

IEEE Recommended Practice for Electric Power Distribution for Industrial Plants

Sponsor

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

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Abstract: A thorough analysis of basic electrical-systems considerations is presented. Guidance is provided in design, construction, and continuity of an overall system to achieve safety of life and preservation of property; reliability; simplicity of operation; voltage regulation in the utilization of equipment within the tolerance limits under all load conditions; care and maintenance; and flexibility to permit development and expansion. Recommendations are made regarding system planning; voltage considerations; surge voltage protection; system protective devices; fault calculations; grounding; power switching, transformation, and motor-control apparatus; instruments and meters; cable systems; busways; electrical energy conservation; and cost estimation.

Keywords: energy management, grounding, industrial power system, industrial power system economics, industrial power system planning, industrial power system protection, power cables, power distribution, power transformers, power system measurements, switches/switchgear, wiring

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Introduction

(This introduction is not part of IEEE Std 141-1993, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants.)

Development of the IEEE Red Book has been an evolving process. With the publication of IEEE Std 141-1993, the Red Book has been in print for about fifty years. Work began on the seventh edition in 1987 with the participation of more than seventy electrical engineers from industrial plants, consulting firms, equipment manufacturers, and academe. It was sponsored and the final version approved by the Power Systems Design Subcommittee of the Power Systems Engineering Committee, Industrial and Commercial Power Systems Department, IEEE Industry Applications Society. The seventh edition was approved by the IEEE Standards Board in 1993 as an IEEE Recommended Practice. It provides pertinent information and recommended practices for the design, construction, operation, and maintenance of electric power systems in industrial plants.

The first publication was developed in 1945 by the Committee on Industrial Power Applications of the American Institute of Electrical Engineers (AIEE). It was entitled *Electric Power Distribution for Industrial Plants* and sold for \$1.00 a copy. It became known by the nickname “Red Book” because of its red cover, and a precedent was established for the present IEEE Color Book series, which now encompasses ten books.

The second edition was published in 1956. The committee responsible for its preparation had become a subcommittee of the Industrial Power Systems Committee of the AIEE. This edition was identified as AIEE Number 952.

By 1964, the AIEE had become the Institute of Electrical and Electronics Engineers and the third edition was identified as IEEE No. 141. The fourth edition was produced in 1969, approved as an IEEE Recommended Practice, and identified as IEEE Std 141-1969. The fifth edition, published in 1976, was IEEE Std 141-1976, and the sixth edition, published in 1986, became an American National Standard as well as an IEEE Recommended Practice, and was identified as ANSI/IEEE Std 141-1986.

The authors of this 1993 edition wish to acknowledge their indebtedness to the several hundred engineers whose expertise and work culminated in the six previous editions. The present stature of the Red Book would not have been achieved without their efforts.

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Contents

CLAUSE	PAGE
Chapter 1	
Overview.....	1
1.1 Scope and general information	1
1.2 Industrial plants.....	1
1.3 Industry Applications Society (IAS).....	5
1.4 Professional registration.....	6
1.5 Professional liability	7
1.6 Codes and standards.....	7
1.7 Handbooks	10
1.8 Periodicals.....	11
1.9 Manufacturers' Data	12
1.10 Safety	12
1.11 Maintenance	15
1.12 Design considerations	15
1.13 Estimating	19
1.14 Contracts	20
1.15 Access and loading	21
1.16 Contractor performance	21
1.17 Environmental considerations.....	22
1.18 Technical files.....	22
1.19 Electronic systems	22
1.20 Programmable logic controller	24
1.21 Bibliography	24
Chapter 2	
System planning.....	27
2.1 Introduction.....	27
2.2 Definitions.....	27
2.3 Basic design considerations	27
2.4 Planning guide for the supply and distribution system.....	31
2.5 Power system modernization and evaluation studies/programs	56
2.6 References.....	58
2.7 Bibliography	59
Chapter 3	
Voltage considerations.....	61
3.1 General	61
3.2 Voltage control in electric power systems	66
3.3 Voltage selection.....	78
3.4 Voltage ratings for low-voltage utilization equipment	81

CLAUSE	PAGE
3.5 Effect of voltage variations on low-voltage and medium-voltage utilization equipment	82
3.6 Voltage drop considerations in locating the low-voltage secondary distribution system power source.....	86
3.7 Improvement of voltage conditions	87
3.8 Phase-voltage unbalance in three-phase systems.....	89
3.9 Voltage sags and flicker.....	91
3.10 Harmonics	95
3.11 Calculation of voltage drops	96
3.12 References.....	107
3.13 Bibliography	108
 Chapter 4	
Short-circuit current calculations	109
4.1 Introduction.....	109
4.2 Sources of fault current.....	109
4.3 Fundamentals of short-circuit current calculations.....	112
4.4 Restraints of simplified calculations.....	115
4.5 Detailed procedure	124
4.6 Example of short-circuit current calculation for a power system with several voltage levels	138
4.7 Example of short-circuit current calculation for a low-voltage system (under 1000 V).....	158
4.8 Calculation of short-circuit currents for dc systems	170
4.9 References.....	170
4.10 Bibliography	171
 Annex 4A	
Typical impedance data for short-circuit studies.....	173
 Chapter 5	
Application and coordination of protective devices	185
5.1 Purpose.....	185
5.2 Analysis of system behavior and protection needs	187
5.3 Protective devices and their applications.....	192
5.4 Performance limitations	222
5.5 Principles of protective relay application [38], [40], [50]	223
5.6 Protection requirements	238
5.7 Use and interpretation of time-current coordination curves	250
5.8 Specific examples—applying the fundamentals.....	260
5.9 Acceptance testing (commissioning), maintenance, and field testing	281
5.10 Bibliography	304

CLAUSE	PAGE
Chapter 6	
Surge voltage protection	311
6.1 Nature of the problem	311
6.2 Traveling-wave behavior	315
6.3 Insulation voltage withstand characteristics	322
6.4 Arrester characteristics and ratings	330
6.5 Arrester selection	336
6.6 Selection of arrester class.....	338
6.7 Application concepts.....	340
6.8 References.....	355
6.9 Bibliography	357
Chapter 7	
Grounding	363
7.1 Introduction.....	363
7.2 System grounding	363
7.3 Equipment grounding.....	370
7.4 Static and lightning protection grounding.....	375
7.5 Connection to earth.....	379
7.6 Ground resistance measurement	383
7.7 References.....	389
7.8 Bibliography	389
Chapter 8	
Power factor and related considerations	393
8.1 General scope.....	393
8.2 Current and power flow fundamentals.....	394
8.3 Benefits of power-factor improvement.....	397
8.4 Typical plant power factor	402
8.5 Instruments and measurements for power-factor studies.....	404
8.6 Techniques to improve the power factor	405
8.7 Calculation methods for improving power factor	410
8.8 Location of reactive power supply.....	411
8.9 Capacitors with induction motors	412
8.10 Capacitor standards and operating characteristics	422
8.11 Controls for switched capacitors.....	425
8.12 Transients and capacitor switching	427
8.13 Protection of capacitors and capacitor banks.....	435
8.14 Resonance and harmonics.....	437
8.15 Inspection and field testing of power capacitors.....	438
8.16 References.....	440
8.17 Bibliography	442

