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UNIFIED FACILITIES CRITERIA (UFC)

INTERIOR ELECTRICAL SYSTEMS

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY (Preparing Activity)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

UNIFIED FACILITIES CRITERIA (UFC)

UNIFIED FACILITIES GUIDE SPECIFICATIONS (UFGS) FORMAT STANDARD

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD(AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the more stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Support Agency (AFCESA) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request (CCR). The form is also accessible from the Internet sites listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site http://dod.wbdg.org/.

Hard copies of UFC printed from electronic media should be checked against the current electronic version prior to use to ensure that they are current.

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CHAPTER 1

GENERAL

1-1 PURPOSE.

1-1.1 This Unified Facilities Criteria (UFC) manual has been issued to provide guidance for the design of interior electrical systems. The criteria contained herein are intended to ensure economical, durable, efficient, and reliable systems and installations.

1-1.2 The following documents are superseded by this manual:

- MIL-HDBK-1004/4, *Electrical Utilization Systems.*
- TM 5-811-2, AFM 88-9-2, *Electrical Design, Interior Electrical System.*
- AFMAN 32-1181, *Design Standards for Facilities Interior Electrical Systems.*
- TM 5-811-14, *Coordinated Power Systems Protection.*
- MIL-HDBK-1004/3, *Switchgear and Relaying.*

1-2 SCOPE.

1-2.1 This manual provides guidance for the design of interior electrical systems. Whenever unique conditions and problems are not specifically covered by this manual, use the applicable referenced industry standards and other documents for design guidance.

1-2.2 Modernization of electrical systems within existing facilities solely for the purpose of meeting design criteria in this manual is not required. Upgrades or modifications of existing facilities should consider the design criteria in this manual, but it is not intended that an entire facility require modernization solely because of a minor modification to a part of the facility.

1-2.3 Comply with the Occupational Safety and Health Administration (OSHA) electrical system requirements, as applicable. The OSHA requirements also apply to "major replacements, modifications, repairs, or rehabilitations", which includes work similar to that involved when a new building or facility is built, a new wing is added, or an entire floor is renovated.

1-3 **REFERENCES**. Appendix A contains a list of references used in this manual. References applicable to a specific topic are also listed and described in the appropriate sections of this manual.

1-4 **CODES AND STANDARDS**.

1-4.1 The minimum requirements of National Fire Protection Association (NFPA) 70, *National Electrical Code* (NEC), and American National Standards Institute (ANSI) C2, *National Electrical Safety Code* (NESC), must be met.

1-4.2 Safety is a fundamental system design requirement that is not met simply by compliance with applicable codes. Safety has to be designed into a system. This manual establishes design criteria that exceed NEC minimum standards in some areas. This manual also follows the design criteria established by OSHA for electrical safety.

1-4.3 Electrical safety requirements applicable to the installation and operation of electrical systems are provided in Air Force Manual (AFM) 32-1185, *Electrical Worker Safety*. Additional guidance is provided in Engineer Memorandum (EM) 385-1-1, *Safety and Health Requirements Manual*.

1-4.4 The applicable standards and other documents, both government and non-government, that apply to a specific case are referenced in the text and are listed in Appendix A.

1-4.5 Codes and standards are referenced throughout this manual. The publication date of the code or standard is not routinely included with the document identification throughout the text of the manual. In general, the latest issuance of a code or standard has been assumed for use. Refer to Appendix A to determine the publication date of the codes and standards referenced in this manual.

1-4.6 Whenever a standard or code allows an alternative arrangement subject to the approval of the Authority Having Jurisdiction (AHJ), this authority is delegated to the individual service (Army, Navy, or Air Force). Also, this manual applies and incorporates a large number of detailed electrical standards. Implementation of these criteria can be difficult for smaller projects, but for larger projects, many of the sections might be applicable. The AHJ for each command has the authority to interpret the applicability of the requirements in this manual as necessary.

1-4.6.1 For the Air Force, the AHJ is delegated to the Major Command (MAJCOM), with the recommendation that it be redelegated to the local Base Civil Engineer (BCE) as the responsibility of the local inspector. In case of conflict or lack of resolution at the local level, issues can be elevated through the MAJCOM to be resolved.

1-4.6.2 For the Army, the AHJ is the Headquarters, U.S. Army Corps of Engineers (HQUSACE), Engineering and Construction Division (CECW-E).

1-4.6.3 For the Navy, the AHJ is the Naval Facilities Engineering Command Criteria Office.

1-5 **SYMBOLS**. Apply ANSI Y32.9, *Graphic Symbols for Electrical Wiring and Layout Diagrams Used in Architecture and Building Construction*, for symbols used in plan and detail drawings. Apply Institute of Electrical and Electronic Engineers (IEEE) 315, *Graphic Symbols for Electrical and Electronics Diagrams*, for symbols used in one-line, three-line, riser, schematic, and wiring diagrams.

1-6 APPLICABILITY.

1-6.1 Compliance with this UFC is mandatory for the design of interior electrical systems at all facilities and bases.

1-6.2 Facilities located outside of the United States must also comply with the applicable host nation standards; refer to Technical Manual TM-5-688, *Foreign Voltages*, for additional information. Different voltages, frequencies, and grounding conventions often apply in other host nations; however, follow the design principles provided in this manual to the extent practical.

1-7 MANUAL CONTENT AND ORGANIZATION.

1-7.1 This UFC establishes criteria for the design of interior electrical systems at all facilities and bases. If adequate design guidance is provided by other manuals, this UFC references these other sources, as applicable.

1-7.2 This UFC establishes system-level design criteria. In some cases, equipment design and operation characteristics are specified to ensure that system-level performance criteria are achieved. This manual is not an equipment specification document; additional equipment specifications will still be necessary as part of any procurement or construction activity. Refer to paragraph 2-1.3 for information regarding specifications.

1-7.3 This UFC provides the starting point for determining the applicable design criteria for a facility. Because of the broad scope of this manual, other industry and tri-services documents are relied on as reference sources. As applicable for the particular design activity, ensure that the appropriate references from the list in Appendix A are available. Throughout this manual, each chapter provides additional information regarding which references offer the most benefit for specific topics.

1-7.4 This manual covers many subjects in detail. In most cases, each topic could be an entire manual or series of manuals by itself. In order to keep this manual to a manageable size, the focus has been on design standards that will be of most value to the users. Other documents will still be necessary to assist the users with electrical design issues. In particular, the IEEE Color Book Series are recommended; these IEEE Recommended Practices provide background information that will assist in identifying and resolving technical design issues.

1-7.5 This manual establishes facility-level criteria for interior electrical systems. In most cases, a facility is a building or structure that has its own service entrance. This is a broad definition that can be applied to a multi-story building or a single-level structure or an aircraft shelter. To further complicate the definition of a facility, some backup power considerations might be applied to a group of buildings or the entire base. These facility-level criteria are intended to be applied with the user determining the appropriate boundaries for each facility. For example, it is not intended that the installation of fire walls within a single building cause each protected area to be treated as a separate facility.

CHAPTER 2

PRELIMINARY AND DETAILED DESIGN ANALYSIS

2-1 PRELIMINARY DESIGN.

2-1.1 Principal Points of Contact.

2-1.1.1 **Air Force**. Contact the MAJCOM with additional support provided by the Air Force Civil Engineer Support Agency (AFCESA) at www.afcesa.af.mil. The following organizations also provide technical support:

- Contact the Air Force Center for Environmental Excellence (AFCEE) at www.afcee.brooks.af.mil for design guidance and support of medical facilities, family housing and architectural design.

- Contact the Power Conditioning and Continuation Interfacing Equipment (PCCIE) Product Group at Hill Air Force Base (AFB) for assistance with power quality design and operation issues. The PCCIE Materiel Group offers optimum centralized processes in the areas of engineering/technical support, acquisition, fielding, and sustainment of all power conditioning equipment, continuous uninterrupted power equipment, power quality systems, and ancillary PCCIE equipment. The web site is located at http://www.hill.af.mil/li/lip/lip.htm.

2-1.1.2 **Army**. Contact the US Army Corps of Engineers (USACE) at http://www.usace.army.mil/inet/functions/cw/cecwe/.

2-1.1.3 **Navy**. Contact the Naval Facilities Engineering Command (NAVFAC) Criteria Office at http://criteria.navfac.navy.mil/criteria.

2-1.2 **Preliminary Design Guidance for Interior Electrical Systems**. Review the following documents for information regarding preliminary design considerations:

- Engineering Regulation (ER) 1110-345-700, *Design Analysis, Drawings, and Specifications* – provides a checklist of electrical issues to consider early in the design phase.

- ER 1110-345-723, *Systems Commissioning Procedures* – provides guidance regarding the planning and review of procedures for the commissioning process, which should be considered as early as possible in the design process.

- Military Handbook (MIL-HDBK) 1004/1, *Electrical Engineering Preliminary Design Considerations* – provides detailed guidance regarding load estimation and power source selection.

- MIL-HDBK-1012/3, *Telecommunications Premises Distribution Planning, Design, and Estimating* – provides detailed guidance regarding telecommunications system planning.

- USACE Technical Instruction 800-01, *Design Criteria* – provides guidance regarding facility planning and design.

2-1.3 **Unified Facilities Guide Specifications (UFGS)**. UFGS are a joint effort of the USACE, NAVFAC, and AFCESA. UFGS are intended for use in specifying construction services or activities for the military services.

2-2 **ELECTRICAL LOAD CRITERIA**.

2-2.1 During the preliminary design stage, evaluate expected facility loading in accordance with MIL-HDBK-1004/1. This document provides suggested demand and load factors for analysis purposes. Include system losses in the overall estimated load requirements; use 6 percent of the maximum load demand as a first approximation of system losses.

2-2.2 Evaluate the load growth design allowance based on the type of facility and its expected mission over time. Include a minimum of 10 percent to 20 percent allowance for load growth unless it is certain that no future expansion is planned. This allowance provides some margin for unexpected changes during the design process and results in a more robust electrical system.

2-2.3 As part of the electrical system design process, evaluate the local commercial system reliability. If the data is available, review a 5-year history of service outages, including the date, time, location, duration, and cause of each outage. The commercial system reliability will influence facility electrical design decisions.

2-2.4 Continue to evaluate the electrical loading throughout the detailed design phase. Verify that the preliminary design load estimates continue to be acceptable or modify the design accordingly.

2-2.5 In accordance with NEC Article 220.35 (2002 Edition), the calculation of a feeder or service load for existing installations can use actual maximum demand to determine the existing load under the following conditions:

2-2.5.1 The maximum demand data is available for a 1-year period. If the maximum demand data for a 1-year period is not available, the calculated load can be based on the maximum demand (measure of average power demand over a 15-minute period) continuously recorded over a minimum 30-day period using a recording ammeter or power meter connected to the highest loaded phase of the feeder or service, based on the initial loading at the start of recording. Ensure the recording reflects the maximum demand of the feeder or service when the building or space is occupied and includes by measurement or calculation the larger of the heating or cooling equipment load, and other loads that might be periodic in nature due to seasonal variations.

2-2.5.2 The maximum demand at 125 percent plus the new load does not exceed the ampacity of the feeder or rating of the service. Determine the required capacity of feeder or service conductors by adding the new load to 125 percent of the maximum existing demand load determined above. This value is then compared to the existing feeder or service capacity to determine whether the existing installation is adequate for the new load.

2-2.5.3 The feeder has overcurrent protection in accordance with NEC Article 240.4 (2002 Edition), and the service has overload protection in accordance with NEC Article 230.90 (2002 Edition).

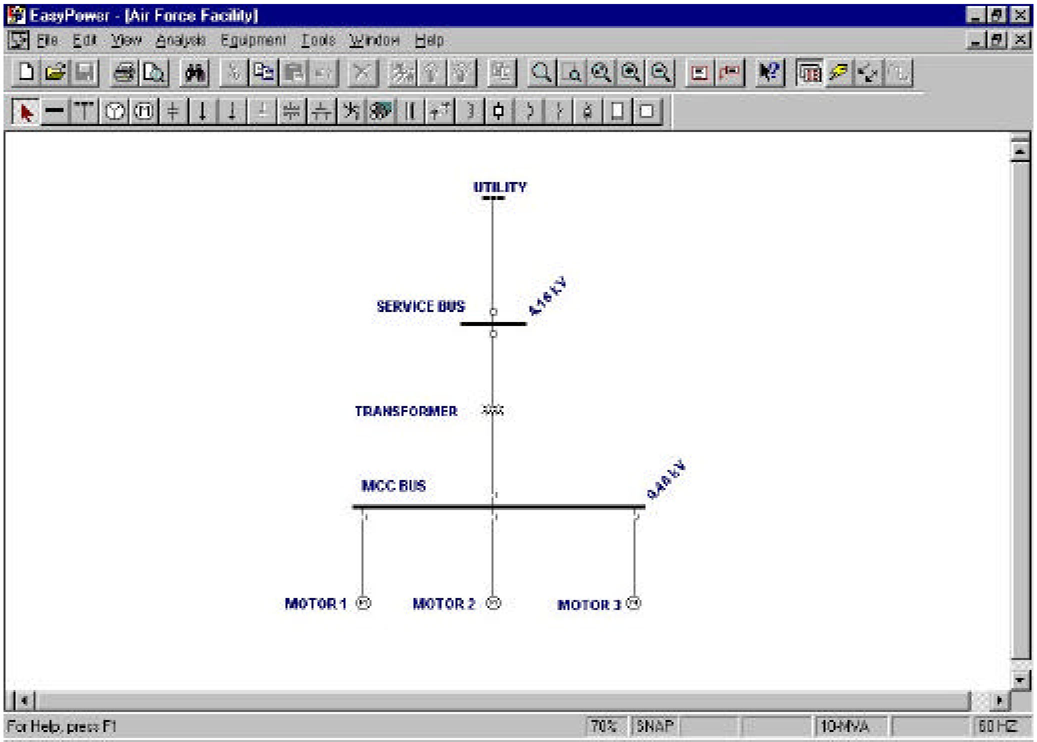
2-2.6 The detailed design process requires additional analysis to ensure the facility is designed properly for the anticipated electrical loads. Refer to the following sections for further information.

2-3 OVERVIEW OF DETAILED ANALYSIS CRITERIA.

2-3.1 Document design decisions throughout the design process. List any special features and alternatives that were considered. Include the method used for sizing conductors, conduit, protective devices, and other equipment. As part of the design analysis process, include a written description of the proposed system and show all calculations used in determining capacities of electrical systems. When tables from industry standards are used in the design, indicate the title, source, and date of the document.

2-3.2 Minor design modifications can often be performed by hand calculations, and the use of tables from the NEC and industry standards. More complex designs require a detailed analysis of the system design and operation during normal and abnormal conditions. The electrical studies to be performed include voltage drop, power flow, short circuit protection, and coordination. The industry standard for these types of studies is that they are performed by computer programs designed for such purpose. Hand calculations usually require simplifying assumptions that limit the accuracy or usefulness of the results. Figure 2-1 shows an example of a simplified electrical system on a computer model.

Figure 2-1. Computer Model of Electrical System



2-3.3 The computer program used for the analysis should have the following minimum features:

2-3.3.1 A graphical user interface is recommended so that the electrical system is shown on a one-line diagram representative of the actual facility electrical system. Tabular presentations require too much effort to evaluate and users have difficulty cross-referencing the results to the actual system one-line diagram.

2-3.3.2 The one-line diagram should include the flexibility to use the actual facility equipment designations. The user should be able to readily find equipment on the computer program one-line diagram without any need for cross-reference lists.

2-3.3.3 The program must perform power flow, short circuit, voltage drop, and motor starting analyses as a minimum. Additional modules for electrical coordination and harmonic analysis are desirable.

2-3.3.4 The program should readily identify overduty equipment in either power flow or short circuit analysis modes. For example, in short circuit analysis mode, the program should be capable of identifying breakers that are potentially exposed to short circuit currents that exceed interrupting ratings. In power flow mode, overloaded equipment or excessive voltage drop should be identified. Equipment sizing features based on this information are desirable.

2-3.3.5 The program should properly account for alternating current (ac) and direct current (dc) decrement characteristics. Programs that use a separate reactance (X) and resistance (R) network for modeling are usually consistent with ANSI standards. This program feature is important to ensure more realistic system X/R ratios, which can directly affect equipment rating assessments.

2-3.3.6 The program should be capable of handling multiple sources of generation.

2-3.3.7 The program should contain features that allow multiple case studies for each type of analysis. This involves features for graphically opening and closing breakers, and temporarily modifying load conditions.

2-3.3.8 The electrical model should be easily modified. For example, a desirable feature is the ability to open or shut breakers with just a click of a mouse. With this capability, many contingencies can be evaluated in a short time.

2-3.4 Several computer programs are available with the above capabilities. Programs that have not been updated since 1993 likely do not have the above capabilities.

2-3.5 The following sections provide specific criteria for the different types of detailed design analyses.

2-4 **SHORT CIRCUIT ANALYSIS**.

2-4.1 **Analysis and Equipment Criteria**.

2-4.1.1 Perform a short circuit study as an integral part of selecting and sizing electrical distribution components. Even the best and most reliable electrical distribution system is not immune to occasional short circuits.

2-4.1.2 Overcurrent protective devices in the system must be designed to isolate faults safely with minimal equipment damage and minimal disruption to facility operation. All equipment exposed to the short circuit current must be capable of withstanding the mechanical and thermal stresses caused by the current until the short circuit is isolated.

2-4.2 **Short Circuit Sources**.

2-4.2.1 All rotating electric machinery in (or electrically near) the facility can contribute to a fault. As part of a short circuit analysis, include the current contributions from the following types of equipment:

2-4.2.1.1 **Electric Transmission and Distribution Systems**. Depending on its size, the distribution system might be capable of producing the maximum short circuit indefinitely until equipment failure occurs within the facility.

2-4.2.1.2 **Generators**. Short circuit current flow from a generator is limited by the generator impedance and the circuit impedance between the generator and the fault. The magnitude of the generator fault current depends on the armature and field characteristics, the time duration of the fault, and the load on the generator.

2-4.2.1.3 **Motors**. Synchronous motors appear as a source of generation during a short circuit, with the current magnitude limited by the motor impedance and the circuit impedance between the motor and the fault. Induction motors also provide short circuit current, but the current supplied decays faster than with a synchronous motor.

2-4.2.1.4 **Transformers**. Supply transformers are not sources of short circuit current, but they have a significant impact on the magnitude of short circuit current supplied to a fault location. The transformer impedance will function to limit the short circuit current, but the short circuit current available at the transformer will be magnified or reduced in accordance with the turns ratio as it passes through the transformer.

2-4.2.2 Short circuit current from the above sources varies with time; not all sources can sustain the peak short circuit current. Instead, the short circuit current available in the system reaches some peak value and decays over the next few cycles to a smaller steady-state value. With time, the short circuit current provided by rotating machines falls to zero as they brake to a complete stop. Short circuit current is modeled as a function of time by three distinct impedances:

- Subtransient reactance (Xd")—the effective reactance defining the short circuit current during the first few cycles after a fault occurs. Use this value in all short circuit studies.

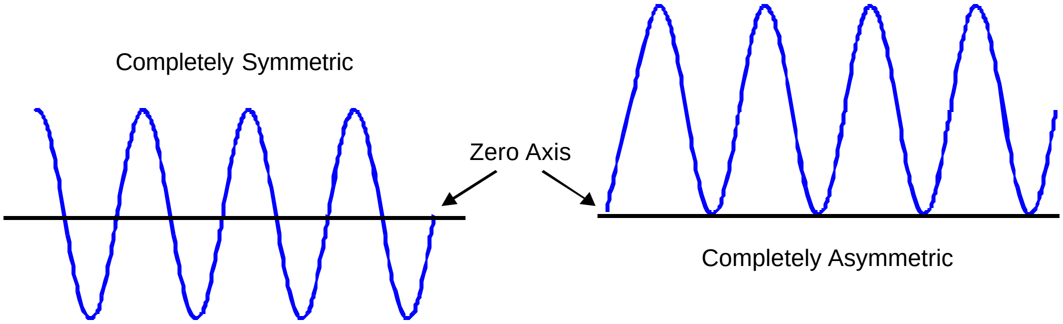
- Transient reactance (Xd')—the effective reactance during the period after the first few cycles up to about 30 cycles after a fault occurs. Use this value in voltage regulation and stability studies.

- Synchronous reactance (Xd)—the effective reactance after a steady-state condition has been reached. In terms of short circuits, steady-state conditions occur several seconds after the fault occurs.

2-4.3 **Symmetrical Versus Asymmetrical Current**.

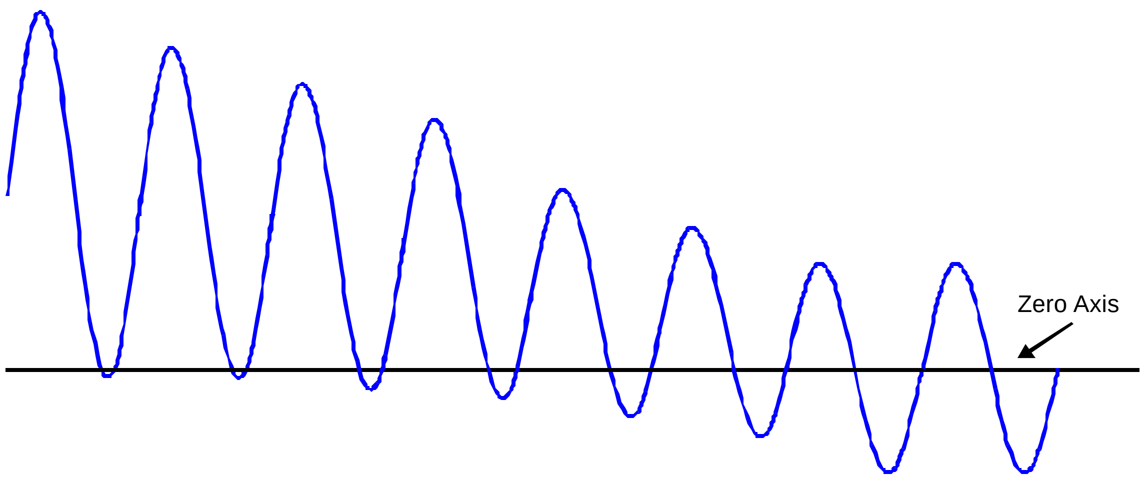
2-4.3.1 Include the effect of asymmetric current in all short circuit studies. Normal current is symmetric about the zero axis. Short circuit current tends to have symmetric and asymmetric behavior. The degree to which the current waveform is asymmetrical depends on when the fault occurs in relation to the voltage waveform peak or zero, and the proportions of resistance and reactance in the circuit. If a short circuit occurs in an inductive reactive circuit at the peak of the voltage waveform, the resulting short circuit current is completely symmetrical as shown in Figure 2-2. If a short circuit occurs in the same circuit but at the zero of the waveform, the resulting short circuit current will be completely asymmetrical.

Figure 2-2. Completely Symmetric or Asymmetric Current



2-4.3.2 Figure 2-3 shows a typical short circuit waveform for a low voltage system. The ratio of reactance to resistance exhibited by a system during a fault affects the instantaneous magnitude and duration of the short circuit current peak and can affect a circuit breaker's interrupting rating. For this reason, consider both the symmetrical and asymmetrical short circuit current in a breaker rating evaluation.

Figure 2-3. Typical Asymmetrical Short Circuit Behavior



2-4.4 **Short Circuit Calculations**.

2-4.4.1 Electrical distribution systems must be designed to withstand the maximum expected fault (short circuit) current until the short circuit current is cleared by a protective device. This is a fundamental electrical requirement. NEC Article 110.9 (2002 Edition) requires that all protective devices intended to interrupt current at fault levels must have an interrupting rating sufficient for the nominal circuit voltage and the current that is available at the line terminals of the equipment. For this reason, the maximum available short circuit current must be determined for all locations throughout the electrical system requiring overcurrent protection.

2-4.4.2 Calculate short circuit currents in support of the following equipment selection activities:

- Verification of interrupting rating of protective devices.

- Determination of system components' ability to withstand mechanical and thermal stresses.

- Evaluation of time-current coordination of protective devices.

2-4.4.3 Calculate short-circuit currents for the following short circuit duration times:

2-4.4.3.1 First-cycle maximum symmetrical values are always required. These are often the only values needed for low voltage breakers with instantaneous trip devices and for fuses.

2-4.4.3.2 Obtain maximum values (1.5 to 4 cycles) for medium-voltage and high-voltage circuit breaker applications.

2-4.4.3.3 Obtain reduced fault current values (about 30 cycles) for estimating the performance of time-delay relays and fuses and for low voltage power circuit breakers without instantaneous trip devices. These values must be calculated so that the proper current is known for setting time delay protective relays. Also, minimum values must be calculated to determine whether sufficient current is available to open the protective device within a satisfactory time.

2-4.4.4 Appendix B provides examples of how the maximum available short circuit current can be affected by system modifications.

2-5 **POWER FLOW ANALYSIS**.

2-5.1 A power flow analysis (also referred to as a load flow analysis) determines if electrical system equipment is potentially overloaded and confirms that adequate voltage is available throughout the system. Perform power flow analyses by a computer program designed for this purpose. The computer program used to perform a short circuit study usually also has power flow analysis capability.

2-5.2 Perform a power flow analysis to determine if the following equipment types are potentially overloaded at expected design conditions:

- Cables and conductors.

- Busways.

- Transformers.

- Circuit breakers.

2-5.3 For small systems or for small modifications to large systems, this analysis can be performed manually by summing loads and comparing load currents to conductor ratings. For larger systems, a computer program is necessary to evaluate properly all of the possible facility modes of operation.

2-6 VOLTAGE DROP ANALYSIS.

2-6.1 Voltage Drop Calculations.

2-6.1.1 A power flow analysis as described in paragraph 2-5 provides equivalent voltage drop results also by displaying the voltages throughout the electrical system. Manual voltage drop calculations are necessary for smaller systems in which a power flow analysis was not performed or to check smaller load panels in larger systems.

2-6.1.2 Verify adequate voltage drop throughout the electrical distribution system. Paragraph B-2 provides information regarding how to calculate voltage drop. The allowed voltage drop is typically no more than 5 percent for continuous loads and depends of the voltage range required by the load. Refer to paragraph 6-2 for specific requirements.

2-6.1.3 As part of a voltage drop study, evaluate the voltage regulation throughout the system while considering the effect of overvoltage and undervoltage on the various load types. Distribute voltage drop throughout the system in the most economical way. Specify transformer tap settings as needed to satisfy system voltage drop limitations. Verify that selected transformer tap settings are acceptable for both full-load and no-load conditions.

2-6.2 Motor Starting Studies.

2-6.2.1 Confirm system loading, conductor sizing, and transformer sizing is adequate to ensure that voltage drops do not reduce motor torque values below minimum values. Ensure that starting current of any motor will not actuate undervoltage protection or cause stalling of other motors.

2-6.2.2 If a computer program was used to perform the power flow analysis, the same electrical system model will often be used to evaluate the voltage drop during motor starting. An impact motor starting analysis is acceptable to determine the minimum voltage during motor starting.

2-6.2.3 If large motors are to be started by an emergency generator, a more detailed transient analysis will be necessary; contact the generator manufacturer for assistance.

2-6.2.4 The voltage drop caused by motor starting can be calculated by hand if a computer program is not available. Calculate the maximum voltage drop under locked rotor conditions to determine the worst-case effect of motor starting. Follow the procedure described in Appendix B. If actual motor data is not available, obtain motor full-load current from NEC Table 430.150 (2002 Edition) and obtain maximum motor locked rotor current from NEC Table 430.151B (2002 Edition). Energy efficient Design B motors can have a locked rotor current near that of Design E motors. Use the maximum locked rotor motor current in the calculation of voltage drop. The impedance is the total impedance from the service entrance to the motor. If other significant loads, such as other large motors, are also contributing to the total feeder current, add this current to the motor starting current in the feeder. If appropriate for the situation, demand factors can be applied to the other load currents.

2-6.2.5 Refer to paragraph 7-2.3 for design alternatives to consider if motor starting current causes more than a 20 percent transient voltage dip during starting.

2-6.2.6 Evaluate the effect of motor starting transients with respect to flicker of incandescent lamps. Refer to IEEE 241, *IEEE Recommended Practice for Electric Power Systems in Commercial Buildings*, for information regarding the calculation and effect of flicker. This is particularly important for any electrical system with a large proportion of motor loads or a system with cycling motor loads.

2-7 **ELECTRICAL COORDINATION**.

2-7.1 Determine if electrical coordination is a design requirement for the electrical system or some portion of the electrical system. If coordination is required, perform a coordination study to ensure that protective device settings are appropriate for the expected range of conditions. The coordination study of an electric power system consists of an organized time-current study of all protective devices in series from the electrical source (commercial power or a backup power source) down to the utilization device. This study compares the time it takes the individual devices to operate when certain levels of normal or abnormal current are sensed. The objective of a coordination study is to generate a comprehensive one-line-diagram representation of the distribution system performance to abnormal currents. This is intended to ensure that protective devices will isolate a fault or overload anywhere in the system with the least possible effect on unfaulted sections of the system. At the same time, the devices and settings selected must provide satisfactory protection against overloads on the equipment and must interrupt short circuits as rapidly as possible. Depending of the design and construction schedule, it might be necessary to design adequate protective devices with adjustable features, followed by a coordination study during construction to specify the correct settings.

2-7.2 Ensure electrical systems are selectively coordinated to the maximum degree practical. Critical systems require selective coordination to the first panelboard level, as a minimum. Refer to Chapter 9 for specific electrical coordination study criteria.

2-8 **POWER QUALITY AND HARMONIC DISTORTION**.

2-8.1 Refer to Chapter 12 for specific analysis criteria for power quality design requirements. Chapter 12 provides a technical basis for power system quality as a design consideration and explains different methods of solving power quality problems. Unlike other system electrical design criteria, power quality design solutions are very dependent on the types of transients and disturbances that can and will occur in power systems.

2-8.2 Power quality solutions often involve a certain level of compromise between the electrical system design and the design of the end-use equipment. In many cases, it will be easier to provide protection and power quality design features to specific equipment rather than generically throughout the facility.

2-9 **LIGHTING**.

2-9.1 Follow the established procedures as described in the Illuminating Engineering Society of North America (IESNA) *Lighting Handbook*, for lighting calculations. Ensure personnel are trained and qualified to perform such calculations.

2-9.2 Appendix F provides an overview on interior lighting.

2-10 **ENERGY ANALYSIS**.

2-10.1 **Overview**.

2-10.1.1 Executive Order (EO) 13123, *Greening the Government Through Efficient Energy Management*, was issued on June 3, 1999. This EO requires that energy efficient products must be considered and applied wherever they are life-cycle cost-effective. EO 13123 requires, through life-cycle cost-effective measures, that each agency reduce energy consumption per gross square foot of its facilities by 30 percent by 2005 and 35 percent by 2010 relative to 1985. The following is an excerpt of Section 403(b), *ENERGY STAR® and Other Energy Efficient Products*:

> "(1) Agencies shall select, where life-cycle cost effective, ENERGY STAR® and other energy efficient products when acquiring energy-using products. For product groups where ENERGY STAR® labels are not yet available, agencies shall select products that are in the upper 25 percent of energy efficiency as designated by FEMP. The Environmental Protection Agency (EPA) and DOE shall expedite the process of designating products as ENERGY STAR® and will merge their current efficiency rating procedures.
>
> (2) GSA and the Defense Logistics Agency (DLA), with assistance from EPA and DOE, shall create clear catalogue listings that designate these products in both print and electronic formats. In addition, GSA and DLA shall undertake pilot projects from selected energy-using products to show a "second price tag", which means an accounting of the operating and purchase costs of the item, in both printed and electronic catalogues and assess the impact of providing this information on Federal purchasing decisions.
>
> (3) Agencies shall incorporate energy efficient criteria consistent with ENERGY STAR® and other FEMP-designated energy efficiency levels

> into all guide specifications and project specifications developed for new construction and renovation, as well as into product specification language developed for Basic Ordering Agreements, Blanket Purchasing Agreements, Government Wide Acquisition Contracts, and all other purchasing procedures."

2-10.1.2 EO 13123, Part 2 – GOALS, lists seven goals for facilities. Six of the seven specifically emphasize that "life-cycle cost-effective" means are to be used to comply with these goals. The EO specifically states that: "agencies shall apply such principles to the siting, design, and construction of new facilities. Agencies shall optimize life-cycle costs, pollution, and other environmental and energy costs associated with the construction, life-cycle operation, and decommissioning of the facility." This emphasis on life-cycle cost effectiveness can, in some instances, make it more difficult to achieve goals established by this EO.

2-10.1.3 Sustainable design is the design, construction, operation, and reuse/removal of the built environment (infrastructure as well as buildings) in an environmentally and energy efficient manner. Sustainable design is intended to meet the needs of today without compromising the ability of future generations to meet its needs. It includes not only efficient use of natural resources, but can also translate into better performance, desirability, and affordability. For the Army, review USACE Engineer Technical Letter (ETL) 1110-3-491, *Sustainable Design for Military Facilities*, for sustainable design considerations with respect to energy efficiency design criteria. For the Navy, review the following documents: Naval Facilities Engineering Command Planning and Design Policy Statements 98-01, *Design of Sustainable Facilities and Infrastructure*, 98-02, *Criteria Supporting the Design of Sustainable Facilities and Infrastructure*, and 98-03, *Procurement of Sustainable Facilities and Infrastructure Through Architect-Engineer (A-E) and Related Contracts*. For the Air Force, review the HQ USAF/ILE memorandum dated December 19, 2001, *Sustainable Development Policy*, available at http://www.afcee.brooks.af.mil/green/resources/policymemo.doc.

2-10.1.4. This manual addresses key electrical-related energy efficiency requirements; however, it does not address the full scope of potential energy efficiency savings from non-electrical system modifications.

2-10.2 **New Facility Criteria**.

