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IEEE Recommended Practice for Electric Power Systems in Commercial Buildings

Sponsor

Power Systems Engineering Committee
of the
IEEE Industry Applications Society

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Abstract: A guide and general reference on electrical design for commercial buildings is provided. It covers load characteristics; voltage considerations; power sources and distribution apparatus; controllers; services, vaults, and electrical equipment rooms; wiring systems; systems protection and coordination; lighting; electric space conditioning; transportation; communication systems planning; facility automation; expansion, modernization, and rehabilitation; special requirements by occupancy; and electrical energy management. Although directed to the power oriented engineer with limited commercial building experience, it can be an aid to all engineers responsible for the electrical design of commercial buildings. This recommended practice is not intended to be a complete handbook; however, it can direct the engineer to texts, periodicals, and references for commercial buildings and act as a guide through the myriad of codes, standards, and practices published by the IEEE, other professional associations, and governmental bodies.

Keywords: Commercial buildings, electric power systems, load characteristics

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IEEE Recommended Practice for Electric Power Systems in Commercial Buildings

1. Introduction

1.1 Scope

IEEE Std 241-1990, IEEE Recommended Practice for Electric Power Systems in Commercial Buildings, commonly known as the "Gray Book" is published by the Institute of Electrical and Electronics Engineers (IEEE) to provide a recommended practice for the electrical design of commercial buildings. It has been prepared on a voluntary basis by engineers and designers functioning as the Gray Book Working Group within the IEEE Power Systems Engineering Committee.

This recommended practice will probably be of greatest value to the power oriented engineer with limited commercial building experience. It can also be an aid to all engineers responsible for the electrical design of commercial buildings. 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 general reference on electrical design for commercial buildings.

Tables, charts, and other information that have been extracted from codes, standards, and other technical literature are included in this recommended practice. Their inclusion is for illustrative purposes; where the correctness of the item is important, the latest referenced document should be used to assure that the information is complete, up to date, and correct. It is not possible to reproduce the full text of these items in this recommended practice.

1.1.1 Voltage Levels

It is important to establish, at the outset, the terms describing voltage classifications. Table 1, which is adapted from IEEE Std 100-1988, IEEE Standard Dictionary of Electrical and Electronics Terms, Fourth Edition (ANSI) [5],[1] indicates these voltage levels. ANSI/NFPA 70-1990, National Electrical Code (NEC) [3],[2] described in 1.6.1, uses the term "over 600 volts" generally to refer to what is known as "high voltage." Many IEEE Power Engineering Society (PES) standards use the term "high voltage" to refer to any voltage higher than 1000 V. All nominal voltages are

[1]The numbers in brackets correspond to those in the references at the end of each chapter. IEEE publications are available from the Institute of Electrical and Electronics Engineers, IEEE Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331.

[2]ANSI publications are available from the Sales Department of the American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036. NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

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expressed in terms of rms. For a detailed explanation of voltage terms, see Chapter 3. ANSI C84.1-1989, Voltage Ratings for Electric Power Systems and Equipment (60 Hz) [2][3] lists voltage class designations applicable to industrial and commercial buildings where medium voltage extends from 1000 V to 69 kV nominal.

Table 1—Voltage Classes

IEEE Std for Industrial & Commercial Power Systems	ANSI	Nominal System Voltage: Two Wire	Nominal System Voltage: Three Wire	Nominal System Voltage: Four Wire	Maximum Voltage
			Single-Phase Systems		
LOW VOLTAGE SYSTEMS	ANSI C84.1-1989 no voltage class stated	(120)			127
LOW VOLTAGE SYSTEMS	ANSI C84.1-1989 no voltage class stated		120/240		127/254
			Three-Phase Systems		
LOW VOLTAGE SYSTEMS	ANSI C84.1-1989 no voltage class stated			208Y/120	220Y/127
LOW VOLTAGE SYSTEMS	ANSI C84.1-1989 no voltage class stated		(240)	240/120	245/127
LOW VOLTAGE SYSTEMS	ANSI C84.1-1989 no voltage class stated		480	480Y/277	508Y/293
LOW VOLTAGE SYSTEMS	ANSI C84.1-1989 no voltage class stated		(600)		635
MEDIUM VOLTAGE	ANSI C84.1-1989 no voltage class stated		(2400)		2540
MEDIUM VOLTAGE	ANSI C84.1-1989 no voltage class stated		4160	4160Y/2400	4400Y/2540
MEDIUM VOLTAGE	ANSI C84.1-1989 no voltage class stated		(4800)		5080
MEDIUM VOLTAGE	ANSI C84.1-1989 no voltage class stated		(6900)		7260
MEDIUM VOLTAGE	ANSI C84.1-1989 no voltage class stated			(8320Y/4800)	8800Y/5080
MEDIUM VOLTAGE	ANSI C84.1-1989 no voltage class stated			(12000Y/6930)	12700Y/7330
MEDIUM VOLTAGE	ANSI C84.1-1989 no voltage class stated			12470Y/7200	13200Y/7620
MEDIUM VOLTAGE	ANSI C84.1-1989 no voltage class stated			13200Y/7620	13970Y/8070
MEDIUM VOLTAGE	ANSI C84.1-1989 no voltage class stated		13800	(13800Y/7970)	14520Y/8380
MEDIUM VOLTAGE	ANSI C84.1-1989 no voltage class stated			(20780Y/12000)	22000Y/12700
MEDIUM VOLTAGE	ANSI C84.1-1989 no voltage class stated			(22860Y/13200)	24200Y/13970
MEDIUM VOLTAGE	ANSI C84.1-1989 no voltage class stated		(23000)		24340
MEDIUM VOLTAGE	ANSI C84.1-1989 no voltage class stated			24940Y/14400	26400Y/15240
MEDIUM VOLTAGE	ANSI C84.1-1989 no voltage class stated		(34500)	34500/19920	36510Y/21080
MEDIUM VOLTAGE	ANSI C84.1-1989 HIGHER VOLTAGE SYSTEMS		(46 kV)		48.3 kV
MEDIUM VOLTAGE	ANSI C84.1-1989 HIGHER VOLTAGE SYSTEMS		69 kV		72.5 kV
HIGH VOLTAGE	ANSI C84.1-1989 HIGHER VOLTAGE SYSTEMS		115 kV		121 kV
HIGH VOLTAGE	ANSI C84.1-1989 HIGHER VOLTAGE SYSTEMS		138 kV		145 kV
HIGH VOLTAGE	ANSI C84.1-1989 HIGHER VOLTAGE SYSTEMS		(161 kV)		169 kV
HIGH VOLTAGE	ANSI C84.1-1989 HIGHER VOLTAGE SYSTEMS		230 kV		242 kV
EHV	ANSI C92.2-1987		345 kV		362 kV
EHV	ANSI C92.2-1987		500 kV		550 kV
EHV	ANSI C92.2-1987		765 kV		800 kV
	ANSI C92.2-1987		1100 kV		1200 kV

NOTE: See Table 17 in Chapter 3 for a complete listing of system voltages.

[3]ANSI publications are available from the Sales Department of the American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036.

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1.2 Commercial Buildings

The term "commercial, residential, and institutional buildings" as used in this chapter, encompasses all buildings other than industrial buildings and private dwellings. It includes office and apartment buildings, hotels, schools, and churches, marine, air, railway, and bus terminals, department stores, retail shops, governmental buildings, hospitals, nursing homes, mental and correctional institutions, theaters, sports arenas, and other buildings serving the public directly. Buildings, or parts of buildings, within industrial complexes, which are used as offices or medical facilities or for similar nonindustrial purposes, fall within the scope of this recommended practice. It is not possible to cover each type of occupancy in this text; however, many are covered in Chapter 16. Medical areas are covered in IEEE Std 602-1986, IEEE Recommended Practice for Electric Systems in Health Care Facilities (ANSI) [10] (the "White Book").

The specific use of the commercial building in question, rather than the nature of the overall development of which it is a part, determines its electrical design category. While industrial plants are primarily machine- and production-oriented, commercial, residential, and institutional buildings are primarily people- and public-oriented. The fundamental objective of commercial building design is to provide a safe, comfortable, energy-efficient, and attractive environment for living, working, and enjoyment. The electrical design must satisfy these criteria if it is to be successful.

Today's commercial buildings, because of their increasing size and complexity, have become more and more dependent upon adequate and reliable electric systems. One can better understand the complex nature of modern commercial buildings by examining the systems, equipment, and facilities listed in 1.2.1.