CLAUSE	PAGE
Chapter 9	
Harmonics in power systems	443
9.1 Introduction.....	443
9.2 Importance of understanding effects of harmonics.....	443
9.3 History of harmonic problems and solutions	444
9.4 Definition and sources of harmonic currents and voltages	445
9.5 Characteristics of harmonics.....	447
9.6 Static power converter theory	449
9.7 System response characteristics.....	455
9.8 Effects of harmonics	458
9.9 Harmonic analysis.....	466
9.10 Mitigation techniques.....	467
9.11 Industry standards	471
9.12 Bibliography	473
Chapter 10	
Power switching, transformation, and motor control apparatus	475
10.1 Introduction.....	475
10.2 Switching apparatus for power circuits.....	478
10.3 Switchgear.....	492
10.4 Transformers	503
10.5 Unit substations.....	519
10.6 Motor control equipment	521
10.7 Adjustable speed drives	529
10.8 Bibliography	532
Chapter 11	
Instruments and meters	537
11.1 Introduction.....	537
11.2 Basic objectives	540
11.3 Switchboard and panel instruments	540
11.4 Portable instruments.....	542
11.5 Recording instruments	543
11.6 Miscellaneous instruments.....	544
11.7 Meters	545
11.8 Auxiliary devices	549
11.9 Typical installations	551
11.10 Bibliography	552
Chapter 12	
Cable systems.....	553
12.1 Introduction.....	553

CLAUSE	PAGE
12.2 Cable construction	554
12.3 Cable outer finishes.....	566
12.4 Cable ratings	570
12.5 Installation.....	579
12.6 Connectors	586
12.7 Terminations	592
12.8 Splicing devices and techniques	601
12.9 Grounding of cable systems.....	605
12.10 Protection from transient overvoltage.....	606
12.11 Testing.....	607
12.12 Locating cable faults.....	613
12.13 Cable specification.....	617
12.14 References.....	617
12.15 Bibliography	619
 Chapter 13	
Busways	621
13.1 Origin	621
13.2 Busway construction.....	621
13.3 Feeder busway	623
13.4 Plug-in busway.....	624
13.5 Lighting busway.....	626
13.6 Trolley busway.....	627
13.7 Standards.....	627
13.8 Selection and application of busways	628
13.9 Layout	634
13.10 Installation.....	635
13.11 Field testing.....	637
13.12 Busways over 600 V (metal-enclosed bus).....	637
13.13 References.....	639
 Chapter 14	
Electrical conservation through energy management	641
14.1 Introduction.....	641
14.2 Finding energy conservation opportunities.....	642
14.3 The energy management process	643
14.4 Calculating energy savings	646
14.5 Load management.....	653
14.6 Efficiencies of electrical equipment.....	655
14.7 Metering	658
14.8 Lighting.....	660
14.9 Cogeneration.....	669
14.10 Peak shaving	670
14.11 Summary	670
14.12 Bibliography	672

CLAUSE	PAGE
Chapter 15	
Industrial substations: plant-utility interface considerations	675
15.1 Introduction.....	675
15.2 Planning stage	678
15.3 Design stage	689
15.4 Construction stage.....	697
15.5 Operating stage	699
15.6 Bibliography	700
Chapter 16	
Cost estimating of industrial power systems	703
16.1 Introduction.....	703
16.2 Information required	703
16.3 Factors to be considered.....	704
16.4 Preparing the cost estimate	704
16.5 Classes of estimates	704
16.6 Equipment and material costs	705
16.7 installation costs.....	705
16.8 Other costs	706
16.9 Example	706
16.10 Bibliography	707
Annex 16A	
Selected sources for cost-estimating information.....	719
Annex A	
Power system device function numbers.....	721
INDEX	729

IEEE Recommended Practice for Electric Power Distribution for Industrial Plants

Chapter 1 Overview

1.1 Scope and general information

This publication provides a recommended practice for the electrical design of industrial facilities. It is likely to be of greatest value to the power-oriented engineer with limited industrial plant experience. It can also be an aid to all engineers responsible for the electrical design of industrial 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 general reference on electrical design for industrial plants and buildings.

Tables, charts, and other information that have been extracted from codes, standards, and other technical literature are included in this publication. Their inclusion is for illustrative purposes; where technical accuracy is important, the latest version of the referenced document should be consulted to assure use of complete, up-to-date, and accurate information.

It is important to establish, at the outset, the terms describing voltage classifications. Table 1-1, adapted from IEEE Std 100-1992 [B5],¹ indicates these voltage levels. The National Electrical Code, described in 1.5.1, 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. All nominal voltages are expressed in terms of root-mean-square (rms). For a detailed explanation of voltage terms, see Chapter 3. ANSI C84.1-1977 [B1] lists voltage class designations applicable to industrial and commercial buildings where medium voltage extends from 1000 V to 69 kV nominal.

1.2 Industrial plants

The term *industrial plants*, as used in this chapter, refers to industrial plants, buildings, and complexes where manufacturing, industrial production, research, and development are performed. It does not include commercial buildings, such as institutional, governmental, public, health-related office buildings, nor apartment and residential buildings.

If commercial buildings are included in industrial complexes, then the use of IEEE Std 241-1990 (the Gray Book) would be appropriate for these specific buildings. If medical facilities

¹The numbers in brackets preceded by the letter B correspond to those of the bibliography in 1.21.

Table 1-1 — Voltage classes

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

are included, IEEE Std 602-1986 (the White Book), should be consulted. (See 1.3.2 for a complete listing of the IEEE Color Books.)

The specific use of the facility or area in question, rather than the overall nature of the facility, 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 industrial plant design is to provide a safe, energy-efficient, and attractive environment for the manufacturing, research, development, and handling of industrial products. The electrical design must satisfy these criteria if it is to be successful.

Today's industrial plants, because of their increasing size, more complex processes, and newer technologies, have become more and more dependent upon adequate and reliable electrical systems. The complex nature of modern industrial plants can be better understood by examining the systems, equipment, and facilities listed in 1.2.1.

1.2.1 System requirements for industrial plants

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

- Building electric service;
- Power distribution systems for manufacturing and process equipment. Plant distribution system for "house loads";
- Power outlet systems for movable equipment: receptacles, trolley systems, plug-in and trolley-busways, festoon-cable systems, and heavy portable cord systems;
- Process control systems, including computer-based equipment such as programmable controllers, robotic equipment, and special-purpose controllers of the relay or solid-state types. On-line, real-time computer systems;
- Materials handling systems: cranes, hoists, distribution systems, automated systems that identify and distribute products (as well as update production data bases);
- Lighting: interior and exterior, security and decorative, task and general lighting;
- 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, medical alert, emergency and medical call, and a variety of other signal systems;
- Fire alarm systems: fire pumps and sprinklers, smoke and fire detection, alarm systems, and emergency public-address systems. Emergency alarm systems relating to dangerous process control failure conditions;
- Transportation: passenger and freight elevators, moving stairways, and dumbwaiters;
- Space-conditioning: heating, ventilation, and air-conditioning. Ambient temperature and dew-point controls relating to the specific manufacturing processes;
- Sanitation: garbage and rubbish storage, recycling, compaction and removal, document disposal equipment, incinerators, and sewage handling. Handling and storage of environmentally hazardous and sensitive waste materials;
- Environmental containment of materials classified as hazardous to the environment, including maintenance of containment systems (e.g., pressure, temperature);
- Plumbing: hot and cold water systems and water-treatment facilities;
- Security watchmen, burglar alarms, electronic access systems, and closed-circuit surveillance television;

- Business machines: typewriters, computers, calculating machines, reproduction machines, and word processors;
- Refrigeration equipment;
- Compressed air, vacuum systems, process gas storage and handling systems;
- “Clean or secure areas” for isolation against contaminants and/or electromagnetic and radio-frequency interference (EMI/RFI);
- Food handling, dining and cafeteria, and food preparation facilities;
- Maintenance facilities;
- Lightning protection;
- Automated facility control systems;
- Showrooms, training areas;
- Medical facilities;
- Employee rest and recreational areas;
- In-plant generation, cogeneration, and total energy provisions. Legally required and optional standby/emergency power and peak-shaving systems;
- Signing, signaling, and traffic control systems. Parking control systems, including automated parking systems.