2-10.2.1 Include an assessment of energy efficiency and energy costs as part of the electrical design of all new facilities. The goal of this assessment is to consider alternative design approaches that demonstrate a life-cycle cost savings attributable to lower energy costs. Higher initial costs for equipment are acceptable provided that the energy analysis shows a cost savings over time.

2-10.2.2 Requirements relating to energy efficiency are covered in ASHRAE 90.1-1999, including supplements.

2-10.3 **Existing Facilities**.

2-10.3.1 Existing facilities should incorporate energy-saving design features into all facility upgrades. Some modifications, such as lighting or ASD installations, can be justified solely on the basis of energy savings.

2-10.3.2 Perform an energy audit to evaluate energy efficiency savings opportunities in the electrical system. The primary purpose of an energy audit is to identify energy conservation and cost savings opportunities among "energy-using" systems such as lighting fixtures, and heating, ventilation and air conditioning (HVAC) equipment. The goal of the energy audit is to evaluate the overall efficiency of building energy systems as well as the efficiency of individual components within those energy systems.

2-10.3.3 Although many buildings have been improved over the years by retrofits, most old buildings still offer greater energy-saving and cost-saving opportunities. Retrofitting entire older energy systems can be an attractive investment because the simple payback for many of these projects is less than two years. However, the initial capital outlay is often substantial and might require the entire building to be vacated for some period of time.

2-10.3.4 An energy audit should also determine the performance and efficiency of each individual component of an electrical system. Although the components of many electrical systems have been replaced since they were first installed, many are still not energy efficient by today's standards. With advances in technology, more energy-efficient replacement components are available today. Many of those components can be replaced relatively easily and numerous no-cost or low-cost opportunities can be identified through a productive energy audit program. For example, high-efficiency fluorescent lights with electronic ballasts can replace older fluorescent or incandescent lights without major modifications.

2-10.3.5 As part of the energy audit process, follow up on completed energy conservation projects to determine if the expected savings have been achieved. This type of audit is important for shared energy savings contracts (or other performance contracting). The AFCESA *Energy Measurement and Verification Handbook* provides guidance regarding measurement and verification.

2-10.4 **Energy Efficiency Design Opportunities in the Electrical System**.

2-10.4.1 Consider the energy savings options listed in Table 2-1.

Table 2-1. Energy Efficiency Design Options That Frequently Show Savings

Equipment	Energy-Savings Design Opportunities
Lighting Systems	Use high-efficiency fluorescent lighting Install high-efficiency ballasts Remove or replace lenses Reduce time of operation Install task lighting Apply daylighting Install dimming systems Illumination levels should conform with IESNA
Power System Losses	Install energy efficient transformers with an Energy Star classification Correct power factor Install larger gauge wiring Replace oversized motors Install energy-efficient motors Install ASDs
Power System Control	Reduce peak load demand Install an energy management and control system

2-10.4.2 This manual provides specific guidance in key areas regarding energy efficiency studies. Refer to the following paragraphs for additional information.

- Paragraph 6-3—sizing wiring for increased energy savings is discussed.
- Paragraph 7-1—minimum motor efficiency requirements are provided.
- Paragraph 7-3—ASDs are described, including analysis methods to assess energy savings.
- Appendix C—design issues relating to power factor correction are discussed.
- Appendix F—energy efficiency criteria related to lighting systems are covered in detail.

2-11 **LIFE-CYCLE COST ANALYSIS**.

2-11.1 Include a life-cycle cost analysis in the comparison of design alternatives. The expected equipment operating life must be based on an engineering assessment of the realistic operational life. Do not use equipment warranty periods as the expected service life unless the manufacturer provides convincing evidence that the equipment is capable of this operational life.

2-11.2 Include installation, operation, and maintenance costs in the life-cycle analysis. Different design options can have a significant impact on long-term operation and maintenance costs.

2-12 ELECTRICAL DRAWINGS.

2-12.1 **Introduction**. Ensure that electrical drawings are complete and reflect the intended design. During and after construction, clearly document changes to the intended design on the drawings. Drawings should be provided in electronic form.

2-12.2 **One-Line Diagrams**. Show the electrical system layout. Include major equipment ratings and sizes. Also, include cables, circuit breakers, buses, relaying, and metering. Provide adequate detail to allow a reviewer to understand how the electrical system is arranged and operated.

2-12.3 **Switchgear Lineups**. Identify each section of the lineup. Clearly show metering and relay requirements. Show internal wiring layouts and show external wiring, including destinations. Show all relay, metering, and instrumentation on one-line diagrams.

2-12.4 **Motor Control Center (MCC) Layouts**. Identify each MCC cubicle. Include the following information: starter data; circuit breaker size and setting; overload heater size; and motor horsepower and feeder size. Include schematic and interconnection diagrams of wiring connections. Show external wiring, including destinations. Note: Overload heater elements are usually sized after the final motors are selected and provided for the project by the suppler/manufacturer. This information might not be available in the initial design.

2-12.5 **Grounding**. Show the details of the grounding system with connection details included on applicable drawings.

2-12.6 **Control Panel Wiring Diagrams**. Provide internal and external wiring diagrams. Include material lists. Show destinations of external wiring and associated conduits.

2-12.7 **Control Schematics**. Document the intended process flow plan on the applicable schematics. Show locations of components. The control schematics must agree with the associated wiring diagrams. Show ladder diagrams on drawings.

2-12.8 **Miscellaneous Interconnection Diagrams**. Provide interconnection diagrams as necessary and ensure they agree with the associated schematics. Identify locations of components.

2-12.9 **Equipment Layouts with Conduit or Cable Tray**. Show all electrical equipment locations and document conduit sizes. Ensure match lines and floor plans are consistent. Provide cross-sections as necessary. Clearly show all destinations.

2-12.10 **Panel Schedules**. Complete all panel schedules. Provide adequate detail to allow reviewers to check panel loading.

2-12.11 **Lighting and Receptacle Layouts**. Show all circuit assignments and ensure they agree with the associated panel schedule. Show fixture and emergency lighting locations.

2-12.12 **Motor List**. Maintain a motor list for the facility and ensure it agrees with the MCC layouts.

2-12.13 **Conduit or Cable Schedule**. Conduits should be labeled. Cable destinations should be shown.

CHAPTER 3

GENERAL POWER SYSTEM CRITERIA

3-1 CHARACTERISTICS.

3-1.1 Voltage.

3-1.1.1 Select electrical characteristics of the power system to provide a safe, efficient, and economical distribution of power, based upon the size and types of loads to be served. Use distribution and utilization voltages of the highest level that is practical for the load to be served. The following guidelines apply:

3-1.1.1.1 Generally, single-phase, three-wire 120/240 volt systems are used to serve single-phase lighting and power loads less than 50 kilovolt-amperes (kVA). This voltage level is usually provided to small-scale and residential facilities.

3-1.1.1.2 Three-phase, four-wire, 208Y/120 volt systems are normally used for lighting and power loads less than 150 kVA. A 208Y/120 volt system is usually most economical when most of the load consists of 120 volt lighting and utilization equipment, and the average feeder length is less than 61 meters (200 feet). This voltage level is usually provided to commercial-type facilities that do not have extensive fluorescent lighting or motor loads. Although there are many existing 208Y/120 volt systems, the 480Y/277 volt system is preferred wherever possible because the higher voltage is more energy-efficient and has more potential for future load growth.

3-1.1.1.3 Three-phase, four-wire, 480Y/277 volt systems should normally be used for lighting and power loads greater than 150 kVA. This voltage level should also normally be used if large motors are a significant portion of the total load or if most of the load can be served by 480Y/277 volts. In this case, design lighting to operate at 277 volts unless specifically prohibited by NEC criteria (such as dwelling units). All three-phase motors should be served at 480 volts. Utilize dry-type transformers as needed to serve smaller 208Y/120 volt loads.

3-1.1.1.4 Perform an economic analysis for 208 volt systems larger than 300 kVA or serving motors larger than 25 horsepower (18,650 watts).

3-1.1.2 Justify exceptions to the above guidelines based on the existing facility design or on unique requirements of the proposed design.

3-1.1.3 Use the standard available voltages of the host nation for facilities located outside of North America; refer to TM-5-688 for additional information. Apply the highest distribution and utilization voltage level that is practical for the load to be served. Use power conversion equipment as necessary to satisfy voltage requirements of specific equipment.

3-1.1.4 Other voltage levels can be used as necessary to serve specific loads.

3-1.2 **Frequency**.

3-1.2.1 Apply a frequency of 60 Hertz for distribution and utilization power. Other frequencies, such as 400 Hertz, are used to serve specific loads or subsystems where required by the using agency.

3-1.2.2 In locations in which the commercially-supplied frequency is other than 60 Hertz, such as 50 Hertz, use the available supplied frequency to the extent practical. Where frequencies other than that locally available are required for technical purposes, frequency conversion or generation equipment can be installed. The facility user will normally provide this equipment.

3-1.3 **Power Factor**.

3-1.3.1 Utilization equipment with an inductive load characteristic should have a power factor of not less than 0.8 to 0.9 lagging under full load conditions as a design goal. Generally, a load group of utilization equipment will have a power factor of between 0.8 to 0.9 lagging if it is comprised of mostly motors, electromagnetic ballasts, and incandescent lights. Electrical systems containing mostly motors might have power factors closer to 0.8 lagging, while loads containing mostly electronic ballasts and incandescent lamps will have power factors closer to unity.

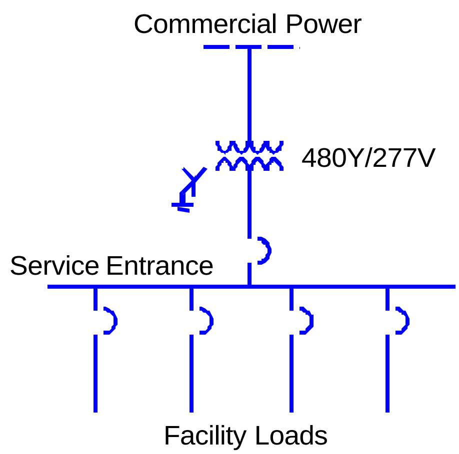
3-1.3.2 Power factors lower than 0.9 lagging are not as energy efficient as desired. Refer to paragraph 8-7 if power factor correction is considered. Power factor correction requires careful coordination with power quality design features.

3-1.4 **Neutral Conductor Grounding**. Solidly ground the neutral conductor of all distribution systems operating at phase-to-phase voltages of 600 volts or less, except for applications such as continuous processes for industrial systems where shutdown would create a hazard, loss of materials, or equipment damage. For those applications, evaluate the use of a solidly grounded wye system with a backup power supply, or a high-resistance grounded wye system. Use of other than solidly grounded systems must be justified on the basis of the need for service continuity. If an ungrounded system is used, include a ground detection system in the design to alert personnel of an inadvertent ground.

3-2 **NORMAL POWER SOURCE**.

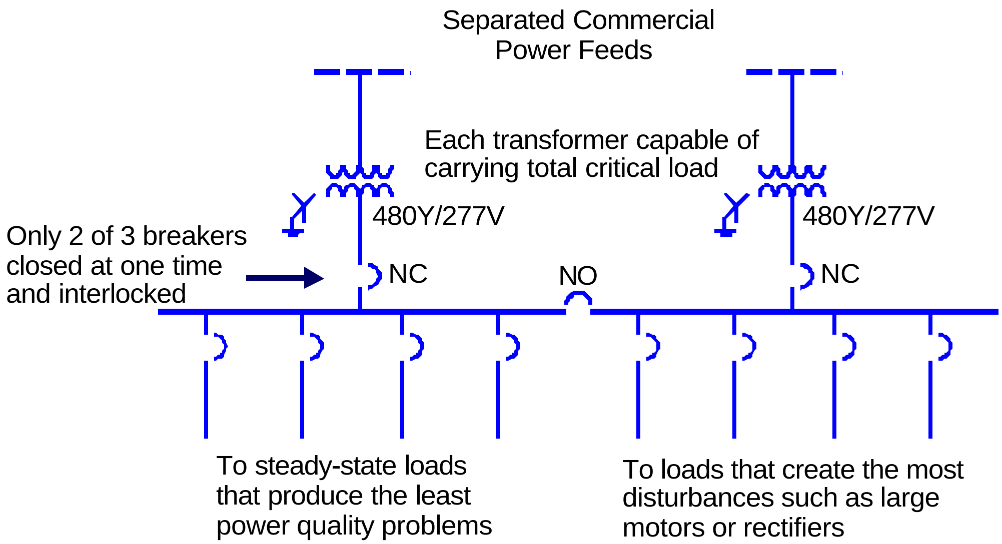
3-2.1 Normal source systems should usually consist of radial distribution configurations consisting of a single transformer for each building or group of buildings for loads of 150 kVA or less at 208 volts, or 2,000 kVA or less at 480 volts. Figure 3-1 shows an example of this arrangement. Higher kVA ratings are allowed provided that the design analysis demonstrates that the system reliability and economic operation are acceptable. The service entrance transformer size will establish interrupting rating and coordination requirements for downstream equipment, which can alone necessitate either dual transformers serving separate loads at the service entrance or a higher service entrance voltage rating. Generally, ratings above 2,000 kVA will necessitate the use of a medium voltage system. Base the choice of the main supply service voltage on an economic analysis of the various electrical system options for any particular facility under design. If the total facility load is large, consider the impact of transformer failure on the facility's mission and consider if dual transformers or backup power might be needed.

Figure 3-1. Single Power Feed to Facility



3-2.2 Mission-critical facilities should normally use secondary-selective configurations, consisting of double-ended transformer installations with normally open, interlocked bus-ties, and either open or closed switchgear lineups (refer to Figure 3-2). Design double-ended transformer installations with incoming sections, transformers, and primary bus in the middle, and the secondary distribution sections on the outside to allow for future load growth. Size each transformer of a double-ended system to serve approximately 60 percent to 80 percent of the total demand load served and ensure each transformer and electric lines are capable of carrying greater than 100 percent of the critical loads. This arrangement effectively provides a spare transformer for the critical loads. Separate the two feeds from commercial power to the degree practical consistent with the overall facility design to minimize the possibility of simultaneous damage to both feeds by lightning, nearby excavation, or other reasons.

Figure 3-2. Redundant Power Feed to Facility



3-2.3 Under normal conditions, use commercial power as the prime source of power. Use base-generated power (Class A) as the prime source for all loads when commercial power is not available or is determined to be inadequate.

3-2.4 Provide duplicate commercial power source, transmission feeders, substations, distribution feeders, or base prime generating plants where approved for system reliability requirements. Duplicate prime sources should be provided for the following loads:

- Tactical mission where either source is subject to attack or sabotage. If possible, the duplicate source should be separated approximately 1.6 kilometers (one mile) from the other source, with adequate protective measures incorporated into the main transformer banks and prime power source.
- Large loads exceeding 20,000 kW design capacity served from any one substation or generating plant.
- Operational loads as specifically determined by the authority having jurisdiction.

3-3 **ALTERNATE AND BACKUP POWER SOURCE**.

3-3.1 An alternate source system should normally consist of battery supplies for small loads such as fire alarm or emergency lighting systems. Diesel engine power generating units should be used to provide electrical power for larger loads during an interruption of the normal power supply. For the Air Force, refer to Air Force Instruction (AFI) 32-1063, *Electric Power Systems*, for additional information.

3-3.2 Loads served by an alternate source normally consist of critical systems and equipment only, unless designated otherwise by specific agency criteria. The types of critical loads include the following:

- Alarm and detection systems.
- Essential communications and computer systems.
- Exit and emergency lighting.
- Security and surveillance systems.
- Lighting and power required to conduct essential operations.
- Generator-location lighting.
- Selected receptacles for critical operations.

3-3.3 Specific facilities can have additional alternate source needs for other communications equipment, essential refrigeration, and other mission essential equipment.

3-3.4 Refer to Chapter 13 for specific design criteria for alternate source systems.

3-4 **SERVICES**.

3-4.1 Locate service entrance equipment in readily accessible spaces to facilitate disconnection of power in case of emergency. Coordinate the service entrance location with the exterior distribution system to ensure that service and feeder circuit lengths are as short as practical.

3-4.2 Service conductors 600 volts and less should be installed underground from transformers, regardless of whether the transformers are on poles or at grade. Aerial services can be provided for buildings having a service ampacity of 200 amperes or less that are located in areas of installation where appearance is of no concern, such as industrial or warehousing areas, and where safe vertical clearances can be maintained. Calculate the ampacity of services in accordance with paragraphs 6-2 and 6-3.

3-4.3 Services greater than 600 volts to structures should be installed underground. Provide incoming services tapped from aerial distribution circuits with surge protectors at the service entrance equipment (refer to Chapter 11 for surge protector design criteria). Limit services exceeding 600 volts to the following types of facilities:

- Large facilities requiring a variety of load centers.
- Facilities having a connected load of 2,000 kVA or larger.
- Facilities where low voltage services are impractical due to cost or technical feasibility.

3-4.4 For services greater than 600 volts, use metal-enclosed, manually operated, fusible load interrupter switches or power circuit breakers. For services 600 volts and less, use molded case breakers, low voltage power circuit breakers, or fusible disconnect switches. Low voltage power circuit breakers should be selected only where the added cost incurred by their use can be justified by operational considerations. Provide a single disconnecting means for each facility. Avoid multiple disconnects unless major economies can be realized in large capacity services or if multiple service voltage requirements exist. Ensure equipment ampacities are adequate for the estimated load demands plus a contingency of 10 percent to 20 percent for future load growth. A larger reserve contingency can be applied if a specific need for future load growth can be documented. Equipment must be capable of safely performing all interrupting functions based on the available system capacity and characteristics.

3-4.5 Provide energy usage and demand meters in accordance with paragraph 8-6.

3-4.6 Equipment room space required by major items of equipment such as switchgear, transformers, generators, cable routing, uninterruptible power supply (UPS) systems, and batteries should be designed in accordance with the NEC. Ensure that equipment can be removed and replaced without interference with other systems or equipment, and without requiring building modifications. Provide ventilation as necessary to permit equipment to operate within normal ambient temperature limitations; otherwise, derate the equipment accordingly for a lower capability and potentially shorter service life. Provide separate air-conditioned electronic equipment rooms as required. Refer to paragraph 8-1 for additional requirements regarding equipment clearances.

3-4.7 Design electrical distribution systems that require high reliability power to comply with ANSI C84.1, *Electrical Power Systems and Equipment—Voltage Ratings (60Hz)*, Range A voltage limits. Facilities that do not have high reliability requirements can be designed to ANSI C84.1 Range B limits.

CHAPTER 4

POWER DISTRIBUTION AND UTILIZATION—TRANSFORMERS

4-1 **RATINGS**.

4-1.1 **Introduction**.

4-1.1.1 The choice of the main supply service voltage should be based on an energy economic analysis of the various electrical system options for any particular facility under design. This is an integral part of determining the transformer primary voltage rating.

4-1.1.2 An economic analysis of the selected transformer can be performed using the analysis tools provided by the Energy Star program at http://www.energystar.gov.

4-1.2 **Voltage and Current**.

4-1.2.1 The transformer primary voltage rating must be determined by the voltage available to the transformer from the facility electrical distribution system. Select the transformer secondary voltage based on the required voltage on the secondary as determined by the most economical facility distribution voltage, the largest loads with previously fixed voltages, and energy usage density.

4-1.2.2 The rated secondary voltage is the voltage at which the transformer secondary is designed to deliver the rated kVA capacity. Transformer windings are connected in either series or parallel to obtain the desired output (secondary) voltage. Common nominal voltages are shown in Table 4-1.

Table 4-1. Common Primary and Secondary Transformer Voltages

Single-Phase Transformer		Three-Phase Transformer	
Primary	Secondary	Primary	Secondary
240 × 480	120	208	208Y/120
120/208/240/277	120/240	240	240/120
480		480	480Y/277
		4,160	4,160
		13,800	

Note: Table 4-1 does not include all possible combinations of transformer ratios. Refer to Table 5-1 for additional primary and secondary voltages that have been used. Also, overseas facilities will commonly be designed around a 400Y/230 volt, 50 Hertz system. Contact the transformer vendor for non-standard voltage and frequency ratings.

4-1.3 **Temperature and kVA**.

4-1.3.1 The kVA capacity of a transformer is the output that it can deliver for a specified period of time, at the rated secondary voltage and rated frequency, without exceeding a specified temperature rise based on insulation life and ambient temperature. Transformers can be loaded above their kVA ratings with no loss of life expectancy only when operated within the manufacturer's stated limits. Select the transformer based on its kVA capacity and temperature rating.

4-1.3.2 The rated kVA capacity is based on the maximum current delivered at rated voltage. The real limit in the transformer's capability is the amount of current that it can provide without exceeding a defined temperature rise. Dry type transformers are designed with various insulation types and the rating and loading of a transformer are based on the temperature limits of the particular system. Note that the transformer's rated temperature will be reached when it is operated at full load under the manufacturer's specified conditions, meaning that some caution is warranted in the selection, application, installation, and loading of a transformer. The following insulation systems are available (refer to Figure 4-1):

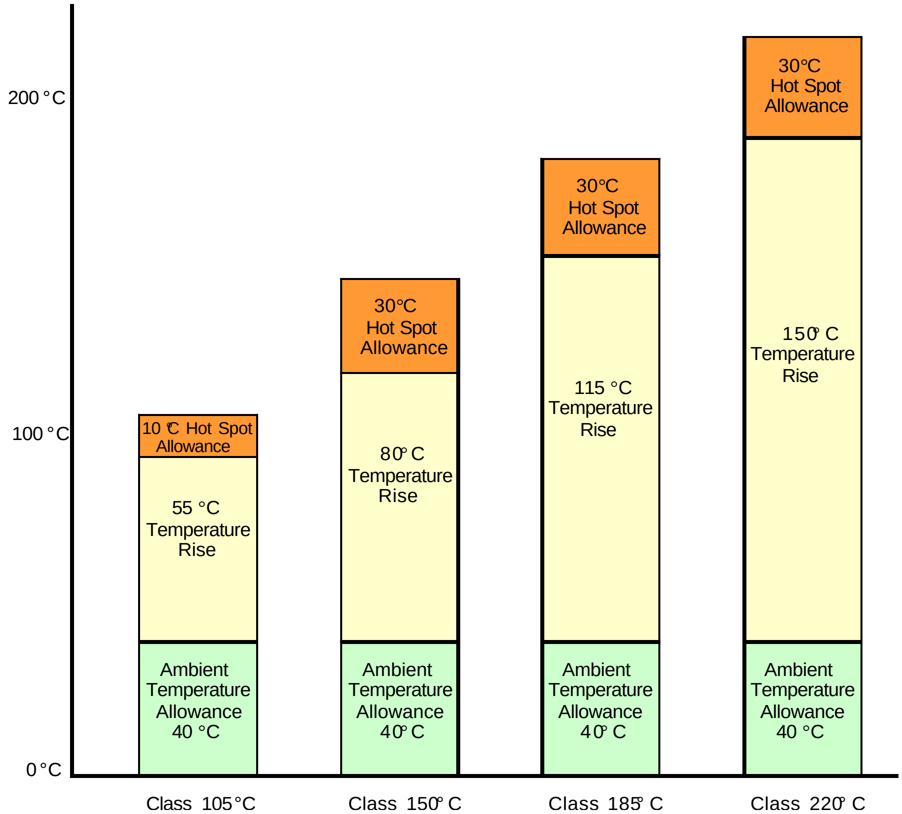
- Class 105—when loaded in an ambient temperature of not over 40 °C, will operate at no more than a 55 °C average temperature rise on the winding conductors, with an added 10 °C allowance for a hot spot. The sum of 40 °C + 55 °C + 10 °C provides the 105 °C designation. This insulation class is used only on very small transformers. Older designs refer to this as a Class A insulation or transformer rating.

- Class 150—allows an 80 °C rise in the winding plus a 30 °C hot spot allowance. Class 150 insulation is often used in transformers rated up to 2 kVA. Older designs refer to this as a Class B insulation or transformer rating.

- Class 185—allows a 115 °C rise in the winding plus a 30 °C hot spot allowance. Class 185 insulation is often used in transformers rated from 3 to 30 kVA. Older designs refer to this as a Class F insulation or transformer rating. Some documents refer to a Class 180 rating also.

- Class 220—allows a 150 °C rise in the winding plus a 30 °C hot spot allowance. Class 220 insulation is commonly used in transformers rated in all significant sizes. Older designs refer to this as a Class H insulation or transformer rating.

Figure 4-1. Insulation System Ratings



4-1.3.3 The kVA rating and the insulation system rating are related. Select the desired kVA rating or insulation system based on the following considerations:

- Relative loading—transformers loaded at or close to their kVA ratings will operate hotter than transformers that are lightly loaded. A higher kVA rating can be selected just to ensure that the transformer operates cooler to avoid long-term thermal damage.

- Duty cycle—the duty cycle might have the transformer fully loaded most of the time or lightly loaded most of the time. The transformer kVA rating has to be capable of supplying the system full-load current, but the capacity margin can be lower for lightly loaded duty cycles.

- Ambient temperature—the average and maximum ambient temperatures at the installation location must be determined (or estimated) as part of the selection process. If necessary, increase the kVA rating or insulation system class to reduce the degree of thermal damage at higher temperatures.

4-1.3.4 Unless there are special application or environmental requirements, transformers rated 15 kVA or greater should have a Class 220 insulation system. Transformers rated less than 15 kVA should have a Class 185 insulation system.

4-1.4 **Impedance**.

4-1.4.1 The transformer impedance is an important design characteristic; the impedance determines how the transformer will regulate voltage with variation in load. Additionally, the impedance limits the maximum fault current that can be supplied through the transformer. Transformer impedances commonly vary between 3 percent and 6 percent. A high impedance might limit short circuit current at the expense of regulation and a low impedance might provide acceptable regulation at the expense of higher short circuit currents.

4-1.4.3 Evaluate the selected transformer's impedance rating to ensure that it will not allow a greater short circuit current in its secondary than the downstream protective devices are capable of interrupting.

4-1.4.3 Impedance affects transformer regulation. As the impedance increases, the voltage regulation tends to increase. Unless the system requires a tighter tolerance, design for a voltage regulation range of 2 percent to 5 percent. For sensitive equipment, tighter regulation requirements might apply; review downstream equipment voltage requirements to verify that the regulation will be acceptable.

4-1.4.4 Transformers are readily available with an Energy Star rating, which are intended to reduce energy losses by a more efficient design. Wherever energy-efficient transformers are used, verify that the available short circuit current does not exceed the interrupting rating of downstream protective devices.

4-1.5 **Number of Phases**.

4-1.5.1 Use single-phase transformers on single-phase systems and on single-phase circuits derived from three-phase systems.

4-1.5.2 Use either three single-phase transformers or one three-phase transformer on three-phase circuits. A three-phase transformer weighs less; requires less space than three single-phase transformers of the same type, construction, and total kVA capacity; and is easier to install. The use of three single-phase transformers has the advantage that failure of one transformer requires only that the failed transformer be replaced and, if necessary, the remaining two transformers can still be connected to deliver about 57 percent of the nameplate rating. Failure of a three-phase transformer requires complete replacement.

4-1.6 **Transformer Taps**.

4-1.6.1 Depending on the system conditions, the nominal secondary voltage might not satisfy the voltage requirements of the loads. General purpose transformers should be provided with several taps on the primary to vary the secondary voltage. Taps are connection points along the transformer coil that effectively change the secondary voltage by changing the transformer turns ratio.

4-1.6.2 If available, two full capacity taps should be provided above nominal and two full capacity taps below nominal to allow increasing or decreasing the secondary voltage. Although designs vary among manufacturers, transformers smaller than 15 kVA usually only have two 5 percent taps below normal to provide a 10 percent voltage adjustment range. Larger transformers often have four 2.5 percent taps below normal and two 2.5 percent taps above normal to provide a 15 percent voltage adjustment range.

4-1.6.3 Select the tap setting to optimize the range between the no-load voltage and full-load voltage as well as possible. Taps are commonly rated at 2.5 percent of nameplate rating and designated as FCAN (full capacity above normal) or FCBN (full capacity below normal), meaning that the kVA rating of the transformer is not affected when taps are adjusted. If taps are not rated as full capacity, then derating of the transformer should be performed per the manufacturer's requirements.

4-1.7 **Noise**.

4-1.7.1 All transformers transmit sound due to vibration generated within the magnetic steel core. Depending on other nearby ambient noise, the transformer sounds might not be noticeable. In low ambient noise areas, the transformer sound can be noticed. Determine if noise rating is a required design consideration for the intended installation location.

4-1.7.2 A transformer located in low ambient noise level areas should have a low decibel hum rating. The average sound level in decibels should not exceed the level specified in NEMA ST 20, *Dry Type Transformers for General Applications*, for the applicable kVA rating range. Manufacturers readily provide sound ratings lower than the limits listed in NEMA ST 20.

4-1.7.3 In addition to the transformer noise rating, consider the following actions to improve the generated sound level:

4-1.7.3.1 Mount the transformer so that vibrations are not transmitted to the surrounding structure. Small transformers can usually be solidly mounted on a reinforced concrete floor or wall. Flexible mounting will be necessary if the transformer is mounted to the structure in a normally low-ambient noise area.

4-1.7.3.2 Use flexible couplings and conduit to minimize vibration transmission through the connection points.

4-1.7.3.3 Locate the transformer in spaces where the sound level is not increased by sound reflection. For example, in terms of sound emission, the least desirable transformer location is in a corner near the ceiling because the walls and ceiling function as a megaphone.

4-1.8 **Basic Impulse Insulation Levels (BIL)**.

4-1.8.1 The transformer winding BIL is the design and tested capability of its insulation to withstand transient overvoltages from lightning and other surges. The rated BIL usually increases with nominal voltage.

4-1.8.2 A 30 kV BIL is usually acceptable for system voltages up to 5 kV and 60 kV BIL is usually acceptable for system voltages up to 15 kV. Higher BIL levels can be applied in locations in which transient overvoltages are expected due to nearby lightning strikes; 60 kV BIL and 95 kV BIL is recommended in this case for 5 kV and 15 kV, respectively.

4-1.8.3 Do not specify lower BIL levels solely because surge protection has been installed.

4-2 **LOW VOLTAGE TRANSFORMERS**.

4-2.1 Transformers having a primary voltage of 600 volts or less for the supply of lower voltages should be of the self-cooled, ventilated dry-type. Do not locate ventilated dry-type transformers in environments containing contaminants including dust, excessive moisture, chemicals, corrosive gases, oils, or chemical vapors. Transformers should be designed for floor or wall mounting.

4-2.2 Three-phase transformers with three-phase legs on one core, and with delta input windings and wye output windings are preferred.

4-2.3 Transformers should have a per unit impedance in the range of 3 percent to 6 percent. Unless required for some specific design requirement, lower impedance transformers should not normally be used because of the higher downstream short circuit currents. If a lower impedance transformer is used, perform an evaluation for the impact of the higher short circuit current on downstream devices. Transformers with an impedance higher than 6 percent should not normally be used because of the lower efficiency and higher voltage regulation unless the design evaluation establishes a specific need for the higher impedance.

4-2.4 Transformers located within buildings where noise is of concern, such as hospitals or administrative facilities, must have a noise-level rating appropriate for the application. Vibration isolators should be provided to minimize sound transmission to the building structural system.

4-2.5 Transformers should not be operated in parallel because the resulting interrupting duty requirements placed upon protective devices will increase the installation cost for such an arrangement. Also, transformers operated in parallel are subject to circulating currents, unless the impedances are carefully matched. In those few cases where parallel operation is unavoidable, provide detailed rationale supporting the proposed arrangement as part of the design analysis.

4-2.6 Do not use autotransformers unless necessary for a special application. Explain why the special application requires an autotransformer as part of the design analysis.

4-2.7 Encapsulated transformers are not usually required. Most transformers are continuously energized and the resultant core losses keep the transformer warm, usually above dew point, so that encapsulation is not required. If necessary because of corrosive or condensing environments, encapsulated transformers can be used. These types of environments should not be observed for most interior applications.

4-3 **MEDIUM VOLTAGE TRANSFORMERS**.

4-3.1 Consider medium voltage transformers for use in large facilities when low voltage transformers are no longer economically viable. Medium voltage transformers can be located within large buildings near load centers to avoid long low voltage feeders or to attain a more economical installation.

4-3.2 Ventilated dry-type or encapsulated cast coil distribution transformers with copper windings should be preferentially used. If liquid-insulated or oil-insulated transformers are specified for interior applications, refer to MIL-HDBK-1008C, *Fire Protection for Facilities Engineering, Design, and Construction*, for guidance regarding installation criteria.

4-3.3 Hermetically sealed dry-type transformers should not be specified because of their large size and the problems associated with loss of gas.

4-3.4 Provide a transformer economic analysis, including the rationale supporting the decision, as part of the design analysis. Include life cycle cost comparisons between units, including all building features required to accommodate each transformer type, such as a vault, drainage system, and fire protection where required. Ensure all transformers and equipment addressed in the analysis are equal in every electrical respect, including but not limited to capacity, voltage, overload capability, and BIL to obtain a fair comparison.

4-3.5 Do not use autotransformers unless necessary for a special application. Explain why the special application requires an autotransformer as part of the design analysis.

4-3.6 Fire protection criteria for transformer installations are provided in MIL-HDBK-1008C.

4-4 **OTHER TRANSFORMERS**.

4-4.1 **Isolation Transformers**.

4-4.1.1 Isolation transformers are commonly used to establish a separately derived system. A separately derived system as defined in the NEC is a wiring system whose power has no direct electrical connection, including solidly connected grounds and neutrals to another wiring system. A separately derived system is usually made when it is desired to provide an isolated ground system for the wiring system.

4-4.1.2 When configured in a delta-wye configuration, the transformer provides a power ground reference close to the point of use. This reduces common-mode noise induced into the circuit from multiple ground loops upstream of the established reference point.