1.2.1 System Requirements for Commercial, Residential, and Institutional Buildings

The systems, equipment, and facilities that must be provided to satisfy functional requirements will vary with the type of facility, but will generally include some or all of the following:

1) Building electric service
2) Power distribution system
3) Lighting — Interior and exterior, both utilitarian and decorative; task and general lighting.
4) Communications — Telephone, facsimile, telegraph, satellite link, building-to-building communications (including microwave, computer link, radio, closed-circuit television, code call, public address, paging, fiber-optic and electronic intercommunication, pneumatic tube, doctors' and nurses' call, teleconferencing), and a variety of other signal systems.
5) Fire alarm systems — Fire pumps and sprinklers, smoke and fire detection, alarm systems, and emergency public address systems.
6) Transportation — Elevators, moving stairways, dumbwaiters, and moving walkways.
7) Space conditioning — Heating, ventilation, and air conditioning.
8) Sanitation — Garbage and rubbish storage, recycling, compaction, and removal; incinerators; sewage handling; and document shredders and pulpers.
9) Plumbing — Hot and cold water systems and water treatment facilities.
10) Security watchmen, burglar alarms, electronic access systems, and closed-circuit surveillance television
11) Business machines — Typewriters, computers, calculators, reproduction machines, and word processors.
12) Refrigeration equipment
13) Food handling, catering, dining facilities, and food preparation facilities
14) Maintenance facilities
15) Lightning protection
16) Automated building control systems
17) Entertainment facilities and specialized audiovisual systems
18) Medical facilities
19) Recreational facilities
20) Legally required and optional standby/emergency power and peak-shaving systems
21) Signing, signaling, and traffic control systems; parking control systems including automated parking systems

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1.2.2 Electrical Design Elements

In spite of the wide variety of commercial, residential, and institutional buildings, some electrical design elements are common to all. These elements, listed below, will be discussed generally in this section and in detail in the remaining sections of this recommended practice. The principal design elements considered in the design of the power, lighting, and auxiliary systems include:

1) Magnitudes, quality, characteristics, demand, and coincidence or diversity of loads and load factors
2) Service, distribution, and utilization voltages and voltage regulation
3) Flexibility and provisions for expansion
4) Reliability and continuity
5) Safety of personnel and property
6) Initial and maintained cost (“own and operate” costs)
7) Operation and maintenance
8) Fault current and system coordination
9) Power sources
10) Distribution systems
11) Legally required and optional standby/emergency power systems
12) Energy conservation, demand, and control
13) Conformance with regulatory requirements
14) Special requirements of the site related to: seismic requirements (see IEEE Std 693-1984 [12]), altitude, sound levels, security, exposure to physical elements, fire hazards (see IEEE Std 979-1984 [13]), hazardous locations, and power conditioning and uninterruptible power supply (UPS) systems

1.3 The Industry Applications Society (IAS)

The IEEE is divided into 35 groups and 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 IEEE Industry Applications Society (IAS) currently encompasses 26 technical committees covering aspects of electrical engineering in specific areas (petroleum and chemical industry, cement industry, glass industry, power systems engineering, and others). Papers of interest to electrical engineers and designers involved in the field covered by this recommended practice are, for the most part, contained in the transactions of the IAS.

The Gray Book is published by the IEEE Standards Department on behalf of the Power Systems Engineering Committee. Individuals who desire to participate in the activities of the committees, subcommittees, or working groups in the preparation and revision of texts such as this should write the IEEE Standards Department, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331.

1.3.1 Grouping of Commercial Buildings

The principal groupings of commercial buildings are:

1) Multiple-story buildings, office buildings, and apartment buildings
2) Public buildings and stores, such as retail shops and supermarkets
3) Institutional buildings, such as hospitals, large schools, colleges, corporate headquarters
4) Airport, railroad, and other transportation terminals
5) Large commercial malls and shopping centers
6) Competitive and speculative buildings of types (1) and (2) above where minimum costs are essential, and where interior finishes are left to future tenants

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The Production and Application of Light, Power Systems Engineering, Power Systems Protection, Codes and Standards, Energy Systems, and Safety Committees of the IAS are involved with commercial building activities and some publish material applicable to many types of commercial facilities.

1.4 IEEE Publications

The IEEE publishes several recommended practices that are similar in style to the IEEE Gray Book, prepared by the Industrial and Commercial Power Systems Department of the IEEE Industry Applications Society.

1) IEEE Std 141-1986, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (ANSI) (the “Red Book”).
2) IEEE Std 142-1982, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (ANSI) (the “Green Book”).
3) IEEE Std 242-1986, IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (ANSI) (the “Buff Book”).
4) IEEE Std 399-1990, IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis (ANSI) (the “Brown Book”).
5) IEEE Std 446-1987, IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (ANSI) (the “Orange Book”).
6) IEEE Std 493-1990, IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (ANSI) (the “Gold Book”).
7) IEEE Std 602-1986, IEEE Recommended Practice for Electric Systems in Health Care Facilities (ANSI) (the “White Book”).
8) IEEE Std 739-1984, IEEE Recommended Practice for Energy Conservation and Cost-Effective Planning in Industrial Facilities (ANSI) (the “Bronze Book”).

1.5 Professional Registration

Most regulatory agencies require that the designs for public and other commercial buildings be prepared under the jurisdiction of state-licensed professional architects or engineers. Information on such registration may be obtained from the appropriate state agency or from the local chapter of the National Society of Professional Engineers.

To facilitate obtaining registration in different states under the reciprocity rule, a National Professional Certificate is issued by the National Council of Engineering Examiners, Records Department[4] to engineers who have obtained their home state license by examination. 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.

1.5.1 Professional Liability

Recent court and regulatory decisions have held the engineer and designer liable for situations that have been interpreted as malpractice. These decisions have involved safety, environmental concerns, specification and purchasing practice, and related items. Claims for accidents, purportedly resulting from poor design or operating practices (e.g., too low lighting levels) or nonconformance to applicable codes and standards have resulted in awards against engineering firms and design staff. It is a good idea for the practicing engineer to determine policies for handling such claims, and to evaluate the need for separate professional liability insurance.

[4]For more information, write to the National Council of Engineering Examiners, Records Department, P.O. Box 1686, Clemson, SC 29633-1686.

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1.6 Codes and Standards

1.6.1 National Electrical Code (NEC)

The electrical wiring requirements of the NEC [3] are vitally important guidelines for commercial building electrical engineers. The NEC is revised every 3 years. It is published by and available from the National Fire Protection Association (NFPA), the American National Standards Institute (ANSI) and from each state's Board of Fire Underwriters (usually located in each state's capital). It does not represent a design specification but does identify minimum requirements for the safe installation and utilization of electricity. It is strongly recommended that the introduction to the NEC, Article 90 [3], which covers purpose and scope, be carefully reviewed.

NFPA CY-70HB90, *NFPA National Electrical Code Handbook* [16][5] contains the complete NEC text plus explanations. This book is edited to correspond with each edition of the NEC. McGraw-Hill's *Handbook of the National Electrical Code* [20][6] and other handbooks provide explanations and clarification of the NEC requirements.

Each municipality or jurisdiction that elects to use the NEC must enact it into law or regulation. The date of enactment may be several years later than issuance of the code; in which event, the effective code may not be the latest edition. It is important to discuss this with the inspection or enforcing authority. Certain requirements of the latest edition of the code may be interpreted as acceptable by this authority.

1.6.2 Other NFPA Standards

NFPA publishes the following related documents containing requirements on electrical equipment and systems:

1) NFPA/SFPE GL-HFPE-88, The SFPE Handbook of Fire Protection Engineering — 1988 Edition.
2) NFPA GL-101ST91, Life Safety Code Handbook — 1991 Edition.
3) NFPA 20-1990, Installation of Centrifugal Fire Pumps.
4) NFPA 70B-1990, Electrical Equipment Maintenance.
5) NFPA 70E-1988, Electrical Safety Requirements for Employee Workplaces.
6) NFPA 71-1989, Installation, Maintenance, and Use of Signaling Systems for Central Station Service.
7) NFPA 72-1990, Installation, Maintenance, and Use of Protective Signaling Systems.
8) NFPA 72E-1990, Automatic Fire Detectors.
9) NFPA 72G-1989, Installation, Maintenance, and Use of Notification Appliances for Protective Signaling Systems.
10) NFPA 75-1989, Protection of Electronic Computer/Data Processing Equipment.
11) NFPA 77-1988, Static Electricity.
12) NFPA 78-1989, Lightning Protection Code.
13) NFPA 92A-1988, Smoke Control Systems.
14) NFPA 99-1990, Health Care Facilities — Chapter 8: Essential Electrical Systems for Health Care Facilities, and Appendix E: The Safe Use of High Frequency Electricity in Health Care Facilities.
15) NFPA 101-1988, Life Safety Code — 1988 Edition.
16) NFPA 110-1988, Emergency and Standby Power Systems.
17) NFPA 110A-1989, Stored Energy Emergency and Standby Power Systems.
18) NFPA 130-1990, Fixed Guideway Transit Systems.

