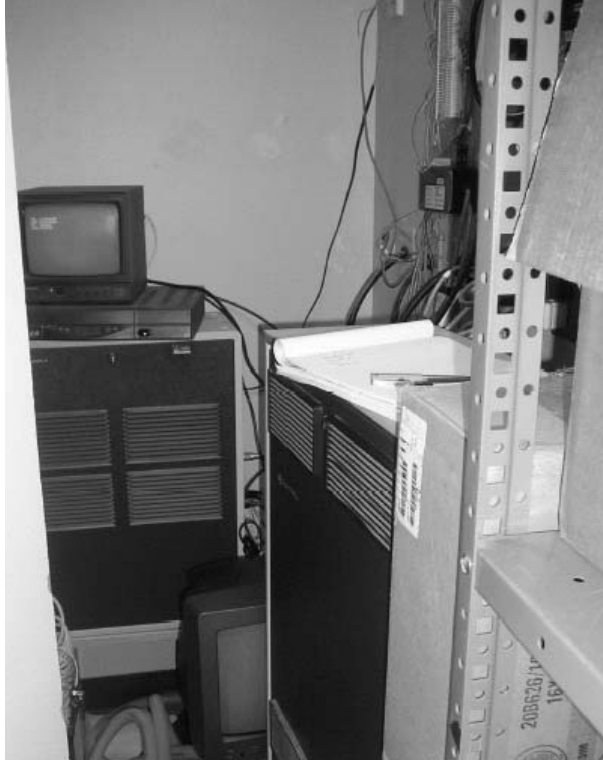


Figure 9-5—Existing communication systems

Most older facilities were built with mechanically coded systems. Such systems typically consist of pull-station risers located near exits with a coded pull station at each level. Detectors (where present) are typically circuited by floor and zone to a central junction box at a riser emanating from the control panel. Coders for the detector circuits, as well as power supplies and drivers for diagnostic and control functions, are located in the control panel. Alarm bell circuits rise up from the control panel through the building, often sharing conduit risers with the pull stations. Annunciators tended to be back-lit panels, usually located in a telephone operator's room, maintenance shops, or the main entrance. Many older systems do not have visual fire alarm devices, and most do not have flashing exit signs as is now required by the Americans with Disabilities Act (ADA).

With the introduction of solid-state electronics some years ago, the mechanical systems began to be phased out and electronically coded systems began to take their place. In facilities having the older mechanical systems, the newer systems were often piggybacked onto the existing system, usually through a single mechanical coder. Such combining of systems often causes resetting problems, as well as problems with alarm location.

Manufacturers have recently begun introducing a new generation of fire alarm systems using microprocessor technology (see Chapter 8). These systems typically are noncoded, with visual annunciation via flashing lights and exit lights, and audio annunciation via march-time chimes or bells with voice indications of zone of alarm. Such systems may be

either hard-wired or multiplexed, and are much more flexible than the older systems. Despite these improvements, however, interfacing these systems with older systems still causes problems that are similar to those mentioned in the preceding paragraph.

The engineer facing the project of renovation of a hospital space will do well to devote considerable time to the fire alarm system. Very often, it is deceptive to consider the needs of the space to be renovated alone; the fire alarm system should be considered as a whole. Patchwork solutions for defined spaces tend to exacerbate existing system problems. Where older systems are present, devices may not be available that will work with the system. Control panels are often extended to the point of capacity, rendering the addition of devices required by current codes impossible. Required control functions may be impossible to achieve. Risers may be old, unreliable, or located in the wrong places.

The engineer planning a space renovation should first define the fire alarm requirements for the proposed project. The engineer should then become intimate with the existing system and accurately assess its capacity to support the required functions without major modifications. Any deficiency that requires an upgrade to support the proposed renovation needs to be carefully coordinated with the regulatory officials. Very often, a lack in the existing system will precipitate an upgrade of the entire system. Engineers should be careful that in adding onto an existing system, their addition is not merely a patchwork addition, but a functional, reliable design that does not cause additional problems to the hospital staff. Similarly, when renovation of an area of the facility requires reworking portions of the existing system, the entire system in that area should be replaced (i.e., old and new system functions should not be mixed in one area).

Two approaches are possible in the replacement of an existing fire alarm system. First, the system can be replaced in total, and all facets can be brought up to code throughout the facility. While this is logically the simpler approach, it can be logistically the most difficult, as operations in every space will be disrupted by the work. Cost is a further disadvantage of this approach.