4-4.1.3 Isolation transformers provide a filtering function by separating the harmonic frequencies between the source and the load. The delta-wye winding configuration effectively cancels the third, ninth, fifteenth (and so on) harmonic currents in the delta primary winding, thereby isolating triplen harmonics from being fed back into the source. (Refer to Chapter 12 for additional criteria related to power quality and harmonic distortion.)

4-4.1.4 Isolation transformers can be used for retrofit applications to address existing facility problems, but should not be arbitrarily used in new facilities because of the higher per-kVA cost.

4-4.2 **Buck-Boost Transformers**.

4-4.2.1. The buck-boost transformer has four separate windings, 2 windings in the primary and 2 windings in the secondary. It is intended to be field connected as an autotransformer to buck (lower) or boost (raise) the line voltage. Apply buck-boost transformers only when required to achieve voltages beyond the capability of the existing utilization equipment.

4-4.2.2. A buck-boost transformer can not be used to develop a 3-phase, 4-wire, wye circuit from a 3-phase, 3-wire delta circuit. A delta to wye buck-boost configuration does not provide adequate carrying capability to allow for unbalanced currents flowing in the neutral of the 4-wire circuit. The neutral current is not stable and will not provide the desired line to neutral voltages under load. This connection also violates NEC Article 210.9 (2002 Edition).

4-4.2.3. Do not use buck-boost transformers to correct for voltage drop on a long circuit run in which the load fluctuates. Voltage drop varies with the load, but buck-boost transformers are connected for a specific voltage drop. If a buck-boost transformer is used to correct voltage drop under full load conditions, high voltages can occur under light load conditions.

4-4.2.4. Do not use buck-boost transformers to create a 120/240 volt single phase service from a 208Y/120 volt 3-phase supply. If done, two neutrals would exist on the same circuit. Also, unbalanced line to neutral voltages would be created; one line would be at 120 volts with the other line greater than 130 volts.

4-4.3 **K-Factor Transformers**.

4-4.3.1 Transformers are available for high harmonic-content power distribution systems without derating, often referred to as *k-factor transformers*, and usually have the following characteristics:

- Low induction core to reduce the flux density. Voltage harmonic distortion increases the core flux density, thereby creating higher core losses, higher magnetizing currents, higher audible noise, and overheating.

- Larger primary winding conductors to compensate for additional heating effects.

- Individual insulated secondary conductors to reduce stray losses.

- Larger neutral connections to compensate for harmonic currents causing larger neutral currents.

4-4.3.2 Evaluate the effect of nonlinear loads as part of the facility design. In some cases, nonlinear loads can require transformer derating or, in extreme cases, a transformer designed specifically for nonlinear loads might be required. Also, the transformer neutral conductors might require sizing for up to 200 percent of rated current. Excessive harmonic distortion causes higher eddy current losses inside a transformer, resulting in overheating. IEEE C57.110, *IEEE Recommended Practice for Establishing Transformer Capability When Supplying Nonsinusoidal Load Currents*, states that a transformer should be capable of carrying its rated current provided that the total harmonic distortion is less than 5 percent. Beyond this amount, derating of the transformer might be necessary. Newer transformers are often, but not always, already designed for some level of a higher harmonic distortion environment. Older transformers likely were not designed for harmonic distortion. Refer to paragraph 12-4 to determine if a transformer requires derating.

4-4.3.3 The k-factor relates transformer capability to serve varying degrees of nonlinear load without exceeding the rated temperature rise limits. The most common k-factor ratings are k-4 and k-13. Manufacturers recommend k-4 transformers if the connected load is 50 percent nonlinear electronic loads and k-13 transformers are recommended for 100 percent nonlinear electronic loads. This simplified approach allows the user to avoid calculating actual k-factor values for the facility. Transformer k-factor ratings greater than k-13 should never be necessary, and the use of such transformers actually can contribute to harmonic distortion problems because of their low impedance.

4-4.3.4 In practice, the system k-factor tends to decrease as the overall load increases. Thus, k-factor measurements taken in lightly loaded conditions can be quite high, but can be significantly lower on a fully loaded system. Transformer coil losses decrease with the square of the load and this reduction far exceeds the increased heating effect of higher harmonics at lighter loads. So, regardless of the load current harmonic distortion variation, the maximum loss point in transformer coils is always at full load. This is why transformer k-factor ratings must be based on full-load conditions. Nationwide surveys indicate average loading levels for dry-type transformers of between 35 percent for commercial facilities and 50 percent for industrial facilities. With such a light loading, a general purpose transformer will provide acceptable performance. A k-4 rating will provide acceptable performance in all but the most extreme harmonic distortion environments.

4-4.3.5 In almost all applications, the service entrance transformer will be acceptable if it is a general purpose dry-type transformer rather than a k-rated transformer. An individual lower-voltage transformer within the facility might need a k-factor rating (or derating if it is a general purpose transformer) under the following conditions:

- It supplies a large concentration of nonlinear electronic equipment, and
- It is operating near full load or there is a reasonable expectation that it will eventually be fully loaded.

4-4.3.6 Equipment suppliers can provide bundled power distribution systems that contain k-rated transformers or otherwise address power quality issues. Evaluate the applicability of this equipment before selecting a k-rated transformer.

4-4.4 **Specialty Transformers**. Specialty transformers include control, industrial control, Class 2, signaling, ignition, and luminous tube transformers. Select these transformers using National Electrical Manufacturers Association (NEMA) ST 1, *Specialty Transformers (Except General Purpose)*, as a guide.

4-5 **TRANSFORMER INSTALLATION CRITERIA**.

4-5.1 **Introduction**.

4-5.1.1 NEC Article 450 (2002 Edition) provides specific criteria applicable to transformers and transformer installations. The NEC location and installation criteria are applicable as described in this manual.

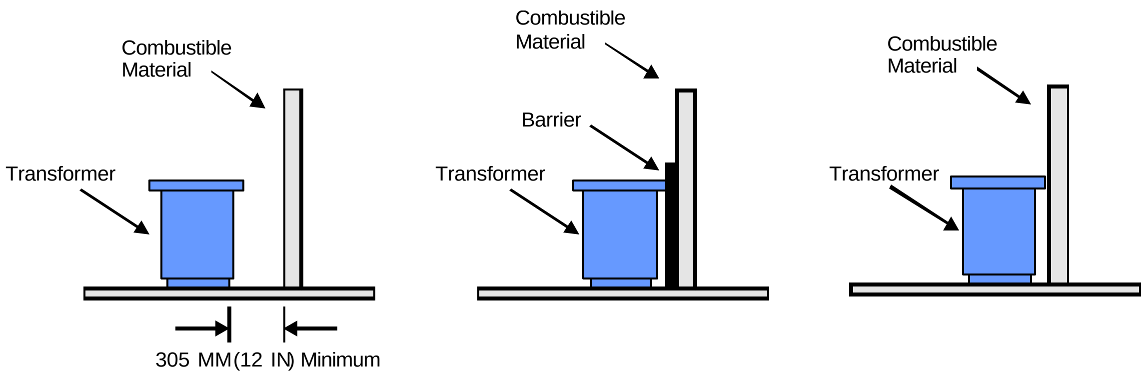
4-5.1.2 For each of the specified criteria in the NEC, exceptions are often provided. As part of any installation design, review the NEC to ensure that applicable criteria, including allowed exceptions, are satisfied. Regardless of the location, ensure transformers have adequate ventilation to avoid overheating. Comply with clearances specified by NEC Articles 110.26 and 110.34 (2002 Edition) for installations below 600 volts or above 600 volts, respectively.

4-5.2 **Dry-Type Transformers**.

4-5.2.1 Dry-type transformers, available at voltage ratings of 15 kV and below, are cooled primarily by internal air flow. The three principal classes of dry-type transformers are: self-cooled (AA), forced-air cooled (AFA) and self-cooled/forced-air cooled (AA/FA). Self-cooled transformers require adequate room ventilation to ensure proper transformer cooling. Forced-air cooled transformers can be integrated into the facility energy conservation design by a heat recovery system.

4-5.2.2 Figure 4-2 shows the installation spacing criteria for transformers rated 112.5 kVA or less. As shown, ensure these transformers have a minimum 0.3 meter (12-inch) spacing from combustible materials or have a fire-resistant, heat-insulating barrier. This requirement does not apply if the transformer is the nonventilating type.

Figure 4-2. Spacing Requirements for Transformers Rated 112.5 kVA or Less



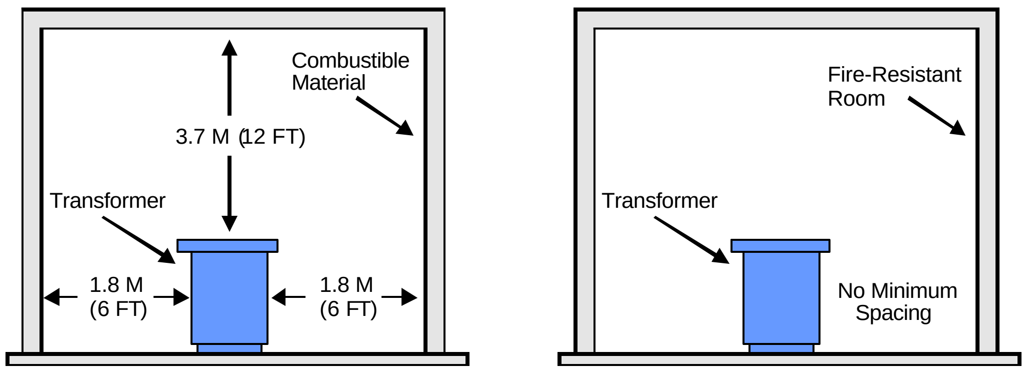
Transformer Minimum Spacing

Transformer With Heat-Insulating, Fire-Resistant Barrier

Completely Enclosed Transformer, With or Without Ventilation Openings

4-5.2.3 Dry-type transformers rated for more than 112.5 kVA have different requirements, depending on the insulation rating as shown in Figure 4-3. Transformers with less than 80 °C (176 °F) temperature rise rated insulation require installation in a fire-resistant room. Transformers with greater than 80 °C (176 °F) temperature rise rated insulation require either the spacing shown in Figure 4-3 or a fire-resistant, heat-insulating barrier.

Figure 4-3. Spacing Requirements for Transformers Rated Over 112.5 kVA

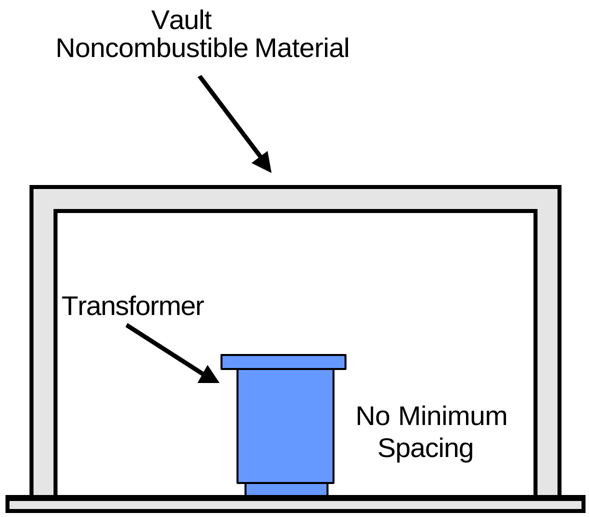


Not Totally Enclosed, Ventilated Transformer With 80 °C Rise Insulation

Transformer With Less Than 80 °C Rise Insulation

4-5.2.4 Install dry-type transformers rated for over 35,000 volts in a vault as shown in Figure 4-4.

Figure 4-4. Installation Requirements for Transformers Rated Over 35,000 Volts



4-5.3 **Less-Flammable, Liquid-Insulated, and Oil-Insulated Transformers**.

4-5.3.1 Use dry-type transformers wherever possible for interior applications.

4-5.3.2 The use of liquid-insulated and oil-insulated transformers must be justified for interior applications. If such use is justified for the particular application, refer to MIL-HDBK-1008C for guidance regarding installation criteria.

4-5.4 **Fire Protection Criteria**. Provide fire protection for transformer installations as specified in MIL-HDBK-1008C.

4-6 **TRANSFORMER SIZING**.

4-6.1 Size transformers to have adequate kVA capacity. Size the associated transformer conductors to accommodate the rated kVA capacity in accordance with NEC criteria. The transformer conductor sizing establishes the overcurrent protection requirements for the system. Appendix B provides a transformer and associated conductor sizing example.

4-6.2 The transformer capability is directly related to its temperature rise during operation. Users in some industries size transformers assuming that they will apply the transformer up to its overload rating. Do not follow this practice for interior installations; instead, size transformers assuming 100 percent of rated capacity and the overload capacity will provide future margin, if necessary.

4-6.3 Do not size transformers to have significant spare capacity unless load growth is the system is expected. Most transformers in service are lightly loaded.

4-7 **INFORMATION SOURCES**. The ANSI and IEEE C57 standards provide the best source of transformer design and application guidance. The most appropriate design guidance varies with transformer design, voltage, kVA rating, and connection. For this reason, numerous standards are available as design references. Review the following ANSI and IEEE standards, as well as other documents listed below, as appropriate for any transformer application:

4-7.1 C57.12.10, *Safety Requirements 230 kV and Below 833/958 Through 8333/10417 kVA, Single-Phase, and 750/862 Through 60,000/80,000/100,000 kVA, Three-Phase Without Load Tap Changing; and 3750/4687 Through 60,000/80,000/100,000 kVA with Load Tap Changing*—provides the basis for performance, interchangeability, and safety of transformers, and includes information useful for proper selection.

4-7.2 C57.12.22, *Requirements for Pad-Mounted, Compartmental-Type, Self-Cooled, Three-Phase Distribution Transformers With High-Voltage Bushing, 2500 kVA and Smaller: High-Voltage, 34500 GrdY/19920 Volts and Below; Low Voltage, 480 Volts and Below*—covers electrical, dimensional, and mechanical characteristics, including safety features, of distribution transformers.

4-7.3 C57.12.23, *Standard for Transformers—Underground-Type, Self-Cooled, Single-Phase Distribution Transformers With Separable, Insulated, High-Voltage Connectors; High Voltage (24940 GrdY/14400 V and Below) and Low Voltage (240/120 V, 167 kVA and Smaller)*—covers electrical, dimensional, and mechanical characteristics, including safety features, of distribution transformers used in underground transformers.

4-7.4 C57.12.25, *Requirements for Pad-Mounted, Compartmental-Type, Self-Cooled, Single-Phase Distribution Transformers with Separable Insulated High-Voltage Connectors: High Voltage, 34500 GrdY/19920 Volts and Below; Low-Voltage, 240/120 Volts; 167 kVA and Smaller*—covers electrical, dimensional, and mechanical characteristics, including safety features, of distribution transformers.

4-7.5 C57.12.26, *Standard for Transformers—Pad-Mounted, Compartmental-Type, Self-Cooled, Three-Phase Distribution Transformers for Use With Separable, Insulated, High-Voltage Connectors; High Voltage, 34500 GrdY/19920 V and Below; 2500 kVA and Smaller*—covers electrical, dimensional, and mechanical characteristics, including safety features, of compartmental type distribution transformers.

4-7.6 C57.12.50, *Requirements for Ventilated Dry-Type Distribution Transformers, 1 to 500 kVA, Single-Phase, and 15 to 500 kVA, Three-Phase, with High-Voltage 601 to 34500 Volts, Low Voltage 120 to 600 Volts*—covers electrical, dimensional, and mechanical characteristics, including safety features, of dry type distribution transformers.

4-7.7 C57.12.51, *Requirements for Ventilated Dry-Type Power Transformers, 501 kVA and Larger, Three-Phase, with High-Voltage 601 to 34500 Volts, Low Voltage 208Y/120 to 4160 Volts*—covers electrical and mechanical characteristics 60 Hertz, two-winding, 3 phase, ventilated dry type transformers.

4-7.8 C57.12.52, *Requirements for Sealed Dry-Type Power Transformers, 501 kVA and Larger, Three-Phase, with High-Voltage 601 to 34500 Volts, Low Voltage 208Y/120 to 4160 Volts*—covers electrical and mechanical characteristics 60 Hertz, two-winding, 3 phase, sealed dry type transformers.

4-7.9 C57.12.70, *Terminal Markings and Connections for Distribution and Power Transformers*—provides terminal marking layouts and requirements for C57-type transformers.

4-7.10 C57.94, *Recommended Practice for Installation, Application, Operation, and Maintenance of Dry-Type General Purpose Distribution and Power Transformers*—covers ventilated, non-ventilated, and sealed applications, self-cooled or forced air cooled.

4-7.11 C57.110—provides transformer sizing criteria for transformers supplying nonsinusoidal loads.

4-7.12 IEEE 141, *IEEE Recommended Practice for Electric Power Distribution for Industrial Plants* (IEEE Red Book)—provides general considerations for transformer applications.

4-7.13 IEEE 241—provides general considerations for transformer applications.

4-7.14 NEMA ST 1—provides design requirements for control, industrial control, Class 2, signaling, ignition, and luminous tube transformers.

4-7.15 NEMA ST 20—provides design requirements for general purpose dry type transformers.

4-7.16 TM 5-686, *Power Transformer Maintenance and Acceptance Testing*.

CHAPTER 5

POWER DISTRIBUTION AND UTILIZATION—SWITCHGEAR, LOAD CENTERS, AND BREAKERS

5-1 **SERVICE ENTRANCE**.

5-1.1 Locate service equipment at the service entrance point.

5-1.2 Ensure equipment is capable of safely performing all interrupting functions based on the available system capacity and characteristics. Protective devices must be able to clear the available short circuit current without damaging the unaffected portions of the system. If the available short circuit current exceeds the ratings of standard electrical equipment, evaluate the following options:

5-1.2.1 **Current Limiting Fuses**. This is usually the most cost-effective method of reducing downstream fault currents. Base downstream equipment ratings on the maximum let-through current of the current limiting fuses. Ensure that the fuse will function in its current-limiting range of operation for the available short circuit current.

5-1.2.2 **Current Limiting Circuit Breakers**. Similar to current limiting fuses, breakers can perform a current-limiting function. Periodic breaker maintenance is crucial to maintaining this current-limiting capability. Also, discuss this option with the manufacturer to ensure that the current-limiting capability is understood completely. Series-combination ratings for MCCBs are not allowed.

5-1.2.3 **Current-Limiting Reactors**. Detailed design analysis is necessary to ensure voltage drop is not excessive and to verify that the installation is adequately braced for short circuit conditions. This option is not recommended without a detailed analysis of all other options.

5-1.2.4 **High Impedance Busway**. This option is not recommended.

5-1.2.5 **High Impedance Transformers**. Although high impedance transformers can reduce the fault current, they also suffer from poor voltage regulation and higher energy costs. This option is not recommended without a detailed analysis of all other options.

5-1.3 Provide a single disconnecting means for each facility. Avoid multiple disconnects unless major economies can be realized in large capacity services or if multiple service voltage requirements exist.

5-1.4 NEC Article 230.95 (2002 Edition) requires ground fault protection (GFP) to be provided for solidly grounded, wye electrical services of more than 150 volts to ground, but not exceeding 600 volt phase-to-phase for each service disconnecting means rated 1,000 amperes or higher. If GFP is provided at the service entrance, it should be provided at downstream branch panels also. Although this will add to the overall system cost, it can be difficult to coordinate the service entrance GFP by itself with other overcurrent protective devices. By incorporating downstream GFP, the overall facility coordination can often be improved so that a single ground fault event is less likely to deenergize the entire facility. Verify that the service entrance GFP is set high enough to allow coordination with downstream devices.

5-1.5 Ensure equipment ampacities are adequate for the estimated load demands plus a contingency of 10 percent to 20 percent for future load growth. A larger reserve contingency can be applied if a specific need for future load growth can be documented.

5-1.6 Install service equipment in an equipment room of sufficient size to allow proper maintenance of the equipment. If electrical equipment is located in a joint electrical/mechanical equipment room, reserve adequate space for the electrical equipment, including provisions for future modifications. Do not allow piping, ducts, and other equipment unrelated to the electrical equipment to pass through or over the space reserved for electrical equipment. When fluid systems are located near electrical equipment, furnish the equipment with splash-shields and water-resistant enclosures.

5-1.7 Design the system with the capability to disconnect all ungrounded conductors in a building or other structure from the service-entrance conductors. Ensure the disconnecting means plainly indicates whether it is in the open or closed position and install it at a readily accessible location nearest the point of entrance of the service-entrance conductors. Each service disconnecting means must simultaneously disconnect all ungrounded conductors.

5-1.8 Clearly and permanently mark all circuit disconnect devices, including switches and breakers, to show the purpose of each disconnect.

5-1.9 Place barriers in all service switchboards such that no uninsulated, ungrounded service busbar or service terminal will be exposed to inadvertent contact by persons or maintenance equipment while servicing load connections.

5-1.10 Depending on the facility design, consider providing the following metering with the service entrance equipment: voltmeter, ammeter, kW meter, kVAR or power factor meter, and kWh meter with peak demand register and pulse generator for future connection to energy monitoring and control systems.

5-2 **SWITCHGEAR AND SWITCHBOARDS GENERAL CRITERIA**.

5-2.1 Select switchgear and switchboards of the dead-front, floor-mounted, freestanding, metal-enclosed type with copper bus and utilizing circuit breakers or fusible switches as circuit protective devices. Space-only cubicles and appropriate bus provisions should be installed for future protective device additions, as necessary to accommodate planned load growth. Ensure switchboards are designed in accordance with NEMA PB 2, *Deadfront Distribution Switchboards*. The term *switchgear* is used here to describe the assembled equipment of switching, interrupting, control, instrumentation, metering, protective, and regulating devices.

5-2.2 Secure switchgear in accordance with the manufacturer's instructions. Support cable routed to the switchgear to minimize forces applied to conductor terminals.

5-2.3 Do not route piping containing liquids, corrosive gases, or hazardous gases in the vicinity of switchgear unless suitable barriers are installed to protect the switchgear from damage in the event of a pipe failure. Do not locate switchgear where foreign flammable or corrosive gases routinely and normally are discharged.

5-2.4 Do not use switchgear enclosure surfaces as physical support for any item unless specifically designed for that purpose. Do not use enclosure interiors as storage areas unless specifically designed for that purpose.

5-2.5 Ground metal instrument cases.

5-2.6 Place a safety sign on any cubicles containing more than one voltage source.

5-2.7 Install switchgear with clearances stated in paragraph 8-1. Enclosed switchgear rooms should have at least two means of egress, one at each extreme end of the area, not necessarily in opposite walls. One door can be used when required by physical limitations if means are provided for unhampered exit during emergencies. Doors must swing out and be equipped with panic bars, pressure plates, or other devices that are normally latched, but open under simple pressure.

5-2.8 Locate switchboards that have any exposed live parts in permanently dry locations and accessible only to qualified persons.

5-2.9 Circuit breakers must clearly indicate whether they are in the open (off) or closed (on) position.

5-2.10 Where circuit breaker handles on switchboards are operated vertically rather than horizontally or rotationally, the up position of the handle must be the closed (on) position.

5-2.11 Clearly and permanently mark all circuit breakers to show the purpose of each breaker.

5-2.12 Refer to NEMA PB 2.1, *General Instructions for Proper Handling, Installation, Operation, and Maintenance of Deadfront Distribution Switchboards Rated 600 Volts or Less*, for installation guidance. This NEMA standard also provides practical guidance regarding energization of the new installation.

5-2.13 Place switchboards as close as possible to the center of the loads to be served.

5-3 **HIGH VOLTAGE SWITCHGEAR**. Although high voltage levels might be available at exterior substations, high voltage switchgear is less commonly used for interior electrical systems. For purposes of this manual, high voltage refers to any application rated above 15 kV.

5-4 **MEDIUM VOLTAGE SWITCHGEAR**.

5-4.1 **Ratings**.

5-4.1.1 **Switchgear**. Use metal-enclosed, manually operated, fusible load interrupter switches or power circuit breakers with copper bus. Table 5-1 indicates the most commonly used voltages; the standard voltages shown without parentheses are preferred.

Table 5-1. Medium Voltage Switchgear Voltage Ratings

Standard Nominal System Voltages	Associated Non-Standard Nominal System Voltages
7.2 kV and under (in kV)	
(2.4)	2.2, 2.3
(4.16Y/2.4)	
4.16	4.0
(4.8)	4.6
(6.9)	6.6, 7.2
15-kV class (in kV)	
(8.32Y/4.8)	
12Y/6.93	11, 11.5
12.47Y/7.2	
13.2Y/7.62	
(13.8Y/7.97)	
13.8	14.4

5-4.1.2 **Standards**. Apply ratings conforming to ANSI C37.06, *Preferred Ratings and Related Required Capabilities for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis*, and ANSI/IEEE C37.04, *American National Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis*, in the selection of circuit breakers.

5-4.1.3 **Voltage Rating**. Determine the voltage rating in terms of three-phase, line-to-line voltage, including the following considerations:

5-4.1.3.1 Maximum nominal system voltage for which the breaker is intended.

5-4.1.3.2 Maximum operating voltage at which the breaker will be used, taking into consideration line voltage regulation, machine over-excitation and overspeed, and shunt capacitance.

5-4.1.4 **Insulation Level Rated Impulse Withstand Voltage**. Referring to IEEE C37.04, the impulse strength of the breaker must be coordinated with the surge protection of the system as follows:

5-4.1.4.1 Across breaker contacts.

5-4.1.4.2 Between breaker contacts and ground. Verify no increase in surge voltage as a result of voltage reflection.

5-4.1.5 **Frequency**. For a frequency of 60 Hertz, compare the calculated ratings with standard ratings. For other frequencies, check with the equipment manufacturer.

5-4.1.6 **Continuous Current**. Calculate the maximum current flow through the breaker by computing the current flow under normal and contingency conditions. Provide for future load growth, if required.

5-4.1.7 **Interrupting Duty**. To select the proper interrupting duty using ANSI/IEEE C37.010, *Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis*, it is necessary to perform a complete fault analysis to determine the required interrupting duty of the circuit breaker under normal and contingency conditions. Use the following criteria:

5-4.1.7.1 Provide for a future system design that might materially affect the interrupting duty of the circuit breaker. Circuit breakers are rated on a symmetrical basis rather than on an asymmetrical (total current) basis. Follow the criteria of ANSI/IEEE C37.010, and IEEE C37.011, *Application Guide for Transient Recovery Voltage for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis*.

5-4.1.7.2 If the operating voltage of the circuit differs from the rated voltage of the circuit breaker, correct the final values to correspond with the rated values given in the manufacturer's circuit breaker rating tables.

5-4.1.7.3 Determine the asymmetrical requirements based on the breaker contact parting time.

5-4.1.7.4 Determine the actual operating duty and interruption time of the breaker from the relay setting calculations.

5-4.1.8 **Altitude Correction**. Correct voltage and current ratings for altitudes above 1,000 meters (3,300 feet). Use ANSI/IEEE C37.20, *Switchgear Assemblies Including Metal-Enclosed Bus*, and NEMA SG 4, *Alternating-Current High-Voltage Power Circuit Breakers*, for correction factors.

5-4.1.9 **Ambient Temperature**. Derate circuit breakers in environments with ambient temperatures higher than +40 °C (104 °F) or lower than -30 °C (-22 °F) in accordance with IEEE C37.010.

5-4.1.10 **Breaker Selection**. Select breakers using the following criteria:

5-4.1.10.1 **Rating Evaluation**. The evaluation of the voltage rating, insulation withstand voltage rating, frequency, continuous current, and interrupting duty provides the required rating of the circuit breaker.

5-4.1.10.2 **Selection Guide**. Vacuum circuit breakers should be used with a suitable enclosure for 1.5 kV through 15.0 kV up to 1,000 MVA interrupting duty. Consider use of sulfur hexafluoride circuit breakers.

5-4.2 **Low Voltage Conductors in Medium Voltage Switchgear**.

5-4.2.1 Do not route low voltage cables or conductors, except those to be connected to equipment within the compartment, through medium or high voltage divisions of switchgear unless installed in rigid metal conduit or isolated by rigid metal barriers. Insulate conductors entering switchgear for the higher operating voltage in that compartment or separate the conductors from insulated conductors of other ratings.

5-4.2.2 Low voltage conductors routed from medium or high voltage sections of switchgear must terminate in a low voltage section before being routed external to the switchgear.

5-5 **LOW VOLTAGE BREAKERS AND PANELS**.

5-5.1 The following types of circuit breakers can be used for low voltage applications:

5-5.1.1 Use molded case circuit breakers (MCCB) wherever possible. Determine if electrical coordination is a design requirement for the electrical system or some portion of the electrical system. If electrical coordination is a requirement for the installation, the use of thermal-magnetic trip units might not allow coordination in the instantaneous trip region.

5-5.1.2 Integrally-fused MCCBs can be used to protect loads if short-circuit currents are high. Standard MCCBs are readily available with 65,000 ampere or higher ratings, which reduces the need for integrally-fused MCCBs for most applications.

5-5.1.3 Select low voltage power circuit breakers only where the added cost incurred by their use can be justified by operational considerations. Apply low voltage power circuit breakers in enclosures in accordance with IEEE C37.13, *Low-Voltage AC Power Circuit Breakers Used in Enclosures*.

5-5.1.4 Insulated-case circuit breakers are rated in a manner similar to MCCBs and can be used instead of low voltage power circuit breakers.

5-5.1.5 Molded case switches can be used for applications in which only equipment isolation is necessary. Electrical protection is still required to be available from upstream devices. Nonfused disconnect switches can also be used as switches.

5-5.2 Do not use series-combination rated breakers. This type of design guarantees loss of entire panelboards or load centers in response to a short circuit. Also, inappropriate breaker replacements will invalidate the rating and create the potential for equipment or personnel damage if a short circuit occurs.

5-5.3 Circuit breakers are preferred over fuses, fusible disconnect switches, or fusible bolted pressure switches to satisfy electrical protection requirements, unless the available fault current requires the higher interrupting rating of these devices.

5-5.4 Ensure circuit breakers used as switches in 120 volt and 277 volt lighting circuits are listed for the purpose and are marked “SWD” or “HID” (switching duty or high-intensity discharge lighting) in accordance with NEC Article 240.83(D) (2002 Edition).

5-5.5 Ensure circuit breakers intended to protect multiple motor and combination load installations associated with heating, air conditioning, and refrigeration equipment are marked “Listed HACR Type” in accordance with NEC Article 430.53(C) (2002 Edition) requirements for group installations. Also, a circuit breaker with this marking is suitable only for use with equipment marked to indicate that an HACR circuit breaker is acceptable.

5-5.6 Provide arc-fault circuit interrupter protection in accordance with NEC Article 210.12 (2002 Edition). This requirement applies to all branch circuits supplying 125 volt, single-phase, 15- and 20- ampere outlets installed in dwelling unit bedrooms.

5-5.7 **Panelboards**.

5-5.7.1 Panelboards are commonly used as a means of electrical distribution between main or sub-distribution points and individual connected loads. Different types of panelboards are commonly available:

5-5.7.1.1 Service equipment panelboards—available for loads up to 1,600 amperes. These panelboards usually contain up to six breakers (or fused switches or fusible bolted pressure switches) connected to the incoming mains.

5-5.7.1.2 Feeder distribution panelboards—usually contain circuit overcurrent devices rated at more than 50 amperes to protect subfeeders to smaller branch circuit panelboards.

5-5.7.1.3 Load center panelboards—normally rated up to 1,200 amperes at 600 volts or less. Similar to feeder distribution panelboards, these contain three-phase control and overcurrent devices for motor or power-circuit loads. Apply switchboard designs for load requirements greater than 1,200 amperes.

5-5.7.1.4 Lighting and appliance branch circuit panelboards—rated for up to about 225 amperes at 600 volts or less, although exceptions to this general rule are common. Individual disconnect devices are often rated for 30 amperes or less. Lighting and appliance branch circuit panelboards are limited by NEC Article 408.15 (2002 Edition) to contain not more than 42 overcurrent devices (other than those provided for in the mains) in any one cabinet or cutout box.

> *Note: For purposes of NEC classification, panelboards are classified as either power panelboards or lighting and appliance branch circuit panelboards. A power panelboard is one having 10 percent or fewer of its overcurrent devices protecting lighting and appliance branch circuits.*

5-5.7.2 Select distribution panelboards of the wall-mounted, dead-front type, either circuit breaker or fusible switch equipped with copper bus. Branch circuit panelboards should be of the wall-mounted, dead-front type, equipped with circuit breakers. Circuit breaker size should be a minimum 25 millimeters (1 inch) per pole with bolt-on breakers. Load center panelboards should be used only where eight or fewer circuits are supplied, and where light duty can be expected, except as authorized for military family housing. Although such use is usually discouraged, panelboards other than the dead-front externally-operable type are permitted where accessible only to qualified persons.

5-5.7.3 Provide overcurrent protection of panelboards in accordance with NEC Article 408.16 (2002 Edition) as follows.

5-5.7.3.1 Protect each lighting and appliance branch circuit panelboard on the supply side by not more than two main circuit breakers or two sets of fuses having a combined rating not greater than that of the panelboard. The preferred configuration is to supply a main disconnect breaker on each panelboard.

5-5.7.3.2 Protect power panelboards with supply conductors that include a neutral and having more than 10 percent of its overcurrent devices protecting branch circuits rated 30 amperes or less on the supply side by an overcurrent protective device having a rating not greater than that of the panelboard.

5-5.7.3.3 Provide overcurrent protection not in excess of 200 amperes for panelboards equipped with snap switches rated at 30 amperes or less.

5-5.7.3.4 The total load on any overcurrent device located in a panelboard must not exceed 80 percent of its rating where, in normal operation, the load will continue for three hours or more unless the overcurrent device is listed for continuous operation at 100 percent of its rating.

5-5.7.3.5 Where a panelboard is supplied through a transformer, provide the overcurrent protection on the secondary side of the transformer.