[5]NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.
[6]McGraw-Hill publications are available from McGraw-Hill Book Company, 1221 Avenue of the Americas, New York, NY 10020.

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1.6.3 Local, State, and Federal Codes and Regulations

While most municipalities, counties, and states adopt the NEC [3] without change or with modifications, some have their own codes. In most instances, the NEC is adopted by local ordinance as part of the building code. Deviations from the NEC may be listed as addenda. It is important to note that only the code adopted by ordinance 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 rulings, 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 (enforcing authority) the code has the power to interpret it. Failure to comply with the NEC or local code provisions, where required, can affect the owner's ability to obtain a certificate of occupancy, may have a negative effect on insurability, and may subject the owner to legal penalty.

Legislation by the U.S. federal government has had the effect of giving standards, such as certain 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) adopted the 1971 NEC for new electrical installations and also for major replacements, modifications, or repairs installed after March 5, 1972. A few articles and sections of the NEC have been deemed to apply retroactively by OSHA. The NFPA created the NFPA 70E (Electrical Requirements for Employee Workplaces) Committee to prepare a consensus standard for possible use by OSHA in developing their standards. Major portions of NFPA 70E-1988, Electrical Safety Requirements for Employee Workplaces [15] have been included in OSHA regulations.

OSHA requirements are published in the *Federal Register* [18].[7] OSHA rules for electric systems are covered in 29 CFR Part 1910 of the *Federal Register* [18].

The U.S. National Institute of Occupational Safety and Health (NIOSH) publishes *Electrical Alerts* [17][8] to warn of unsafe practices or hazardous electrical equipment.

The U.S. Department of Energy, by encouraging building energy performance standards, has advanced energy conservation standards. A number of states have enacted energy conservation regulations. These include ASHRAE/IES legislation embodying various energy conservation standards such as ASHRAE/IES 90.1-1989, Energy Efficient Design of New Buildings Except New Low Rise Residential Buildings [4]. These establish energy or power budgets that materially affect architectural, mechanical, and electrical designs.

1.6.4 Standards and Recommended Practices

In addition to NFPA, a number of organizations publish documents that affect electrical design. Adherence to these documents can be written into design specifications.

The American National Standards Institute (ANSI) coordinates the review of proposed standards among all interested affiliated societies and organizations to assure a consensus approval. It is in effect a clearinghouse for technical standards. Not all standards are ANSI approved.

Underwriters Laboratories, Inc. (UL)[9] and other independent testing laboratories may be approved by an appropriate jurisdictional authority (e.g., OSHA) to investigate materials and products including appliances and equipment. Tests may be performed to their own or to another agency's standards; and a product may be “listed” or “labeled” The UL publishes an *Electrical Construction Materials Directory, Electrical Appliance and Utilization Equipment Director, Hazardous Location Equipment Directory*, and other directories. It should be noted that other testing laboratories

[7]The *Federal Register* is available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 (telephone 202-783-3238) on a subscription or individual copy basis.
[8]Copies of this bulletin are available from NIOSH Publications Dissemination, 4676 Columbia Parkway, Cincinnati, OH 45226.
[9]UL publications are available from Underwriters Laboratories, 333 Pfingsten Road, Northbrook, IL 60062.

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(where approved) and governmental inspection agencies may maintain additional lists of approved or acceptable equipment; the approval must be for the jurisdiction where the work is to be performed.

The Electrification Council (TEC)[10] representative of the investor-owned utilities publishes several informative handbooks, such as

1) *Industrial and Commercial Power Distribution*
2) *Industrial and Commercial Lighting*
3) An energy analysis computer program, AXCESS, for forecasting electricity consumption and costs in existing and new buildings.

The National Electrical Manufacturers Association (NEMA)[11] represents equipment manufacturers. Its publications serve to standardize certain design features of electrical equipment, and provide testing and operating standards for electrical equipment. Some NEMA Standards contain important application information for electrical equipment, such as motors and circuit breakers.

The IEEE publishes several hundred electrical standards relating to safety, measurements, equipment testing, application, maintenance, and environmental protection.

The following three publications from the IEEE and ANSI are general in nature:

1) IEEE Std 100-1988, IEEE Standard Dictionary of Electrical and Electronics Terms, Fourth Edition (ANSI).
2) IEEE Std 315-1975 (Reaff. 1989), IEEE Standard Graphic Symbols for Electrical and Electronics Diagrams (ANSI, CSA Z99-1975), and Supplement IEEE Std 315A-1986 (ANSI).
3) ANSI Y32.9-1972 (Reaff. 1989), American National Standard Graphic Symbols for Electrical Wiring and Layout Diagrams Used in Architecture and Building Construction. (Important for the preparation of drawings.)

The Electrical Generating Systems Association (EGSA)[12] publishes performance standards for emergency, standby, and co-generation equipment.

The Intelligent Buildings Institute (IBI)[13] publishes standards on the essential elements of “high-tech” buildings.

The Edison Electric Institute (EEI)[14] publishes case studies of electrically space-conditioned buildings as well as other informative pamphlets.

The International Electrotechnical Commission (IEC) is an electrical and electronics standards generating body with a multinational membership. The IEEE is a member of the U.S. National Committee of the IEC.

1.7 Handbooks

The following handbooks have, over the years, established reputations in the electrical field. This list is not intended to be all-inclusive. Other excellent references are available, but are not listed here because of space limitations.

1) Fink, D. G. and Beaty, H. W. *Standard Handbook for Electrical Engineers*, 12th edition, New York: McGraw-Hill, 1987. Virtually the entire field of electrical engineering is treated, including equipment and systems design.

[10] TEC publications are available from the Electrification Council, 1111 19th Street, N.W., Washington, DC 20036.
[11] NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street, N.W., Washington, DC 20037.
[12] EGSA publications are available from the Electrical Generating Systems Association, 10251 West Sample Road, Suite D, P.O. Box 9257, Coral Springs, FL 33075-9257.
[13] IBI publications are available from the Intelligent Buildings Institute, 2101 L Street, N.W., Washington, DC 20037.
[14] EEI publications are available from the Edison Electric Institute, 1111 19th Street, N.W., Washington, DC 20036.

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2) Croft, T., Carr, C. C., and Watt, J. H. *American Electricians Handbook*, 11th edition, New York: McGraw-Hill, 1987. The practical aspects of equipment, construction, and installation are covered.
3) *Lighting Handbook*, Illuminating Engineering Society (IES).[15] This handbook in two volumes (Applications, 1987; Reference, 1984) covers all aspects of lighting, including visual tasks, recommended lighting levels, lighting calculations, and design, which are included in extensive detail.
4) *Electrical Transmission and Distribution Reference Book*,[16] Westinghouse Electric Corporation, 1964. All aspects of transmission and distribution, performance, and protection are included in detail.
5) *Applied Protective Relaying*, Westinghouse Electric Corporation, 1976. The application of protective relaying to commercial-utility interconnections, protection of high-voltage motors, transformers, and cable are covered in detail.
6) *ASHRAE Handbook*,[17] American Society of Heating, Refrigerating, and Air-Conditioning Engineers. This series of reference books in four volumes, which are periodically updated, detail the electrical and mechanical aspects of space conditioning and refrigeration.
7) *Motor Applications and Maintenance Handbook*, second edition, 1987, Smeaton, R. S., ed., McGraw-Hill, 1987. Contains extensive, detailed coverage of motor load data and motor characteristics for coordination of electric motors with machine mechanical characteristics.
8) *Industrial Power Systems Handbook*, Beeman, D. L., ed., McGraw-Hill, 1955. A test on electrical design with emphasis on equipment, including that applicable to commercial buildings.
9) *Electrical Maintenance Hints*, Westinghouse Electric Corporation, 1984. The preventive maintenance procedures for all types of electrical equipment and the rehabilitation of damaged apparatus are discussed and illustrated.
10) *Lighting Handbook*,[18] Philips Lighting Company, 1984. The application of various light sources, fixtures, and ballasts to interior and exterior commercial, industrial, sports, and roadway lighting projects.
11) *Underground Systems Reference Book*, Edison Electric Institute, 1957. The principles of underground construction and the detailed design of vault installations, cable systems, and related power systems are fully illustrated, and cable splicing design parameters are also thoroughly covered.
12) *Switchgear and Control Handbook*, Smeaton, R. S., ed., McGraw-Hill, 1977 (second edition 1987). Concise, reliable guide to important facets of switchgear and control design, safety, application, and maintenance including high- and low-voltage starters, circuit breakers, and fuses.
13) *Handbook of Practical Electrical Design*, McPartland, J. M., ed., McGraw-Hill, 1984.

A few of the older texts may not be available for purchase, but are available in most professional offices and libraries.