1.2.2 Electrical design elements

In spite of the wide variety of industrial buildings, some electrical design elements are common to all. These elements, listed below, will be discussed generally in this chapter and in detail in the remaining chapters of this Recommended Practice. The principal design elements considered in the design of the power, lighting, and auxiliary systems include the following:

- Magnitudes, quality, characteristics, demand, and coincidence or diversity of loads and load factors;
- Service, distribution, and utilization voltages and voltage regulation;
- Flexibility and provisions for expansion;
- Reliability, continuity;
- Safety of personnel and property;
- Initial and maintained cost (“own-and-operate” costs);
- Operation and maintenance;
- Fault current and system coordination;
- Power sources;
- Distribution systems;
- Legally required and optional standby/emergency power systems;
- Energy conservation, demand, and control;
- Conformity with regulatory requirements;
- Special requirements associated with industrial processes;
- Special requirements of the site related to seismic requirements [B5], altitude, sound levels, security, exposure to physical elements, fire hazards [B6], and hazardous locations. Power conditioning and uninterruptible power supplies (UPS) systems.

1.3 Industry Applications Society (IAS)

The IEEE is divided into 37 societies and technical councils that specialize in various technical areas of electrical and electronics engineering. Each group or society conducts meetings and publishes papers on developments within its specialized area.

The IAS currently encompasses 20 technical committees that cover the specific aspects of electrical engineering listed in 1.3.1, below. Papers of interest to electrical engineers and designers involved in the fields covered by the IEEE Red Book are, for the most part, contained in the *Transactions of the IAS*.

1.3.1 Committees within the IAS

The IAS is concerned with the power and control aspects of industrial plant and commercial buildings. To that end, in addition to the more general Power Systems Engineering and Power Systems Protection Committees within the Industrial and Commercial Power Systems Department, the following committees are involved with specific types of industries:

- Appliance Industry
- Cement Industry
- Electric Machines
- Electrostatic Processes
- Glass Industry
- Industrial Drives
- Industrial Automation and Control
- Industrial Power Converter
- Marine Transportation
- Metal Industry
- Mining Industry
- Petroleum and Chemical Industry
- Power Electronics Devices and Components
- Pulp and Paper Industry
- Rubber and Plastics Industry
- Rural Electric Power
- Textile, Fiber, and Film Industry

The Production and Application of Light (PALC), Power Systems Engineering, Power Systems Protection, Codes and Standards, Energy Systems, and Mining Safety Standards Committees of the IAS are involved with industrial power activities, and some publish material applicable to many types of industrial facilities.

All of the committees mentioned develop standards and articles for conference records and for the IAS Transactions. These publications deal with specialized electrical aspects of manufacturing and with electrical power and control systems for specific industries in greater detail than is possible in the Red Book.

1.3.2 The IEEE Color Books

The IEEE Red Book is one of a series of standards that are published by IEEE and are known as the IEEE Color Books. These standards are prepared by the Industrial and Commercial Power Systems Department of the IEEE Industry Applications Society. They are as follows:

- IEEE Std 141-1993, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (IEEE Red Book).
- IEEE Std 142-1991, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (IEEE Green Book).
- IEEE Std 241-1990, IEEE Recommended Practice for Power Systems in Commercial Buildings (IEEE Gray Book).
- IEEE Std 242-1986, IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE Buff Book).
- IEEE Std 399-1990, IEEE Recommended Practice for Industrial and Commercial Power System Analysis (IEEE Brown Book).
- IEEE Std 446-1987, IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (IEEE Orange Book).
- IEEE Std 493-1990, IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (IEEE Gold Book).
- IEEE Std 602-1986, IEEE Recommended Practice for Electric Systems in Health Care Facilities (IEEE White Book).
- IEEE Std 739-1984, IEEE Recommended Practice for Energy Conservation and Cost-Effective Planning in Industrial Facilities (IEEE Bronze Book).
- IEEE Std 1100-1992, IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment (IEEE Emerald Book).

1.4 Professional registration

Most regulatory agencies require that design for public and other 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 Records Department of the National Council of Engineering Examiners² to engineers who 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 four years of progressive professional experience.

²P.O. Box 1686, Clemson, SC 29633-1686.

1.5 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 practice (e.g., too low lighting levels), have resulted in awards against engineering firms and design staff. Practicing engineers are encouraged to determine policies for handling such claims and to evaluate the need for separate professional liability insurance.

1.6 Codes and standards

1.6.1 National Electrical Code

The electrical wiring requirements of the National Electrical Code (NEC) (ANSI/NFPA 70-1993 [B1]), are vitally important guidelines for electrical engineers. The NEC is revised every three years. It is published by and available from the National Fire Protection Association (NFPA).³ It is also available from the American National Standards Institute (ANSI)⁴ and from each State's Board of Fire Underwriters (usually located in the State 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, covering purpose and scope, be carefully reviewed.

The *NFPA Handbook of the National Electrical Code*, No. 70HB, sponsored by the NFPA, 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*, 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 the authority.

1.6.2 Other NFPA standards

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

- NFPA HFPE and Society of Fire Protection Engineers' *SFPE Handbook of Fire Protection Engineering*
- NFPA 101H, Life Safety Code Handbook
- NFPA 20, Centrifugal Fire Pumps, 1987

³Batterymarch Park, Quincy, MA 02269.

⁴11 West 42nd Street, 13th Floor, New York, NY 10036.

- NFPA 70B, Electrical Equipment Maintenance, 1990
- NFPA 70E, Electrical Safety Requirements for Employee Workplaces, 1988
- NFPA 72, National Fire Alarm Code
- NFPA 75, Protection of Electronic Computer/Data Processing Equipment, 1992
- NFPA 77, Static Electricity, 1993
- NFPA 78, Lightning Protection Code, 1992
- NFPA 79, Electrical Standard for Industrial Machinery, 1991
- NFPA 92A, Smoke Control Systems, 1993
- NFPA 99, Health Care Facilities, 1990: Chapter 8: Essential Electrical Systems for Health Care Facilities; Appendix E: The Safe Use of High Frequency Electricity in Health Care Facilities
- NFPA 101, Life Safety Code, 1991
- NFPA 110, Emergency and Standby Power Systems, 1993
- NFPA 130, Fixed Guideway Transit Systems, 1990

1.6.3 Local, state, and federal codes and regulations

While most municipalities, counties, and states use the NEC (either with or without 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 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 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) 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 by OSHA to apply retroactively. The NFPA created an NFPA 70E (Electrical Requirements for Employee Workplaces) Committee to prepare a con-

sensus standard for possible use by OSHA in developing their standards. Major portions of NFPA 70E have been included in OSHA regulations.

OSHA requirements for electrical systems are covered in 29 CFR Part 1910 of the Federal Register.⁵

The U.S. National Institute of Occupational Safety and Health (NIOSH) publishes “Electrical Alerts” to warn of unsafe practices or hazardous electrical equipment.⁶

The U.S. Department of Energy, in 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 90.1P, Energy Efficient Design of New Buildings Except Low Rise Residential Buildings. These establish energy or power budgets that materially affect architectural, mechanical, and electrical designs.

1.6.4 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.