5-5.7.3.6 Refer to NEC Article 408.16 (2002 Edition) for allowed exceptions to the above criteria.

5-5.7.4 Ensure that circuit breakers clearly indicate whether they are in the open (off) or closed (on) position.

5-5.7.5 Clearly fill out panelboard circuit directories.

5-5.7.6 Panelboards should have hinged fronts to allow easier maintenance access.

5-5.7.7 Place panelboards as close as possible to the center of the loads to be served.

5-6 **MOTOR CONTROL CENTERS**.

5-6.1 An MCC is a dead-front assembly of cubicles, each of which contains branch circuit overcurrent protection, motor disconnect means, motor controller, and motor running overcurrent protection. It is a type of switchboard that usually contains all of the protective and control devices for the supplied motors.

5-6.2 MCCs with copper bus are recommended for motor control applications and newer style MCCs can include panelboards, energy monitoring equipment, and other devices. Refer to paragraph 7-2 for motor control criteria.

5-6.3 Refer to NEMA ICS 2.3, *Instructions for the Handling, Installation, Operation, and Maintenance of Motor Control Centers*, for installation guidance. This NEMA document also provides practical guidance regarding energization of the new installation.

5-7 **DISCONNECT SWITCHES**.

5-7.1 Fusible disconnect switches should be used where special considerations require their use. Fuses, fusible disconnect switches, or fusible bolted pressure switches might be used in combination with circuit breakers when circuit breakers alone cannot provide adequate fault duty and must be coordinated with current-limiting fuses. For example, low voltage power breakers alone are often available with short circuit ratings up to 65,000 amperes. Beyond this level, current limiting fuses are often required.

5-7.2 Circuit breakers are preferred over fusible switches for general-purpose applications for the following reasons:

- Circuit breakers cannot single phase—all phases open in response to a disturbance.

- Fuse replacement is not required.

5-7.3 Disconnect switches can be used as a means to satisfy circuit lockout requirements. For example, a disconnect switch can be installed between a transformer and an MCC to allow for an OSHA-recognized positive means of deenergizing the MCC for maintenance.

5-7.4 All disconnect switches must be lockable.

5-7.5 Rate disconnect switches for motor applications for the horsepower rating of the associated motor.

5-8 **CIRCUIT LOCKOUT REQUIREMENTS**. Circuit breakers, disconnect switches, and other devices that meet the OSHA definition of energy-isolating device must be lockable. OSHA has determined that lockout is a more reliable means of deenergizing equipment than tagout and that it is the preferred method to be used. An energy-isolating device is considered capable of being locked out if it meets one of the following requirements:

- It is designed with a hasp to which a lock can be attached.
- It is designed with any other integral part through which a lock can be affixed.
- It has a locking mechanism built into it.
- It can be locked without dismantling, rebuilding, or replacing the energy isolating device or permanently altering its energy control capability.

5-9 **INFORMATION SOURCES**. The following references provide additional information regarding circuit breaker selection and sizing:

5-9.1 ANSI C37 Series—provides several standards related to switchgear and circuit breakers and should be used as a reference source when preparing specifications.

5-9.2 IEEE 141—provides an application overview of switchgear, breakers, and other switching devices.

5-9.3 IEEE 241—provides an application overview of switchgear, breakers, and other switching devices.

5-9.4 IEEE 1015, *IEEE Recommended Practice for Applying Low-Voltage Circuit Breakers Used in Industrial and Commercial Power Systems* (IEEE Blue Book)—provides detailed application guidance for low voltage power circuit breakers and MCCBs.

5-9.6 NEMA AB 3, *Molded Case Circuit Breakers and Their Application*—provides guidance for the application of MCCBs and molded case switches. IEEE 1015 should be used preferentially as a reference document.

5-9.7 NFPA 70, *National Electrical Code*—provides specific requirements related to the sizing and application of circuit breakers.

5-9.8 OSHA 29 CFR—provides the requirements for circuit disconnection and lockout. Refer to Appendix A for a listing of applicable OSHA regulations.

5-9.9 EM 385-1-1—provides additional requirements for circuit disconnection and lockout.

CHAPTER 6

POWER DISTRIBUTION AND UTILIZATION—RACEWAY AND WIRING

6-1 RACEWAY CRITERIA.

6-1.1 Design raceways used for interior wiring systems to comply with the NEC. Depending on the application, the following raceway types are preferred (other conduit types can be used for specific applications as justified by the design):

- Rigid, threaded zinc-coated steel conduit – typically 40 gauge.
- Intermediate metal conduit – wall thickness less than rigid conduit by larger than EMT, typically 20 gauge.
- Electrical metallic tubing – typically 10 gauge.
- Flexible metal conduit.
- Surface metal raceways.
- Nonmetallic conduit.

6-1.2 Do not use rigid aluminum conduit unless justified by the application and documented in the design package. For example, aluminum conduit is preferred for 400 Hertz applications. Do not imbed aluminum conduit in concrete or masonry, buried in earth, or used to penetrate vertical or horizontal firewalls. If conduit runs penetrate firewalls, use steel conduit for a minimum of 0.9 meters (3 feet) on each side. Do not mix metal types if avoidable.

6-1.3 Nonmetallic conduit, including flexible nonmetallic conduit, can be used within structures below concrete slab-on-grade construction and in highly corrosive, nonhazardous locations where metallic conduits might corrode due to atmospheric conditions. Nonmetallic conduit is not preferred for general-purpose applications. Follow NEC criteria for the application of nonmetallic conduit.

6-1.4 Flexible metal conduit is not intended as a general-purpose raceway for long distances. Use liquid-tight flexible metal conduit for permanent connections to large appliances, equipment, and motors to allow for vibration or movement. Flexible metal conduit can be used for lighting fixture connections above suspended ceilings in accordance with the NEC and with Underwriters Laboratory (UL) listed and labeled equipment and control assemblies.

6-1.5 Use surface metal raceways or multi-outlet assemblies only for building improvements or renovations, or for applications where a variety of cord-and-plug connected equipment will be utilized in a limited space, such as in some areas of medical facilities, shops, and laboratories.

6-1.6 Underfloor ducts can be used in large administrative areas or other areas where extensive power and communications facilities are required that cannot be adequately served by normally provided wall outlets. Duct specifications and spacing should be selected to meet the specific needs of the project.

6-1.7 Busways or cablebus should be used for feeders and service entrances if dictated by space limitations or if it is determined to be more economical than equivalent-ampacity insulated conductors in raceways. Plug-in busways can be used in industrial or shop areas to serve a variety of power outlets or motors.

6-1.8 Cable trays should be used as a support system for conductor types that could be otherwise supported, including metal-clad cable, conductors in conduit, multiconductor type cables such as underground feeder (UF) or service entrance (SE), or single conductors where permitted by the NEC and OSHA 29 CFR 1910.305. Do not support conduit or cable from or attached to the underside of cable tray.

6-1.9 Cellular steel floor should be used in large structures having extensive power, lighting, and communications wiring requirements if the combination of structural adequacy and raceway access capability will result in major economies compared to conventional building systems. If the use of cellular steel floor is anticipated, electrical and structural designs should be closely coordinated, beginning at the earliest opportunity in the design phase.

6-1.10 Branch circuit wiring within lightweight, removable, metal-stud partitions should either be installed in conduit or can consist of properly supported metal-clad cable or nonmetallic-sheathed cable systems installed through nonmetallic bushed or grommeted holes or slots in the framing members. Outlet boxes for such applications should be of metal, grounded by the cable-grounding conductors, and securely supported by bar hangers or equivalent means within framing members.

6-1.11 Mineral-insulated cable systems, type MI, can be used instead of exposed conduit and wiring, if required by the application or if it can be shown that it is economically justified. Mineral-insulated cable will usually not be cost-effective for use. If used, make cable connections and terminations in accordance with the manufacturer's recommendations to assure a proper connection.

6-1.12 Surface mounted outlet boxes in conduit and tubing systems in normally dry locations should be of the cast metal, hub-type or one piece sheet metal with covers designed for surface work. Do not allow surface boxes with nail holes or openings that can admit insects.

6-1.13 Protect conductors entering boxes, cabinets, or fittings from abrasion. Close openings through which conductors enter. Close unused openings in cabinets, boxes, and fittings.

6-1.14 Provide all pull boxes, junction boxes, and fittings with covers approved for the purpose. Ground metal covers if they are used. In completed installations, install a cover, faceplate, or fixture canopy on each outlet box. Provide covers of outlet boxes having holes through which flexible cord pendants pass with bushings designed for the purpose or furnish with smooth, well-rounded surfaces on which the cords can bear.

6-1.15 Ensure pull and junction boxes for systems over 600 volts provide a complete enclosure for the contained conductors or cables. Close boxes by suitable covers securely fastened in place. This requirement also applies to underground box covers that weigh over 45.5 kilograms (100 pounds). Permanently mark covers for boxes with "DANGER—HIGH VOLTAGE. KEEP OUT." Install the marking on the outside of the box cover, and ensure it is readily visible and legible.

6-1.16 Wiring systems in hazardous locations must conform to the NEC for the particular hazard encountered. Outline the extent of each hazardous location on project construction drawings, describing the applicable vertical and horizontal limits of the hazard and identifying each hazardous location by NEC Class, Division, and Group or by Zone (refer to paragraph 8-3 for a description of hazardous locations). Designation of either specific maximum operating temperatures of equipment or temperature ranges should also be indicated. The following considerations apply to hazardous locations:

6-1.16.1 Require sealing fittings to be shown on the drawings where needed to ensure compliance with NEC criteria.

6-1.16.2 Locate electrical equipment in nonhazardous areas of facilities having hazardous locations. Exceptions to this requirement include lighting fixtures in paint-spray booths and similar situations where electrical equipment must be located within a hazardous location due to functional requirements.

6-1.16.3 Instances do occur where military terminology is not expressed in terms consistent with the civilian sector. In such cases, the function to be performed should govern the requirement for hazardous location design. As an example, repair shops in vehicle or motor maintenance facilities and self-help garages are normally considered hazardous locations similar to commercial garages with regard to function. Accordingly, follow NEC requirements for commercial garages for such a military-equivalent facility.

6-2 **WIRING SYSTEM CRITERIA**.

6-2.1 Wiring systems consist of insulated conductors installed in raceways, except that in combustible construction, branch circuit wiring can consist of metal-clad or moisture- and corrosion-resistant nonmetallic sheathed cables installed in areas as permitted by the NEC. Conceal raceways and cables wherever possible in finished spaces.

6-2.2 Size conductors to satisfy the electrical requirements of the system. As a minimum, size conductors at 125 percent of the associated breaker continuous current rating for the insulation temperature rating. The selected conductor size usually depends on the following factors:

- Load current.
- Voltage drop and regulation.
- Temperature rise based on the insulation rating.
- Energy losses.
- Ability to withstand short circuit heating.
- Allowance for future load growth.

6-2.3 NEC Article 310.10 (2002 Edition) prohibits applying conductors in a manner that will exceed the temperature rating for its insulation. Ensure an acceptable temperature rating as follows:

6-2.3.1 Determine the current required by the loads.

6-2.3.2 Select the conductor size in accordance with NEC Article 310.15 (2002 Edition) for a given temperature rating.

6-2.3.3 Size cables with conductors rated for the next higher temperature. For example, a circuit sized for a 75 °C (167 °F) insulated conductor would have a 90 °C (194 °F)-rated insulation actually installed.

6-2.3.4 Refer to paragraph 6-2.13 for the minimum rating requirements.

6-2.4 All conductors must be copper, except aluminum conductors of equivalent ampacity can be used instead of copper for #4 American wire gauge (AWG) and larger sizes.

6-2.5 Select power conductor insulation suitable for the installation and conforming to NEC requirements for each application. Select heat-resistant insulation for conductors #6 AWG and larger.

6-2.6 Ensure feeders have an ampacity adequate for the loads to be served. Base demand factors applicable to feeder loads upon the nature of the individual loads and their use characteristics. Select demand factors in accordance with NEC Article 220 (2002 Edition).

6-2.7 Rate branch circuits for a minimum of 20 amperes, except where lesser ratings are required for specific applications. Branch circuit conductors, including power and lighting applications, will in no case be less than #12 AWG copper. Although the

NEC allows the use of #14 AWG wiring, use #12 AWG conductors wherever #14 AWG wiring is authorized by the NEC to ensure a better overall design.

6-2.8 Do not exceed 5 percent combined voltage drop on feeders and branch circuits if the transformer providing service is located within the facility. If the transformer is located exterior to the facility, limit the combined voltage drop for service conductors, feeders, and branch circuits to 5 percent. Individual voltage drop on branch circuits should not exceed 3 percent. The NEC is generally concerned with ampacity more than voltage drop and only addresses the above limits in NEC Articles 210.19(A)(1) (Fine Print Note [FPN] No. 4) and 215.2(A)(4) (FPN No. 2) (2002 Edition). Furthermore, branch circuits supplying sensitive circuits should be limited to less voltage drop, usually 1 percent to 2 percent. IEEE 1100, *Powering and Grounding Sensitive Electronic Equipment*, recommends a maximum voltage drop of 1 percent for electronic installations. Paragraph 2-6 provides information regarding the calculation of voltage drop.

6-2.9 Conductors can be placed in parallel for sizes #1/0 AWG and larger, provided they are of the same length and size, and have the same type of insulation and conductor material in accordance with NEC Article 310.4 (2002 Edition). Arrange the conductors and terminate them at each end in such a manner as to ensure equal division of the total current between all of the parallel conductors. These requirements apply to the parallel conductors in each phase to assure equal division of current within that phase; it is not required for one phase to be the same as another phase, although this is the preferred approach.

6-2.10 No more than three to six outlets per circuit should be used even if sizing in accordance with the NEC indicates that more outlets can be installed on the circuit. This is intended to accomplish the following:

- Minimize the number and variety of sensitive equipment sharing a common circuit.
- Minimize voltage drop.
- Minimize the likelihood of interaction between circuits.
- Allow flexibility for future load growth or equipment changes.

6-2.11 Provide receptacle branch circuits feeding predominantly nonlinear loads with fully sized neutral conductors. The phase and neutral conductors should be labeled in a manner that associates these conductors together for each circuit.

6-2.12 Locations, such as offices, data centers, and communications complexes, that use computers, electronic equipment, and other potentially electrically sensitive equipment should provide dedicated “computer” circuits off of branch panels for each work location. If the equipment type and sensitivity warrants it, provide separate panel boards fed from separate feeders back to the service entrance.

6-2.13 Base branch circuit and feeder sizes upon temperature rating requirements established by the NEC. The conductor must be sized so that termination temperatures do not exceed 60 °C (140 °F) for conductors smaller than 100 amperes or #1 AWG, and 75 °C (167 °F) for conductors larger than 100 amperes or 1/0 AWG. This means that the 60 °C (140 °F) column of NEC Table 310.16 (2002 Edition) should be used for conductor sizing of circuits 100 amperes and smaller, and the 75 °C (167 °F) column of NEC Table 310.16 (2002 Edition) should be used for conductors larger than 100 amperes.

6-2.14 Terminate all conductors properly in accordance with the manufacturer's recommended procedures. Ensure that the proper crimping tools are available for each type of termination, as applicable.

6-2.15 The use of splices is discouraged unless required for a specific application. If splices are used, splice or join conductors with splicing devices suitable for the use. Cover all splices and joints and the free ends of conductors with an insulation equivalent to that of 150 percent of the conductors or with an insulating device suitable for the purpose. Do not intermix conductors of dissimilar metals where physical contact occurs between the dissimilar metals (such as copper and aluminum) unless the device is identified for the purpose and conditions of use. Conductors in conduit or raceway systems must be continuous from outlet to outlet. If necessary, splices are permitted for the service entrance conductors in accordance with NEC Article 230.46 (2002 Edition). Install splices only in areas such as boxes and panels designed to allow splices. The above criteria regarding splices do not prohibit the use of wire nuts or other connection devices to connect conductors to end use devices.

6-2.16 Nonmetallic sheathed cable with ground conductor can be used for branch circuits in wood frame buildings or in stud walls of concrete, masonry, or metal buildings, subject to the limitations specified by NEC Article 334 (2002 Edition). Protect the cable from physical damage where necessary by one or more of the methods allowed by NEC Article 334 (2002 Edition).

6-3 SIZING WIRING SYSTEMS FOR ENERGY SAVINGS.

6-3.1 Paragraph 6-2 provides the minimum required design criteria for conductor sizing. Although not a specific design requirement, every design should be evaluated for the energy savings possible by installing conductors of one size larger than required by the NEC. By increasing the wire size, reduced power losses offset the wire cost and often show a payback within a relatively short time. Also, the increased wire size improves the system flexibility to accommodate future design changes. In summary, increasing the wire size to one size larger than required by the NEC produces the following benefits:

- Energy savings will be realized due to lower heating losses in the larger conductors.

- Less heat will be generated by the wiring system.

- The conductors will have smaller voltage drop, which will often be necessary to meet other design criteria. For example, IEEE 1100 recommends a maximum voltage drop of 1 percent for electronic installations.

- Greater flexibility will be available in the existing system to accommodate future load growth.

- The system can better accommodate the adverse effects of nonlinear loads.

6-3.2 In many cases, no changes to the raceway system will be necessary to accommodate a larger cable. In these cases, the payback period for energy savings is often less than 2 years. Even if a larger conduit is required, a reasonable payback period is often achievable. Appendix B provides example calculations.

6-3.3 To ensure that energy savings can actually be obtained without other hidden costs, ensure that the larger conductor is compatible with the upstream breaker or fuse, as well as the downstream load, in terms of physical size and termination ability.

6-4 **CONVENIENCE OUTLETS AND RECEPTACLES**.

6-4.1 Receptacles for installation on 15 ampere and 20 ampere branch circuits should be of the grounding type with the grounding contacts effectively grounded. Ensure these receptacles conform to UL 498, *Attachment Plugs and Receptacles*, and NEMA WD 1, *General Requirements for Wiring Devices*.

6-4.2 Incorporate the grounding pole into the body of a polarized receptacle for the following applications:

- Three phase outlets.

- Outlets supplied with voltages in excess of 150 volts between conductors.

- All voltages installed in hazardous locations.

6-4.3 Use a separate conductor (green wire or bare copper) to ground all grounding type outlets and receptacles.

6-4.4 Provide a separate single-branch circuit for each three-phase receptacle. Branch circuits should be three-phase, five-wire, each protected by a three-pole thermal magnetic molded case circuit breaker. Regulation of the circuit should be limited to not more than 5 percent below normal.

6-4.5 Install computer-related circuits and receptacles separate from motor load circuits. If required by the manufacturer to minimize noise, provide a separate grounding conductor back to the branch circuit breaker for each circuit, consistent with NEC grounding criteria.

6-4.6 Provide ground fault circuit interrupters (GFCI) for personnel protection and GFP for equipment protection in accordance with NEC requirements.

6-4.7 Receptacles used in medical facilities must comply with NFPA 99, *Health Care Facilities*, and NEC Article 517 (2002 Edition). Use hospital grade receptacles listed for this purpose. Identify receptacles fed from the emergency system and indicate the panelboard and circuit number supplying them.

6-4.8 Locking-type receptacles should be used where positive engagement of the plug is required or where a strain on the portable cord can be anticipated.

6-4.9 Design three-phase power receptacles installed in hangars, aprons, and ramps for supply of electrical energy to aircraft support equipment to fit the plug used as the standard on the support equipment. Design receptacles for inserts with a metal enclosure for wall or flush mounting, weather-tight, load rated, three-phase, four-wire, six-pole. Design receptacles to provide an adjustable source of power for 240/416-254/440-265/460 volt, 60-Hertz equipment with transformer tap adjustment, if required. Use a phase rotation of ABC, clockwise, looking into the receptacle. Provide receptacle enclosures with a means for attaching an internal grounding conductor.

6-4.10 Install receptacles in a floor or apron flush-mounted with an adjacent concrete pad slightly mounded and slotted to permit drainage. Orient the slots in pavement to avoid snowplow blades.

6-4.10.1 Utilize the receptacle enclosure for the pull or junction box. No other opening or hand hole for this purpose can be constructed in the floor or apron.

6-4.10.2 Mount the contactor for the circuit, control relay, and control devices in a single enclosure, installed on a wall of a hangar or at the rear of the apron, according to clearance requirements. Wall-mounted receptacles can be installed as integral parts of contactor enclosures. Contactor enclosures for wall-mounted receptacles can be of the general-purpose type if they are mounted on interior walls, and they should be mounted sufficiently high to be outside of hazardous areas.

6-4.11 Receptacles installed in office furniture should be considered in the facility electrical layout planning. Depending on the office layout and design, either floor-mounted receptacles or ceiling drops might be necessary to provide power to furniture receptacles.

6-5 WIRING FOR TEMPORARY POWER AND LIGHTING.

6-5.1 Temporary electrical power and lighting wiring methods can be of a class less than would be required for a permanent installation. Except as specifically allowed in this section for temporary wiring, apply all other criteria for permanent wiring to temporary wiring installations.

6-5.2 Temporary electrical power and lighting installations 600 volts, nominal, or less can be used only for the following applications:

- During and for remodeling, maintenance, repair, or demolition of buildings, structures, or equipment, and similar activities.

- For experimental or development work.

- For a period not to exceed 90 days for Christmas decorative lighting, carnivals, and similar purposes.

6-5.3 Temporary wiring over 600 volts, nominal, can be used only during periods of tests, experiments, or emergencies.

6-5.4 Originate feeders for temporary wiring in an approved distribution center. The conductors should be run as multiconductor cord or cable assemblies, or, where not subject to physical damage, they can be run as open conductors on insulators not more than 3 meters (10 feet) apart.

6-5.5 Originate branch circuits for temporary wiring in an approved power outlet or panelboard. Conductors should be multiconductor cord or cable assemblies or open conductors. If run as open conductors, fasten them at ceiling height every 3 meters (10 feet). No branch-circuit conductor can be laid on the floor. Each branch circuit that supplies receptacles or fixed equipment must contain a separate equipment grounding conductor if run as open conductors.

6-5.6 Receptacles must be of the grounding type. Unless installed in a complete metallic raceway, each branch circuit must contain a separate equipment grounding conductor and all receptacles must be electrically connected to the grounding conductor. Provide GFCI protection in accordance with NEC Article 527.6 (2002 Edition).

6-5.7 No bare conductors nor earth returns can be used for the wiring of any temporary circuit.

6-5.8 Suitable disconnecting switches or plug connectors should be installed to permit the disconnection of all ungrounded conductors of each temporary circuit.

6-5.9 Protect lamps for general illumination from accidental contact or breakage. Protection should be provided by elevation of at least 2.1 meters (7 feet) from the normal working surface or by a suitable fixture or lampholder with a guard.

6-5.10 Protect flexible cords and cables from accidental damage. Avoid sharp corners and projections. Where passing through doorways or other pinch points, provide flexible cords and cables with protection to avoid damage.

6-5.11 Do not wrap aluminum foil or other conductive material around fuses to keep temporary loads, such as Christmas lights on with fuses blown.

6-6 ACCEPTANCE TESTING OF WIRING SYSTEMS.

6-6.1 Ensure that the facility electrical acceptance process includes a detailed inspection of the wiring system from the service entrance to the loads. Table 6-1 shows typical wiring-related problems that can be encountered.

Table 6-1. Electrical System Problems Caused by Improper Wiring

Wiring Problem	Effect on Facility
Loose connections	Impulses, voltage drop-out
Neutral-to-ground tie	Ground current
Neutral and ground reversal	Ground current
High impedance neutral (open) in polyphase circuit	Extreme voltage fluctuation (high or low), neutral to ground voltage fluctuation
High impedance neutral-to-ground bond at transformer	Voltage fluctuation, neutral to ground voltage fluctuation
High impedance neutral-to-ground bond at service entrance	Voltage fluctuation, neutral to ground voltage fluctuation
High impedance open circuit grounding	Neutral to ground voltage fluctuation

6-6.2 If infrared scanning equipment is available, perform an infrared scan of connections to identify high resistance connections. An infrared scan provides the best information when the circuits being checked have been operating at full-load for at least one hour so that connections have had time to heat up. Infrared scans of deenergized or lightly loaded circuits will usually provide no useful information.

CHAPTER 7

POWER DISTRIBUTION AND UTILIZATION—MOTORS AND MOTOR CONTROL CIRCUITS

7-1 **BASIC MOTOR CRITERIA**.

7-1.1 Ensure motors have mechanical and electrical characteristics suitable for the application. Three-phase motors have better starting torque, run more quietly, have better efficiency, and are smaller than single-phase motors of the same horsepower rating. In ratings of 5 horsepower (3,730 watts) or more, they are also less expensive. For these reasons, use three-phase motors if more than 0.5 horsepower (373 watts) rating when such service is available. If three-phase service is not available, operate motors 0.5 horsepower (373 watts) and larger at phase-to-phase voltage rather than phase-to-line voltage. Motors smaller than 0.5 horsepower (373 watts) should be single phase, with phase-to-phase voltage preferred over phase-to-ground voltage.

7-1.2 The kilowatt horsepower rating of motors should be limited to no more than 125 percent of the maximum load being served unless a standard size does not fall within this range. In this case, select the next larger standard size.

7-1.3 Use motor voltage ratings suitable for the voltage supplied. Do not use 230 volt motors on 208 volt systems because the utilization voltage will commonly be below the -10 percent tolerance on the voltage rating for which the motor is designed (a 230 volt motor is intended for use on a nominal 240 volt system).

7-1.4 Ensure three-phase motors of 1 horsepower (746 watts) or more meet the minimum full-load efficiencies as indicated in Table 7-1. New motors should be rated as high efficiency. Replacement motors should also be of the high efficiency type provided that the upstream protective devices can continue to provide adequate electrical protection. For more information, refer to Air Force Pamphlet (AFPAM) 32-1192, *Energy Efficient Motors and Adjustable Speed Drives*.

Table 7-1. Minimum Full-Load Motor Efficiencies

Horsepower	Watts	Open Motors			Enclosed Motors		
		1,200 RPM	1,800 RPM	3,600 RPM	1,200 RPM	1,800 RPM	3,600 RPM
1	746	80.0	82.5	—	80.0	82.5	75.5
1.5	1,119	84.0	84.0	82.5	85.5	84.0	82.5
2	1,492	85.5	84.0	84.0	86.5	84.0	84.0
3	2,238	86.5	86.5	84.0	87.5	87.5	85.5
5	3,730	87.5	87.5	85.5	87.5	87.5	87.5
7.5	5,595	88.5	88.5	87.5	89.5	89.5	88.5
10	7,460	90.2	89.5	88.5	89.5	89.5	89.5
15	11,190	90.2	91.0	89.5	90.2	91.0	90.2
20	14,920	91.0	91.0	90.2	90.2	91.0	90.2
25	18,650	91.7	91.7	91.0	91.7	92.4	91.0
30	22,380	92.4	92.4	91.0	91.7	92.4	91.0
40	29,840	93.0	93.0	91.7	93.0	93.0	91.7
50	37,300	93.0	93.0	92.4	93.0	93.0	92.4
60	44,760	93.6	93.6	93.0	93.6	93.6	93.0
75	55,950	93.6	94.1	93.0	93.6	94.1	93.0
100	74,600	94.1	94.1	93.0	94.1	94.5	93.6
125	93,250	94.1	94.5	93.6	94.1	94.5	94.5
150	111,900	94.5	95.0	93.6	95.0	95.0	94.5
200	149,200	94.5	95.0	94.5	95.0	95.0	95.0
250	186,500	95.4	95.4	94.5	95.0	95.0	95.4
300	223,800	95.4	95.4	95.0	95.0	95.4	95.4
350	261,100	95.4	95.4	95.0	95.0	95.4	95.4
400	298,400	—	95.4	95.4	—	95.4	95.4
450	335,700	—	95.8	95.8	—	95.4	95.4
500	373,000	—	95.8	95.8	—	95.8	95.4

7-1.5 Select motors according to expected service conditions. Usual service conditions, as defined in NEMA MG 1, *Motors and Generators*, include:

- Exposure to an ambient temperature between 0 °C (32 °F) and 40 °C (104 °F).
- Installation in areas or enclosures that do not seriously interfere with the ventilation of the machine.
- Operation within a tolerance of ± 10 percent of rated voltage.
- Altitude not above 1,006 meters (3,300 feet). Table 7-2 provides the typical motor derating for operation above this altitude.
- Operation within a tolerance of ± 5 percent of rated frequency.
- Operation with a voltage unbalance of 1 percent or less.

Table 7-2. Motor Altitude Derating Factors

Altitude Range (feet)	Altitude Range (meters)	Derating by Service Factor			
		1.0	1.15	1.25	1.35
3,300 – 9,000	1,006 – 2,743	93%	100%	100%	100%
9,000 – 9,900	2,743 – 3,018	91%	98%	100%	100%
9,900 – 13,200	3,018 – 4,023	86%	92%	98%	100%
13,200 – 16,500	4,023 – 5,029	79%	85%	91%	94%
Over 16,500	Over 5,029	Consult Manufacturer			

7-1.6. Consult the manufacturer if the motor operating conditions will be unusual. This includes:

- Dirty areas.
- Explosive areas.
- Areas with chemical fumes.
- Salt-laden or oil-laden air.
- Excessive voltage and frequency variations from rated values.

7-2 **MOTOR CONTROL CIRCUITS**.

7-2.1 Provide motor controllers (starters) for motors larger than 0.125 horsepower (93.25 watts) and apply the design criteria of NEMA ICS 1, *Industrial Control and Systems: General Requirements* and NEMA ICS 2, *Industrial Control and Systems: Controllers, Contactors and Overload Relays, Rated Not More Than 2000 Volts AC or 750 Volts DC*. Motors smaller than 0.125 horsepower (93.25 watts) must comply with NEC requirements.

7-2.2 The motor starting circuit should be full voltage-type starting (also referred to as line starting). Energizing the motor with full line voltage is the most economical starting method and allows the most rapid acceleration. Accordingly, motor controllers should normally be of the magnetic, across-the-line type.

7-2.3 High-efficiency motors (either Design E or energy efficient Design B) often have very high starting currents that can cause voltage dips below the system voltage tolerances. If the starting current will result in more than a 20 percent transient voltage dip or if the analyzed voltage dip is otherwise determined to be unacceptable (refer to paragraph 2-6 for information regarding voltage drop during motor starting), apply one of the following methods for motor starting:

7-2.3.1 **Reduced Voltage Starters**. Several different designs are available, including primary resistor, autotransformer, part winding, wye delta, and solid-state. For more information, refer to AFPAM 32-1192.

7-2.3.2 **Adjustable Speed Drives**. If an ASD is required for other reasons, it can also address motor starting current design needs. Refer to paragraph 7-3 for additional information regarding these devices.

7-2.4 Manual controllers can be used within the limitations imposed by the NEC, if appropriate for the application. MCCs having disconnect devices, branch circuit overload protection, and controllers mounted in a single assembly can be used where several motors are grouped in a particular area, as in mechanical equipment rooms. Do not exceed a control circuit voltage of 150 volts to ground.

7-2.5 If designed for direct control, use control devices—such as thermostats, float switches, or pressure switches—to automatically control the starting and stopping of motors that are designed for that purpose and have adequate kilowatt/horsepower rating. Typically, these devices should be rated for the motor's horsepower rating to ensure that the contacts can handle inrush starting current. If the automatic control device does not have an adequate rating, use a magnetic starter actuated by the automatic control device. Review the wiring requirements and control scheme for complex direct digital control circuit; these systems typically require more attention in the design phase to ensure the system operates as desired.

7-2.6 If the motor starting circuit provides automatic starting, such as by a level switch or temperature switch, or if the starting device is not in sight, or more than 15.2 meters (50 feet) from the motor and all parts of the machinery operated, design the power or control circuit so that it can be positively locked open. All motors designed such that an unexpected starting of the motor might create an exposure of personnel to injury must have the motor control circuit designed to block automatic reenergization after a power supply interruption of sufficient duration for moving equipment to become stationary. Design the motor control circuit so that an operator has to take some action to restart the motor or else have automatic restarting preceded by warning signals and a time delay sufficient for personnel action to limit the likelihood of injury. This requirement does not apply to motors with an emergency function where opening of the circuit could cause less safe conditions. Identify motors that can automatically start with a caution tag stating, "Caution. Motor will automatically start."

7-2.7 Where combination manual and automatic control is specified and the automatic control operates the motor directly, use a double-throw, three-position switch or other suitable device (marked MANUAL-OFF-AUTOMATIC) for the manual control.

7-2.8 Where combination manual and automatic control is specified and the automatic control device actuates the pilot control circuit of a magnetic starter, provide the magnetic starter with a three-position selector switch marked MANUAL-OFF-AUTOMATIC.

7-2.9 When making connections to the above selector switches, ensure that only the normal automatic control devices are bypassed when the switch is in the manual position. Confirm that all safety control devices, such as low- or high-pressure cutouts, high-temperature cutouts, and motor overload protective devices, remain connected in the motor control circuit in both the manual and automatic positions.

7-2.10 Provide all motors with overcurrent protection in accordance with the NEC to automatically disconnect the motor from the supply source in the event of an internal short circuit or sustained overload in the motor. Provide each motor of 0.125 horsepower (93.25 watts) or larger with thermal overload protection. Provide three-phase motors with overload protection in each ungrounded conductor. Overload protection can be provided either integral with the motor or controller, or can be mounted in a separate enclosure. Provide ambient temperature-compensated overload protection if the ambient temperature varies by more than 10 °C (18 °F).

7-3 ADJUSTABLE SPEED DRIVES.

7-3.1 Adjustable speed drives (also referred to as variable speed drives or variable frequency drives) are electronic devices that control a motor's speed to match an actual load demand signal.

7-3.2 Refer to NEMA ICS 7, *Industrial Control and Systems: Adjustable Speed Drives*, for design criteria related to the selection and design of ASDs. For additional information, refer to AFPAM 32-1192. For the Navy, guidance is provided in Appendix D of MIL-HDBK-1003/3, *Heating, Ventilating, Air Conditioning, and Dehumidifying Systems*. The following provides additional design criteria.