The second, less drastic, approach is to merely replace the central equipment (and that of the space to be renovated) with the new microprocessor-based generation of equipment. This equipment will then tie into the existing system and allow for future expansion of the system using the inherent flexibility of this type of system. This approach, while attractive from both the cost and disruption standpoints, may still pose many operational problems. In essence, it is repeating the piggybacking of systems, with all of the attendant problems. Having different areas of the hospital on different fire alarm systems, tied together tenuously at best, can cause severe problems. One compromise solution to this problem is to completely replace the existing control boards with the new system and terminate all of the old risers directly into the new system. This approach will not solve all of the reliability problems of the remote devices, nor will it immediately solve all of the code-violation problems, but it will be fairly inexpensive, and will solve, to a great extent, the problem of tying several generations of alarm control systems together. All aspects of the fire alarm system should be carefully coordinated with the facility administration, engineering, and fire and security departments, as well as regulatory agents.

Very often, a renovation project can reuse existing central equipment, adding or reusing existing devices, control sequences, and zoning. In such cases, however, the engineer should be careful to check the capacities of door holder circuits and audio, visual, and audiovisual circuits that are to be reused or extended. Alarm system zoning also needs to be reviewed and modified as required.

9.8.2 Sound/paging systems

Often overlooked, the public address (PA) systems in health care facilities deserve special attention in the renovation of an existing space. As technology drives fire alarm systems in the direction of noncoded voice systems, the PA system becomes a central element in the fire safety systems of the facility; therefore, it should be of supreme reliability. “Code blue” functions are often performed over the PA system, so patients’ lives are often at stake. Yet in the face of these emerging demands for system performance, amplifiers are often overloaded, circuits are tapped into unknown points, volume is gradually lost by continuing additions, wiring is strung above ceilings instead of in conduits or trays, and speaker placement and settings are random at best.

In planning the renovation of a particular space within a facility, the prudent engineer should closely examine both the central system and the circuits in that space, if possible. Load readings at the amplifiers should be recorded to ensure that the addition of the proposed speakers can be accommodated. As much as possible, the existing circuits that will be used should be traced, and their capacity assessed, as well as their condition. If possible, the vendor who supplied the system should be consulted in assessing the system’s capacity to support the proposed renovation. Within the renovated space, the cabling should be run in conduits or in cable trays provided for the purpose. Speaker placement should be planned carefully to provide the required personnel (fire response teams or “code blue” teams, for instance) the ability to hear any announcements. If the system is integrated with the telephone system and provided by the telephone vendor, the design should be coordinated with the vendor. The potential to “quiet” the hospital ambiance by using alternates, such as radio pagers, or local area paging in lieu of overhead paging, should also be explored.

Very often, a close examination of the overhead paging system will lead to the realization that it is inadequate. In that event, new amplifiers or speaker circuits may need to be provided as part of the project. It is better to discover such a problem while planning the renovation, rather than blowing an amplifier when the project is complete.

9.8.3 Nurse-call systems

Nurse-call systems tend to be easier to deal with in renovating a space than the previous systems, as they tend to be much more localized. Again, because of the rapid changes in technologies and manufacturers, obtaining replacement parts for an existing system may be extremely difficult. Sometimes the maintenance personnel of a hospital may have some extra parts in stock, or a manufacturer may be able to supply parts to make the system work. With larger renovations—because of shifting usages and needs by the staff, maintenance, reliability, and sheer availability reasons—the engineer should replace the entire nurse-call system for that area. See Figure 9-6.



Figure 9-6—Patient holding pillow speaker and call button

9.8.3.1 Clock systems

Clock systems come in three varieties: battery-powered individual clocks, synchronous (hardwired), or electronic (line powered or frequency corrected). The concern here is with only the last two, but the engineer should determine the system that the owner uses and/or prefers. Clock systems seem to have long lifetimes and to be prone to fewer failures than the systems previously discussed. For that reason, existing systems may typically be reused. Again, however, the engineer should determine the feeder circuit to be used and ensure that it can support the proposed renovation. The engineer should determine (synchronous system) which branch of the circuit carries the clock signal and also determine if it is the appropriate system. The engineer should avoid placing capacitors onto the same branch of the electrical system, as capacitors will divert the carrier current signal to ground and will render the system useless. Finally, some of the newer generations of fire alarm systems can act as signal generators to local areas. So, small clock systems using the fire alarm system as the master clock may be created for the renovations of particular spaces. Such an approach can help to overcome capacity application problems, as well as any other systemic problems posed by the existing installation.