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 clearing house for technical standards. Not all standards are ANSI-approved. Underwriters Laboratories, Inc. (UL), 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, an Electrical Appliance and Utilization Equipment Directory, a Hazardous Location Equipment Directory, and other directories. It should be noted that other testing laboratories (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),⁷ representative of investor-owned utilities, publishes several informative handbooks, such as the Industrial and Commercial Power Distribution Handbook and the Industrial and Commercial Lighting Handbook, as well as an energy analysis computer program, called AXCESS, for forecasting electricity consumption and costs in existing and new buildings.

The National Electrical Manufacturers Associations (NEMA)⁸ represents equipment manufacturers. Their publications serve to standardize certain design features of electrical equipment and provide testing and operating standards for electrical equipment. Some NEMA

⁵The Federal Register is available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402, (202) 783-3238 on a subscription or individual copy basis.

⁶Copies of the bulletin are available from NIOSH Publications Dissemination, 4676 Columbia Parkway, Cincinnati, OH 45226.

⁷1111 19th Street, NW, Washington, DC 20036.

⁸2101 L Street, NW, Suite 300, Washington, DC 20037.

standards contain important application information for 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. Also published are standards on more general subjects, such as the use of graphic symbols and letter symbols. The IEEE Standard Dictionary of Electrical and Electronics Terms is of particular importance.

The Electric Generating Systems Association (EGSA)⁹ publishes performance standards for emergency, standby, and cogeneration equipment.

The Intelligent Buildings Institute (IBI)¹⁰ publishes standards on the essential elements of “high-tech” buildings.

The Edison Electric Institute (EEI)¹¹ publishes case studies of electrically space-conditioned buildings as well as other informative pamphlets.

The International Electrotechnical Commission (IEC) is an electrical and electronic 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.

- Fink, D. G. and Beaty, H. W., *Standard Handbook for Electrical Engineers*, 12th edition, McGraw-Hill,¹² 1987. Virtually the entire field of electrical engineering is treated, including equipment and systems design.
- 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.
- *Lighting Handbook*, Illuminating Engineering Society (IES).¹³ This handbook is in two volumes (Applications, 1987; Reference, 1984). All aspects of lighting, including visual tasks, recommended lighting levels, lighting calculations, and lighting design are included in extensive detail in this comprehensive text.

⁹P.O. Box 9257, Coral Springs, FL 33065.

¹⁰2101 L Street, NW, Washington, DC 20037.

¹¹1111 19th Street, NW, Washington, DC 20036.

¹²1221 Avenue of the Americas, New York, NY 10020.

¹³345 East 47th Street, New York, NY 10017.

- *Electrical Transmission and Distribution Reference Book*, Westinghouse Electric Corporation,¹⁴ 1964. All aspects of transmission, distribution, performance, and protection are included in detail.
- *Applied Protective Relaying*, Westinghouse Electric Corporation, 1976. The application of protective relaying to customer-utility interconnections, protection of high-voltage motors, transformers, and cable are covered in detail.
- *ASHRAE Handbook*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).¹⁵ This series of reference books in four volumes, which are periodically updated, details the electrical and mechanical aspects of space conditioning and refrigeration.
- *Motor Applications and Maintenance Handbook*, 2nd edition, Smeaton, R. S., editor, McGraw-Hill, 1987. Contains extensive, detailed coverage of motor load data and motor characteristics for coordination of electric motors with machine mechanical characteristics.
- *Industrial Power Systems Handbook*, Beeman, D. L., editor, McGraw-Hill, 1955. A text on electrical design with emphasis on equipment, including that applicable to commercial buildings.
- *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.
- *Lighting Handbook*, Philips Lighting Company,¹⁶ 1984. The application of various light sources, fixtures, and ballasts to interior and exterior commercial, industrial, sports, and roadway lighting projects.
- *Underground Systems Reference Book*, Edison Electric Institute, 1957. The principles of underground construction and detailed design of vault installations, cable systems, and related power systems are fully illustrated; cable splicing design parameters are thoroughly covered.
- *Switchgear and Control Handbook*, 2nd edition, Smeaton, R. S., editor, McGraw Hill, 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.
- *Handbook of Practical Electrical Design*, J. M. McPartland, Editor, McGraw Hill, 1984.

A few of the older texts may no longer be available for purchase but are available in most professional offices and libraries.

1.8 Periodicals

Spectrum, the monthly magazine of the IEEE that is circulated to all of its members, contains articles that cover current developments in all areas of electrical and electronics engineering. It contains references to IEEE books; technical publication reviews; technical meetings and

¹⁴Printing Division, Forbes Road, Trafford, PA 15085.

¹⁵1791 Tullie Circle, NE, Atlanta, GA 30329.

¹⁶200 Franklin Square Drive, P.O. Box 6800, Somerset, NJ 08875-6800.

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 IAS of the IEEE are directly useful to industrial facility electrical engineers. Some other well-known periodicals follow:

- *ASHRAE Journal*, American Society of Heating, Refrigerating and Air-Conditioning Engineers
- *Electrical Construction and Maintenance (EC&M)*, Intertec Publishing Corp.¹⁷
- *Fire Journal*, National Fire Protection Association (NFPA)
- *IAEI News*, International Association of Electrical Inspectors
- *Lighting Design and Application (LD&A)*, Illuminating Engineering Society
- *Electrical Systems Design*, Andrews Communications, Inc.¹⁸
- *Engineering Times*, National Society of Professional Engineers (NSPE)¹⁹
- *Consulting-Specifying Engineer*, Cahners Publishing Co.²⁰
- *Plant Engineering*, Cahners Publishing Co.

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 a 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 electrical system. In industrial facilities, continuity of the production and related processes may be critical. The loss of production may result in financial loss because of idle time for employees and machinery, the inability to meet schedules for deliveries, and materials handling and spoilage of materials in process. Safety considerations may be aggravated by

¹⁷1221 Avenue of the Americas, New York, NY 10020.

¹⁸123 West Chester Pike, P.O. Box 556, Edgemont, PA 19028.

¹⁹1420 King Street, Alexandria, VA 22314.

²⁰Cahners Plaza, 1350 East Touhy Avenue, P.O. Box, 508, Des Plaines, IL 60017-8800.

the sheer amount of complex electrical connections and the nature of the machinery. The poor quality or failure of electric power to equipment can cause, in some industrial processes, conditions that can result in hazardous situations. Electromagnetic interference (EMI) can cause safety controls to fail in marginally designed systems.

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:

- Safety for maintenance and operating personnel;
- Safety for others, including visitors, production staff, and non-production staff in the vicinity.

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, grounding methods, and identification of equipment.

Safety for others requires that all circuit-making-and-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 grilles), proper clearances, adequate insulation, and similar provisions outlined in this standard.

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

The National Electrical Safety Code (NESC) (Accredited Standards Committee C2-1993) is available from the IEEE. It covers basic provisions for safeguarding from hazards arising from the installation operation or maintenance of a) conductors in electric supply stations, and b) overhead and underground electric supply and communication lines. It also covers work rules for construction, maintenance, and operation of electric supply and communication equipment. Part 4 deals specifically with safe working methods.

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. Fault protection, covered in Chapters 5 and 6, 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 UL, OSHA, or other approved laboratories is recommended. The Association of Home Appliance Manufacturers (AHAM)²¹ and the Air-Conditioning and Refrigeration Institute (ARI)²² specify the manufacture, testing, and application of many common appliances and equipment. High-voltage equipment and power cable is manufactured in accordance with UL, NEMA, ANSI, and IEEE standards. Engineers should make sure that the equipment they specify and accept 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 the identification of unnecessary costs, which utilizes such methods as life-cycle cost analysis, and related techniques.