7-3.3 At the rated full load of the driven equipment, the output voltage and frequency of the ASD should be the same as the motor's rating. Note that this design recommendation also places limits on the motor design; the motor should not have a significantly higher full load horsepower or speed rating than the driven load. Mismatches can easily cause operational problems, including efficiency losses and increased ASD input current. In extreme cases, a mismatch can cause the ASD to trip on overcurrent during motor starting or cause the ASD input current to be substantially higher than the design without the ASD.

7-3.4 The ASD short term current rating should be adequate to produce the required motor starting torque, including loads with high starting torque. Inappropriate designs, such as operating an 1,800 rpm motor at reduced speed to drive an 870 rpm load can cause the ASD to exceed its short term current rating.

7-3.5 Motors can overheat at the lower operating speed set by an ASD and, in some cases, they can overheat even at full load/full speed operation because of the ASD's non-sinusoidal output. On fan-cooled motors, decreasing the motor's shaft speed by 50 percent decreases the fan's cooling effects proportionately. If the motor is fully loaded and speed decreases, the motor must supply full torque with less than intended cooling. In extreme cases, this can cause the motor insulation to fail or can reduce the motor life. For many applications, the load will be well less than full load and the motor will be able to operate at reduced speed without overheating.

7-3.6 The motor should have a minimum 1.15 service factor or be rated well above the actual load it will be carry. Verify with the manufacturer that the motor is capable of acceptable operation with an ASD. Standard motors can often operate down to 50 percent of rated speed, high efficiency motors can often operate down to 20 percent of rated speed, and "inverter duty" motors can operate below 20 percent of rated speed without problems in a variable load application. Motors designed specifically for ASD operation usually incorporate special cooling provisions and might use a higher class insulation.

7-3.7 Ensure that the final installation does not create voltage or current harmonic distortion beyond acceptable limits. The amount of harmonic current distortion generated depends on the ASD design and the ASD filter design. Some ASD manufacturers provide software to assist with a harmonic distortion evaluation; AFPAM 32-1192 describes one commercially-available software program designed for ASD analysis. Power quality field measurements should be taken after the installation is complete to confirm that the system total harmonic distortion is not degraded beyond acceptable levels. If the ASD can be provided power from a standby generator upon loss of normal commercial power, the harmonic distortion evaluation must include the system effects when powered from the standby generator.

7-3.8 Voltage sags can cause nuisance tripping. Ensure that the ASD either has a minimum of 3-cycle ride-through capability or automatic reset circuitry.

7-3.9 Nearby capacitor switching can cause transient overvoltages, resulting in nuisance tripping. In this case, ensure the ASD either has input filtering to reduce the overvoltage or automatic reset circuitry.

7-3.10 Important applications should include bypass operation capability to allow motor operation independent of the ASD. Refer to AFPAM 32-1192 for additional information.

7-3.11 Refer to Appendix B for additional information regarding an energy efficiency economic evaluation associated with ASDs.

CHAPTER 8

POWER DISTRIBUTION AND UTILIZATION—OTHER DESIGN CRITERIA

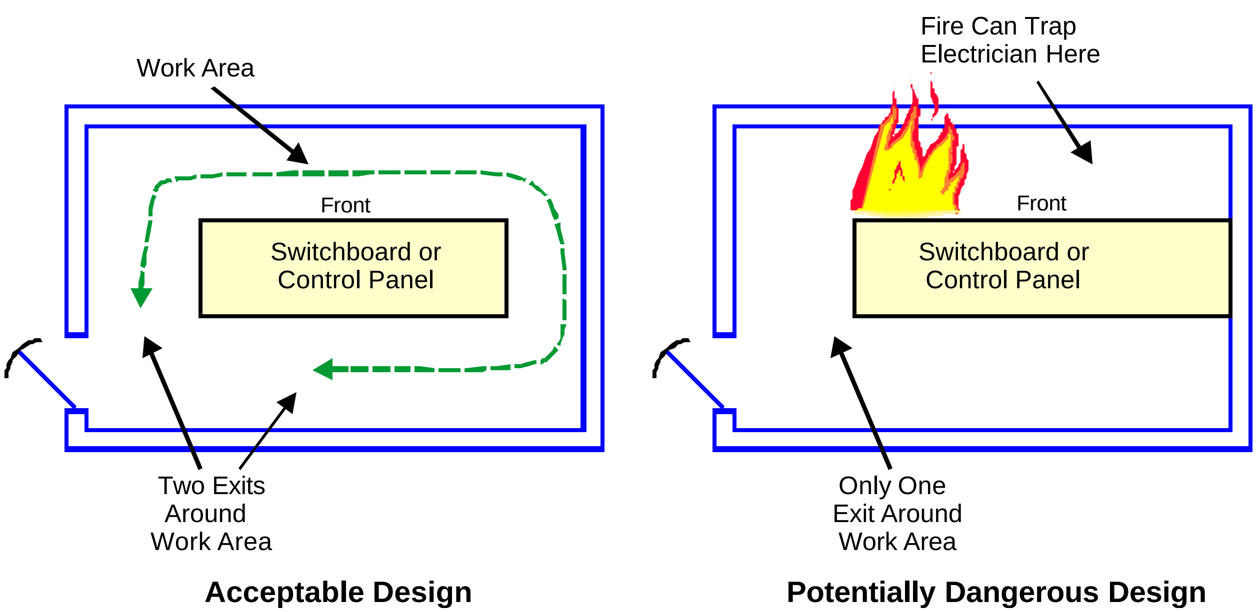
8-1 ELECTRICAL EQUIPMENT CLEARANCES AND GUARDS.

8-1.1 Background.

8-1.1.1 Adequate equipment clearances must be maintained to allow safe access to and around equipment. The clearances are also intended to minimize the possibility of unsafe conditions while personnel work with and around electrical equipment. Adequate clearance is so important that several industry documents provide similar guidance, including the NEC, NFPA 70E, NESC, and OSHA.

8-1.1.2 Figure 8-1 illustrates how equipment layouts must be carefully considered. Not only must personnel have adequate work clearances, but safe escape routes must be established. Note in Figure 8-1 that even in cases in which there is only a single door to an equipment room a safer layout can be achieved. In some equipment rooms, it might be necessary to provide two doors to ensure safe egress from the room.

Figure 8-1. Equipment Positioning to Allow Escape Around Equipment



8-1.2 Equipment Rated 600 Volts and Lower.

8-1.2.1 **Basic Requirement**. Design and install power distribution and utilization equipment to provide adequate clearance for safe operation and maintenance of the equipment.

8-1.2.2 **Access and Entrance to Working Space**. Provide at least one entrance to give access to the working space about electric equipment.

8-1.2.3 **Working Space**. Provide working space not less than indicated in Table 8-1 in the direction of access to energized parts operating at 600 volts or less that require examination, adjustment, servicing, or maintenance while energized. In addition to the dimensions shown in Table 8-1, provide a working space in front of the electric equipment to be the width of the equipment or 0.9 meters (3 feet), whichever is greater. Measure distances from the energized parts if such are exposed or from the enclosure front or opening if such are enclosed. Concrete, brick, or tile walls can be considered grounded. Working space is not required in back of assemblies, such as dead-front switchboards or MCCs, provided that there are no renewable or adjustable parts on the back and all connections are accessible from locations other than the back.

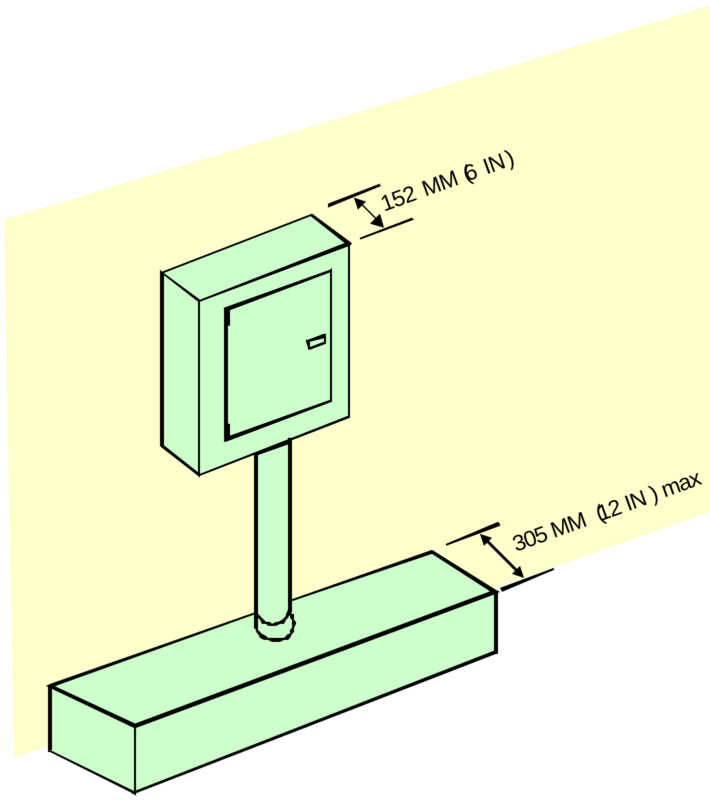
Table 8-1. Working Space Clearances 600 Volts and Below

Voltage to Ground	Condition	Clear Distance (feet)	Clear Distance (meters)
0 – 150	All.	3	0.9
151 – 600	Exposed energized parts on one side and no energized or grounded parts on the other side of the working space, or exposed energized parts on both sides effectively guarded by suitable wood or other insulating materials. Insulated wire or insulated bus bars operating at not over 300 volts will not be considered energized parts. Condition 1 of NEC Table 110.26(A)(1) (2002 Edition).	3	0.9
151 – 600	Exposed energized parts on one side and grounded parts on the other side. Concrete, brick, or tile walls can be considered grounded. Condition 2 of NEC Table 110.26(A)(1) (2002 Edition).	3.5	1.0
151 – 600	Exposed energized parts on both sides of the work space (not guarded). Condition 3 of NEC Table 110.26(A)(1) (2002 Edition).	4	1.2

8-1.2.4 **Headroom Working Space**. The headroom of working spaces about switchboards or control centers should not be less than 2.1 meters (7 feet). Headroom is defined as the distance from the floor to the ceiling. The NEC headroom requirement is 2 meters (6.5 feet); in this instance, greater headroom space is recommended whenever possible. If the electrical equipment exceeds 2 meters (6.5 feet), provide minimum headroom not less than the height of the equipment.

8-1.2.5 **Clearance of Other Equipment**. Within the headroom working space height requirement of paragraph 8-1.2.4, other equipment associated with the electrical installation located above or below the electrical equipment will be permitted to extend not more than 152.4 millimeters (6 inches) beyond the front of the electrical equipment (refer to Figure 8-2). The intent of this requirement is to preclude the installation of equipment, such as a transformer, in the working space for other electrical equipment, such as a panelboard; this type of installation impedes access and can create an unsafe working condition.

Figure 8-2. Associated Equipment Maximum Extension into Work Space



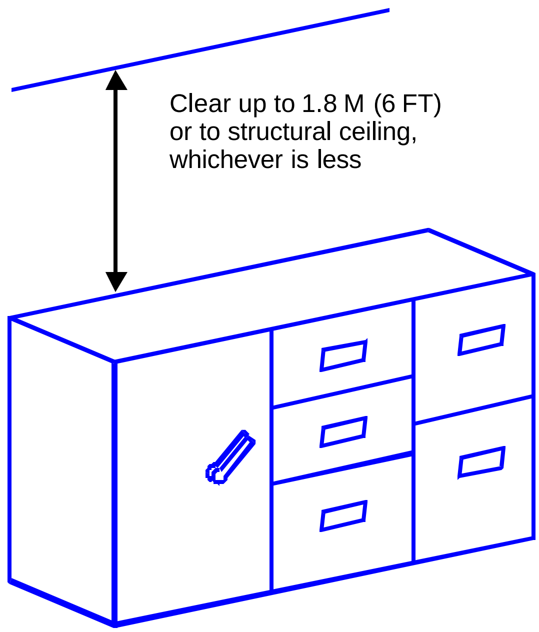
8-1.2.6 **Front Working Space**. In all cases where there are energized parts normally exposed on the front of switchboards or MCCs, provide a working space width in front of such equipment not less than 0.9 meters (3 feet) or the width of the equipment, whichever is greater. This exceeds the minimum space required by the NEC.

8-1.2.7 **Clear Spaces**. Do not use for storage or otherwise block working space required for equipment operation and maintenance. Guard the working space when normally enclosed energized parts are exposed for inspection or servicing, if in a passageway or general open space.

8-1.2.8 **Dedicated Equipment Space**. The requirements for working space and dedicated space are closely related. Working space is the area intended for use by personnel. Dedicated space is the area intended for use by the equipment itself. Provide dedicated space for switchboards, panelboards, and MCCs in accordance with NEC Article 110.26(F) (2002 Edition). Summarizing the NEC, dedicate the space equal to the width and depth of the equipment and extending from the floor to a height of 1.8

meters (6 feet) above the equipment or to the structural ceiling, whichever is lower, to the electrical installation (refer to Figure 8-3). Do not locate piping, ducts, or equipment foreign to the electrical installation in this zone. NEC-specified exceptions regarding protection for foreign systems are allowed.

Figure 8-3. Dedicated Clear Space Above Equipment



8-1.2.9 **Illumination**. Provide illumination for all working spaces about service equipment, switchboards, panelboards, and MCCs installed indoors.

8-1.2.10 **Guarding**.

8-1.2.10.1 Guard live parts of electric equipment operating at 50 volts or more against accidental contact by approved cabinets or other forms of approved enclosures, or by any of the following means:

- By location in a room, vault, or similar enclosure that is accessible only to qualified persons.

- By suitable permanent, substantial partitions or screens so arranged that only qualified persons will have access to the space within reach of the live parts. Size and locate any openings in such partitions or screens so that persons are not likely to come into accidental contact with the live parts or to bring conducting objects into contact with them.

- By locations on a suitable balcony, gallery, or platform so elevated and arranged so as to exclude unqualified persons.

- By elevation of 2.4 meters (8 feet) or more above the floor or other working surface.

8-1.2.10.2 In locations where electric equipment can be exposed to physical damage, enclosures or guards must be so arranged and of such strength as to prevent such damage.

8-1.2.10.3 Mark entrances to rooms and other guarded locations containing exposed live parts with conspicuous warning signs forbidding unqualified persons to enter.

8-1.3 **Equipment Rated Above 600 Volts**. Provide equipment rated above 600 volts with clearances for safe operation and maintenance in accordance with OSHA Standard 29 CFR 1910.303, Section *h*; the NESC, Section 12; and NFPA 70E, Section 1-9.

8-2 **ENCLOSURES**.

8-2.1 Select equipment enclosures to provide the following:

- To protect facility personnel from coming in contact with live parts.
- To protect the equipment as necessary.

8-2.2 NEMA classifies enclosures based on the degree of protection provided by the enclosure and the environmental conditions to which the enclosure will be exposed. Table 8-2 summarizes the NEMA enclosure types. For additional information, refer to NEMA 250, *Enclosures for Electrical Equipment (1000 Volts Maximum)*. If needed, contact the enclosure manufacturer to determine the closest International Electrotechnical Commission (IEC) equivalent designation (NEMA 250, Appendix A, also provides limited information).

Table 8-2. NEMA Enclosure Types

NEMA Type	Description	Application
NEMA 1 (vented)	General purpose. Primarily used to provide a degree of protection against contact with the enclosed equipment or locations where unusual service conditions do not exist.	Indoor
NEMA 1	General purpose against limited amounts of falling dirt. Primarily used to provide a degree of protection against contact with the enclosed equipment or locations where unusual service conditions do not exist.	Indoor
NEMA 2 (vented)	General purpose and drip-proof. Provides protection against limited amounts of falling water and dirt. Not dust-tight.	Indoor
NEMA 2	General purpose, drip-proof and dust-proof. Provides protection against limited amounts of falling water and dirt.	Indoor
NEMA 3	Dust tight, rain tight, and sleet/ice resistant.	Outdoor
NEMA 3R (vented)	Rain-proof, sleet/ice resistant. Vented version is not dust-tight.	Outdoor
NEMA 3R	Rain-proof, sleet/ice resistant.	Outdoor
NEMA 3S	Dust tight, rain tight, and sleet/ice proof.	Outdoor
NEMA 4	Water tight, dust tight. Provides protection against windblown dust and rain, splashing water, and hose directed water. Undamaged by ice formation.	Indoor/Outdoor
NEMA 4X	Water tight, dust tight, corrosion resistant. Provides protection against corrosion, windblown dust and rain, splashing water, and hose directed water. Undamaged by ice formation.	Indoor/Outdoor
NEMA 5	General purpose against dust and falling dirt	Indoor
NEMA 6	Temporary submersion, dust tight, rain tight, sleet/ice resistant.	Indoor/Outdoor
NEMA 6P	Prolonged submersion, dust tight, rain tight, sleet/ice resistant.	Indoor/Outdoor
NEMA 7	Class 1, Division 1, Groups A, B, C, or D.	Indoor hazardous locations
NEMA 8	Class 1, Division 1, Groups A, B, C, or D.	Indoor/Outdoor hazardous locations
NEMA 9	Class 2, Division 1, Groups E, F, or G.	Indoor hazardous locations
NEMA 10	Mining enforcement safety requirements.	
NEMA 11	Corrosion resistant by oil immersion.	Indoor
NEMA 12	Industrial use, drip tight, dust tight, non-corrosive liquids.	Indoor
NEMA 12K	Industrial use with knockouts, drip tight, dust tight, non-corrosive liquids.	Indoor
NEMA 13	Oil tight, dust tight, non-corrosive coolants.	Indoor

8-2.3 Select enclosures for indoor applications in accordance with the conditions specified in Tables 8-3 and 8-4 for non-hazardous and hazardous locations, respectively. Refer to paragraph 8-3 and NEC Article 500 (2002 Edition) for the definition of various hazardous locations. Contact the equipment manufacturer for assistance with hazardous environment applications.

Table 8-3. Indoor Nonhazardous Locations

NEMA Enclosure Type	1	2	4	4X	5	6	6P	11	12	13
Accidental Contact	x	x	x	x	x	x	x	x	x	x
Falling Dirt	x	x	x	x	x	x	x	x	x	x
Light Splashing		x	x	x	x	x	x	x	x	x
Dust and Fibers			x	x	x	x	x		x	x
Washdown with Water			x	x		x	x			
Oil and Coolant Seepage									x	x
Oil and Coolant Spraying										x
Corrosive Agents				x			x			
Occasional Submersion						x	x			
Sustained Submersion							x			

Table 8-4. Indoor Hazardous Applications

Protection Provided For:	Class	Type of Enclosure NEMA 7 and 8 A	B	C	D	NEMA 9 E	F	G
Acetylene	I	x						
Hydrogen, manufactured gas	I	x	x					
Ethyl ether, ethylene, cyclopropane	I	x	x	x				
Gasoline, jet fuel, hexane, butane, naphtha, propane, acetone, toluene, isoprene	I	x	x	x	x			
Metal dust	II	x	x	x	x	x		
Carbon black, coal dust, coke dust	II	x	x	x	x		x	
Flour, starch, grain dust	II	x	x	x	x	x	x	x
Fibers, flyings	III	x	x	x	x	x	x	X

Note: Refer to NEC Article 500.4 (2002 Edition) for information regarding hazardous substances not listed in this table.

8-2.4 Evaluate the enclosure temperature rise and determine if special cooling options will be required to dissipate the generated heat. Enclosure manufacturers can provide application guidance to assist in the selection and sizing of cooling options.

8-3 **HAZARDOUS LOCATIONS**.

8-3.1 NEC Article 500 (2002 Edition) establishes hazardous location classifications based on the flammable vapors, liquids, or gases, or combustible dusts or fibers that might be present. The classification also considers the likelihood that a flammable or combustible concentration or quantity is present. Electrical design criteria are based on the specific location classification. Table 8-5 lists the various hazardous location classifications; refer to NEC Article 500 (2002 Edition) for the definition of each location.

Table 8-5. Hazardous Location Classifications

Class	Group	Examples
I	A	Acetylene
I	B	Hydrogen, manufactured gas
I	C	Ethyl ether, ethylene, cyclopropane
I	D	Jet fuel, gasoline, hexane, butane, naphtha, propane, acetone, toluene, isoprene
II	E	Metal dust
II	F	Carbon black, coal dust, coke dust
II	G	Flour, starch, grain dust

8-3.2 Referring to Table 8-5, a Class I location contains flammable gases or vapors that might be present in air in sufficient quantities to produce explosive or ignitable mixtures. Class I locations are further subdivided into Division 1 and Division 2, as described below.

8-3.3 In accordance with NEC Article 500.5 (2002 Edition), a Class I, Division 1 classification applies to the following types of locations.

- Locations in which ignitable concentrations of flammable gases or vapors can exist under normal operating conditions.

- Locations in which ignitable concentrations of such gases or vapors might frequently exist because of repair or maintenance operations or because of leakage.

- Locations in which breakdown or faulty operation of equipment or processes might release ignitable concentrations of flammable gases or vapors, and might also cause simultaneous failure of electrical equipment in such a way as to directly cause the electrical equipment to become a source of ignition.

8-3.4 In accordance with NEC Article 500.5 (2002 Edition), a Class I, Division 2 classification applies to the following types of locations.

- Locations in which volatile flammable liquids or flammable gases are handled, processed, or used, but in which the liquids, vapors, or gases will normally be confined within closed containers or closed systems from which they can escape only in cases of accidental rupture or breakdown of such containers or systems, or in case of abnormal operation of equipment.

- Locations in which ignitable concentrations of gases or vapors are normally prevented by positive mechanical ventilation, and which might become hazardous through failure or abnormal operation of the ventilating equipment.

- Locations that are adjacent to a Class I, Division 1 location and to which ignitable concentrations of gases or vapors might occasionally be communicated unless such communication is prevented by adequate positive-pressure ventilation from a source of clean air, and effective safeguards against ventilation failure are provided.

8-3.5 Evaluate each location for a possible classification as a hazardous area. All hazardous areas must comply with the design criteria specified in NEC Articles 500 and 501 (2002 Edition). Refer to NEC Article 504 (2002 Edition) for the design criteria for intrinsically safe systems.

8-3.6 The Zone classification system described in NEC Article 505 [2002 Edition] can be applied as an alternative to the Class and Division designations.

8-3.7 Refer to NEC Article 511 (2002 Edition) for design criteria for commercial-type garages in which service or repair operations are performed on all or all types of self-propelled vehicles.

8-3.8 Refer to NEC Article 514 (2002 Edition) for design criteria for gasoline dispensing and service stations. This applies to any location where gasoline or other volatile flammable liquids or liquefied flammable gases are transferred to the fuel tanks (or auxiliary fuel tanks) of self-propelled vehicles or approved containers.

8-3.9 Refer to NEC Article 515 (2002 Edition) for design criteria for bulk storage plants. This applies to any location where flammable liquids are received by tank vessel, pipeline, tank car, or tank vehicle, and are stored or blended in bulk for the purpose of subsequent distributing of such liquids.

8-3.10 Wherever possible, do not locate electrical distribution or utilization equipment in zones classified as hazardous.

8-4 **400-HERTZ DISTRIBUTION SYSTEMS**.

8-4.1 Some equipment is designed for 400-Hertz operation. Normally, a 400-Hertz voltage is obtained from 60-Hertz power (50 Hertz outside North America) by motor-generator sets or UPS conversion equipment. Small 400-Hertz power systems are often located near the end-use equipment, but larger systems might be installed as accessory equipment in a nearby electrical equipment room.

8-4.2 A 400-Hertz system requires a different design approach than a 60-Hertz (or 50-Hertz) system. For example, conductors that carry 400-Hertz power cannot be installed in ferrous metal conduit, but can be installed in aluminum conduit. The high frequency magnetic fields around conductors carrying 400-Hertz power can induce heating in ferrous metals, thereby causing excessive temperature rise in the conductors. Furthermore, greater care is necessary to minimize voltage drop in 400-Hertz systems.

8-4.3 Refer to MIL-HDBK-1004/5, *400-Hertz Medium Voltage Conversion/ Distribution and Low-Voltage Utilization Systems*, for further information regarding the design of 400-Hertz power systems.

8-5 **METERING**.

8-5.1 Provide all facilities with a revenue-metering installation ahead of the main disconnecting device at the service entrance. This requirement applies to military residential housing also. Submetering provisions should also be provided for multiple tenants in a facility or for monitoring energy usage throughout a large facility.

8-5.2 Use watthour meters conforming to ANSI C12.1, *Code for Electricity Metering*. In general, electronic meters are preferred.

8-5.3 If electromechanical meters are used, apply ANSI C12.10, *Electromechanical Watthour Meters*, except that the numbered terminal wiring sequence and case size can be the manufacturer's standard. Watthour meters can be the drawout switchboard type or the socket-mounted type, depending on which type is most appropriate for the application. Watthour meters should have a 15-minute, cumulative form, demand register meeting ANSI C12.4, *Mechanical Demand Registers*, and should be provided with not less than two and one-half stators. Watthour demand meters should have factory-installed electronic pulse initiators meeting ANSI C12.1. Pulse initiators should be solid-state devices incorporating light-emitting diodes, phototransistors, and power transistors. Initiators must be totally contained within watthour demand meter enclosures, must be capable of operating up to speeds of 500 pulses per minute with no false pulses, and must require no field adjustments. Initiators should be calibrated for a pulse rate output of 1 pulse per one-fourth disc revolution of the associated meter and must be compatible with the indicated equipment.

8-5.4 Where required, install submetering provisions for energy-consuming mechanical/electrical systems such as lighting, large motor, or HVAC systems.

8-5.5 Do not use meters as the principal method of service disconnect. Paragraph 5-1 provides the disconnect requirements for service connections.

8-6 **POWER FACTOR CORRECTION**. Power factor correction is not routinely applied to interior electrical systems. Refer to Appendix C for guidance if power factor correction is necessary.

CHAPTER 9

ELECTRICAL SYSTEM PROTECTION AND COORDINATION

9-1 PROTECTION SYSTEM DESIGN.

9-1.1 Electrical protection initiates the prompt removal from service of any component of a power system when it suffers a short circuit or operates abnormally in a manner that might interfere with the effective operation of the rest of the system.

9-1.2 When a fault occurs within a system, the primary protection closest to the fault should act promptly to isolate the fault. Depending on the design and function, backup protection farther from the fault might begin to operate but should not actually initiate any tripping functions as long as the primary protection functions properly. If the primary protection fails to isolate the faulted condition, the backup protection should complete its operation to isolate the fault.

9-1.3 Refer to IEEE 242, *Protection and Coordination of Industrial and Commercial Power Systems* (IEEE Buff Book), for guidance regarding electrical protection. These documents provide specific guidance regarding the protection needed for each equipment type.

9-1.4 Not all installations offer the same level of reliability and protection. Three basic system design approaches are available for low voltage systems:

- Fully rated—all installations must be fully rated.
- Selectively coordinated—selectively coordinate critical installations down to the first panelboard as a minimum.
- Series-combination rated—do not use series-combination ratings. This type of design guarantees loss of entire panelboards or load centers in response to a short circuit. Also, inappropriate breaker replacements will invalidate the rating and create the potential for equipment or personnel damage when a short circuit occurs.

9-2 ELECTRICAL COORDINATION ANALYSIS CRITERIA.

9-2.1 Introduction.

9-2.1.1 Most facilities tend to have fully rated systems with some level of selective coordination available. Determine if electrical coordination is a design requirement for the electrical system or some portion of the electrical system. If coordination is a design requirement, a coordination study must be completed.

9-2.1.2 Selectively coordinate critical installations down to the first panelboard as a minimum. Coordinate circuit breaker performance with upstream and downstream circuit breakers and protective devices to the maximum extent possible. Often, selectivity is possible only when circuit breakers with delayed trip devices are used in all circuit positions except the one closest to the load.

9-2.1.3 Evaluate electrical coordination and include the evaluation as part of the system design package by the system designer, if applicable. The construction contractor is responsible for installing a system that meets the electrical coordination design requirements. Medium voltage relay coordination is often a separate task after completion of project design and installation; determine who will perform this analysis and specify required settings.

9-2.2 **Coordination Study Description**.

9-2.2.1 The system designer will perform a coordination study as part of the system design. The coordination study of an electric power system consists of an organized time-current study of all protective devices in series from the utilization device to the facility source (the service entrance). The objective of a coordination study is to generate a comprehensive one-line-diagram representation of the electrical system performance to abnormal currents. Additionally, the study must determine the characteristics, ratings, and settings of overcurrent protective devices. This is intended to ensure that protective devices will isolate a fault or overload anywhere in the system with the least possible effect on unfaulted sections of the system. At the same time, the devices and settings selected must provide satisfactory protection against overloads on the equipment and must interrupt short circuits as rapidly as possible.

9-2.2.2 The coordination study provides information necessary for the selection of instrument transformer ratios; protective relay characteristics and settings; fuse ratings; and low voltage circuit breaker ratings, characteristics, and settings. The coordination study also provides information regarding relative protection and selectivity, coordination of devices, and the most desirable arrangement of these devices. To obtain complete coordination of the protective equipment applied, determine the following short-circuit currents for each bus (refer to paragraph 2-4 for other criteria associated with short circuit studies).

9-2.2.2.1 **Momentary Duty**. The maximum and minimum 0 to 1 cycle momentary duty currents are used to determine the maximum and minimum currents to which instantaneous and direct-acting trip devices must respond. They also verify the capability of the applied apparatus to withstand the maximum electromechanical stresses to which they could be subjected.

9-2.2.2.2 **Interrupting Duty**. The maximum 3 to 8 cycle interrupting duty current, at maximum generation, is used to verify the ratings of circuit breakers, fuses, and cables. This is also the value of current at which the circuit protection coordination interval is established. The maximum 3 to 8 cycle interrupting duty current, at minimum generation, is needed to determine whether the circuit protection is sensitive enough to protect against damage that could result from low level faults.

9-2.2.2.3 **Ground Fault Currents**. The most common faults in electrical systems are ground faults. The magnitudes of ground fault currents are calculated using the method of symmetrical components, using the impedance values for both the momentary duty and interrupting duty. The ground fault current for a solidly grounded system can range from 25 percent to 125 percent of the bolted three-phase fault current values, but for most systems does not exceed the calculated three-phase fault current value. For low and high resistance grounded systems, the ground fault current is limited by the impedance of the grounding device and is substantially less than the three-phase fault current. The maximum and minimum generation cases need to be determined, just as for three-phase faults, to determine whether the circuit protection is sensitive enough to protect against damage that could result from low level faults. Separate ground fault relays are usually applied to the system with separate coordination studies performed for the GFP system.

9-2.3 **Coordination Time Intervals**.

9-2.3.1 **Purpose**. When plotting coordination curves, maintain certain time intervals between the curves of various protective devices in order to ensure correct sequential operation of the devices. These intervals are required because relays have overtravel; fuses have damage and tolerance characteristics; and circuit breakers have minimum speeds of operation. The coordination time interval is intended to allow the device closest to the fault the time necessary to detect, respond, and clear the fault before other upstream devices respond or suffer damage. The following provides the required coordination time intervals.

9-2.3.2 **Overcurrent Relays**.

9-2.3.2.1 When coordinating inverse time overcurrent relays, the time interval or margin should be set between 0.3 to 0.4 second. Time margin is measured between relay curves either at the instantaneous setting of the load side feeder circuit breaker relay or the maximum short-circuit current (which can flow through both devices simultaneously) whichever is the lower value of current. The interval might consist of the following components:

- Circuit breaker opening time (5 cycles)—0.08 second.
- Overtravel—0.10 second (electromechanical relays only).
- Safety factor—0.12 to 0.22 second.

9-2.3.2.2 The 0.3 to 0.4 second margin can be decreased if field tests of relays and circuit breakers indicate the system still coordinates with the decreased margins; however, the facility maintenance program is then obligated to periodically confirm performance to ensure that coordination is maintained.

9-2.3.2.3 The overtravel of very inverse and extremely inverse time overcurrent relays is somewhat less than that for inverse relays. This allows a decrease in time interval to 0.3 second for carefully tested systems.

9-2.3.2.4 If electronic multifunction relays are used, overtravel is eliminated and the coordination time interval can be reduced by the amount normally included for overtravel.

9-2.3.2.5 For systems using induction disk relays, a decrease of the time interval can be made by using an overcurrent relay with a special high-dropout instantaneous element. This is set at approximately the same pickup as the time element, with its contact wired in series with the main relay contact. This eliminates overtravel in the relay. The time interval often used on carefully calibrated systems with high-dropout instantaneous relays is 0.25 second. The minimum time interval using a high-dropout instantaneous relay could be 0.15 second (that is, 0.03 second instantaneous reset, plus 0.05 second circuit breaker opening time, plus 0.07 second safety factor).

9-2.3.2.6 Do not reduce the margin unless needed to resolve a particular coordination problem. Multifunction relays can be very accurate, which can allow for reduced margins if needed.

9-2.3.3 **Relays and Fuses**. When coordinating relays with downstream fuses, the relay overtravel and circuit breaker opening time do not exist for the fuse. The margin for overtravel is plotted beneath the relay curve, and because a safety factor is desirable above the total clearing time of the fuse, the same time margin is needed as for relay-to-relay coordination. Reduction of the margin is acceptable, however, when below 1 second. The same margin is used between a downstream relayed circuit breaker and the damage curve of the fuse. A similar process should be used for upstream fuses. The relay should actuate and the associated breaker should clear the fault before reaching the minimum melting time curve of the fuse. Once again, the time margin should be provided as for relay-to-relay coordination.