1.8 Periodicals

IEEE Spectrum, the monthly magazine of the IEEE, covers all aspects of electrical and electronics engineering with broad-brush articles that bring the engineer up to date. It contains references to IEEE books; technical publication reviews; technical meetings and conferences; IEEE group, society, and committee activities; abstracts of papers and publications of the IEEE and other organizations; and other material essential to the professional advancement of the electrical engineer.

The transactions of the IEEE Industrial Applications Society are directly useful to commercial building electrical engineers. Following are some other well-known periodicals:

1) *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers.
2) *Electrical Construction and Maintenance (EC&M)*, Intertec Publishing Corp.[19]
3) *Fire Journal*, National Fire Protection Association (NFPA).

[15]IES publications are available from the Illuminating Engineering Society, 345 East 47th Street, New York, NY 10017.
[16]Westinghouse publications are available from Westinghouse Electric Corporation, Printing Division, Forbes Road, Trafford, PA 15085.
[17]ASHRAE publications are available from the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 1791 Tullie Circle, N.E., Atlanta, GA 30329.
[18]Phillips Lighting publications are available from Phillips Lighting Company, 200 Franklin Square Drive, P.O. Box 6800, Somerset, NJ 08875-6800.
[19]EC&M publications are available from EC&M, Intertec Publishing Corporation, 1221 Avenue of the Americas, New York, NY 10020.

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4) *IAEI News*, International Association of Electrical Inspectors.[20]
5) *Lighting Design and Application (LD&A)*, Illuminating Engineering Society
6) *Electrical Systems Design*, Andrews Communications Inc.[21]
7) *Engineering Times*, National Society of Professional Engineers (NSPE).[22]
8) *Consulting-Specifying Engineer*, Cahners Publishing Company.[23]
9) *Plant Engineering*, Cahners Publishing Company.

1.9 Manufacturers' Data

The electrical industry, through its associations and individual manufacturers of electrical equipment, issues many technical bulletins, data books, and magazines. While some of this information is difficult to obtain, copies should be available to each major design unit. The advertising sections of electrical magazines contain excellent material, usually well illustrated and presented in a clear and readable form, concerning the construction and application of equipment. Such literature may be promotional; it may present the advertiser's equipment or methods in its best light and should be carefully evaluated. Manufacturers' catalogs 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. A few manufacturers publish regularly scheduled magazines containing news of new products and actual applications. Data sheets referring to specific items are almost always available from marketing offices.

1.10 Safety

Safety of life and preservation of property are two of the most important factors in the design of the electric system. This is especially true in commercial buildings because of public occupancy, thoroughfare, and high occupancy density. In many commercial buildings, the systems operating staff have very limited technical capabilities and may not have any specific electrical training.

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

Personnel safety may be divided into two categories:

1) Safety for maintenance and operating personnel
2) Safety for the general public

Safety for maintenance and operating personnel is achieved through the 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, grounding methods, and identification of equipment.

Safety for the general public requires that all circuit-making and circuit-breaking equipment, as well as other electrical apparatus, be isolated from casual contact. This is achieved by using dead-front equipment, locked rooms and enclosures, proper grounding, limiting of fault levels, installation of barriers and other isolation (including special ventilating grills), proper clearances, adequate insulation, and similar provisions outlined in this recommended practice.

The U.S. Department of Labor has issued the "Rule on Lockout/Tagout" published in the *Federal Register* (53 FR 1546) [18], January 2, 1990, which is concerned with procedures for assuring the safety of workers who are directly involved in working with or near energized conductors or conductors that, if energized, could be hazardous.

[20] IAEI publications are available from the International Association of Electrical Inspectors, 930 Busse Highway, Park Ridge, IL 60068.
[21] This publication is available from Andrews Communications, Inc., 5123 West Chester Pike, P.O. Box 556, Edgemont, PA 19028.
[22] NSPE publications are available from the National Society of Professional Engineers, 1420 King Street, Alexandria, VA 22314.
[23] This publication is available from Cahners Publishing Company, Cahners Plaza, 1350 East Touhy Avenue, P.O. Box 5080, Des Plaines, IL 60017-8800.

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ANSI C2-1990, National Electrical Safety Code (NESC) [1] is available from the IEEE. It covers basic provisions for safeguarding from hazards arising from the installation, operation, or maintenance of (1) conductors in electric supply stations, and (2) overhead and underground electrical supply and communication lines. It also covers work rules for construction, maintenance, and operation of electrical supply and communication equipment. Part 4 of the NESC deals specifically with safe working methods.

Circuit protection is a fundamental safety requirement of all electric systems. Adequate interrupting capacities are required in services, feeders, and branch circuits. Selective, automatic isolation of faulted circuits represents good engineering practice. Fault protection, which is covered in Chapter 9, should be designed and coordinated throughout the system. Physical protection of equipment from damage or tampering, and exposure of unprotected equipment to electrical, chemical, and mechanical damage is necessary.

1.10.1 Appliances and Equipment

Improperly applied or inferior materials can cause electrical failures. The use of appliances and equipment listed by the Underwriters Laboratories (UL), Inc., or other approved laboratories is recommended. The Association of Home Appliance Manufacturers (AHAM)[24] and the Air-Conditioning and Refrigeration Institute (ARI)[25] specify the manufacture, testing, and application of many common appliances and equipment. High-voltage equipment and power cable is manufactured in accordance with IEEE, UL, NEMA, and ANSI Standards, and the engineer should make sure that the equipment he or she specifies and accepts 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 utilizing such methods as life-cycle cost analysis, and related techniques.

1.10.2 Operational Considerations

When the design engineers lay out equipment rooms and locate electrical equipment, they cannot always avoid having some areas accessible to unqualified persons. Dead-front construction should be utilized whenever practical. Where dead-front construction is not available (as in existing installations), all exposed electrical equipment should be placed behind locked doors or gates or otherwise suitably “guarded.”

In commercial buildings of modern design, the performance of work on live power systems should be prohibited unless absolutely necessary, and then only if qualified personnel are available to perform such work.

A serious cause of failure, 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 and barriers, and by enforcement of published work safety rules, the designer can minimize this hazard. Unanticipated backfeeds through control circuitry from capacitors, instrument transformers, or test equipment presents a danger to the worker.

Protective devices, such as ground-fault relays and ground-fault detectors (for high-resistance or ungrounded systems), will minimize damage from electrical failures. Electrical fire and smoke can cause staff to disconnect all electric power, even if there is not direct danger to the occupants. Electrical failures that involve smoke and noise, even though occurring in nonpublic areas, may panic occupants. Nuisance tripping can be minimized by careful design and selection of protective equipment.

1.11 Maintenance

Maintenance is essential to proper operation. The installation should be designed so that maintenance can be performed with normally available maintenance personnel (either in-house or contract). Design details should provide proper space, accessibility, and working conditions so that the systems can be maintained without difficulty and excessive cost.

[24]AHAM publications are available from the Association of Home Appliance Manufacturers, 20 North Wacker Drive, Chicago, IL 60606.
[25]ARI publications are available from the Air-Conditioning and Refrigeration Institute, 1815 North Fort Meyer Drive, Arlington, VA 22209.

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Generally, the external systems are operated and maintained by the electric utility, though at times they are a part of the commercial building distribution system. Where continuity of service is essential, suitable transfer equipment and alternate source(s) should be provided. Such equipment is needed to maintain minimum lighting requirements for passageways, stairways, and critical areas as well as to supply power to critical loads. These systems usually include automatic or manual equipment for transferring loads on loss of normal supply power or for putting battery- or generator-fed equipment into service.

Annual or other periodic shutdown of electrical equipment may be necessary to perform required electrical maintenance. Protective relaying systems, circuit breakers, switches, transformers, and other equipment should be tested on appropriate schedules. Proper system design can facilitate this work.

1.12 Design Considerations

Electrical equipment usually occupies a relatively small percentage of 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 electric systems in terms of layout and placement.

Architectural considerations and appearances are of paramount importance in determining the marketability of a building. 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 negotiate design criteria to accommodate the desires of other members of the design team.

1.12.1 Coordination of Design

The electrical engineer is concerned with professional associates such as the architect, the mechanical engineer, the structural engineer, and, where underground services are involved, the civil engineer. They must also be concerned with the builder and 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, or the project manager; and must cooperate with the safety engineer, fire protection engineer, perhaps the environmental enginner, and a host of other concerned people, such as space planners and interior decorators, all of whom have a say in the ultimate design. The electrical designer must become familiar with local rules and know the authorities having jurisdiction over the design and construction. It can be inconvenient and embarrassing to have an electrical project held up at the last moment because proper permits have not been obtained, for example, a permit for a street closing to allow installation of utilities to the site or an environmental permit for an on-site generator.