1.10.2 Operational considerations

When 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 may be the case for certain industrial configurations or in existing installations, all exposed electrical equipment should be placed behind locked doors or gates or otherwise suitably guarded. Proper barricading, signing, and guarding should be installed and maintained on energized systems or around machinery that could be hazardous, or is located in occupied areas. Work rules, especially in areas of medium or high voltage, should be established.

Work on energized power systems or equipment should be permitted only where qualified staff is available to perform such work and only if it is essential. This is foremost a matter of safety, but is also required to prevent damage to equipment. A serious cause of failure, attributable to human error, is unintentional grounding or phase-to-phase short circuiting of equipment that is being worked on. 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 maintenance 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 unoccupied areas, may cause confusion to the working population. Nuisance tripping, which may interrupt industrial processes, can be minimized by careful design and selection of protective equipment.

²¹20 North Wacker Drive, Chicago, IL 60606.

²²815 North Fort Myer Drive, Arlington, VA 22209.

1.11 Maintenance

Maintenance is essential to proper operation. The installation should be so designed 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.

Generally, the external systems are operated and maintained by the electrical utility, though at times they are a part of the plant distribution system. Where continuity of service is essential, suitable transfer equipment and alternate sources 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 shut-down 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 the total plant 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 plant engineering, 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 recognizing the flexibility of electrical systems in terms of layout and placement.

It is essential that the electrical engineer responsible for designing plant power systems have an understanding of the manufacturing processes and work flow to the extent that he can form part of the planning team and assure that the optimum design is provided. In manufacturing areas, considerations of architectural finishes and permanence are usually secondary to production efficiency and flexibility. Special provisions could be required, as part of the manufacturing process, for reduction of EMI (see 1.19.3), for continuity of supply, and for complex control systems.

1.12.1 Coordination of design

Depending on the type and complexity of the project, the engineer will need to cooperate with a variety of other specialists. These potentially include mechanical, chemical, process, civil, structural, industrial, production, lighting, fire protection, and environmental engineers; maintenance planners; architects; representatives of federal, state, and local regulatory agencies; interior and landscape designers; specification writers; construction and installation contractors; lawyers; purchasing agents; applications engineers from major equipment suppliers

and the local electrical utility; and management staff of the organization that will operate the facility.

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 non-electrical sections of the specifications. For example, 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 (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.

1.12.2 Flexibility

Flexibility of the electrical system means adaptability to development and expansion as well as to changes to meet varied requirements during the life of the facility. Sometimes a designer is faced with providing power in a plant where the loads may be unknown. For example, some manufacturing buildings are constructed with the occupied 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 the tenant requirements are developed, fill in the details. A manufacturing division or tenant may provide working space designs.

Because it is usually difficult and costly to increase the capacity of feeders, it is important that provisions for sufficient capacity be provided initially. Industrial processes, including manufacturing, may require frequent relocations of equipment, addition of production equipment, process modifications, and even movement of equipment to and from other sites; therefore, a high degree of system flexibility is an important design consideration.

Extra conductors or raceway space should be included in the design stage when additional loads are added. In most industrial plants, the wiring methods involve exposed conduits, cable trays, and other methods where future changes will not affect architectural finishes. When required, space must be provided for outdoor substations, underground systems including spare ducts, and overhead distribution.

Flexibility in an electrical 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. Space on spare raceway hangers and openings (sealed until needed) between walls and floors may be provided at relatively low cost for future work. Consideration should be given to the provision of electrical distribution areas for future expansion. Openings through floors should be sealed with fireproof (removable) materials to prevent the spread of fire and smoke between floors. For computer rooms and similar areas, 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.

Industrial facilities most frequently use exposed wiring systems in manufacturing areas for greater economy and flexibility. Plug-in busways and trolley-type busways can provide a convenient method of serving machinery subject to relocation. Cable trays for both power and control wiring are widely used in industrial plants. Exposed armored cable is a possible convenient method of feeding production equipment.

1.12.3 Specifications

A contract for installation of electrical systems consists of both a written document and drawings. The written document contains both legal (non-technical) and engineering (technical) sections. The legal section contains 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 includes the technical specifications. The specifications give descriptions of the work to be done and the materials to be used. It is common practice in larger installations to use a standard outline format listing division, section, and subsection titles or subjects of the Construction Specifications Institute (CSI).²³ Where several specialties are involved, Division 16 covers the electrical installation and Division 15 covers the mechanical portion of the work. The building or plant 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. Division 16 has a detailed breakdown of various items, such as switchgear, motor starters, and lighting equipment, specified by CSI.

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. Government General Services Administration and the Veterans Administration, develop their own standard specifications. The engineer should keep several cautions in mind when using standard specifications. First, they are designed to cover a wide variety of situations, and consequently they will contain considerable material that will not apply to the specific facility under consideration, and they may lack other material that should be included. Therefore, standard specifications must be appropri-

²³601 Madison Avenue, Industrial Park, Alexandria, VA 22314.

ately edited and supplemented to embody the engineer's intentions fully and accurately. Second, many standard specifications contain material primarily for non-industrial facilities, and may not reflect the requirements of the specific industrial processes.

MASTERSPEC, issued by American Institute of Architects (AIA),²⁴ permits the engineer to issue a full-length specification in standardized format. SPECTEXT II, which is an abridged computer program with similar capabilities, is issued by CSI. CEGS and NFGS are the U.S. Army Corps of Engineers and the U.S. Naval Facilities Engineering Command Guide Specifications.

Computer-aided specifications (CAS) have been developed that will automatically create specifications as an output from the CAE-CADD process (see 1.12.4).

1.12.4 Drawings

Designers will usually be given preliminary architectural drawings as a first step. These drawings permit the designers to arrive at the preliminary scope of the work, roughly estimate the requirements, 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 primary and secondary distribution systems and major items of equipment will be decided. The early requirements for types of machinery to be installed will be determined. If a typical plant of the type to be built or modernized exists, it would be well for the engineer to visit such a facility and to study its plans, cost, construction, and operational history.

Early in the design period, the designer should emphasize the need for room to hang conduits and cable trays, crawl spaces, structural reinforcements for equipment, and special floor loadings; and for clearances around substations, switchgear, transformers, busways, cable trays, panelboards, 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 need for installing, removing, and relocating machinery must also be considered.

The one-line diagrams should then be prepared in conformity with the utility's service requirements. Based on these, the utility will develop a *service layout*. Checking is an essential part of the design process. The checker looks for design deficiencies in the set of plans. The designer can help the checker by having on hand reference and catalog information detailing the equipment he has selected. The degree of checking is a matter of design policy.

Computer-aided engineering (CAE) and computer-aided design and drafting (CADD) systems 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.

²⁴1735 New York Avenue, NW, Washington, DC 20006.

1.12.5 Manufacturer's or shop drawings

After the design has been completed and contracts are awarded, contractors, manufacturers and other suppliers will submit drawings for review or information. It is important to review and comment upon these drawings and return them as quickly as possible; otherwise, the supplier and/or contractor may claim that the work was delayed by the engineer's review process. Unless the drawings contain serious errors and/or omissions, it is usually a good practice not to reject them but to stamp the drawings with terminology such as "revise as noted" and mark them to show errors, required changes, and corrections. The supplier can then make appropriate changes and proceed with the work without waiting to resubmit the drawings for approval.

If the shop drawings contain major errors or discrepancies, however, they should be rejected with a requirement that they be resubmitted to reflect appropriate changes that are required on the basis of notes and comments of the engineer.