9-2.3.4 **Direct-Acting Trip Circuit Breakers and Fuses**. When coordinating direct-acting trip low voltage power circuit breakers or MCCBs with source-side fuses at the same voltage level, a 10 percent current margin can be used. This allows for possible fuse damage below the average melting time characteristics. The published minimum melting time-current curve should be corrected for ambient temperature or preloading if the fuse manufacturer provides the data necessary to perform this correction. If the fuse is preloaded to less than 100 percent of its current rating and the ambient temperature is lower than about 50 °C (122 °F), the correction to the minimum melting time-current curve of the fuse is usually less than 20 percent in time. Because the characteristic curves are relatively steep at the point where the margin is measured, the normal current margin applied is usually adequate to allow coordination without making a fuse characteristic correction also. Refer to IEEE 1015 for additional considerations regarding coordination of direct-acting trip circuit breakers with fuses.

9-2.3.5 **Direct-Acting Trip and Relayed Circuit Breakers**. When low voltage circuit breakers equipped with direct-acting trip units are coordinated with relayed circuit breakers, the coordination time interval should be 0.4 second. This interval can be decreased to a shorter time as explained previously for relay-to-relay coordination.

9-2.3.6 **Direct-Acting Trip Circuit Breakers**. When coordinating circuit breakers equipped with direct-acting trip units, the characteristic curves should not overlap. In this case, only a slight separation is necessary between the different characteristic curves. This lack of a specified time margin is based on the incorporation of all the variables plus the circuit breaker operating times for these devices within the band of the device characteristic curve.

9-2.4 **Pickup Current**.

9-2.4.1 **Description**. The term pickup has acquired several meanings. For many devices, pickup is defined as the minimum current that starts an action. It is accurately used when describing a relay characteristic. It is also used in describing the performance of a low voltage power circuit breaker. The term does not apply accurately to the thermal trip of a molded case circuit breaker, which operates as a function of stored heat.

9-2.4.2 **Overcurrent Relay**. The pickup current of an overcurrent protective relay is the minimum value of current that will cause the relay to close its contacts. For an induction disk time-overcurrent relay, pickup is the minimum current that will cause the disk to start to move and ultimately close its contacts. For solenoid-actuated devices with time-delay mechanisms, this same definition applies. For solenoid-actuated devices without time-delay mechanisms, the time to close the contacts is extremely short. Taps or current settings of these relays usually correspond to pickup current.

9-2.4.3 **Low Voltage Circuit Breakers**. For low voltage power circuit breakers, pickup is defined as that calibrated value of minimum current, subject to certain tolerances, which will cause a trip device to ultimately close its armature. This occurs when either unlatching the circuit breaker or closing an alarm contact. A trip device with a long-time delay, short-time delay, and an instantaneous characteristic will have three pickups. All these pickups are given in terms of multiples or percentages of trip-device rating or settings.

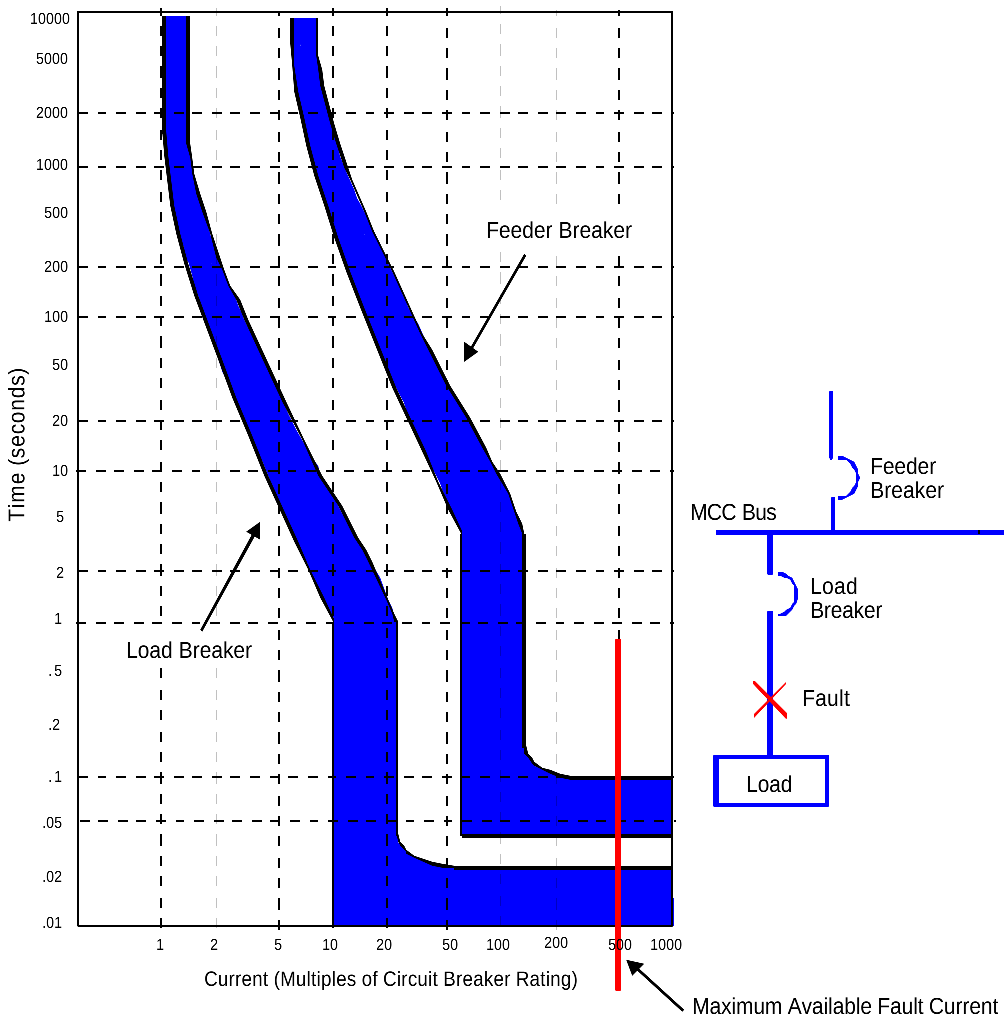
9-2.4.4 **MCCBs**. For MCCBs with thermal trip elements, tripping times, not pickups, are defined. The instantaneous magnetic setting could be called a pickup in the same way as that for low voltage power circuit breakers.

9-2.5 **Coordination Curves**.

9-2.5.1 Provide coordination curves as part of the facility design package. On a coordination curve, time 0 is considered as the time at which the fault occurs, and all times shown on the curve are the elapsed time from that point. A coordination curve is arranged so the region below and to the left of the curve represents an area of no operation. The curves represent a locus of a family of paired coordinates (current and time) that indicate the period of time required for device operation at a selected current value. Protective relay curves are usually represented by a single line only. Circuit breaker tripping curves, which include the circuit breaker operating time and the trip device time, are represented as bands. The bands represent the limits of maximum and minimum times at selected currents during which circuit interruption is expected. The region above and to the right of the curve or band represents an area of operation. Fuse characteristics are represented by a tolerance band bounded by minimum melting time and total fault current interrupting time curves. A specific current above the fuse current rating is expected to blow the fuse at some value between these times.

9-2.5.2 Figure 9-1 shows a time-current curve represented as a band. Reading current along the y-axis of the time-current curve, the time or range of times in which any device is expected to operate is shown on the x-axis. Notice that the x-axis is shown in terms of the multiples of circuit breaker rating; this scale applies specifically to the load breaker and its rating, and the feeder breaker current values have been converted to this scale to allow plotting both breakers on the same scale. It is often easier to plot in terms of amperes rather than multiples of circuit breaker rating.

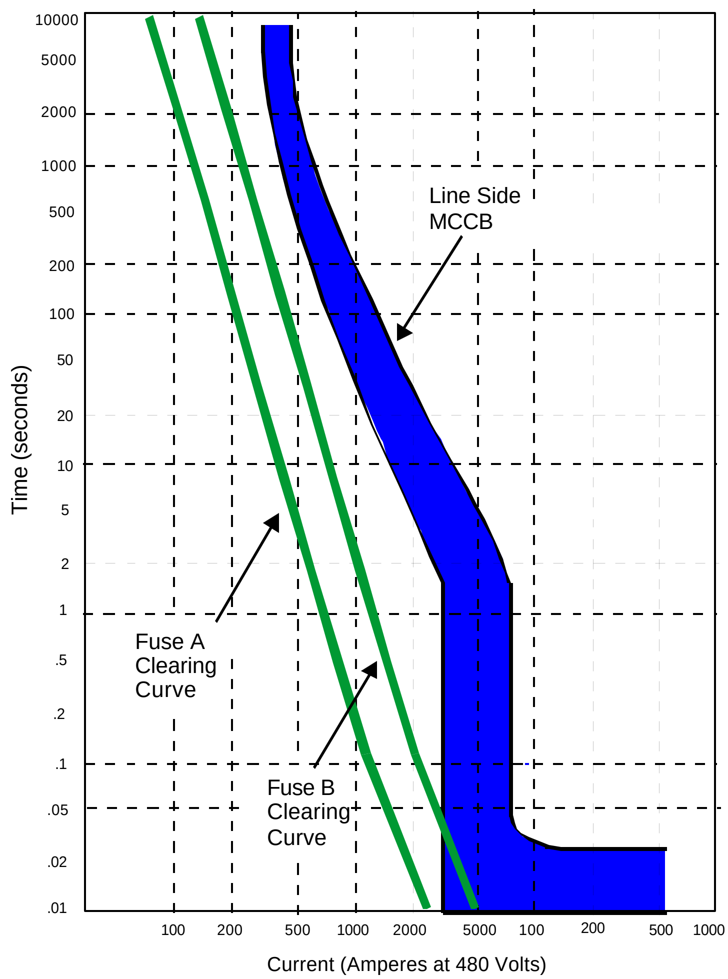
Figure 9-1. Selective Coordination Example



9-2.5.3 Circuit breaker curves usually begin at a point of low current close to the trip device rating or setting and an operating time of 1,000 seconds. Relay curves begin at a point close to 1.5 times pickup and the corresponding time for this point. Curves usually end at the maximum short-circuit current to which the device under consideration can be subjected. A single curve can be drawn for any device under any specified condition, although most devices (except relays) plot an envelope within which operation takes place. This envelope takes into consideration most of the variables that affect operation. Some of these variables are ambient temperature, manufacturing tolerances, and resettable time delay.

9-2.5.4 Figure 9-2 shows another example of selective coordination between an MCCB and two fuses. Referring to Figure 9-2, it appears that Fuse A does coordinate with the breaker while Fuse B does not coordinate above about 3,000 amperes. Confirm that Fuse A is operating within its current-limiting range before accepting the coordination. Fuses are commonly used with breakers if short circuit currents are very high to accomplish a current-limiting function so as to protect the breaker. At relatively low short circuit currents, fuse clearing characteristics might not prevent the instantaneous breaker trip. Coordination within the breaker's instantaneous trip region means that the fuse must exhibit current-limiting characteristics.

Figure 9-2. Selective Coordination Example with Fuses



9-2.5.5 Figures 9-1 and 9-2 only show a portion of the electrical system for the sake of clarity in the examples. For an actual coordination study, provide the coordination curves for all components in series, from the lowest evaluated voltage upstream to the next level beyond the service entrance, usually the feeder serving the building service transformer.

9-2.6 **Coordination Analysis**.

9-2.6.1 Protective device coordination requires a careful evaluation of the electrical system under various operating conditions. Perform the following steps to verify the protective coordination throughout the electrical system.

9-2.6.2 Obtain the following system information:

- System one-line diagram.

- Acceptable system lineups and operating configurations.
- Protective device locations.
- Protective device time-current characteristics.
- Load currents—normal and maximum.
- Motor full-load current, locked rotor current, starting time, and damage time.
- Fault currents at each protective device location.

9-2.6.3 Provide the following data on the one-line diagram and associated documentation:

- Apparent power and voltage ratings, as well as the impedance and connections of all transformers.
- Normal and emergency switching conditions.
- Nameplate ratings and subtransient reactance of all major motors and generators, as well as transient reactances of synchronous motors and generators, plus synchronous reactances of generators.
- Conductor sizes, types, and configurations, and type of insulating material.
- Current transformer ratios.
- Relay, direct-acting trip, and fuse ratings, characteristics, and ranges of adjustment.
- Cable lengths, particularly if an impedance diagram is not included.

9-2.6.4 Determine the minimum and maximum fault currents at each protective device location and at the end of all lines. The short-circuit current study should include maximum and minimum expected three-phase and ground fault duties, as well as available short-circuit current data from all sources.

9-2.6.5 Determine the settings for all protective devices. The settings have to be specified before time-current curves can be generated. Draw a composite set of time characteristic curves showing the coordination of all protective devices. A computer program designed specifically for plotting coordination curves is recommended. Although the coordination study plots can be prepared by hand, this manual method will usually cost more than a computer-generated study. Also, a computer-generated study is more easily maintained.

9-2.6.6 Evaluate the results to verify that the selected settings are acceptable. Review the GFP and its coordination with other devices. Refer to ANSI/IEEE 242 for a detailed discussion of GFP coordination.

9-2.7 **Coordination Study Report**.

9-2.7.1 The coordination study report demonstrates that the maximum possible degree of selectivity has been obtained between specified devices, consistent with protection of equipment and conductors from damage from overloads and fault conditions.

9-2.7.2 Include the following in the coordination study report:

- A narrative describing the analyses performed, the bases and methods used, and the desired method of coordinated protection of the power system.

- Descriptive and technical data for existing devices and new protective devices proposed. Include the manufacturers published data, nameplate data, and definition of the fixed or adjustable features of the existing or new protective devices.

- Documentation of the utility company data including system voltages, fault MVA, system X/R ratio, time-current characteristic curves, current transformer ratios, and relay device curves and protective device ratings and settings.

- Fully coordinated composite time-current characteristic curves for each bus in the system, as required to ensure coordinated power system protection between protective devices or equipment. Include recommended ratings and settings of all protective devices in tabulated form.

- The calculations performed for the analyses, including computer analysis programs utilized. Include the name of the software package, developer, and version number.

9-3 **PROTECTIVE RELAYS**.

9-3.1 Protective relays are designed to provide various types of electrical protection. Protective relays detect abnormal conditions and isolate these conditions from the rest of the electrical system by initiating circuit breaker operation. If used, protective relays will usually be located at the service entrance or at major load centers in applications 480 volts and above. Relays are often provided as part of standby power systems.

9-3.2 Protective relaying is an integral part of electrical power system design. The fundamental objective of system protection is to quickly isolate a problem so that the unaffected portions of the system can continue to function, but also should not interrupt power for acceptable operating conditions, including tolerable transients.

9-3.3 Ensure protective relays comply with ANSI/IEEE C37.90, *Relays and Relay Systems Associated with Electric Power Apparatus*.

9-3.4 The most common condition requiring protection is a short circuit or overload. Protective relays will be used to provide overcurrent protection for medium voltage applications and possibly for larger low voltage load centers. Lower voltages usually have overcurrent protection provided by direct-trip breakers or fuses. There are other abnormal conditions that also require protection, including undervoltage, overvoltage, open-phase, overcurrent, unbalanced phase currents, reverse power flow, underfrequency, overfrequency, and overtemperature. Larger power systems require even more types of protection. These types of protection require the use of protective relays. Refer to IEEE 242 for guidance regarding electrical protection of specific equipment types.

9-3.5 The functions performed by protective relays can be accomplished using electromechanical or electronic multifunction devices. Originally, all protective relays were electromechanical devices and it is not uncommon for a 50 year old electromechanical relay to still be in service. Solid-state designs have been available for many years and are preferentially used for new installations. Solid-state relays are also referred to as multi-function relays because a single relay can be configured to provide different types of protection simultaneously. This relay type is preferred because it minimizes the variability of relay types throughout the power system.

9-3.6 Select overcurrent relays to maximize the level of selective coordination with other devices. By selecting a relay with inverse, very inverse, or extremely inverse characteristics, coordination can be improved for a specific situation. Solid-state relays can be programmed for a specific overcurrent response. Refer to IEEE 242 for additional guidance.

9-3.7 Relays should be flush-mounted or semi-flush-mounted, back-connected, and dustproof for switchgear or a switchboard panel.

9-3.8 Connect to external circuits via permanent wiring to the relay case. Ensure the chassis is designed to slip in and out without disturbing the case or external connections, thus allowing easy removal for testing and maintenance.

9-3.9 Ensure necessary test devices are incorporated within each relay and provide a means for testing either from an external source of electric power or from associated instrument transformers.

9-3.10 Ensure each relay is provided with an operation indicator and reset device.

9-3.11 Design each relay for operation with the associated instrument transformer and connections provided.

9-3.12 In areas of limited panel mounting space, multifunction relays should be used because they offer the advantage of including several relay protective functions in a single enclosure. By this design, more protective functions can be implemented in a smaller space.

9-4 **INSTRUMENT TRANSFORMERS**.

9-4.1 **Background**.

9-4.1.1 Instrument transformer design and performance is an important part of relay design. Protective relays can be no more accurate than the instrument transformers that provide the input information. Instrument transformers operate on the same principles as ordinary transformers; however, they are specifically designed to duplicate the input waveform as closely and predictably as possible.

9-4.1.2 Ensure instrument transformers comply with IEEE C57.13, *Instrument Transformers*.

9-4.2 **Current Transformers (CT)**.

9-4.2.1 CTs should deliver a secondary current that is directly proportional to the primary current with as little distortion as possible. In most cases, the secondary output current is usually reduced to a level less than 5 amperes. Although CTs are available with 1 ampere or 10 ampere secondaries, the most common rating of 5 amperes should be used.

9-4.2.2 All CT circuits require a shorting terminal block. Confirm that CT shorting blocks have been installed.

9-4.2.3 Include an evaluation of CT saturation in the design and selection of CTs. Design for the highest CT ratio that provides acceptable performance. Multiratio CTs are acceptable for use.

9-4.2.4 Evaluate CT accuracy in accordance with IEEE 242.

9-4.3 **Potential Transformers (PT)**. For the typical primary voltages used in facilities, design the PT turns ratio to provide an output voltage of 120 volts.

9-5 **FUSES**.

9-5.1 Fuses can be current limiting or non-current limiting, and can be rated for low voltage or high voltage applications. Ensure that current-limiting fuses are designed to operate within their current-limiting range. Refer to IEEE 242 for a detailed discussion of fuse types and fuse applications.

9-5.2 The interrupting rating denotes the maximum symmetrical fault current permitted at the fuse location. Generally, both symmetrical and asymmetrical root-mean-square (RMS) ratings are given. Select an interrupting rating greater than the maximum expected short-circuit current at the installed location.

9-5.3 The voltage rating of a fuse is the nominal system voltage application. Associated with the voltage rating is the maximum design voltage, marked on the nameplate, which is the highest system voltage for which the fuse is designed to operate. Apply the fuse for the proper phase-to-phase circuit voltage.

9-5.4 Table 9-1 shows the various UL fuse classes. Each UL class defines certain required operating characteristics; however, a certain fuse classification does not mean that its operating characteristics are identical to those of the same class provided by other manufacturers. Class RK and Class L fuses are preferred over Class K and Class H because of their greater interrupting capacity. Ensure low voltage fuses comply with the appropriate UL standard.

Table 9-1. Low Voltage Fuse Classifications

UL Class	Rating		Interrupting Rating (Amperes)	Typical Application—Comments
	AC Volts	Amperes		
L	600	601–6,000	200,000	Transformers, mains
J	600	1 – 600	200,000	Motors, mains, load centers, panelboards—current limiting, high interrupting capacity
RK1	250, 600	0.1 – 600	200,000	Motors, mains, load centers, panelboards— current limiting
RK5	250, 600	0.1 – 600	200,000	Transformers, motors—current limiting
CC	600	0.1 – 30	200,000	Transformer control circuit—current limiting, high interrupting capacity
G	480	1 – 60	100,000	Current limiting, high interrupting capacity
T	300, 600	1 – 1,200	200,000	Current limiting, high interrupting capacity
K5	250, 600	1 – 600	50,000	Motor, branch circuit—non current limiting labeled although they might have current limiting features
H	250, 600	1 – 600	10,000	Residential use

9-6 OVERLOAD RELAYS.

9-6.1 Overload relays provide motor overload protection. If an overcurrent condition persists that can cause motor damage by overheating, the overload relay responds to clear the overcurrent. Thermal overload relays detect and respond to motor overcurrent by converting the line current to heat by a resistive element. Solid-state overload relays can also be used and have programmed response characteristics. Overload relays are designed to protect against an overload condition; other protective devices provide short circuit current protection.

9-6.2 Two types of thermal overload relays are available:

- Bimetallic thermal overload relays in which a bimetallic element bends as it heats, eventually causing a set of contacts to open. Bimetallic relays automatically reset as they cool; however, the design frequently includes a manual reset switch.

- Melting alloy overload relays in which the heat generated by the current melts a metallic alloy. These relays are usually reset after a few minutes when the alloy solidifies again. Melting alloy overload relays are not the preferred type for use.

9-6.3 Standard, slow, and fast response relays are available. Standard units should be used for motor starting times up to 7 seconds. Slow units should be used for motor starting times in the 8 to 12 second range. Fast units should be applied only to special purpose applications with very fast starting times.

9-6.4 Thermal overload relays are sensitive to ambient temperature; they trip sooner in a high temperature and longer at a low temperature. Use ambient temperature-compensated overload relays if the motor is located in a nearly constant ambient temperature environment and the thermal overload device is located in a varying environment.

9-6.5 Magnetic overload relays are solenoids that respond magnetically to an overcurrent. Magnetic overload relays are used only for unusual applications and should not normally be considered an alternative to solid-state or thermal overload relays.

9-6.6 Provide motor overload protection in accordance with NEC Article 430, Part III (2002 Edition). Apply overload protection to each motor 0.125 horsepower (93.25 watts) and larger. Provide three phase motors with overload protection in each ungrounded conductor. The following explains the principal NEC requirements:

9-6.6.1 NEC Article 430.32 (2002 Edition) requires continuous duty motors rated above one horsepower having a marked service factor of not less than 1.15 or a temperature rise not over 40 °C (104 °F) to have overload protection rated for no more than 125 percent of the motor nameplate full-load rating. All other continuous duty motors above one horsepower must have overload protection rated for no more than 115 percent of the motor nameplate full load rating.

9-6.6.2 Automatically started motors, permanently installed motors, or motors not in sight of the controller location that are rated one horsepower or less have essentially the same requirements as for motors above one horsepower. A non-automatically started motor rated at one horsepower or less is allowed to be protected by the branch circuit short-circuit and ground-fault protective device, provided that it is within sight of the controller and is not permanently installed.

9-6.7 Verify that an overload relay is properly sized for the associated motor and then check the overload relay tripping time for the motor's rated locked rotor current. The overload relay tripping time as a function of current should allow sufficient time for the motor to start, accelerate, and reach full speed. The selected overload relay should not actuate throughout the motor's operating current range, from starting current to long term operation at full load current. If the overload relay size is not adequate to start the motor or carry the load, the next higher size overload relay is permitted by the NEC, provided that it does not exceed the following percentages of motor full load rating:

- 140 percent for motors with a marked service factor of not less than 1.15.
- 140 percent for motors marked with a temperature rise not over 40 °C (104 °F).
- 130 percent for all other motors.

9-6.8 Overload protection can be provided as an integral part of the motor or controller. If necessary for the design, the overload protection can be installed in a separate enclosure, provided that the enclosure is accessible and is clearly marked regarding its purpose.

9-6.9 Verify overload relay coordination by the following process:

9-6.9.1 Determine motor full-load amperes.

9-6.9.2 Select overload relay ampere rating in accordance with NEC Article 430, Part III (2002 Edition).

9-6.9.3 Evaluate overload relay time-current characteristic curves.

9-6.9.4 Evaluate overload relay performance in relation to motor locked rotor amperes and starting time.

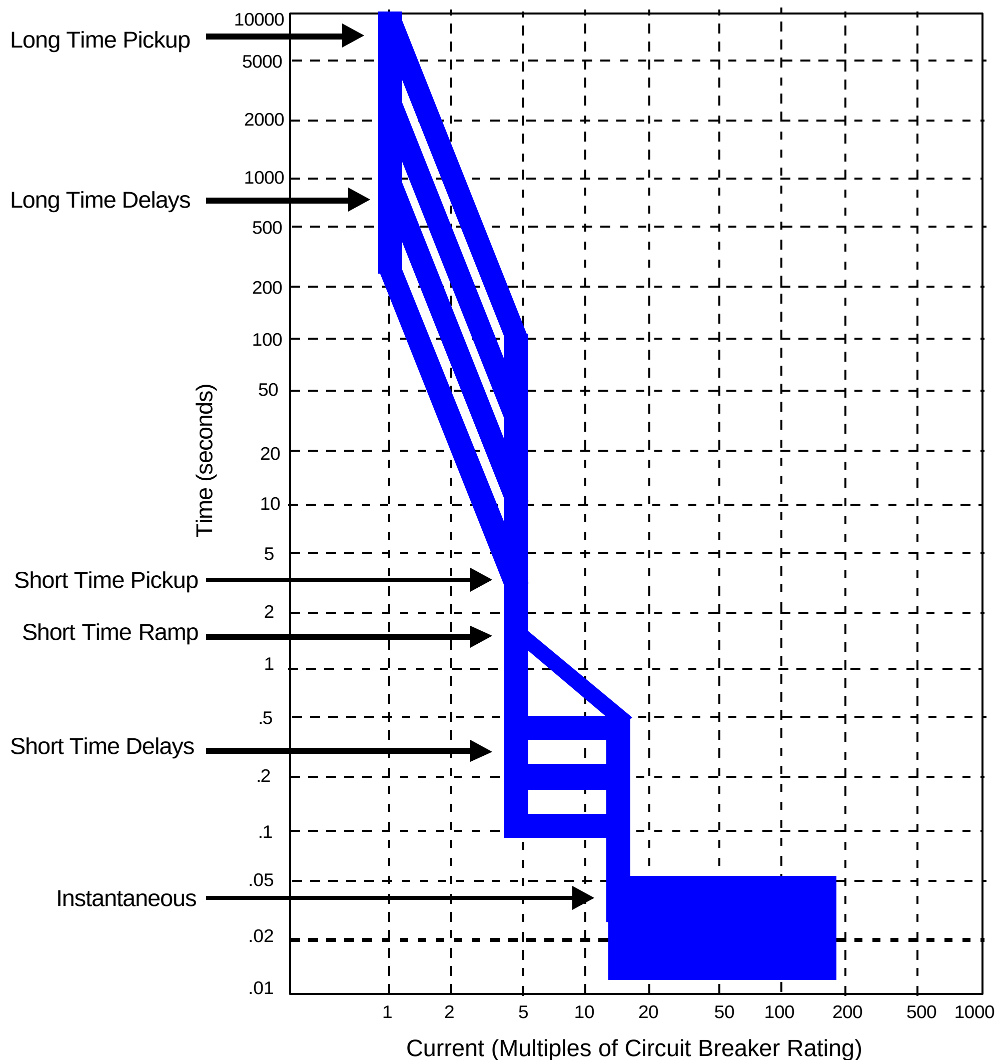
9-6.9.5 Evaluate overload relay performance in relation to motor locked rotor ampere damage time for medium voltage motors.

9-6.10 Ensure overload relays comply with NEMA ICS 2 and UL 508, *Industrial Control Equipment*.

9-7 **CIRCUIT BREAKERS**.

9-7.1 Paragraph 5-2 provides circuit breaker requirements, including requirements for protection and coordination. Low voltage power breakers, insulated case breakers, and MCCBs contain integral current sensing and trip units. Smaller breakers usually have electromechanical trip devices and larger breakers usually have solid-state trip units. Solid-state trip units offer greater flexibility in coordination and can be set more precisely to obtain the desired level of protection. Figure 9-3 shows the range of available time-current characteristics provided by a typical solid-state trip unit. Some or all of the possible solid-state trip unit settings should be used to establish the required level of coordination. Solid-state trip units are usually necessary to assure coordination in the instantaneous trip region.

Figure 9-3. Simplified Solid-State Trip Unit



9-8 PROTECTIVE DEVICE DESIGNATIONS.

9-8.1 Every protective device has an associated device function number. These numbers are designated by ANSI/IEEE C37.2, *IEEE Standard Electrical Power System Device Function Numbers*. The numbering scheme defined by this national standard is used in electrical schematics, engineering specifications, textbooks, and other documents referring to electrical devices. The designations most likely to be used in interior electrical facilities are provided in Table 9-2. Refer to ANSI/IEEE C37.2 for a complete list of protective device designations. Use these designations as applicable on all electrical drawings.

Table 9-2. Protective Device Designations

Device Function Number	Definition and Function
1	Master Element is the initiating device, such as a control switch, voltage relay, or float switch, which serves either directly, or through such permissive devices as protective and time-delay relays to place an equipment in or out of operation.
2	Time-Delay Starting, or Closing, Relay is a device that functions to give a desired amount of time delay before or after any point or operation in a switching sequence or protective relay system, except as specifically provided by device numbers 62 or 79 described later.
3	Checking or Interlocking Relay is a device that operates in response to the position of a number of other devices, or to a number of predetermined conditions in an equipment to allow an operating sequence to proceed, to stop, or to provide a check of the position of these devices or of these conditions for any purpose.
4	Master Contactor is a device, generally controlled by device number 1 or equivalent, and the necessary permissive and protective devices, which serves to make and break the necessary control circuits to place an equipment into operation under the desired conditions and to take it out of operation under other or abnormal conditions.
5	Stopping Device functions to place and hold an equipment out of operation.
6	Starting Circuit Breaker is a device whose principal function is to connect a machine to its source of starting voltage.
8	Control Power Disconnecting Device is a disconnecting device - such as a knife switch, circuit breaker, or pull-out fuse block - used for the purpose of connecting and disconnecting, respectively, the source of control power to and from the control bus or equipment. Control power is considered to include auxiliary power that supplies such apparatus as small motors and heaters.

Device Function Number	Definition and Function
23	Temperature Control Device functions to raise or to lower the temperature of a machine or other apparatus, or of any medium, when its temperature falls below, or rises above, a predetermined value.
27	Undervoltage Relay is a device that functions on a given value of undervoltage.
29	Isolating Contactor is used expressly for disconnecting one circuit from another for the purposes of emergency operation, maintenance, or test.
30	Annunciator Relay is a nonautomatically reset device that gives a number of separate visual indications upon the functioning of protective devices, and that may also be arranged to perform a lockout function.
32	Directional Power Relay is one that functions on a desired value of power flow in a given direction, or upon reverse power resulting from arc back in the anode or cathode circuits of a power rectifier.
33	Position Switch makes or breaks contact when the main device or piece of apparatus, which has no device function number, reaches a given position.
46	Reverse-Phase, or Phase-Balance, Current Relay is a device that functions when the polyphase currents are of reverse-phase sequence, or when the polyphase currents are unbalanced or contain negative phase-sequence components above a given amount.
47	Phase-Sequence Voltage Relay is a device that functions upon a predetermined value of polyphase voltage in the desired phase sequence.
48	Incomplete Sequence Relay is a device that returns the equipment to the normal, or off, position and locks it out if the normal starting, operating, or stopping sequence is not properly completed within a predetermined time.
49	Machine, or Transformer, Thermal Relay is a device that functions when the temperature of an ac machine armature, or of the armature or other load carrying winding or element of a dc machine, or converter or power rectifier or power transformer (including a power rectifier transformer) exceeds a predetermined value.
50	Instantaneous Overcurrent, or Rate-of-Rise Relay is a device that functions instantaneously on an excessive value of current, or on an excessive rate of current rise, thus indicating a fault in the apparatus or circuit being protected.
51	AC Time Overcurrent Relay is a device with either a definite or inverse time characteristic that functions when the current in an ac circuit exceeds a predetermined value.

Device Function Number	Definition and Function
52	AC Circuit Breaker is a device that is used to close and interrupt an ac power circuit under normal conditions or to interrupt this circuit under fault or emergency conditions.
53	Exciter or DC Generator Relay is a device that forces the dc machine field excitation to build up during starting or that functions when the machine voltage has built up to given value.
54	High-Speed DC Circuit Breaker is a circuit breaker that starts to reduce the current in the main circuit in 0.01 second or less, after the occurrence of the dc overcurrent or the excessive rate of current rise.
55	Power Factor Relay is a device that operates when the power factor in an ac circuit becomes above or below a predetermined value.
56	Field Application Relay is a device that automatically controls the application of the field excitation to an ac motor at some predetermined point in the slip cycle.
57	Short-Circuiting or Grounding Device is a power or stored energy operated device that functions to short-circuit or to ground a circuit in response to automatic or manual means.
59	Overvoltage Relay is a device that functions on a given value of overvoltage.
60	Voltage Balance Relay is a device that operates on a given difference in voltage between two circuits.
61	Current Balance Relay is a device that operates on a given difference in current input or output of two circuits.
62	Time-Delay Stopping, or Opening, Relay is a time-delay device that serves in conjunction with the device that initiates the shutdown, stopping, or opening operation in an automatic sequence.
64	Ground Protective Relay is a device that functions on failure of the insulation of a machine, transformer or of other apparatus to ground, or on flashover of a dc machine to ground. This function is assigned only to a relay that detects the flow of current from the frame of a machine or enclosing case or structure of a piece of apparatus to ground, or detects a ground on a normally ungrounded winding or circuit. It is not applied to a device connected in the secondary circuit or secondary neutral of a CT, or CTs, connected in the power circuit of a normally grounded system.
67	AC Directional Overcurrent Relay is a device that functions on a desired value of ac overcurrent flowing in a predetermined direction.