9.8.4 Miscellaneous systems

Hospitals contain examples of every other type of system, including observational video, patient television, building management systems, data processing, narcotics alarms, telephones, intercoms, patient monitoring, security, and dictation. There are no firm rules in extending these systems into a renovated area, but extensive coordination, discovering user needs early, installing sufficient raceways, and providing room for central equipment is necessary. These systems are all very user-intensive, and require power, wiring, and

cooling. The engineer should, in all cases, talk to the users, maintainers, and to the vendors who provided and/or serviced the system to investigate the best ways to extend the systems. The needs of the space to be renovated should be carefully determined from the future users, and any impact to other spaces should be dealt with. The engineer should carefully plan all required risers for the various systems, and should coordinate their routing with the various owners' parties. Finally, if the engineer needs to provide central equipment for any of these systems, the power quality at the proposed location should be checked, and the appropriate filtering and battery backup should be checked, to ensure that proper system operation is provided.

One excellent system for distribution of the growing masses of communications wiring is cable trays. The trays run throughout the corridors to gather cabling from the individual devices and carry it to the central equipment/riser location(s). Such a system can be extremely useful in keeping the areas above ceilings free of clutter and tends to be less expensive than all-conduit systems. Even this system should be coordinated, as some communications systems require a divider in such a tray to isolate their cables, or they may require shielded or plenum-listed conductors, or low-smoke combustion conductors. The location of the tray in the ceiling should be carefully coordinated with the other trades to ensure access to it.

9.9 Medical equipment and instrumentation

The primary issues for dealing with the installation of new medical equipment into an existing space are the same issues discussed in the rest of this chapter. Of particular importance are the issues of power quality required by the new equipment, and power demand of the new equipment, as compared to the available system capacity.

When renovating existing facilities, the engineer may encounter nonstandard voltages. A relatively common nonstandard system found in existing facilities is 240 V (ground delta) or 120/240 V (open delta). Today it is common to install 120/208 V, three-phase, 4-wire (grounded wye) systems in lieu of 240 V systems. Therefore, when renovating a health care facility, the engineer may encounter an existing piece of equipment rated for 240 V that must be served by a 120/208 V, three-phase, 4-wire panel. The opposite situation may occur where a new piece of equipment rated for 208 V must be served by a 240 V or 120/240 V panel (replacing the old 240 V equipment, with attendant gains in efficiency and reliability, may also be an option). In both cases, buck-boost transformers may be used to step the voltage up or down as needed.

In many instances, existing 120/240 V panels serve only single-phase loads and may be reconnected to a 120/208 V system. If several such panels are reconnected, the engineer should be careful to coordinate the phases the loads are reconnected to, or the phases may become highly unbalanced. Finally, other transformers may be used to serve loads of various voltages. Transformers of 480 V to 240 V are available, as are 240 V to 208 V transformers. Also, the transformers may be connected reversed, or 208 V to 240 V, if required for selective loads.

9.10 Preparing for renovations

The final consideration in a renovation project, and indeed in any project, is the preparation for the future renovation. Small, simple elements of a design can help facilitate future renovations without greatly increasing the project cost and should be incorporated. Besides the obvious provision of physical spaces for future equipment, other such elements might include stubbing spare conduits up from flush-mounted panel boards; providing spare conduits between electrical rooms; and providing spare risers with junction boxes at each floor location. Circuits (both power and communications) can be moderately loaded so as to afford easy expansion; cable trays can be installed to facilitate addition of communications wiring; spare capacity, both in terms of load capacity and spare/space capacity in switchgear, can be added. The system itself should be designed to be as flexible as possible, including liberal use of main breakers, especially on panels served by feeders with several panel loads. Many microprocessor-based communication systems are tremendously flexible in their expansion/reconfiguration capability. The last and perhaps most important preparation for future renovation is proper documentation and preparation of record drawings. Planning for any future renovation is greatly facilitated by accurate, complete drawings of the project, both in terms of locating potential difficulties and in locating areas of the design that lend themselves to easy expansion.

9.11 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 142, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (*IEEE Green Book*).³

NFPA 70, National Electrical Code® (NEC®).⁴

NFPA 99, Standard for Health Care Facilities.

NFPA 101, Life Safety Code®.

9.12 Bibliography

Additional information may be found in the following sources:

[B1] Bacon, Kenneth H., "Medical Waste; Hospital Construction Booms, Driving Cost of Health Care Up," *The Wall Street Journal*, col. 1, p. A1, January 10, 1990.

³IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

⁴NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA (<http://www.nfpa.org/>).

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[B3] Kubal, Joseph, “Health Care Construction Boom to Continue in ‘90s,” *Health Facilities Management*, March 1990.

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