Unless otherwise directed, communication 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 is usually 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 placing the responsibility for shop drawing correctness (in those cases and possibly future cases) upon 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, per process machine, per production area, by the horsepower or number of motors, or on a similar basis for a comparable facility.

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 from sketches and architectural layouts the type of lighting fixtures as well as many items of heavy equipment that are to be used. Lighting fixtures, as well as most items of heavy equipment, can be priced directly from the 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. The estimating procedure of the designer in this case is similar to that of the contractor's estimator. It involves first the takeoffs, 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).²⁵ For preliminary estimates, there are a number of general estimating books that give unit cost figures (often per square foot) and other general costs, such as the following three titles: *Building Construction Cost Data*; *Mechanical Cost Data*; and *Electrical Cost Data*.²⁶ Several computer programs permit streamlining and standardizing engineering estimating.

Chapter 16 illustrates the detailed procedures for making estimates for industrial facilities.

Extra work ("extras") refers to work performed by the contractor that has to be added to the contract because of 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 would be if included in the original contract. Extra cost on any project can be minimized by giving 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. A 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 when a contractor, in order to provide a lump-sum contract, might have to overestimate the job to cover items that could not accurately be determined 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 highest on which payment would be received first or those items that would be most likely to increase in quantity.

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 a part of the work is not clearly defined, a combination of the three pricing methods might be in order.

²⁵7315 Wisconsin Avenue, Bethesda, MD 20814.

²⁶Published by R. Snow Means Co., 100 Construction Plaza Avenue, Kingston, MA.

1.15 Access and loading

It is imperative that the equipment fit into the area specified and that the floor-load rating be adequate for the weight of the equipment. Sizes of door openings, corridors, and elevators for moving of equipment (initially and for maintenance and replacement purposes) must 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 must be adequate for this. If floor strengths are not adequate, provision must 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 also must be made for removal of equipment for replacement purposes. Clearances must be in accordance with code provisions regarding working space. Clearance must 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 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 policies may mandate 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 work may be awarded to an electrical subcontractor by the overall general contractor.

The performance of the work will usually be monitored and inspected by representatives of the owner and the engineer-of-record. The work may be 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.

It is essential that designers, in attempting to expedite the contract, not place themselves in the position of requesting without proper authorization, or “reading into” the contract, what is not clearly required by the specifications or drawings.

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 other items that have an environmental impact. The limited availability of energy sources and the steadily increasing cost of electric energy require that energy conservation be addressed.

This issue is 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 14. Environmental studies, which include the effect of noise, vibration, exhaust gasses, lighting, and effluence, must be considered in relationship to the working environment, the general environment, and the public.

Landscape architects can provide pleasing designs of trees and shrubbery to completely conceal outdoor substations and overhead lines may, of course, be replaced by underground systems. Substations situated in residential areas must be carefully located so as not to create a local nuisance. Precast 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 [B9]). The engineer should keep up-to-date on developments in the areas of environmental protection and energy conservation. Federal Environmental Protection Agency guidelines and judicial rulings on local environmental litigation are generally covered in the Federal Register 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 when many such items are involved. A computerized data base 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 be made available on viewers or enlarger-printers. Microfiche involves placing the microfilm on computer-type cards for handling manually or in data-processing type systems.

1.19 Electronic systems

Electronic systems are a major item in industrial facilities for control purposes, motor control, lighting ballasts, communication systems, data processing, computer applications, industrial process control, data management, and plant (building) management systems. This subclause is concerned primarily with the effects of the power supply, control and power

wiring, and interference on these systems; and with some indication of the extent of the use of electronic equipment in industrial facilities.

Industrial processes often require a degree of speed and torque control of motors, which is obtainable through the use of electronic controllers and computer-based control systems (see Chapter 10). Electronic power supplies/controllers are used for supplying power to heat-process systems and to electrochemical processes. The electronic controller has the advantage of being able to tie together the power equipment, the control computers, the sensing equipment, data acquisition and display systems, robotics, and telemetering equipment into an effective package. Subclause 1.3.1 lists the committees, by industry and application, that are involved with and publish extensive technical material in this area.

1.19.1 Power supply disturbances

The power supply to equipment may contain transients and other short-term under- or over-voltages that result primarily from switching operations, faults, motor starting, lightning disturbances, switching of capacitors, electric welding, and operation of heavy manufacturing equipment. The system may also contain a harmonic content as described in 1.19.2 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 deficiencies is *power quality*. The IEEE Emerald Book (see 1.3.2) examines in detail the effects of the power supply on equipment performance. It covers methods of diagnosing and correcting performance problems related to the power supply.

1.19.2 Harmonics

Chapter 9 of this book, Chapter 10 of the Brown Book, the Emerald Book, and IEEE Std 519-1992 [B5] all contain discussion 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 EMI in sensitive electronic systems, abnormal heating or cables and 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 must be sized at greater than full rating, and transformers must be derated or designed for high-harmonic content. A full discussion of harmonics is beyond the scope of this subclause; reference should be made to the previously mentioned publications.

1.19.3 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, and effective use of conduit (especially steel conduit) for control and power (where practical) circuits [B3], [B4]. 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.

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 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 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, thereby avoiding the need to use the conventional software languages. The equipment can be housed in cases suitable for mounting in exposed locations and on production floors.

1.21 Bibliography

[B1] ANSI C84.1-1989, American National Standard Electric Power Systems and Equipment—Voltage Ratings (60 Hz).

[B2] ANSI/NFPA 70-1993, National Electrical Code.

[B3] Griffith, D. C., *Uninterruptible Power Supplies*, Marcel Decker, Inc., 1989.

[B4] IEEE Std 518-1982 (Reaff 1990), IEEE Guide for the Installation of Electrical Equipment to Minimize Noise Inputs to Controllers from External Sources (ANSI).

[B5] IEEE Std 519-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems (ANSI).

[B6] IEEE Std 100-1992, The New IEEE Standard Dictionary for Electrical and Electronics Terms (ANSI).

[B7] IEEE Std 693-1984 (Reaff 1991), IEEE Recommended Practices for Seismic Design of Substations (ANSI).

[B8] IEEE Std 979-1984 (Reaff 1988), IEEE Guide for Substation Fire Protection (ANSI).

[B9] IES Committee Report CP-46-85, "Astronomical Light Pollution and Light Trespass."

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Chapter 2

System planning

2.1 Introduction

The continuity of production in an industrial plant is only as reliable as its electric power distribution system. This chapter outlines procedures and various considerations for system planning and presents a guide to the use of the succeeding chapters.

No standard electric distribution system is adaptable to all industrial plants, because two plants rarely have the same requirements. The specific requirements must be analyzed qualitatively for each plant and the system designed to meet its electrical requirements. Equal and adequate consideration must be given to both the present and future operating and load conditions.

2.2 Definitions

See 2.4.1.3 for definitions related to demand.

2.3 Basic design considerations

The approach to system planning should include several basic considerations that will affect the overall design and operation.

2.3.1 Safety

Safety of life and preservation of property are two of the most important factors to be considered in the design of the electric system. Codes must be followed and recommended practices or standards should be followed in the selection and application of material and equipment.

Equally important is providing equipment that is properly and adequately sized and rated to handle available fault levels in the system in accordance with established fault duty calculation procedures. Adequate safety features should be incorporated into all parts of the system.

Listed below are the electric system operating and design limits that should be considered in order to provide safe working conditions for personnel:

- a) Interrupting devices must be able to function safely and properly under the most severe duty to which they may be exposed.
- b) Protection must be provided against accidental contact with energized conductors, such as enclosing the conductors, installing protective barriers, or installing the conductors at sufficient height to avoid accidental contact.