Device Function Number	Definition and Function
69	Permissive Control Device is generally a two-position manually operated switch that in one position permits the closing of a circuit breaker, or the placing of an equipment into operation, and in the other position prevents the circuit breaker or the equipment from being operated.
72	DC Circuit Breaker is used to close and interrupt a dc power circuit under normal conditions or to interrupt this circuit under fault or emergency conditions.
73	Load-Resistor Contactor is used to shunt or insert a step of load limiting, shifting, or indicating resistance in a power circuit, or to switch a space heater in circuit, or to switch a light, or regenerative, load resistor of a power rectifier or other machine in and out of circuit.
76	DC Overcurrent Relay is a device that functions when the current in a dc circuit exceeds a given value.
79	AC Reclosing Relay is a device that controls the automatic reclosing and locking out of an ac circuit interrupter.
86	Lockout Relay is a hand or electrically reset auxiliary relay that is operated upon the occurrence of abnormal conditions to maintain associated equipment or devices inoperative until it is reset.
87	Differential Protective Relay is a protective device that functions on a percentage or phase angle or other quantitative difference of two currents or of some other electrical quantities.
94	Tripping, or Trip-Free, Relay is a device that functions to trip a circuit breaker, contactor, or equipment, or to permit immediate tripping by other devices; or to prevent immediate reclosure of a circuit interrupter, in case it should open automatically even though its closing circuit is maintained closed.

9-8.2 A similar series of numbers, prefixed by the letters RE (for "remote") are normally used for interposing relays performing functions that are controlled directly from a supervisory system. For example, a remote stopping device controlled by the remote supervisory system would be designated RE5.

9-8.3 A device function number can include a letter suffix. A suffix provides additional information about auxiliary equipment associated with the device, distinguishing features or characteristics of the device, or conditions that describe the use of the device. Because a suffix letter can have more than one meaning, care should be used when interpreting device function numbers that contain a suffix. If ambiguity exists regarding the meaning of a suffix, refer to ANSI/IEEE C37.2 to help with an interpretation. Table 9-3 lists common suffixes used in conjunction with protective relay device function numbers.

Table 9-3. Protective Device Suffix Designations

Suffix Letter	Relay Application	Amplifying Information
A	Alarm only or automatic	
B	Bus protection	
G	Ground-fault or generator protection	System neutral type
GS	Ground-fault protection	Toroidal or ground sensor type
L	Line protection	
M	Motor protection	
N	Ground-fault protection	Relay coil connected in residual CT circuit
T	Transformer protection	
V	Voltage	
U	Unit protection	Generator and transformer

9-9 **INFORMATION SOURCES**. Refer to IEEE 141, IEEE 241, and IEEE 242 for additional guidance regarding electrical protection and coordination.

CHAPTER 10

GROUNDING, BONDING, AND LIGHTNING PROTECTION

10-1 **INTRODUCTION**.

10-1.1 The term *ground* refers to the earth, or a large body that serves in place of the earth. The term *grounded* refers to a system in which one of the elements is purposely connected to ground. The term *grounding* refers to the process of establishing a grounded system. Grounding is commonly performed incorrectly and poor grounding is the principal cause of power quality problems.

10-1.2 The electric interconnection of conductive parts to maintain a common electric potential is referred to as *bonding*.

10-1.3 In the context of this manual, lightning protection consists of the facility design features intended to withstand direct lightning strikes and then channel the lightning surge to ground.

10-1.4 The term *surge* refers to a voltage or current transient wave, typically lasting less than a few milliseconds. Protection against surges is referred to as *surge protection*. Chapter 11 provides surge protection design criteria.

10-2 **NEC GROUNDING AND BONDING REQUIREMENTS**.

10-2.1 Electrical systems and circuit conductors are grounded to limit voltages during lightning and to facilitate overcurrent device operation in case of a ground fault. NEC Article 250 (2002 Edition) allows the system neutral to be grounded and limits the location of this neutral to earth connection to the source side of the service entrance disconnect or at a separately derived system.

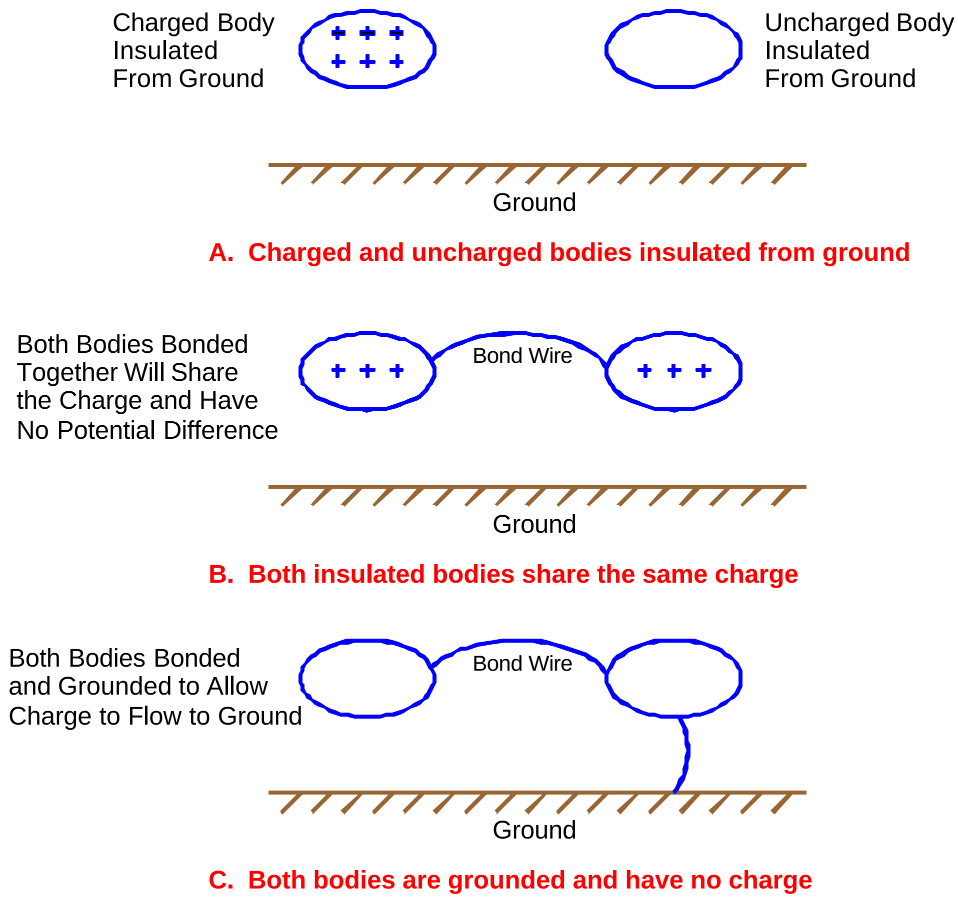
10-2.2 For the Army and Navy, refer to NEC criteria for grounding and bonding requirements.

10-2.3 For the Air Force, refer to Air Force Instruction (AFI) 32-1065, *Grounding Systems*, for grounding and bonding requirements.

10-3 **STATIC PROTECTION**.

10-3.1 A static ground is a connection between a piece of equipment and earth to drain off static electricity charges before they reach a sparking potential. Figure 10-1 shows an example of static protection. Typically, static grounding involves connecting large metal objects such as fuel tanks or an aircraft to earth through a ground rod. Static grounds are not part of an electrical power system, but if an equipment grounding conductor is adequate for power circuits, it is also adequate for static grounding.

Figure 10-1. Purpose of Static Grounding



10-3.2 For the Army and Navy, refer to NFPA 77, *Static Electricity*, criteria for static protection requirements.

10-3.3 For the Air Force, refer to AFI 32-1065 and NFPA 77 for static protection requirements.

10-4 COMMUNICATIONS SYSTEMS GROUNDING AND BONDING.

10-4.1 Introduction.

10-4.1.1 Most discussion of grounding relates to compliance with the NEC. The NEC's purpose is to establish safety requirements related to grounding. Communications systems grounding and bonding is an additional level of grounding and bonding specifically for communications systems to accomplish the following:

- Lower the system ground reference potentials.
- Augment electrical bonding.
- Minimize electrical surge effects and hazards.

10-4.1.2 Electrical system grounding is not replaced by communications system grounding. Instead, communications systems grounding supplements the existing grounding system with additional bonding between communications cable pathways between telecommunications entrance facilities, equipment rooms, and telecommunications closets. Significant differences in ground potentials can exist even in a well-designed building during electrical transients. By bonding additional conductors throughout the communications systems to the facility grounding system, the overall system can be made more resistant to these transients. Note that these additional conductors primarily serve to reduce or eliminate ground potential differences in the communications system while still satisfying NEC grounding criteria.

10-4.1.3 Communications system grounding and bonding is intended to accomplish its purpose by the following methods:

10-4.1.3.1 **Equalization**. The potential between different ground points depends on the impedance between the two points. Additional conductor bonding for communications systems reduces the impedance to ground throughout the facility, thereby improving the ground equalization.

10-4.1.3.2 **Diversion**. By installing additional ground connections throughout the communications systems, electrical transients are more likely to be diverted to ground, thereby minimizing the effect on the communications systems.

10-4.1.3.3 **Coupling**. By having bonding conductors close to communications cables, mutual coupling between the two is improved. During electrical transients, this coupling can partially cancel the transient's effects. Note this is independent of any shielding that might also be provided for the conductors.

10-4.2 **Connection to the Grounding Electrode**.

10-4.2.1 A suitable connection to ground has to be established for the communications systems. The preferred grounding method is to connect to the facility's electrical service grounding electrode system. The communications systems are powered from the electrical system and all cabling, power and communications, need to be effectively at equal potential with respect to ground. NEC Article 800.40 (2002 Edition) establishes the grounding requirements.

10-4.2.2 Separate grounding electrodes are not normally necessary for the communications systems. NEC Article 800.40 (2002 Edition) allows the use of separate grounding electrodes if there is no electrical service ground or if additional grounding is needed to improve the overall impedance to ground. Whenever a separate grounding electrode is used, it must be bonded to the existing grounding electrode system as required by the NEC.

10-4.3 **Commercial Building Grounding and Bonding Requirements for Telecommunications**.

10-4.3.1 ANSI/TIA (Telecommunications Industry Association)/EIA (Electronics Industries Association)-607, *Commercial Building Grounding and Bonding Requirements for Telecommunications*, provides the pertinent criteria for communications systems grounding and bonding. The grounding and bonding approach recommended in this standard is intended to coordinate with the cabling topology specified in TIA/EIA-568B and installed in accordance with TIA/EIA-569A. The purpose of this standard is to enable the planning, design, and installation of telecommunications grounding systems within a building with or without prior knowledge of the telecommunications systems that will subsequently be installed.

10-4.3.2 Apply ANSI/TIA/EIA-607 to all new facilities with many telecommunications connections, extensive equipment rooms and telecommunications closets, or separate entrance facilities. In this context, an entrance facility is an entrance to a facility for both public and private network cables, including antenna.

10-4.3.3 Consider ANSI/TIA/EIA-607 as part of the maintenance, renovation, or retrofit of telecommunications grounding systems in existing buildings. The wiring systems in older buildings might not readily accept application of ANSI/TIA/EIA-607. In these cases, perform an analysis to determine the cost of the application of ANSI/TIA/EIA-607. Upgrades are permitted where the cost-benefit is considered acceptable.

10-4.3.4 The following summarizes the principal ANSI/TIA/EIA-607 design criteria:

10-4.3.4.1 Install a permanent telecommunications grounding and bonding system independent of the telecommunications cabling. Use approved components and install bonding connections in accessible locations.

10-4.3.4.2 Install a telecommunications bonding backbone (TBB) through every major telecommunications pathway and directly bonded to a telecommunications grounding busbar (TGB). A TBB provides direct bonding between different locations in a facility, usually between equipment rooms and telecommunications closets. A TBB is usually considered part of a grounding and bonding system, but is independent of other equipment or cable. The TBB is intended to minimize ground potential variations throughout the communications system. As a minimum, the TBB must consist of #6 AWG insulated copper bonding conductors and should be as large as #3/0 AWG insulated copper bonding conductors for sensitive or very large systems. Each TBB that reaches a location with a TGB must be bonded to the TGB. Visibly label each TBB and TGB.

10-4.3.4.3 Bond each telecommunications main grounding busbar (TMGB) to the electrical service ground. All TBBs terminate at this busbar. Generally, each TBB should be a continuous conductor from the TMGB to the farthest TGB. Splice intermediate TGBs to the TBB with a short bonding conductor.

10-4.3.4.4 Bond each TGB to building structural steel or other permanent metallic systems, if close and accessible.

10-4.3.4.5 Install a communications surge protector near the TMGB. Typically, the TMGB is installed adjacent to the surge protector and serves as the path to ground for surges diverted by the protector.

10-4.3.5 Refer to the Building Industry Consulting Service International (BICSI) *Telecommunications Distribution Methods Manual*, Chapter 20, *Grounding, Bonding, and Electrical Protection*, for background information on the subject of communications bonding and grounding.

10-5 **LIGHTNING PROTECTION**.

10-5.1 In the context of this manual, lightning protection consists of the facility design features intended to withstand direct lightning strikes and then channel the lightning surge to ground.

10-5.2 For the Army and Navy, refer to NFPA 780, *Standard for the Installation of Lightning Protection Systems*, criteria for lightning protection systems.

10-5.3 For the Air Force, refer to AFI32-1065 and NFPA 780 for lightning protection systems.

10-5.2 Surge protection is intended to protect facility electrical equipment from lightning-induced or other surges once they enter the facility through the power system or other electrical connection. Refer to Chapter 11 for surge protection guidance.

10-6 **INFORMATION SOURCES**. The following references provide additional information on the subject of grounding.

10-6.1 AFI 32-1065—establishes Air Force requirements for grounding systems, lightning protection systems, static protection, and bonding. AFI 32-1065 also relies on other industry documents as well as MIL-HDBK-419A, *Grounding, Bonding, and Shielding for Electronic Equipment and Facilities*.

10-6.2 NFPA 70, *NEC*—provides the minimum safety requirements related to grounding systems. Article 250 provides the requirements related to electrical power circuits and low voltage control and signaling circuits. Article 800 provides additional guidance related to communications systems.

10-6.3 NFPA 77—provides NFPA requirements related to static grounding and bonding requirements.

10-6.4 NFPA 780—provides NFPA requirements for lightning protection systems. This is the industry standard for lightning protection.

10-6.5 IEEE 142, *IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems* (IEEE Green Book)—provides the bases for grounding practices. The theory of grounding is described.

10-6.6 IEEE 1100, *IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment* (IEEE Emerald Book)—provides specific guidance related to sensitive electronic equipment to ensure acceptable power quality.

10-6.7 ANSI/TIA/EIA-607—describes grounding and bonding requirements for telecommunications applications within commercial buildings. ANSI/TIA/EIA-607 is not intended to replace NEC requirements; it provides additional guidance related to grounding and bonding.

10-6.8 Federal Information Processing Standards Publication (FIPS PUB) 94, *Guideline on Electrical Power for ADP Installations*—provides information relating to the purposes and techniques of grounding, as well as the control of static electricity. This document is listed here as a useful background document, but it was officially withdrawn in July 1997.

10-6.9 BICSI *Telecommunications Distribution Methods Manual*—explains in detail the ANSI/TIA/EIA-607 grounding requirements.

CHAPTER 11

SURGE PROTECTION

11-1 INTRODUCTION.

11-1.1 Consider surge protection as part of the facility design criteria. The extent to which surge protection will be required depends on the facility's mission and the facility occupant's reliability target. Surge protection should be applied to the following types of facilities:

- Medical treatment facilities.
- Air navigation aids and facilities.
- Petroleum, oil, and lubricant (POL) storage and dispensing facilities.
- Critical utility plants and systems.
- Communication facilities and telephone exchanges.
- Fire stations, including fire alarm, fire control, and radio equipment.
- Critical computer automatic data processing facilities.
- Air traffic control towers.
- Base weather stations.
- Surveillance and warning facilities.
- Command and control facilities.
- Weapon systems.
- Security lighting systems.
- Mission, property, and life support facilities at remote and not readily accessible sites, such as split-site aircraft warning and surveillance installations.

11-1.2 Consider surge protection for all types of facilities located in the following areas:

- In regions with a high lightning strike probability (refer to IEEE C62.41, *IEEE Recommended Practice on Surge Voltages in Low Voltage AC Power Circuits*).

- Near commercial utility systems with routine substation capacitor switching.

11-1.3 The design criteria in this chapter apply to permanently installed, hard-wired surge protectors and should not be applied to smaller plug-in type surge protectors, although the principles of surge protection are similar, regardless of the size and location of the surge protector. Specific end-use equipment might still warrant a small plug-in type surge protector even if the facility is protected in accordance with the criteria of this chapter.

11-1.4 Point-of-use only surge protection (smaller plug-in types) can be applied by the facility occupant for those facilities with little or no critical equipment. Examples of these types of facilities include residential housing, barracks, warehouses, and other facilities in which equipment damage by surge transients will not interfere with the facility's mission.

11-1.5 This section does not apply to electromagnetic interference (EMI) filters installed on, or connected to, 600 V or lower potential circuits and listed in accordance with UL 1283, *Electromagnetic Interference Filters*.

11-1.6 Appendix D provides recommended performance evaluation criteria for surge protectors. The recommended performance evaluation criteria are based on NEMA LS 1, *Low Voltage Surge Protective Devices*, and UL 1449, *Transient Voltage Surge Suppressors*.

11-2 **SURGE PROTECTION DESIGN**.

11-2.1 **Parallel Versus Series Protection**.

11-2.1.1 Surge protectors within the scope of this manual should normally be of the parallel type rather than the series type.

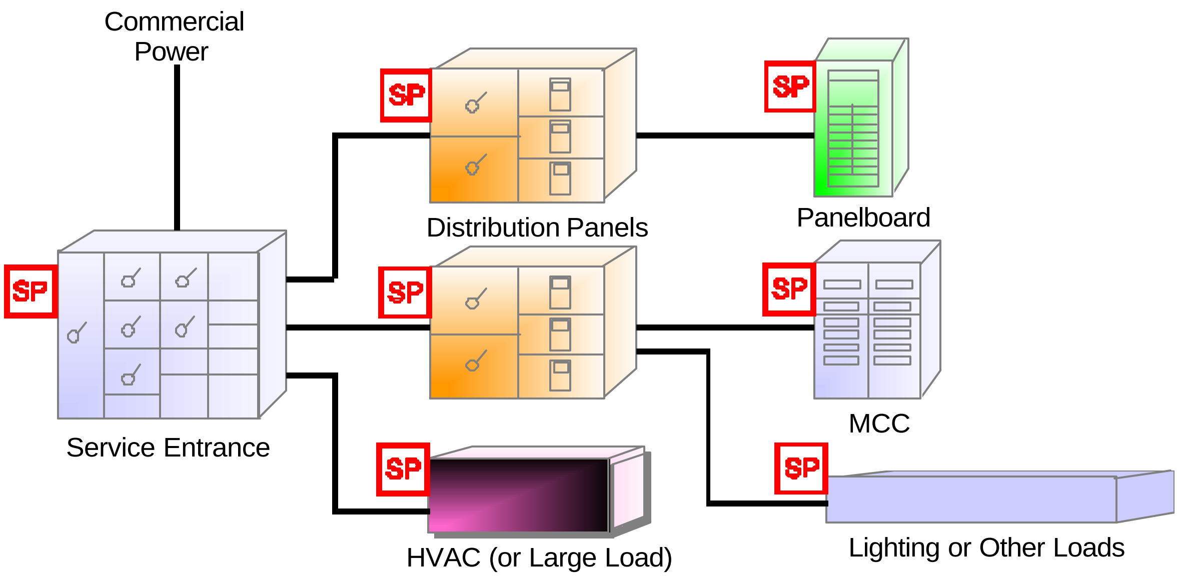
11-2.1.2 Parallel surge protectors are connected in parallel with the circuit and operate when a transient voltage exceeds a preset limit. Parallel surge protectors have little interaction with the circuit under normal conditions.

11-2.1.3 Series surge protectors are connected in series with the circuit and must be capable of carrying the circuit's full load current. Also, loss of the series surge protector will mean loss of power to all downstream equipment. For this reason, series surge protectors are usually used only to protect individual loads and usually include some level of filtering also.

11-2.2 **Multiple Layer Protection Design**.

11-2.2.1 Apply surge protection in a multiple layer approach. Figure 11-1 shows the preferred design approach with surge protection installed at the service entrance, and additional layers of surge protection provided at load centers, panelboards, and MCCs. Referring to Figure 11-1, a protector installed at the service entrance provides some protection against externally-induced transient surges; however, there will always be some amount of surge let-through at the service entrance. For this reason, install surge protectors on downstream distribution panels to provide additional protection against surges. The locations marked with the symbol  are typical surge protector locations. The surge protectors downstream of the service entrance also limit internally-induced surges as well as any let-through from the service entrance.

Figure 11-1. Simplified Facility Layout



11-2.2.2 Critical loads downstream of the distribution panels should have an additional level of surge protection as shown above. Switching loads such as MCCs should have surge protection to limit the transmission of switching transients to the rest of the facility. It is not necessary to install a surge protector on every panelboard in the facility; the selection of which panelboards should have surge protection depends on the importance of the loads served by each panelboard. HVAC equipment usually contain electronic controls that are sensitive to surges. Lighting electronic ballasts often are equipped with internal surge protection; however, once installed, there is often no easy method of confirming that the internal protection is either present or functional.

11-2.2.3 The surge protector at the service entrance must have a minimum surge current rating of 80,000 amperes per phase or per protection mode. Downstream surge protectors must have a minimum surge current rating of 40,000 amperes per phase or per protection mode. Refer to Appendix D for additional equipment ratings.

11-2.2.4 By the arrangement shown in Figure 11-1, protection is provided within the facility for both internally and externally induced transient surges. Proper operation of this cascaded design requires that the installation criteria specified in paragraph 11-3 are met. For example, excessive lead length on a surge protector could mean that it would never respond to a surge event; the other surge protectors would respond first.

11-2.2.5 Point-of-use (plug-in type) surge protectors should be used to protect specific critical equipment that plugs into wall receptacles.

11-3 **INSTALLATION CRITERIA**.

11-3.1 **Minimizing Lead Length for Parallel Surge Protectors**.

11-3.1.1 Lead length refers to the length of conductor between the circuit connection and the surge protector, and is the critical installation attribute for parallel-type surge protectors. For typical installations, the lead conductor has negligible resistance, but a significant inductance when subjected to a high frequency surge transient. This inductance can develop a substantial voltage drop under surge conditions, thereby proportionately increasing the let-through voltage. Refer to Appendix B for an example calculation of the lead length effect.

11-3.1.2 Some lead length is unavoidable in an installation; however, make every effort to minimize the lead length and associated inductance. Figures 11-2 and 11-3 show examples of optimal installations in which the lead conductors are less than 1 foot in length. Notice that the leads have been connected to the circuit breaker panel without making any high-inductance coils or sharp bends in the conductors.

Figure 11-2. Optimal Installation of Surge Protector Leads – First Example

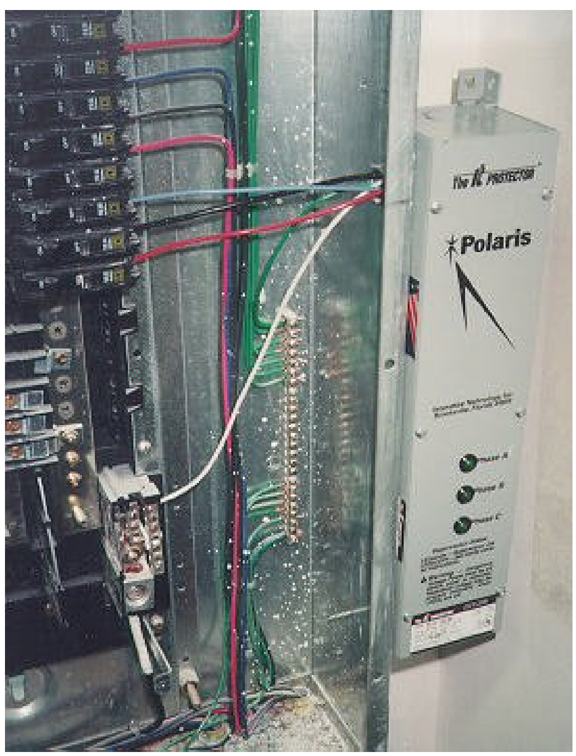
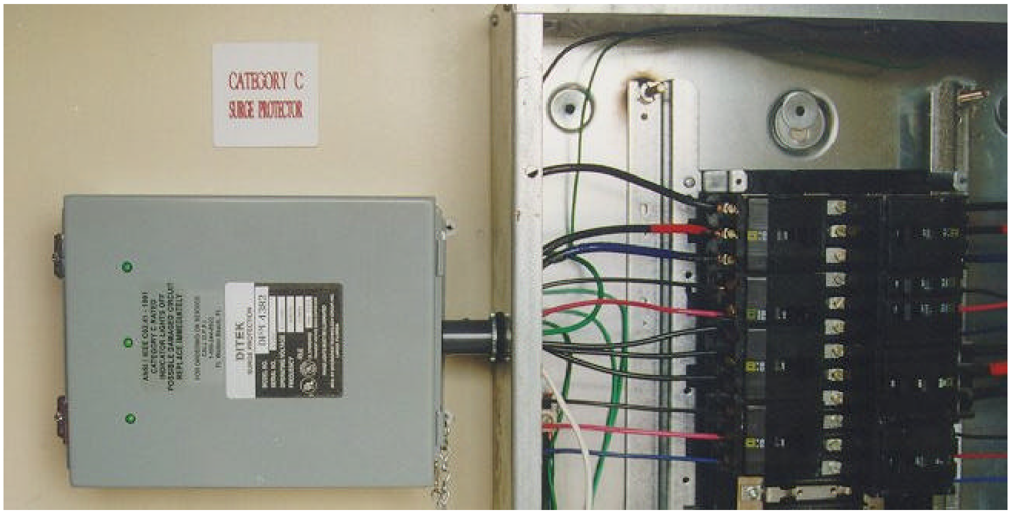


Figure 11-3. Optimal Installation of Surge Protector Leads – Second Example



11-3.1.4 The installation instructions provided by some manufacturers specify that the surge protector should be installed within 3 meters (10 feet) of the circuit connection point. This long of a lead length is unacceptable because the allowed let-through voltage would be too large to protect the downstream equipment. This effect applies to all parallel surge protectors, regardless of rating and quality. Figure 11-4 shows an example of a surge protector that is located on the other side of a room from the load center; in this case, the surge protector provides no meaningful protection against surges. Figure 11-5 shows another poor installation in which a safety switch is installed between the surge protector and the breaker panel. Although the safety switch application is well-intended, its use adds several feet of cable between the surge protector and the breaker panel. In summary, the best surge protector will be rendered useless by installing long leads between it and the circuit connection point.

Figure 11-4. Unacceptable Installation with Long Surge Protector Leads

Figure 11-5. Less-Than-Optimal Installation by Including Safety Switch

11-3.2 **Breaker Connection**.

11-3.2.1 Whenever possible, connect parallel-type surge protectors to a spare breaker in the associated breaker panel. In addition to providing a close electrical connection that minimizes lead length, the breaker provides traditional overcurrent protection for faults between the breaker and the surge protector. Also, the breaker provides a convenient means of deenergizing the circuit to work on or replace a surge protector.

11-3.2.2 Verify with the manufacturer the minimum required breaker size to ensure proper surge protector performance. This is important because breaker instantaneous trip units also respond to surge currents. Testing by one manufacturer determined that a 60 ampere breaker can usually withstand a 65,000 ampere 8/20 surge. A 30-ampere rated breaker tended to trip above a 25,000 ampere surge. Based on the above results, lower-rated breakers can be expected to trip at lower current levels. For sub-panels, a 30-ampere minimum breaker should be used to minimize the likelihood of breaker tripping during a surge event. This is important because breaker tripping removes the surge protector from the circuit, thereby disabling surge protection for subsequent surges.

11-3.2.3 Some surge protectors have been listed based on the connection to an upstream breaker. Review the manufacturer's installation instructions to determine if special electrical connection requirements apply.

11-3.2.4 If a spare breaker is not available, it is acceptable to connect to the load side of an existing used breaker. Parallel surge protectors are passive devices that draw a negligible current during operation.

11-3.3 **Grounding**. Verify that the surge protector is properly grounded. Without a low impedance ground, the surge protector cannot effectively shunt the surge to ground. Also, surge protection will be less effective if the entire facility does not have a low impedance grounding system.

11-3.4 **Acceptance Tests**. Perform the following checks:

11-3.4.1 Inspect for physical damage and compare nameplate data with drawings and specifications.

11-3.4.2 Verify that the surge protector rating is appropriate for the voltage (this is a common error).

11-3.4.3 Inspect for proper mounting and adequate clearances.

11-3.4.4 Verify that the installation achieves the minimum possible lead lengths. Inspect the wiring for loops or sharp bends that add to the overall inductance.

11-3.4.5 Check tightness of connections by using a calibrated torque wrench. Refer to the manufacturer's instructions or Table 10-1 of International Electrical Testing Association (NETA) ATS, *Acceptance Testing Specifications for Electrical Power Distribution Equipment and Systems*, for the recommended torque.

11-3.4.6 Check the ground lead on each device for individual attachment to the ground bus or ground electrode.

11-3.4.7 Perform insulation resistance tests in accordance with the manufacturer's instructions.

11-3.4.8 For surge protectors with visual indications of proper operation (indicating lights), verify that the surge protector displays normal operating characteristics.

11-3.4.9 Record the date of installation.

11-3.5 **Periodic Maintenance**. Ensure periodic maintenance is assigned to perform checks of installed surge protectors in accordance with Section 7.19 of NETA MTS, *Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems*.

11-4 SURGE PROTECTION FOR COMMUNICATIONS AND RELATED SYSTEMS.

11-4.1 The following systems, including related systems, should have surge protection:

- Fire alarm systems.
- Telephone systems.
- Computer data circuits.
- Security systems.
- Television systems.
- Coaxial cable systems.
- Intercom systems.
- Electronic equipment data lines.

11-4.2 Electrical power to the above equipment should be protected against surge transients in accordance with the criteria provided in the previous sections.

11-4.3 Ensure surge protection equipment used for communications and related systems is listed with UL 497A, *Standard for Secondary Protectors for Communication Circuits*, or UL 497B, *Standard for Protectors for Data Communication and Fire Alarm Circuits*, as applicable.

11-4.4 Ensure telephone communication interface circuit protection is listed to UL 497A and it should provide a minimum surge current rating of 9,000 amperes. Ensure central office telephone line protection is listed to UL 497A and it should have multi-stage protection with a minimum surge current rating of 4,000 amperes.

11-4.5 Ensure intercom circuit protection is listed to UL 497A and it should provide a minimum surge current rating of 9,000 amperes. Protection should be provided on points of entry and exit from separate buildings.

11-4.6 Fire alarm and security alarm system loops and addressable circuits that enter or leave separate buildings should have a minimum of 9,000 amperes surge current rating. Ensure the protection is listed to UL 497A for data communications and UL 497B for annunciation.

11-4.7 Coaxial lines should be protected at points of entry and exit from separate buildings. Single stage gas discharge protectors can be used for less critical circuits. Multistage protectors utilizing a gas discharge protector with solid-state secondary stages should be used to obtain lower let-through voltages for more critical equipment.

CHAPTER 12

POWER SYSTEM QUALITY

12-1 INTRODUCTION.

12-1.1 This chapter provides a technical basis for power system quality as a design consideration and explains different methods of solving power quality problems. Unlike other electrical design requirements, power quality design solutions are very dependent on the types of transients and disturbances that can and will occur in power systems. Also, power quality solutions often involve a certain level of compromise between the electrical system design and the design of the end-use equipment. In many cases, it will be easier to provide protection and power quality design features to specific equipment rather than generically throughout the facility. Nonetheless, power quality is an issue that should be addressed at the facility level in order to be certain that the electrical distribution system is designed properly for the anticipated disturbances and the effects of harmonic distortion.

12-1.2 Voltage and current surge transients caused by lightning or switching operations are discussed in Chapter 11. Surge protection is not considered a power quality issue, but instead is considered a part of electrical system protection. Power quality design considerations focus on 1) longer-term degradation of the ideal sinusoidal voltage and current caused by harmonic distortion or unbalanced system operation and 2) power system disturbances.

12-2 UNBALANCED VOLTAGES.

12-2.1 The principal source of a steady-state voltage unbalance is unbalanced single-phase loads on a three-phase system. Voltage unbalance is particularly important for three-phase motor loads. ANSI C84.1 specifies a no-load service entrance voltage unbalance of less than 3 percent to avoid motor overheating or failure. High efficiency motors are particularly susceptible to unbalanced voltages; these motors have a lower negative sequence reactance which causes higher negative sequence currents during unbalanced voltage conditions. Unbalanced voltages can also be caused by blown fuses on one phase of a circuit or single phasing conditions.

12-2.2 At the design stage, evaluate the loading on each phase and balance the loads as well as possible. As part of acceptance testing, monitor the degree of unbalance and make corrections if necessary.