Local contractors are usually familiar with local ordinances and union work rules and can be of great help in avoiding pitfalls. 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. Certain electrical work may appear in nonelectrical sections of the specifications. For example, the furnishing and connecting of electric motors and motor controllers may be covered in the mechanical section of the specifications. 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 designer will be concerned are: preliminary cost estimates, final cost estimates, plans or drawings, technical specifications (which are the written presentation of the work), materials, manuals, factory inspections, laboratory tests, and temporary power. The designer may also be involved in providing information on electrical considerations that affect financial justification of the project in terms of owning and operating costs, amortization, return on investment, and related items.

Many electrical designs follow the concept of competitiveness in the commercial sense. Here, cost is a primary consideration, and such designs tend toward minimum code requirements. There is great pressure on the designer to consider cost above maintainability and long life. However, the experienced designer can usually adopt effective compromises.

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In cases where the owner or builder is the ultimate occupant, and in buildings such as libraries, municipal buildings, and hospitals, considerations of safety, long life, use by the public, and even prestige may dictate a type of construction often referred to as "institutional." Such design emphasizes reliability, resistance to wear and use, safety to public, and special aesthetic considerations, such as the "agelessness" of the structure. Smaller buildings, shops, and stores may provide more latitude to the designers in that they are, within budget limitations, subject to a minimum of control in selecting lighting fixtures, equipment, and accessories.

1.12.2 Flexibility

Flexibility of the electric system means the adaptability to development and expansion as well as to changes to meet varied requirements during the life of the building. Often a designer is faced with providing utilities where the loads may be unknown. For example, many office buildings are constructed with the tenant space designs incomplete ("shell and core" designs). In some cases, the designer will provide only the core utilities available for connection by others to serve the working areas. In other cases, the designer may lay out only the basic systems and, as tenant requirements are developed, fill in the details. Often the tenant provides all of his or her own working space designs.

Because it is usually difficult and costly to increase the capacity of risers and feeders, it is important that provisions for sufficient capacity be provided initially. Extra conductors or raceway space should be included in the design stage if additional loads may be added later. This consideration is particularly important for commercial buildings with the increasing use of electronic equipment and air conditioning. The cost and difficulties in obtaining space for new feeders and larger switchgear, which would be required when modernizing or expanding a building, may well be considered in the initial design. A load growth margin of 50% applied to the installed capacity of the major feeders is often justified where expansion is anticipated. Each project deserves careful consideration of the proper load growth margin to be allowed.

Flexibility in an electric wiring system is enhanced by the use of oversize or spare raceways, cables, busways, and equipment. The cost of making such provisions is usually relatively small in the initial installation.

Empty riser shafts and holes through floors may be provided at relatively low cost for future work. Consideration should be given to the provision of satellite electric closets initially for future expansion. Openings through floors should be filled in with fireproof, easily removed materials to prevent the spread of fire and smoke between floors. For computer rooms and the like, flexibility is frequently provided by raised floors made of removable panels, providing access to a wiring space between the raised floor and the slab below.

1.12.3 Specifications

A contract for installation of electric systems consists of a written document and drawings. These become part of the contract, which contains legal and engineering sections. The legal nontechnical sections contain the general terms of the agreement between contractor and owner, such as payment, working conditions, and time requirements; and it may include clauses on performance bonds, extra work, penalty clauses, and damages for breach of contract.

The engineering section consists of the technical specifications. The specifications give descriptions of the work to be done and the materials to be used. In larger installations, it is common practice to use a standard outline format listing division, section, and subsection titles or subjects of the Construction Specifications Institute (CSI).[26] Where several specialties are involved, CSI Division 16 covers the electrical installation and CSI Division 15 covers the mechanical portion of the work. The building automation system, integrating several building control systems, is covered in CSI Division 13, Special Construction. It is important to note that some electrical work will almost always be included in CSI Divisions 13 and 15. Each division has a detailed breakdown of various items, such as switchgear, motor starters, and lighting equipment as specified by CSI.

[26]CSI publications are available from the Construction Specifications Institute, 601 Madison Street, Industrial Park, Alexandria, VA 22314.

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In order to assist the engineer in preparing contract specifications, standard technical specifications (covering construction, application, technical, and installation details) are available from technical publishers and manufacturers (which may require revision to avoid proprietary specifications). Large organizations, such as the U.S. General Services Administration (GSA) and the Veterans Administration (VA) develop their own standard specifications. In using any prepared or computer-generated specification, it should be understood that a detailed review of the generated document will be necessary to ensure a meaningful product. Where a high degree of unique considerations are involved, these tools may be useful only as a guide.

MASTERSPEC, issued by the American Institute of Architects (AIA),[27] permits the engineer to issue full-length specifications in a standardized format. SPECTEXT II, which is an abridged computer program with similar capabilities, is issued by CSI. The U.S. Army Corps of Engineers publishes *The Corps of Engineers Guide Specifications*, known as "CEGS;" and the *U.S. Navy publishes the U.S. Naval Facilities Engineering Command Guide Specifications*, known as "NFGS" (Naval Facilities Guide Specifications).

Computer-aided specifications (CAS) are being developed that will automatically develop specifications as an output from the computer-aided engineering/computer-aided design and drafting (CAE/CADD) process.

1.12.4 Drawings

Designers will usually be given preliminary architectural drawings as a first step. These will permit them to arrive at the preliminary scope of the work; roughly estimate the requirements for, and determine in a preliminary way, the location of equipment; and the methods and types of lighting. In this stage of the design, such items as hung ceilings, recessed or surface-mounted fixtures, and general types of distribution will be decided. It is important to discuss the plans with the senior engineer, and with the architect who has the advantage of knowing the type of construction and building finishes. The mechanical engineer will indicate the mechanical loads that will exist.

It is during this early period that the designer should emphasize the need for: room to hang conduits and other raceways, crawl spaces, structural reinforcements for heavy equipment, special floor loadings; clearances around switchgear, transformers, busways, cable trays, panelboards, and switchboards; and other items that may be required. It is much more difficult to obtain such special requirements once the design has been committed.

The single-line diagrams should then be prepared in conformity with the utility's service requirements. Based on these, the utility will develop a service layout. Electrical drawings are based on architectural drawings and, while prepared at the same time as the structural and mechanical drawings, they are usually the last ones completed because of the need to resolve physical interferences.

Checking is an essential part of the design process. The checker looks for design deficiencies in the set of plans. It is usually a shock to the young designer or drafter when he or she receives their first drawing marked up in red to indicate all kinds of corrections that are required. The designer can help the checker by having at hand reference and catalog information detailing the equipment he or she has selected. The degree of checking is a matter of design policy.

CAE and CADD are tools by which the engineer/designer can perform automatic checking of interferences and clearances with other trades. The development of these computer programs has progressed to the level of automatically performing load flow analysis, fault analysis, and motor starting analysis from direct entry of the electrical technical data of the components and equipment.

1.12.5 Manufacturers' or Shop Drawings

After the design has been completed and contracts are awarded, manufacturers and other suppliers will submit manufacturers' or shop drawings for approval or information. It is important to return these shop drawings as quickly as possible, otherwise the contractor may claim that his or her work was delayed by failure to receive approval or other permission to proceed. Unless drawings are unusable, it is a good idea not to reject them but to stamp the drawings

[27] AIA publications are available from the American Institute of Architects, 1735 New York Avenue, N.W., Washington, DC 20006.

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approved as noted and mark them to show changes and corrections. The supplier can then make whatever changes are indicated and will not have to wait for a completely approved set of drawings before commencing work.

Unless otherwise directed, communications with contractors and suppliers is always through the construction (often inspection) authority. In returning corrected shop drawings, remember that the contract for supplying the equipment usually rests with the general contractor and that the official chain of communication is through him or her. Sometimes, direct communication with a subcontractor or a manufacturer may be permitted; however, the content of such communication should always be confirmed in writing with the general contractor. Recent lawsuits have resulted in the placing of responsibility for shop drawing correctness (in those cases and possibly future cases) on the design engineer, leaving no doubt that checking is an important job.

1.13 Estimating

A preliminary estimate is usually requested. Sometimes, the nature of a preliminary estimate makes it nothing more than a good guess. Enough information is usually available, however, to perform the estimate on a square foot or similar basis. The preliminary estimate becomes part of the overall feasibility study for the project.

A second estimate is often provided after the project has been clearly defined, but before any drawings have been prepared. The electrical designer can determine the type of lighting fixtures and heavy equipment that is to be used from sketches and architectural layouts. Lighting fixtures as well as most items of heavy equipment can be priced directly from catalogs, using appropriate discounts.

The most accurate estimate is made when drawings have been completed and bids are about to be received or the contract negotiated. In this case, the estimating procedure of the designer is similar to that of the contractor's estimator. It involves first the take-offs, that is, counting the number of receptacles, lighting fixtures, lengths of wire and conduit, determining the number and types of equipment, and then applying unit costs for labor, materials, overhead, and profit. The use of standard estimating sheets is a big help. Various forms are available from the National Electrical Contractors Association (NECA).[28] For preliminary estimates, there are a number of general estimating books that give unit cost (often per square foot) figures and other general costs, such as *Building Construction Cost Data, Mechanical Cost Data, and Electrical Cost Data* by R. S. Means.[29] Several computer programs permit the streamlining and standardizing of engineering estimating.