- c) Isolating switches must not be operated while they are carrying current, unless they are designed to interrupt such current. They should be equipped with safety interlocks and warning signs if load or transformer magnetizing current-load-interrupting and fault-closing capability are not provided.
- d) In many instances it is desirable to isolate a power circuit breaker using disconnect switches. In such cases, the circuit breaker must be opened before the disconnect switches. Safety interlocks to ensure this sequence should be used, together with detailed and specific personnel operating instructions.
- e) The system should be designed so that maintenance work on circuits and equipment can be accomplished with the particular circuits and equipment de-energized and grounded. System design should provide for locking out circuits or equipment for maintenance, including grounding instructions. A written procedure should be established to provide instructions on tagging or locking out circuits during maintenance, and re-energizing after completion of the maintenance work following disconnection of the grounding equipment.
- f) Electric equipment rooms, especially those containing apparatus over 600 V, such as transformers, motor controls, or motors, should be equipped and located to eliminate or minimize the need for access by nonelectrical maintenance or operating personnel. Conveniently located exits should be provided to allow quick exit during an emergency.
- g) Electric apparatus located outside special rooms should be provided with protection against mechanical damage due to equipment location, personnel access, and vehicular traffic. The area should be accessible to maintenance and operating personnel for emergency operation of protective devices.
- h) Equipment location should be carefully considered. A nonhazardous area should be set aside for electrical equipment, or it may be necessary to locate explosion-proof equipment in the hazardous area. The advantages and disadvantages of not only initial cost but the maintenance cost and the ability to maintain the integrity of the equipment should all be carefully considered.
- i) Warning signs should be installed on electric equipment accessible to unqualified personnel, on fences surrounding electric equipment, on doors giving access to electrical rooms, and on conduits or cables above 600 V in areas that include other equipment or pipelines. An electrical single-line diagram should be installed in each electrical switching room.
- j) An adequate grounding system must be installed.
- k) Emergency lights should be provided where necessary to protect personnel against sudden lighting failure. In facilities, the Life Safety Codes requires that escape routes and exits have emergency lighting. In addition, process control locations and electric switching centers should be equipped with standby lighting.
- l) Operating and maintenance personnel should be provided with complete operating and maintenance instructions, including wiring diagrams, equipment ratings, and protective device settings. Spare fuses of the correct ratings should be stocked.

2.3.2 Reliability of plant primary utility supply service

The continuity of service required is dependent on the type of manufacturing or process operation of the plant and the cost of that operation, especially if it is interrupted. Some plants can

tolerate interruptions while others require the highest degree of service continuity. The system should always be designed to isolate faults with a minimum disturbance to the system and should have features to give the maximum dependability consistent with the plant requirements and justifiable cost.

The majority of utilities today supply energy to medium and large industrial customers directly at 34.5, 69, 115, 138, 161 and 230 kV using dedicated substations. Small industrial complexes may receive power at voltages as low as 4 kV.

Some industrial plants accept supplies directly from utility area distribution substations at 4.16, 12.5, 13.8 kV, etc. In most instances, the utility substations also serve other customers so that there are usually several distribution lines connected to the same bus as the plant supply line(s), although in some cases dedicated services, including bus(es) and lines, are provided. For the most part, plant personnel feel secure with this type of supply, especially if the supply substation is nearby and if multiple supply lines are provided to meet *firm power* or first contingency requirements. However, these provisions can create a false sense of security, especially when the facts regarding the reliability of distribution lines, the impact of nearby customer faults and system operations on such services, and the impact this has on plant operations are overlooked. For example, when a fault occurs on the supply system near the plant, there is an accompanying voltage sag on all of the plant primary distribution and utilization voltage buses. This lowered voltage persists while the utility relays operate and until the utility breaker trips, at which point the voltage will be reduced to zero on the faulted line and will be restored to near normal on the unfaulted portions of the system. Experience has shown that these short-time voltage sags are often severe enough and persist long enough to cause the solenoid coils of mechanical contactors and relays to open automatically. When this occurs in a plant there will be parts damage, tool breakage, lost production, etc., all of which cause major disruptions in plant operations even though the supply may be lost only temporarily. Furthermore, new customers added to the area distribution supply substation can also reduce the quality and reliability of the service.

Lower voltage distribution services often tend to be older systems that are susceptible to a more frequent rate of system interruption and failure than higher voltage transmission systems. Underground, lower voltage cable systems are especially susceptible, although some underground cable systems have proven to have high reliability. This reliability tends to be very site- and utility-specific. Installation, maintenance, age, and workmanship quality on cable terminations and splices can all significantly affect the reliability of such systems. Statistically, 138 kV lines may have interruption rates of four or five interruptions per hundred miles per year. On the other hand, distribution lines in the 8–23 kV voltage range may have interruption rates of 100 or more interruptions per hundred miles per year. Thus, the probability of damaging voltage sags is at least 20 times as great on distribution lines as on transmission voltage lines. This difference in probabilities is magnified even more when it is realized that the exposure to voltage sag incidents includes many nearby interconnected lines not necessarily dedicated to the plant supply.

Depending upon circumstances, the capacity available for future expansion from area substations may often be limited, even with or without a single contingency situation occurring. Available capacity may be limited by a transformer, switch, circuit breaker, bus, protective

device(s) and supplying cable capacity and, therefore, requires careful evaluation for both normal and abnormal operating conditions. In addition, if firm or first contingency capacity is desired, then the availability of duplicate capacity in the transformer(s), protective device(s), and cables must all be taken into account. Expansion of available capacity in such circumstances to meet first contingency needs may present difficulties due to station configuration and the impact on other customers, especially if available user fault levels are changed as a result of the expansion. This aspect requires very careful consideration so capacity constrained conditions do not develop that will later present significant technical and economical difficulties in meeting increased plant loads.

2.3.3 Plant distribution system reliability analysis

One of the questions often raised during the design of the plant power distribution system is how to make a quantitative comparison of the failure rate and the forced downtime in hours per year for different circuit arrangements, including radial, primary-selective, secondary-selective, simple spot network, and secondary-network circuits. This quantitative comparison could be used in trade-off decisions involving the initial cost versus the failure rate and forced downtime per year. The estimated cost of power interruptions at the various distribution points should be considered in deciding which type circuit arrangement to use. The decisions should be based upon total owning cost over the useful life of the equipment rather than the first cost.

In general, electric power systems are designed on a first contingency basis. The incremental cost to provide such services is typically a relatively small cost as compared to the total facility or plant cost. The risk and cost of a long-term interruption due to system failure far outweighs the added incremental cost required to provide first contingency capacity at the time of installation.

2.3.3.1 Reliability data for electrical equipment

In order to calculate the failure rate and the forced downtime per year, it is necessary to have reliability data on the electric utility supply and each piece of electrical equipment used in the power distribution system. One of the best sources for this type of data are the extensive IEEE surveys on the reliability of electrical equipment in industrial plants and commercial buildings. (See IEEE Std 493-1990.¹) While this data may be quite useful, it represents a limited data base; therefore, it may not be representative of an individual company's experience. In-house data, if available, may be more appropriate in this analysis.

2.3.3.2 Reliability analysis and total owning cost

Statistical analysis methods involving probability of failure may be used to make calculations of the failure rate and the forced downtime for the power distribution system. The methods and formulas used in these calculations are given in IEEE Std 493-1980. This includes the minimum revenue requirements method for calculating the total owning cost over the useful

¹Information on references can be found in 2.6.

life of the equipment. Data and calculations for determining the cost of power interruptions are also given in IEEE Std 493-1990.