The estimator/designer must include special costs, such as vehicles, temporary connections, temporary or construction power, rental of special tools, scaffolding, and many other items. Because of interference with local operations, as at a public terminal, work may have to be performed during overtime periods. Electricians generally receive overtime premium pay, usually at a rate of time-and-a-half or double-time.

Electrical base pay may represent about half the total cost when considering employee benefits, overhead, and supervision. The designer will typically estimate 15% to 25% for overhead and 10% for profit, with possibly an additional 5% to 10% markup when the electrical contractor is a subcontractor.

In pricing equipment and materials, manufacturers' catalogs can be used. There is often an appropriate discount to be applied that may be listed in the front of the catalog. The determination of the correctness of this discount and which discount table is to be used must be made by the distributor or manufacturer. Many companies publish a catalog with list prices and simply issue revised discount lists to take care of price changes. Certain items, for example, copper cable, vary in price from day to day, dependent upon the cost of base materials. When the owner purchases equipment or materials for installation by the contractor, costs for the installation, handling, overhead, and profit will be added on by the contractor.

[28]Write to the National Electrical Contractors Association, 7315 Wisconsin Avenue, Bethesda, MD 20814.
[29]To obtain this publication, write to R. S. Means Company, 100 Construction Plaza Avenue, Kingston, MA 02364.

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Extra work ("extras") is that work performed by the contractor that has to be added to the contract for unforeseen conditions or changes in the scope of work. The contractor is not usually faced with competition in making these changes, therefore, extra work is expected to be more costly than the same work if included in the original contract. Extra cost on any project can be minimized by greater attention to design details in the original planning stage. On rehabilitation or modification work, extras are more difficult to avoid; however, with careful field investigation, extras can be held to a minimum.

1.14 Contracts

Contracts for construction may be awarded on either a lump-sum or a unit-price basis, or on a cost-plus (time-and-material) basis. Lump sum involves pricing the entire job as one or several major units of work.

The unit-price basis simply specifies so much per unit of work, for example, so many dollars per foot of 3 inch conduit. The lump-sum contract is usually preferable when the design can be worked out in sufficient detail. The unit-price contract is desirable when it is not possible to determine exactly the quantities of work to be performed and where a contractor, in order to provide a lump-sum contract, might have to overestimate the job to cover items that he or she could not accurately determine from the drawings.

If the unit-price basis is used, the estimated quantities should be as accurate as possible, otherwise it may be advantageous for the contractor to quote unit prices of certain items as high as possible and reduce other items to a minimum figure. It could be to the contractor's advantage to list those items on which he or she would receive payment first or which would be most likely to increase in quantity at their highest prices.

The time-and-material basis is valuable for emergency or extra work where it would be impractical to use either of the above two methods. It has the disadvantage of requiring a close audit of manpower and material expenditures of the contractor. Where only part of the work is not clearly defined, a combination of these three methods of pricing might be in order.

1.15 Building Access and Loading

It is imperative that the equipment fit into the area specified, and that the floor load rating is adequate for the weight of the equipment. Sizes of door openings, corridors, and elevators for the moving of equipment (initially and for maintenance and replacement purposes) should be checked. However, it is easy to forget that equipment has to be moved across floors, and that the floor load ratings of the access areas for moving the equipment should be adequate. If floor strengths are not adequate, provision should be made to reinforce the floor, or, if practical, to specify that the load be distributed so that loading will not exceed structural limitations.

It is important to review weights and loadings with the structural engineers. Sometimes, it is necessary to provide removable panels, temporarily remove windows, and even to make minor structural changes in order to move large and heavy pieces of equipment or machinery. Provisions should also be made for removal of equipment for replacement purposes. Clearances should be in accordance with code provisions regarding working space. Clearance should also be provided for installation, maintenance, and such items as cable pulling, transformer replacement, maintenance/testing, and switchgear-drawout space. It is often essential to phase items of work in order to avoid conflict with other electrical work or the work of other trades.

1.16 Contractor Performance

Contractors may be selected on the basis of bid or quoted price or by negotiation. Governmental or corporate requirements may mandate the selection of the lowest qualified bidder. Where the relative amount of electrical work is large, the contract may be awarded to an electrical contractor. In other instances, the electrical work may be awarded as a subcontract by the overall or general contractor, except where prohibited by state law, as in New York, for certain public works.

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The performance of the work will usually be monitored and inspected by representatives of the owner or architect/engineer. The work is subject to the inspection of governmental and other assigned approval agencies, such as insurance underwriters. The designer may communicate with the contractor only to the extent permitted by the agency exercising control over the contract: the architect, builder, or general contractor, as may be appropriate. It is essential that the designers, in attempting to expedite the contract, not place themselves in the position of requesting or interpreting into the contract things that are not clearly required by the specifications or drawings without proper authorization.

The contract may require the contractor to deliver, at the end of the work, revised contract drawings, known as "as-built" drawings. These show all changes in the work that may have been authorized or details that were not shown on the original drawings.

1.17 Environmental Considerations

In all branches of engineering, an increasing emphasis is being placed on social and environmental concerns. Today's engineer must consider air, water, noise, lighting, and all other items that have an environmental impact. For example, see IEEE Std 980-1987, IEEE Guide for Containment and Control of Oil Spills in Substations (ANSI) [14] and IEEE Std 640-1985, IEEE Guide for Power Station Noise Control [11]. The limited availability of energy sources and the steadily increasing cost of electric energy require a concern with energy conservation.

These items are becoming more than just a matter of conscience or professional ethics. Laws, codes, rules, and standards issued by legislative bodies, governmental agencies, public service commissions, insurance, and professional organizations (including groups whose primary concern is the protection of the environment and conservation of natural resources) increasingly require an assessment of how the project may affect the environment. Energy conservation is covered in Chapter 17. Environmental studies, which include the effects of noise, vibration, exhaust gases, lighting, and effluents must be considered in their relationship to the immediate and the general environment and the public.

Pad-type transformers (see Chapter 5) can eliminate unsightly fences and walls, where design considerations permit. Landscape architects can provide pleasing designs of trees and shrubbery to completely conceal outdoor substations, and, of course, overhead lines may be replaced by underground systems. Substations situated in residential areas must be carefully located so as not to create a local nuisance. Pre-case sound barriers can reduce transformer and other electrical equipment noise. Floodlighting and parking lot lighting must not spill onto adjacent areas where it may provide undesirable glare or lighting levels (see IES Committee Report CP-46-85, *Astronomical Light Pollution and Light Trespass* [21]). The engineer should keep up to date on developments in the areas of environmental protection and energy conservation; Environmental Protection Agency (EPA) guidelines and judicial rulings, and local environmental litigation are generally covered in the *Federal Register* [18] and in the periodicals previously listed.

1.18 Technical Files

Drawings and other technical files are often kept in file cabinets as originals or copies. A system of filing and reference is essential where many such items are involved. A computerized database may be a valuable method of referencing and locating the proper document.

When drawings are produced by computer graphic systems, such as CADD, magnetic tape may be used for storage. Plotters can be used with computer systems to produce hard copy. Original drawings (often prepared on "tracing" material) can be stored photographically on film; the drawings can also be made available on viewers or enlarger-printers. Microfiche involves the placing of microfilm on computer-type cards for handling manually or in data-processing-type systems.

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1.19 Electronic Systems

Electronic systems are a major item in commercial buildings: for control purposes, motor control, lighting ballasts, communication systems, data processing, computer applications, data management, and building management systems.

1.20 Power Supply Disturbances

The power supply to equipment may contain transients and other short-term undervoltages or overvoltages, which result primarily from switching operations, faults, motor starting, (particularly large airconditioning chiller motors), and lightning disturbances.

The system may also contain a harmonic content as described in 1.20.2 below. These electrical disturbances may be introduced anywhere on an electric system or in the utility supply, even by other utility customers connected to the same circuits. A term frequently applied to describe the absence or presence of these power supply deficiencies is "power quality" P1100 (Recommended Practice for Power and Grounding Sensitive Electronic Equipment in Industrial and Commercial Power Systems [the "Emerald Book"]) will examine in detail the effects of the power supply on equipment performance. It will also cover methods of diagnosing and correcting performance problems related to the power supply.

1.20.1 Harmonics

Chapter 9 of IEEE Std 141-1986 (ANSI) [6], Chapter 10 of IEEE Std 399-1990 (ANSI) [7], P1100 (the "Emerald Book"), and IEEE Std 519-1981 [9] all contain discussions of harmonics. Harmonics are integral multiples of the fundamental (line) frequency involving nonlinear loads or control devices, including electromagnetic devices (transformers, lighting ballasts), and solid-state devices (rectifiers, thyristors, phase controlled switching devices). In the latter grouping are power rectifiers, adjustable speed electronic controllers, switching-mode power supplies (used in smaller computers), and UPS systems.

Harmonics can cause or increase electromagnetic interference in sensitive electronic systems, abnormal heating of cables, motors, transformers, and other electromagnetic equipment, excessive capacitor currents, and excessive voltages because of system resonances at harmonic frequencies.

Recently, it has been determined that the harmonic content of multiwire systems having a high proportion of switching-mode power supplies is very high. The neutral conductors of these systems should be sized at greater than full rating; transformers derated or designed for high-harmonic content should be used.

A full discussion of harmonics is beyond the scope of this section; reference should be made to the above listed texts.

1.20.2 Electromagnetic Interference (EMI)

EMI is the impairment of a wanted electromagnetic signal by an electromagnetic disturbance. EMI can enter equipment either by conduction through power, grounding, control, data, or shielding conductors; or by induction from local electromagnetic or electrostatic fields. The most common causes of EMI problems in sensitive equipment, such as computers, communications equipment, and electronic controllers, are poor inherent design of the equipment or power supply, poor grounding, and unsound design of the equipment interfaces.

It can be reduced by the use of effective grounding (both electronic and equipment grounds); shielding, twisted conductors (pairs), and coaxial cables; effective use of conduit (especially steel conduit) for control and power circuits (where practical) (see IEEE Std 518-1982 [8] and Reference [19]). EMI and other power problems can cause control and equipment malfunctions, slowing of computer operations, lack of reliability, and failure of critical systems. These failures can affect product quality and, in some cases, worker safety.

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The use of filters, voltage regulators, surge capacitors, surge arresters, isolation transformers (particularly with electrostatic shielding between coils), power conditioners, UPS systems, or motor-generator sets used for isolation are all methods of reducing EMI. Fiber-optic cables and electro-optical isolation at interfaces are extremely effective methods of providing isolation between systems.

1.20.3 Programmable Logic Controller (PLC)

The PLC is a microprocessor designed for control and telemetering systems. It is programmed to accept ladder-type logic, which enables the operator to use relay-type logic; which, in turn, avoids the need to use the conventional software languages. The equipment can be housed in weather and environmental contaminant-resistant housings for field use.

1.21 Definitions

The following definitions should be used in conjunction with this recommended practice:

air, ambient: *See* ambient air.

air, recirculated: *See* recirculated air.

air, return: *See* return air.

air conditioning: The process of treating air so as to simultaneously control temperature, humidity, and distribution to the conditioned space.

air ventilation: The amount of supply air required to maintain the desired quality of air within a designated space.

ambient air: The air surrounding or occupying a space or object.

ballast: An electrical device that is used with one or more discharge lamps to supply the appropriate voltage to a lamp for starting, to control lamp current while it is in operation, and, usually, to provide for power factor correction.

branch-circuit load: The load on that portion of a wiring system extending beyond the final overcurrent device protecting the circuit.

brightness: The subjective attribute of any light sensation, including the entire scale of the qualities “bright,” “light,” “brilliant,” “dim,” and “dark”.

British thermal unit (Btu): The quantity of heat required to raise one pound of water 1 °C.

cable tray: A unit or assembly of units or sections, and associated fittings, made of metal or other noncombustible material forming a continuous rigid structure used to support cables.

calorie: The quantity of heat required to raise one gram of water 1 °F.

capacity, heat: *See* heat capacity.

chromaticity: The measure of the warmth or coolness of a light source, which is expressed in the Kelvin (K) temperature scale.

coefficient of performance (heat pump): Ratio of heating effect produced to the energy supplied.

coefficient of utilization (CU): For a specific room, the ratio of the average lumens delivered by a luminaire to a horizontal work plane to the lumens generated by the luminaire's lamps alone.

coincident demand: Any demand that occurs simultaneously with any other demand; also the sum of any set of coincident demands.

“cold” standby redundant UPS configuration: Consists of two independent, non-redundant modules with either individual module batteries or a common battery.

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commercial, residential, and institutional buildings: All buildings other than industrial buildings and residential dwellings.

conductivity, thermal: *See* thermal conductivity.

connected load: The sum of the continuous ratings of the power consuming apparatus connected to the system or any part thereof in watts, kilowatts, or horsepower.

contrast: Indicates the degree of difference in light reflectance of the details of a task compared with its background.

control: Any device used for regulation of a system or component.

creep: Continued deformation of material under stress.

critical load: That part of the load that requires continuous quality electric power for its successful operation.

degree day: A unit based upon temperature difference and time, which is used for estimating fuel consumption and for specifying nominal heating loads of buildings during the heating season. Degree days = Number of degrees (°F) that the mean temperature is below 65 °F × days.

dehumidification: Condensation of water vapor from the air by cooling below the dew point, or removal of water vapor from air by physical or chemical means.

demand (or demand load): The electrical load at the receiving terminals averaged over a specified interval of time. Demand is expressed in kilowatts, kilovoltamperes, kilovars, amperes, or other suitable units. The interval of time is generally 15 minutes, 30 minutes, or 60 minutes.

NOTE — If there are two 50 hp motors (which drive 45 hp loads) connected to the electric power system but only one load is operating at any time, the demand load is only 45 hp but the connected load is 100 hp.

demand factor: The ratio of the maximum demand of a system to the total connected load of the system.

NOTES:

1 — Since demand load cannot be greater than the connected load, the demand factor cannot be greater than unity.

2 — Those demand factors permitted by the NEC (for example, services and feeders) must be considered in sizing the electric system (with few exceptions, this is 100%); otherwise, the circuit may be sized to support the anticipated load.

diversity factor: The ratio of the sum of the individual maximum demands of the subdivisions of the system to the maximum demand of the complete system.

NOTE — Since maximum demand of a system cannot be greater than the sum of the individual demands, the diversity factor will *always* be equal to or greater than unity.

efficacy: *See* lumens per watt (lm/W).

efficiency: The power (kW) output divided by the power (kW) input at rated output.

electric power cable shielding: The practice of confining the electric field of the cable to the insulation surrounding the conductor by means of conducting or semiconducting layers, or both, which are in intimate contact or bonded to the inner and outer surfaces of the insulation.

electromagnetic interference (EMI): The impairment of a wanted electromagnetic signal by an electromagnetic disturbance.

equivalent sphere illumination (ESI): The measure of the effectiveness with which a practical lighting system renders a task visible compared with the visibility of the same task that is lit inside a sphere of uniform luminance.

extra work (extras): Work performed by the contractor that has to be added to the contract for unforeseen conditions or changes in the scope of work.

fixture: *See* luminaire.

flexibility of the electric system: The adaptability to development and expansion as well as to changes to meet varied requirements during the life of the building.

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footcandle (fc): A unit of illuminance (light incident upon a surface) that is equal to 1 lm/ft^2. In the international system, the unit of illuminance is lux (1 fc = 10.76 lux).

footlambert (fL): The unit of illuminance that is defined as 1 lm uniformly emitted by an area of 1 ft^2. In the international system, the unit of luminance is candela per square meter (cd/m^2).

fuse: An overcurrent protective device with a circuit opening, fusible element part that is heated and severed by the passage of overcurrent through it. (To re-energize the circuit, the fuse should be replaced.)

glare: The undesirable sensation produced by luminance within the visual field.

gross demand load: The summation of the demands for each of the several group loads.

heat, specific: The ratio of the quantity of heat required to raise the temperature of a given mass of a substance 1° to the heat required to raise the temperature of an equal amount of water by 1°.

heat capacity: The amount of heat necessary to raise the temperature of a given mass of a substance 1° — the mass multiplied by the specific heat.

heat pump: A refrigerating system employed to transfer heat into a space or substance. The condenser provides the heat, while the evaporator is arranged to pick up heat from the air, water, etc. By shifting the flow of air or other fluid, a heat pump system may also be used to cool a space.

heating system, radiant: A heating system in which the heat radiated from panels is effective in providing heating requirements. The term “radiant heating” includes panel *and* radiant heating.

heating unit, electric: A structure containing one or more heating elements, electrical terminals or leads, electric insulation and a frame or casing, all of which are assembled into one unit.

high-intensity discharge (HID) lamps: A group of lamps filled with various gases that are generically known as mercury, metal halide, high-pressure sodium, and low-pressure sodium.

high voltage: A class of nominal system voltages equal to or greater than 100 000 V and equal to or less than 230 000 V.

humidity: Water vapor within a given space.

humidity, relative: The ratio of the mole fraction of water vapor that is present in the air to the mole fraction of water vapor that is present in saturated air.

infiltration: Leakage of outside air into a building.

illuminance: The unit density of light flux (lm/unit area) that is incident on a surface.

institutional design: Emphasizes reliability, resistance to wear and use, safety to public, and special aesthetic considerations, such as the “agelessness” of the structure.

insulation, thermal: *See* thermal insulation.

interrupter switch: An air switch equipped with an interrupter that makes or breaks specified currents.

isolated redundant UPS configuration: Uses a combination of automatic transfer switches and a reserve system to serve as the bypass source for any of the active systems.

isothermal: A process that occurs at a constant temperature.

kilowatt: A measure of the instantaneous power requirement. lag. The delay in action of a sensing element of a control element. lamp. Generic term for a manmade source of light.

load, estimated maximum: The calculated maximum heat transfer that a heating or cooling system will be called upon to provide.

load factor: The ratio of the average load over a designated period of time to the peak load occurring in that period.

load profile: The graphic representation of the demand load, usually on an hourly basis, for a particular day.