2.3.4 Simplicity of operation

Simplicity of operation is very important in the safe and reliable operation and maintenance of the industrial power system. The operation should be as simple as possible to meet system requirements.

2.3.5 Voltage regulation

Poor voltage regulation is detrimental to the life and operation of electrical equipment. Voltage at the utilization equipment must be maintained within equipment tolerance limits under all load conditions, or equipment must be selected to operate safely and efficiently within the voltage limits. Use load-flow studies and motor-starting calculations to verify voltage regulation.

2.3.6 Maintenance

The distribution system should include provisions for predictive and preventive maintenance requirements in the initial design. Accessibility and availability for inspection and repair with safety are important considerations in selecting equipment. Space should be provided for inspection, adjustment, and repair in clean, well-lighted, and temperature-controlled areas.

2.3.7 Flexibility

Flexibility in an electric system means expandability as well as adaptability to changing requirements during the life of the plant. Consideration of the plant voltages, equipment ratings, space for additional equipment, and capacity for increased load must be given serious study.

2.3.8 First cost

While first costs are important, safety, reliability, voltage regulation, maintenance, and the potential for expansion should also be considered in selecting the best from alternate plans.

2.4 Planning guide for the supply and distribution system

The following procedure will guide the engineer in the design of an electric distribution system for an industrial plant. The system designer should also have or acquire knowledge of the plant's processes in order to select the proper system and its components.

2.4.1 Load definition and forecasting

Load definition entails load surveys, demand and diversity analysis, and load characteristic definition. In addition, load forecasting for future requirements must be considered.

2.4.1.1 Load survey

Obtain a general plant or facility layout, mark it with the known major loads at various locations, and determine the approximate total plant load in kilowatts or kilovoltamperes. Initially the amount of accurate load data may be limited; therefore, some loads, such as lighting and air conditioning, may be estimated from generalized data. The majority of industrial plant loads are a function of the process equipment, and such information will have to be obtained from process and equipment designers. Since their design is often concurrent with power system design, initial information will be subject to change. It is important, therefore, that there be continuing coordination with the other design disciplines. For example, a change from electric powered to absorption refrigeration or a change from electrostatic to high-energy scrubber air-pollution control can change the power requirements for these devices by several orders of magnitude. The power system load estimates will require continual refinement until job completion.

2.4.1.2 Load requirements and characteristics

The following items define the various requirements and characteristics of the loads and must be determined and defined in the planning process:

- a) Load development/build-up schedule
 - 1) Peak load requirements in kilovoltamperes
 - 2) Temporary/construction power requirements
 - 3) Timing
- b) Load variations in kilovoltamperes expected during low load (non-productive periods), average load, and peak load conditions.
- c) Nature of load in terms of its occurrence
 - 1) Continuous
 - 2) Intermittent
 - 3) Cyclical
 - 4) Special or unusual loads
 - 5) Combination of above
- d) Expected power factor during low load (nonproductive periods), average load, and peak load periods.
- e) Expected daily and annual load factor:

$$\text{Daily } \frac{\text{kWh for 24 h/24 h}}{\text{peak kW during the 24 h}} = \frac{\text{avg. kW}}{\text{peak kW}}$$

$$\text{Annual } \frac{\text{kWh for 8670 h/8670 h}}{\text{peak kW during the 8670 h}} = \frac{\text{avg. kW}}{\text{peak kW}}$$

- f) Large motor-starting requirements
 - 1) Horsepower and other nameplate data
 - 2) Type (synchronous/induction)
 - 3) System nominal voltage
 - 4) Starting requirements
 - 5) Application

- g) Special or unusual loads such as
 - 1) Resistance welding
 - 2) Arc welding
 - 3) Induction melting
 - 4) Induction heating
 - 5) Heat treating
 - 6) SCR controlled ovens
 - 7) Variable speed drives (large press drives)
 - 8) Large power conversion devices
- h) Harmonic-generating loads
 - 1) Converter/inverter drives
 - 2) Arc discharge lighting
 - 3) Arc furnaces
 - 4) Other
- i) Special power quality requirements for sensitive or critical loads
 - 1) Data processing operations
 - 2) Special machines
 - 3) Continuous process loads
 - 4) Others

2.4.1.3 Demand

The sum of the electrical ratings of each piece of equipment will give a total connected, non-coincident load. Because some equipment operates at less than full load and some intermittently, the resultant demand upon the power source is always less than the total connected load, so appropriate load diversity considerations should be considered in the analysis. In general, equipment diversities range from slightly less than 100% for a continuous process to as low as 2% to 5% for certain types of press and welding operations. The diversity expectation associated with each type of equipment should be used to develop a specific, total, actual expected load. An appropriate diversity should then also be applied to each large grouping of equipment and to the entire load to reflect randomness and physical reality, based on experience.

Standard definitions for these load combinations and their ratios have been devised.

2.4.1.3.1 demand: The electric load at the receiving terminals averaged over a specified interval of time.

Note that demand is expressed in kilowatts, kilovoltamperes, amperes, or other suitable units. The interval of time is generally 15 min, 30 min, or 1 h, based on the particular utility's demand metering interval.

2.4.1.3.2 peak load: The maximum load consumed or produced by a unit or group of units in a stated period of time. It may be the maximum instantaneous load or the maximum average load over a designated period of time.

2.4.1.3.3 maximum demand: The greatest of all demands that have occurred during a specified period of time such as one-quarter, one-half, or one hour.

Note that for utility billing purposes the period of time is generally one month.

2.4.1.3.4 demand factor: The ratio of the maximum coincident demand of a system, or part of a system, to the total connected load of the system, or part of the system, under consideration. The resultant is always 1 or less and can range from 0.8 to 1 to as low as 0.15 to 0.25 for some plants with very low diversity.

2.4.1.3.5 diversity factor: The ratio of the sum of the individual non-coincident maximum demands of various subdivisions of the system to the maximum demand of the complete system. The diversity factor is always 1 or greater. The (unofficial) term *diversity*, as distinguished from *diversity factor* refers to the percent of time available that a machine, piece of equipment, or facility has its maximum or nominal load or demand (i.e., a 70% diversity means that the device in question operates at its nominal or maximum load level 70% of the time that it is connected and turned on).

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

Note that although not part of the official definition, the term *load factor* is used by some utilities and others to describe the equivalent number of hours per period the peak or average demand must prevail in order to produce the total energy consumption for the period.

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

Information on these factors for the various loads and groups of loads is useful in designing the system. For example, the sum of the connected loads on a feeder, multiplied by the demand factor of these loads, will give the maximum demand that the feeder must carry. The sum of the individual maximum demands on the circuits associated with a load center or panelboard, divided by the diversity factor of those circuits, will give the maximum demand at the load center and on the circuit supplying it. The sum of the individual maximum demands on the circuits from a transformer, divided by the diversity factor of those circuits, will give the maximum demand on the distribution transformer. The sum of the maximum demand on all distribution transformers, divided by the diversity factor of the transformer loads, will give the maximum demand on their primary feeder. By the use of the proper factors, as outlined, the maximum demands on the various parts of the system from the load circuits to the power source can be estimated. Allowances should also be made for future load expansion in these calculations.

2.4.1.4 Forecasting and planning

Essentially, the load forecasting and planning process involves at least six separate considerations. These are as follows:

- a) Impact of nominal load growth over time. Typically, some slight growth in kilowatt demand will be experienced over time. This may be upwards of $1/2$ to 1% per year;