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low voltage: A class of nominal system voltages 1000 V or less.

lumen (lm): The international unit of luminous flux or the time rate of the flow of light.

lumens per watt (lm/W): The ratio of lumens generated by a lamp to the watts consumed by the lamp. *See also* efficacy.

luminaire: A complete lighting unit that consists of parts designed to position a lamp (or lamps) in order to connect it to the power supply and to distribute its light.

luminaire efficiency: The ratio of lumens emitted by a luminaire and of the lumens generated by the lamp (or lamps) used.

luminance: The light emanating from a light source or the light reflected from a surface (the metric unit of measurement is cd/m^2).

lux: The metric measure of illuminance that is equal to 1 lm uniformly incident on 1 m^2 (1 lux = 0.0929 fc).

maximum demand: The greatest of all the demands that have occurred during a specified period of time; determined by measurement over a prescribed time interval.

maximum system voltage: The highest system voltage that occurs under normal operating conditions, and the highest system voltage for which equipment and other components are designed for satisfactory continuous operation without derating of any kind.

medium voltage: A class of nominal system voltages greater than 1000 V and less than 100 000 V.

nominal system voltage: The voltage by which a portion of the system is designated, and to which certain operating characteristics of the system are related. Each nominal system voltage pertains to a portion of the system that is bounded by transformers or utilization equipment.

nominal utilization voltage: The voltage rating of certain utilization equipment used on the system.

nonredundant UPS configuration: Consists of one or more UPS modules operating in parallel with a bypass circuit transfer switch and a battery.

parallel redundant UPS configuration: Consists of two or more UPS modules with static inverter turn-off(s), a system control cabinet, and either individual module batteries or a common battery.

peak load: The maximum load of a specified unit or group of units in a stated period of time.

radiator: A heating unit that provides heat transfer to objects within a visible range by radiation and by conduction to the surrounding air, which is circulated by natural convection.

rated life of a ballast or a lamp: The number of burning hours at which 50% of the units have burned out and 50% have survived.

recirculated air: Return air passed through the air conditioner before being supplied again to the conditioned space.

return air: Air returned from the conditioned space.

reflectance: The ratio of the light reflected by a surface to the light incident.

relative visual performance (RVP): The potential task performance based upon the illuminance and contrast of the lighting system performance.

service voltage: The voltage at the point where the electric system of the supplier and the electric system of the user are connected.

short-circuit current: An overcurrent resulting from a fault of negligible impedance between live conductors having a difference in potential under normal operating conditions. The fault path may include the path from active conductors via earth to neutral.

solar constant: The solar intensity incident on a surface that is oriented normal to the sun's rays and located outside the earth's atmosphere at a distance from the sun that is equal to the mean distance between the earth and the sun.

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subtransient reactance: The apparent reactance of the stator winding at the instant the short circuit occurs.

symmetrical: The shape of the ac current waves about the zero axis (when both sides have equal value and configuration).

synchronous reactance: The reactance that determines the current flow when a steady-state condition is reached.

system voltage: The root-mean-square phase-to-phase voltage of a portion of an ac electric system. Each system voltage pertains to a portion of the system that is bounded by transformers or utilization equipment.

task-ambient lighting: A concept involving a component of light directed toward tasks from appropriate locations by luminaires located close to the task for energy efficiency.

temperature, dew point: The temperature at which condensation of water vapor begins in a space.

temperature, dry bulb: The temperature of a gas, or a mixture of gases, that is indicated by an accurate thermometer after correction for radiation.

temperature, effective: An arbitrary index that combines, into a single value, the effects of temperature, humidity, and air movement on the sensation of hot or cold felt by the human body.

temperature, wet bulb: The temperature at which liquid or solid water, by evaporating into the air, can bring the air into saturation adiabatically at the same temperature.

therm: A quantity of heat that is equal to 100 000 Btu.

thermal conductivity: The time rate of heat flow through a unit area of a homogeneous substance under steady conditions when a unit temperature gradient is maintained in the direction that is normal to the area.

thermal diffusivity: Thermal conductivity divided by the product of density and specific heat.

thermal insulation: A material having a high resistance to heat flow and used to retard the flow of heat to the outside.

thermal transmittance (U factor): The time rate of heat flow per unit temperature difference.

thermostat: A device that responds to temperature and, directly or indirectly, controls temperature in a building.

ton of refrigeration: Is equal to 12 000 Btu/hour.

transient overvoltages (or spikes): Momentary excursions of voltage outside of the normal 60 Hz voltage wave.

transient reactance: Determines the current flowing during the period when the subtransient reactance is the controlling value.

transmittance, thermal: *See* thermal transmittance.

uninterruptible power supply (UPS): A device or system that provides quality and continuity of an ac power source.

uninterruptible power supply (UPS) module: The power conversion portion of the uninterruptible power system.

utilization equipment: Electrical equipment that converts electric power into some other form of energy, such as light, heat, or mechanical motion.

utilization voltage: The voltage at the line terminals of utilization equipment.

veiling reflections: Reflected light from a task that reduces visibility because the light is reflected specularly from shiny details of the task, which brightens those details and reduces the contrast with the background.

velocity, room air: The average sustained residual air velocity in the occupied area in the conditioned space.

visual comfort probability (VCP): A rating of a lighting system expressed as a percentage of people who, if seated at the center of the rear of a room, will find the lighting visually acceptable in relation to the perceived glare.

visual task: Work that requires illumination in order for it to be accomplished.

work plane: The plane in which visual tasks are located.

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1.22 References

The following references shall be used in conjunction with this chapter:

[1] ANSI C2-1990, National Electrical Safety Code.

[2] ANSI C84.1-1989, Voltage Ratings for Electric Power Systems and Equipment (60 Hz).

[3] ANSI/NFPA 70-1990, National Electrical Code.

[4] ASHRAE/IES 90.1-1989, Energy Efficient Design of New Buildings Except New Low-Rise Residential Buildings.

[5] IEEE Std 100-1988, IEEE Standard Dictionary of Electrical and Electronics Terms, Fourth Edition (ANSI).

[6] IEEE Std 141-1986, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (ANSI).

[7] IEEE Std 399-1990, IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis (ANSI).

[8] IEEE Std 518-1982, IEEE Guide for the Installation of Electrical Equipment to Minimize Noise Inputs to Controllers from External Sources (ANSI).

[9] IEEE Std 519-1981, IEEE Guide for Harmonic Control and Reactive Compensation of Static Power Converters (ANSI).

NOTE — When the revision of IEEE Std 519-1981 is published, it will supersede IEEE Std 519-1981, and will become a recommended practice.

[10] IEEE Std 602-1986, IEEE Recommended Practice for Electric Systems in Health Care Facilities (ANSI).

[11] IEEE Std 640-1985, IEEE Guide for Power Station Noise Control.

[12] IEEE Std 693-1984, IEEE Recommended Practices for Seismic Design of Substations (ANSI).

[13] IEEE Std 979-1984 (Reaff. 1988), IEEE Guide for Substation Fire Protection (ANSI).

[14] IEEE Std 980-1987, IEEE Guide for Containment of Oil Spills in Substations (ANSI).

[15] NFPA 70E-1988, Electrical Safety Requirements for Employee Workplaces.

[16] NFPA CY-70HB90, NFPA National Electrical Code Handbook, 1990 Edition.

[17] *Electrical Alerts*, U.S. National Institute of Occupational Safety and Health (NIOSH), 4676 Columbia Parkway, Cincinnati, OH 45226.

[18] *Federal Register* (53 FR 1546), U.S. Government Printing Office, Washington, DC 20402 (Telephone: 202-783-3238).

[19] Griffith, D.C. “Uninterruptible Power Supplies,” New York: Marcel Decker, 1989.

[20] *Handbook of the National Electrical Code*, New York: McGraw-Hill.

[21] IES Committee Report CP-46-85, *Astronomical Light Pollution and Light Trespass*.

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