12-2.3 The degree to which a system is unbalanced can be evaluated by symmetrical components. The ratio of the negative or zero sequence component to the positive sequence component is used as an indicator of the percent unbalance:

$$Percent\ Unbalance = \frac{V_2 - V_1}{V_1} \times 100\%$$

12-2.4 A more commonly used method of evaluating voltage unbalance that does not require knowledge of symmetrical components is as follows:

$$\textit{Percent Unbalance} = \frac{\textit{Maximum Phase Deviation from Average Voltage}}{\textit{Average Voltage}} \times 100\%$$

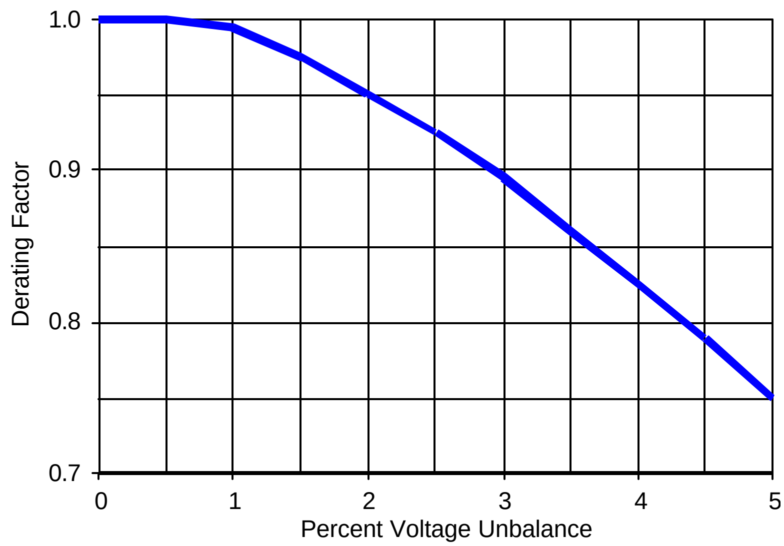
EXAMPLE: Assume that phase voltages are 460, 464, and 450. The average phase voltage is 458. The maximum deviation from the average voltage is 8 volts and the percent unbalance is given by:

$$\textit{Percent Unbalance} = \frac{8}{458} \times 100\% = 1.75\%$$

12-2.5 Either of the above methods are acceptable for evaluating voltage unbalance. If the percent unbalance exceeds 3 percent, evaluate the electrical system in more detail to determine if corrective action is necessary.

12-2.6 The rated load capability of three-phase equipment is normally reduced by voltage unbalance. For example, Figure 12-1 shows a typical derating factor for three-phase induction motors as a function of voltage unbalance.

Figure 12-1. Typical Derating Factor for Three-Phase Induction Motors



12-3 **HARMONIC DISTORTION EVALUATION**.

12-3.1 If a significant number of nonlinear loads are installed in the facility, perform a harmonic distortion evaluation during the facility design phase. If the effect of nonlinear loads is expected to be minor, a detailed harmonic distortion evaluation is not required. Monitoring of the electrical system power quality is recommended to ensure that harmonic distortion limits are not exceeded.

12-3.2 IEEE 519, *IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*, provides the industry-accepted method of evaluating harmonic voltages and currents. IEEE 519 provides *system level* guidance, not equipment specific guidance. What this means is that harmonic distortion limits are established for the facility and the installation of any equipment should not degrade the system to beyond acceptable levels. Meeting IEEE 519 limits can be easy for a facility with primarily linear loads and it can be more difficult for a facility with predominantly nonlinear loads. As an example, some facilities have installed many ASDs for HVAC system motors in an attempt to reduce energy usage. Unfortunately, each ASD can generate a large current harmonic distortion and nuisance tripping of other equipment has occurred at some facilities as a consequence.

12-3.3 IEEE 519 provides the distortion limits for a low voltage system; Table 12-1 summarizes the various limits. Treat IEEE 519 distortion limits as design limits for interior applications. Hospitals and airports are classified as special applications and have the most stringent criteria. The criterion of most interest in this table is the voltage total harmonic distortion (THD) limit of 3 percent for special applications or 5 percent for general applications. Treat all critical systems as special applications.

Table 12-1. Low Voltage System Classification and Distortion Limits

	Special Applications	General System	Dedicated System
Notch Depth	10%	20%	50%
THD (Voltage)	3%	5%	10%
Notch Area (A_N – volt microseconds)	16,400	22,800	36,500

12-4 **HARMONIC CURRENT EFFECTS ON TRANSFORMERS**.

12-4.1 Excessive harmonic distortion causes higher eddy current losses inside a transformer, resulting in overheating. ANSI C57.110, *IEEE Recommended Practice for Establishing Transformer Capability When Supplying Nonsinusoidal Load Currents*, states that a transformer should be capable of carrying its rated current provided that the total harmonic distortion is less than 5 percent. Beyond this amount, derating of the transformer might be necessary. Newer transformers are often, but not always, already designed for a higher harmonic distortion environment. Older transformers likely were not designed for harmonic distortion. Evaluate the effects of harmonic currents on transformers in accordance with the following subsections.

12-4.2 Whenever significant nonlinear loads are expected in a facility, evaluate the system to determine if transformer derating will be required. Transformer derating is not the same as calculating the transformer k-factor. The k-factor is used to match a harmonic current condition with a k-factor rating. For transformers without a k-factor rating, derating must be used to determine the maximum fundamental load current that the transformer can maintain with the additional harmonic currents

Note: Derating applies to the full-load capability of the transformer when applied in an environment containing significant harmonic distortion. If the transformer is not fully loaded, the derating process might have little or no practical significance unless it is expected that the transformer will eventually be fully loaded. Nationwide surveys indicate average loading levels for dry-type transformers of between 35 percent for commercial facilities and 50 percent for industrial facilities.

12-4.3 Refer to ANSI/IEEE C57.110 for additional information regarding the evaluation and derating process.

12-4.4 If it is determined that a transformer will require derating because of harmonic distortion, perform the following additional reviews:

12-4.4.1 Determine if the harmonic distortion environment can be improved by design changes for the most offending loads.

12-4.4.2 If the transformer requires more than 10 percent derating, evaluate the feasibility of installing a new transformer designed for a harmonic distortion environment (often referred to as a k-factor transformer). Include delivery and replacement time scheduling as well as cost in the evaluation.

12-4.4.3 If transformer derating is the selected option, annotate the percent derating on the applicable design drawings and install a label near the transformer nameplate indicating that the transformer has been derated. The purpose of these actions is to prevent inadvertent overloading of the transformer in the future.

12-4.5 If it is determined that an installed transformer requires derating, perform a transformer inspection to confirm whether the transformer has been operating in an overloaded condition. Because of the method by which flux is produced in a transformer, current heating paths can develop along any magnetic material. Signs of overheating include the following:

- General excessive heating of the enclosure.
- Bubbled, peeling, discolored, or burnt paint on the enclosure.
- Evidence of overheating at the ends of internal components.
- Premature gasket failure.
- Methane gas generation.
- Heat-damaged bayonet fuse holders.

12-5 POWER QUALITY DESIGN.

12-5.1 A facility should be designed to withstand the most likely power quality problems, commensurate with the importance of the facility's mission. For critical equipment, include power quality features at the design stage to ensure that system reliability goals are maintained. Acceptable power quality is not achieved by a single system design feature. Evaluate the following elements as part of the facility design:

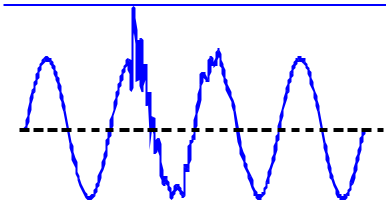
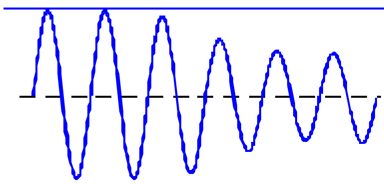
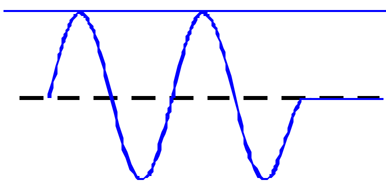
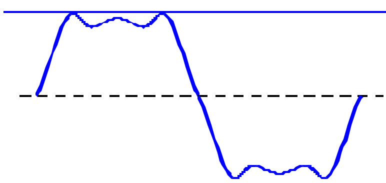
- Appropriate grounding, including considerations of unbalanced and nonlinear loads.
- Voltage sag and power interruption impacts.
- Effect of switching transients, particularly if the local utility operates capacitors electrically near the facility.
- Harmonic distortion limits.
- Power factor correction requirements.
- Voltage variations associated with motor starting and other transients.
- Degree of unbalanced voltage for three phase systems supplying single phase loads.

12-5.2 Consider the requirement for continued reliable facility operation, the impact of electrical system-related power disruptions, the types of power disturbances that can occur, and the various cost-effective methods of ensuring power quality.

12-5.3 The addition of power quality design equipment often has an iterative effect on the electrical system design. For example, the addition of power conditioners affects the system voltage drop to downstream devices. Not all power quality issues can be addressed during the system design. Monitor power system quality at the service entrance to determine if additional design measures will be needed.

12-5.4 Each power quality issue can require a different type of design solution; a single standardized design approach will not satisfy all power quality issues. Table 12-2 provides a summary of typical design approaches to power quality problems.

Table 12-2. Power Quality Summary

Example Waveform	Power Quality Category	Typical Cause	Typical Solutions
	Impulsive transients	Lightning Capacitor switching Load switching	Surge protectors Filters/reactors Isolation transformers
	Oscillatory transients	Capacitor switching Line switching Load switching	Surge protectors Filters/reactors Isolation transformers
	Sags and Swells	Remote system faults Overloads Switching operations	UPS systems Ferroresonant transformers Energy storage devices
	Interruptions	System fault clearing Loss of generation	UPS systems Backup generators
	Harmonic distortion	Nonlinear loads System resonance	Filters/reactors Isolation transformers K-factor transformers Rotary UPS

12-5.5 The following subsections provide additional information regarding different possible equipment types and design solutions.

12-5.5.1 **Surge Protectors**. Surge protectors are not normally considered a solution for power quality problems; their principal purpose is to protect against surge transients. Refer to Chapter 11 for surge protection criteria.

12-5.5.2 **Filter Reactors**.

12-5.5.2.1 Reactors can be a cost-effective solution in an existing facility where rewiring is difficult or costly. Reactors provide a filtering function by blocking offending harmonic currents, thereby lessening the harmonic effects elsewhere in the facility.

12-5.5.2.2 Reactors are rated in terms of percent impedance. Higher impedance reactors provide greater filtering, but also increase the voltage drop. For example, a 3 percent impedance reactor will introduce a 3 percent voltage drop across it under rated conditions. Evaluate the effect of the additional voltage drop as part of any filter application. Reactors use energy or consume power in proportion to their impedance, and will decrease overall efficiency because of these added losses.

12-5.5.2.3 The filter design depends on the equipment and where it is installed. If the equipment is changed, the filter might no longer be effective for its intended purpose. Also, the filtering characteristics are strongly influenced by the source impedance, which is not always known accurately and varies with the system configuration. For this reason, filters should be carefully selected for the application and location. Filters can be relatively expensive on a per-kVA basis and they can cause more problems than they solve if they are applied improperly.

12-5.5.2.4 The filters described in this section are called *passive filters*. Active filters have been developed that act as current sources to nonlinear inductive loads to cancel current harmonics. These products are still new to the market and require professional design assistance in their selection and application.

12-5.5.3 **Shielded Isolation Transformers**. Shielded isolation transformers provide a filtering function by separating the harmonic frequencies between the source and the load. These transformers can be used for retrofit applications to address existing facility problems, but should not be arbitrarily used in new facilities because of the high per-kVA cost.

12-5.5.4 **K-Factor Transformers**. Transformers are available for high harmonic-content power distribution systems without derating, often referred to as *k-factor transformers*. Refer to paragraph 4-4.3 for additional information regarding k-factor transformer selection.

12-5.5.5 **Phase Shifting Transformers**. Phase shifting transformers are intended to cancel harmonic currents produced by nonlinear loads. These transformers can be used for retrofit applications to address existing facility problems, but should not be arbitrarily used in new facilities because of the high per-kVA cost.

12-5.5.6 **UPS Systems**. UPS systems provide protection from many power quality problems. Refer to Chapter 13 for additional information regarding UPS design considerations.

12-5.5.7 **Power Conditioners**. Power conditioners are available in a variety of designs. As the name implies, these devices provide a power conditioning function to achieve a pre-defined result. The design of each type of power conditioner varies and a detailed evaluation of equipment specifications is necessary to ensure that the desired result will be achieved.

12-5.5.8 **Grounding**. Grounding is not necessarily a power quality design feature. However, many power quality problems can be traced back to poor wiring and grounding practices. For this reason, any power quality evaluation must consider the grounding system design.

12-6 NONLINEAR LOAD DESIGN CONSIDERATIONS.

12-6.1 Analyze planned electrical loads on new projects to determine whether or not they are considered potential nonlinear loads with high harmonic content. The following guidelines are provided if nonlinear loads are a significant portion of the total load.

12-6.1.1 Derate transformer, motor, and generator outputs if necessary to prevent overheating or burnout. Ensure that design documents and equipment nameplates reflect the derated capability.

12-6.1.2 If standby generators represent the only power source upon loss of normal power, the generator design must account for nonlinear loads. Generators are designed to deliver a pure sinusoidal frequency, usually at a frequency of 60 Hertz in North America and 50 Hertz elsewhere. When harmonic currents are drawn through a generator, losses increase causing greater heat generation. Voltage distortions can cause generator and voltage regulator stability problems. Harmonics can also affect the parallel operation of multiple generators. If the generator cannot be protected from the effect of harmonic load currents, advise the generator supplier of the nonlinear load environment to ensure that the generator is designed and sized properly. If a significant portion of the load is nonlinear, it might be necessary to apply a multiplying factor of 1.3 to 1.5 to the generator size to compensate for the expected heat losses. Also, the generator manufacturer can design the generator to withstand better a harmonic environment by adjusting the generator pitch and decreasing the subtransient reactance. Specify a voltage regulator capable of achieving proper voltage regulation in high harmonic content and distorted sine wave load conditions. If the generator manufacturer lowers the generator subtransient reactance, ensure that the facility design remains acceptable for short circuit conditions.

12-6.1.3 Use a single three-phase transformer with common core, delta connected primary and wye connected secondary instead of three single-phase transformers connected for three-phase service. Evaluate the use of a k-factor transformer if a standard transformer has to be derated by more than 10 percent. Compare the cost of a k-factor transformer to an equivalent standard transformer. Even if derating of a standard transformer is not required, select the k-factor transformer if the cost of the two types is within 5 percent, provided that the lead time of a k-factor transformer satisfies facility schedule requirements.

12-6.1.4 If common-mode noise is a concern, specify electrostatically shielded isolation transformers for critical loads and locate each transformer as near to the served loads as practical to reduce the load requirement and cost of each transformer. Bond and ground the shield in accordance with the manufacturer's requirements. Ground the transformer in accordance with the NEC. Refer to paragraph 4-4.1 for additional information.

12-6.1.5 UPS systems must be capable of performing properly with nonlinear loads. The UPS should be capable of withstanding high crest factors (the ratio of peak current to RMS current). The UPS should provide a sine wave output with a total harmonic distortion of less than 5 percent. If the presence of nonlinear loads causes a leading power factor, the UPS must still operate properly. Determine the total demand distortion (TDD) that the UPS can create on its input terminals that will be seen as harmonic distortion to other electrically connected loads. Evaluate the TDD at UPS full-load and light-load conditions.

12-6.1.6 Specify harmonic filters as necessary to minimize the localized effects of harmonics. If separate harmonic filters are installed specifically to protect against offending loads, locate each filter as close to each load as practical.

12-6.1.7 Specify true RMS sensing meters, relays, and circuit breaker trip elements.

12-6.1.8 The end-use equipment has the most impact on the system power quality and is the easiest to address on an individual level. Wherever possible, ensure that reduced harmonic generation specifications are produced for equipment. For example, a simple input filter on an ASD can reduce the generated harmonic currents by half. Adjustable speed drives are an example of a type of equipment that can quickly degrade the power quality as they are added throughout a facility.

12-6.2 Analysis alone will not always adequately predict power quality problems. Power quality monitoring after the facility is in full operation is needed because many of the nonlinear loads might not be running during initial system operation. If standby or emergency power is provided upon loss of normal power, perform monitoring with the system powered from these sources also. Correct power quality problems as necessary based on the results of the monitoring. Refer to IEEE 1159, *IEEE Recommended Practice for Monitoring Electric Power Quality*, for additional information regarding power quality monitoring.

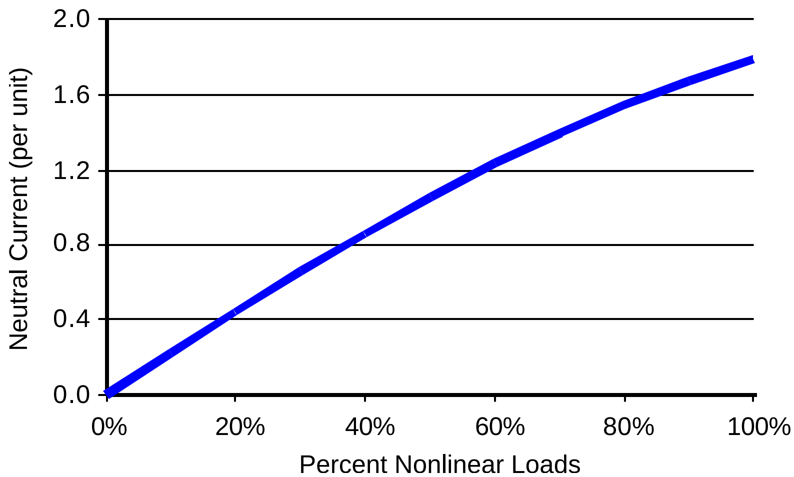
12-7 **NEUTRAL CIRCUIT SIZING FOR NONLINEAR LOAD CONDITIONS**.

12-7.1 **Potential Neutral Current Magnitudes**.

12-7.1.1 Nonlinear electrical loads distort the shape of the electrical system voltage and current waveform, thereby generating harmonics, eddy currents, increased hysteresis losses, and skin effects. In extreme cases, wiring systems, transformers, motors, and generators can overheat, leading to deteriorating equipment performance. One common result of nonlinear loads is overloading of the neutral conductor because of the increased neutral current created by the distorted waveform.

12-7.1.2 Single phase nonlinear loads such as computers and electronics equipment can have significant triplen frequency harmonic currents (3, 9, 15, and so on). When these single phase loads are combined in a three phase circuit, these harmonic currents appear as zero sequence components, adding in magnitude in the neutral. For example, if there are 5 amperes of third harmonic current on each phase of a three phase circuit, the neutral current will include 15 amperes of third harmonic current. Because of this effect, neutral currents in low voltage systems can be higher than the phase currents. Figure 12-2 shows one estimate of the change in neutral current as the single phase load becomes dominated by nonlinear loads. Notice that the neutral current can be as high as 1.73 times the phase current.

Figure 12-2. Effect of Single Phase Nonlinear Loads on Neutral Currents



12-7.2 **Installation Design Criteria**.

12-7.2.1 Minimize neutral circuit overheating by specifying separate neutral conductors for line-to-neutral connected nonlinear loads with high harmonic content. When a shared neutral conductor must be used for three-phase, four-wire systems, size the neutral conductor to have an ampacity equal to at least 1.73 times the ampacity of the phase conductors. Some cable manufacturers provide cable with oversized or extra neutral conductors included to meet this design requirement.

12-7.2.2 Two paralleled, full size neutral conductors can be used to obtain the required neutral ampacity for conductors sized #1/0 AWG and larger. Size the neutral conductor between the transformer and the panelboard to be a minimum of 1.73 times the ampacity of the phase conductors. Select panelboards that have been rated for nonlinear loads. Circuits for nonlinear loads approaching 100 percent should be provided a neutral ampacity of a minimum of 1.73 times the phase ampacity.

12-7.2.3 If necessary, install third harmonic filters at specific analyzed locations in the electrical distribution system. Ensure that the selected locations provide the best benefit in terms of neutral current reduction.

12-7.2.4 Although other power quality designs could be implemented to reduce the electrical system neutral currents, the above approach has been selected to ensure that neutral currents do not exceed wiring system limits. This method also ensures greater system flexibility in the future.

12-8 INFORMATION SOURCES.

12-8.1 Power quality is a broad topic and the industry standards are still developing in many areas. The following references provide additional information regarding power quality:

12-8.1.1 IEEE 519—provides the industry-accepted position of harmonic distortion limits and methods of analysis.

12-8.1.2 IEEE 1100—addresses power quality issues and provides an overview of power quality design approaches.

12-8.1.3 IEEE 1159—provides information regarding power quality monitoring.

12-8.1.4 IEEE 1346, *Recommended Practice for Evaluating Electric Power System Compatibility with Electronic Process Equipment*—provides guidance for ensuring acceptable operation of electronic equipment.

12-8.1.5 FIPS PUB 94—a widely referenced publication devoted to assuring acceptable power quality for computer installations. This document is listed here as a useful background document, but it was officially withdrawn in July 1997.

12-8.2 In addition to the above references, manufacturers of power quality-related equipment provide extensive technical literature to help users better understand the subject.

CHAPTER 13

EMERGENCY AND STANDBY POWER SYSTEMS

13-1 **ESTABLISHING THE NEED FOR BACKUP POWER**.

13-1.1 Establishing the need for backup power can be a challenging process with many decision points. First, determine what loads or facilities need to continue to function following a loss of normal power. Then, evaluate which loads must be uninterruptible, can experience momentary power loss, or can experience a longer duration power loss. Even the types of power disturbances that might be anticipated have to be considered in the selection of a backup power system. The following industry documents provide useful background information regarding how to determine which loads require backup power and should be reviewed as part of a backup power need analysis:

- AFI 32-1063, *Electric Power Systems*—authorizes the use of emergency generators and related wiring systems when needed to support certain essential functions.

- IEEE 446, *IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications* (IEEE Orange Book)—provides a detailed discussion of how to evaluate the need for backup power.

- MIL-HDBK-1003/11, *Diesel-Electric Generating Plants*—provides specific guidance related to satisfying backup power needs.

- MIL-HDBK-1190B, *Facility Planning and Design Guide*—provides authorization for emergency power for various applications.

- NFPA 110, *Emergency and Standby Power Systems*—provides specific criteria for backup power systems.

- NFPA 111, *Stored Electrical Energy Emergency and Standby Power Systems*—establishes the NFPA requirements associated with backup power systems.

13-1.2 The following are examples of military facilities or functions that have been provided with at least one source of backup power:

13-1.2.1 Operational facilities—typical facilities include air traffic control towers, central fire stations, communications facilities, command and control facilities, munitions facilities, weapons systems, and security facilities.

13-1.2.2 Maintenance and production facilities—for quality process control, fail-safe shutdown, security, and safety.

13-1.2.3 Hospitals—for life safety.

13-1.2.4 Research, development, and test facilities—for quality process control, fail-safe shutdown, preservation of research and development test results, security, and safety.

13-1.2.5 Liquid fueling and dispensing facilities—aircraft dispensing for support of operational missions.

13-1.2.6 Other liquid fueling and dispensing facilities—when specifically determined by the facility mission requirements.

13-1.2.7 Communications and navigational aids.

13-1.2.8 Airfield lighting.

13-1.2.9 Supply facilities—for direct tactical support, security, preservation of storage, and safety.

13-1.2.10 Utilities and ground improvements—for initial start-up, control, and complete operation of essential plants and systems. For fail-safe shutdown, safety, and security of noncritical plants and systems.

13-1.3 Paragraph 13-3.2 provides a list of applications and facilities that are authorized for the use of standby generators.

13-1.4 Backup power takes several forms. The following definitions are important to consider when developing facility backup power criteria:

13-1.4.1 **Emergency Power System**. An emergency power system is an independent reserve source of electric energy. Upon failure or outage of the normal or primary power source, the system automatically provides reliable electric power within a specified time. The electric power is provided to critical devices and equipment whose failure to operate satisfactorily would jeopardize the health and safety of personnel, or result in damage to property, or jeopardize a critical mission. The emergency power system is usually intended to operate for a period of several hours to a few days.

13-1.4.2 **Standby Power System**. An independent reserve source of electric energy which, upon failure or outage of the normal source, provides electric power of acceptable quality and quantity so that the user's facilities can continue satisfactory operation. The standby system is usually intended to operate for periods of a few days to several months, and might augment the primary power source under mobilization conditions.

13-1.4.3 **UPS**. A UPS is designed to provide continuous power and to prevent the occurrence of transients on the power service to loads which cannot tolerate interruptions and/or transients due to sensitivity or critical operational requirements.

13-1.5 For facilities having emergency generating systems in excess of 200 kW, or where energy monitoring systems exist or are planned for installation, evaluate the installation of a demand controller. The economic viability should be based on the ability to reduce demand charges by peak-shaving with the emergency generator(s) typically provided for such facilities as hospitals and communications installations. The utility company's permission will be required if the two electrical systems must interconnect.

13-2 **CLASSIFYING EMERGENCY POWER LOADS**.

13-2.1 Once the need for backup power has been established, the next step is to decide which type of backup power system will satisfy the load requirements. The total load, uninterruptible power requirements, and demand duration all influence the selected backup power method. For example, a relatively small computer load that only has to be safely shut down following a power outage has a different need than a communications system that must operate continuously until normal power is eventually restored. In the first case, a UPS system with a small battery might be adequate. In the second case, UPS power might be backed up with larger batteries as well as an engine generator.

13-2.2 As part of the backup power equipment selection process, classify each load as to the type of power that it should have. The following simple classifications are recommended as the starting point:

13-2.2.1 Critical—loads in this category require continuous power and can not experience even momentary power disruptions. Loads in this category usually include computer and communications systems. These loads will likely require the use of a UPS system.

13-2.2.2 Essential—loads in this category require backup power, but momentary power loss is acceptable. Loads in this category usually include heating, ventilating, and air conditioning loads to vital facilities or other load types that can be deenergized for short periods without severe consequence. Engine generator backup is often acceptable for these loads.

13-2.2.3 Nonessential—loads in this category can be deenergized for extended periods without severe consequence. Although these loads might be classified as nonessential, they might still be capable of being energized from engine generators, depending on the facility design.

13-2.3 Determine which loads are continuous, non-continuous, or non-coincident. Continuous loads are energized for periods greater than 3 hours, such as lighting and HVAC equipment. Non-continuous loads do not meet the definition of continuous and the proportion of on to off time varies with each load. Non-coincident loads are dissimilar loads, fed from a common source that are not likely to be energized at the same time.

13-3 ENGINE GENERATORS.

13-3.1 Engine generators are used to provide backup power when the backup power duration or the load requirement exceeds the capability of a stationary battery system. As the load increases or the discharge duration increases, a stationary battery must be made correspondingly larger. In addition to the initial battery cost, the facility must be made larger to accommodate a larger battery and the ongoing maintenance expense will be higher. Although there are no firm limits and there will be natural exceptions to any criteria, an engine generator should be used if the required backup power duration exceeds 4 hours.

13-3.2. Emergency generators and related wiring systems are authorized for use when needed to support the following types of applications and facilities:

- Medical treatment facilities.
- Air navigation aids and facilities.
- Refrigerated storage rooms.
- POL storage and dispensing facilities.
- Critical utility plants and systems.
- Civil engineer control centers.
- Communication facilities and telephone exchanges.
- Fire stations, including fire alarm, fire control, and radio equipment.
- Critical computer automatic data processing facilities.
- Air traffic control towers.
- Base weather stations.
- Surveillance and warning facilities.
- Command and control facilities.
- Weapon systems.
- Security lighting systems.
- Aircraft and aircrew alert facilities.

- Law enforcement and security facilities.

- Disaster preparedness control center.

- Mission, property, and life support facilities at remote and not readily accessible sites, such as split-site aircraft warning and surveillance installations.

- Industrial facilities that have noxious fumes requiring removal—provide power for exhaust system only.

- Readiness facilities relying on electrical power to support tactical or critical missions.

- Photographic laboratories providing critical and essential support to combat and contingency tactical missions.

13-3.3 A number of documents are available to assist with engine generator design and selection. The key references are listed below and should be used for design guidance once the decision has been made to include engine generator backup power.

- MIL-HDBK-1003/11—provides specific guidance related to engine generator selection and application.

- AFI 32-1062, *Electrical Power Plants and Generators*—provides operations and maintenance information related to engine generators.

- IEEE 446, *IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications* (IEEE Orange Book)—discusses engine generator applications in detail.

- NFPA 110—provides specific criteria for backup power systems.

- NFPA 111—establishes the NFPA requirements associated with backup power systems.

- Electrical Generating Systems Association (EGSA), *On-Site Power Generation: A Reference Book*—provides a detailed overview of design and application considerations. This reference book is highly recommended.

- EGSA 100B, *Performance Standard for Engine Cranking Batteries Used with Engine Generator Sets*—contains guidance for rating, classifying, applying, installing and maintaining engine cranking batteries. Note: EGSA standards are available for free download at www.egsa.org.

- EGSA 100C, *Performance Standard for Battery Chargers for Engine Starting Batteries and Control Batteries (Constant Potential Static Type)*—contains guidance for voltage and temperature limits, application and accessories for charging engine cranking batteries.

- EGSA 100D, *Performance Standard for Generator Overcurrent Protection, 600 Volts and Below*—contains performance specifications for circuit breakers, field breakers, thermostats, thermistors and other temperature detectors.

- EGSA 100E, *Performance Standard for Governors on Engine Generator Sets*—contains classifications, performance guidance and optional accessories for generator set engine governors.

- EGSA 100F, *Performance Standard for Engine Protection Systems*—contains performance specifications for engine control systems including temperature, level, pressure and speed sensing.

- EGSA 100G, *Performance Standard for Generator Set Instrumentation, Control and Auxiliary Equipment*—contains guidance for generator set engine starting controls, instrumentation and auxiliary equipment.

- EGSA 100M, *Performance Standard for Multiple Engine Generator Set Control Systems*—contains performance guidance for manual, automatic fixed sequence and random access generator set paralleling systems.

- EGSA 100R, *Performance Standard for Voltage Regulators Used on Electric Generators*—contains application and performance guidance for generator voltage regulators.

- EGSA 100S, *Performance Standard for Transfer Switches for Use with Engine Generator Sets*—contains classifications, applications and performance guidance for transfer switches for emergency and standby transfer switches.

- EGSA 100T, *Performance Standard for Diesel Fuel Systems for Engine Generator Sets with Above Ground Steel Tanks*—contains application and performance guidance for diesel fuel supply systems with above ground steel tanks for diesel engine driven generator sets.

- EGSA 101P, *Performance Standard for Engine Driven Generator Sets*—contains classifications of use, prime mover configuration and ratings, and performance guidance for complete generator sets.

- EGSA 101S, *Guideline Specification for Engine Driven Generator Sets, Emergency or Standby*—provides a guideline specification in blank form for preparing specifications for emergency or standby generator sets.

13-3.4 Refer to Chapter 12 if the generator will be applied to an electrical system with significant harmonic distortion. Special generator or facility design features might be needed to ensure a reliable design.

13-4 **UPS SYSTEMS**.

13-4.1 **Introduction**.

13-4.1.1 UPS systems are intended to provide stable power and minimize the effects of electric power supply disturbances and variations. Although momentary voltage disturbances can often be accommodated by other design features such as voltage regulators or ferroresonant transformers, longer duration disturbances beyond a momentary duration will usually require some form of UPS system to ensure uninterrupted power to critical loads.

13-4.1.2 A UPS system must be capable of providing a reliable, regulated, and filtered source of uninterrupted power to critical loads. A properly selected UPS system will provide continuous power to its loads throughout most disturbances encountered by the power source.

13-4.1.3 For long duration outages, additional backup by an engine generator might be required. The purpose of the engine generator is to provide ac power before the UPS battery becomes depleted. An engine generator is not alone a suitable alternative to a UPS system if uninterrupted power is a design requirement; a UPS system will still be necessary.

13-4.1.4 Several industry standards are available to assist with the selection and specification of UPS systems. The key standards include:

- IEEE 241—provides a detailed overview of UPS design and application considerations.
- IEEE 446—provides detailed information regarding backup power systems, including design considerations for UPS systems.
- IEEE 944, *IEEE Recommended Practice for the Application and Testing of Uninterruptible Power Supplies for Power Generating Stations*—covers application criteria for UPS systems.
- NEMA PE 1, *Uninterruptible Power System*—provides guidance regarding the design of static UPS systems.

13-4.2 **Selection and Performance**.

13-4.2.1 Table 13-1 provides a summary of selected UPS designs. There is not necessarily a single design that is ideal for all situations; each design has advantages and disadvantages that require evaluation for the specific application. Also, evaluate system cost as part of any design evaluation process. The double-conversion UPS design provides the best isolation between the input and the output. The term *Input Power Quality* in Table 13-1 refers to how the UPS design affects the electrical system on the input. For example, the double-conversion type tends to reflect harmonic distortion back to the source.

Table 13-1. Performance of Selected UPS Designs

UPS Type	Power Reliability	Disturbance Suppression	Dynamic Response	Input Power Quality	Energy Efficiency
Off-line	Fair	Fair	Fair	Excellent	Excellent
Double-Conversion	Excellent	Excellent	Excellent	Fair	Fair
Line-Interactive	Very Good	Fair	Excellent	Very Good	Very Good
Rotary	Good	Good	Fair	Excellent	Fair

13-4.2.2 The UPS selection process also depends on the types of loads to be supplied. As part of the UPS selection process, categorize the types of critical loads as follows:

- Loads that cannot withstand a sustained loss of voltage.
- Loads that cannot withstand voltage or frequency fluctuations beyond specified limits.
- Loads that cannot withstand harmonic distortion beyond specified tolerances.

13-4.2.3 UPS selection should also be based on past operating experience. Even when two UPS system designs are based on the same technology, they might not be equal. For example, some UPS systems are designed such that the batteries are virtually inaccessible during operation. This sort of maintenance-proof design almost guarantees a future UPS system failure; dead batteries will be detected only when the system is needed.

13-4.3 **Sizing**.

13-4.3.1 Size the UPS to be large enough to power the total expected connected load during normal and abnormal conditions. UPS systems are rated in kVA at a given power factor. The UPS system loads will usually set the required system size. Obtain the following load data:

- Total continuous load.
- Load power factor.
- Short-duration or momentary loads that add to the continuous loads.
- Inrush current requirements of the loads.

13-4.3.2 Depending on the electrical distribution system, determining the required UPS size can be difficult, especially if a number of noncontinuous loads are present. When the actual load can vary, size the UPS for 125 percent of the maximum expected load to provide margin for any uncertainty in the total load. The UPS should be sized for the following:

- 125 percent of the total real power load.
- 125 percent of the total reactive power load.
- 0.8 lagging power factor unless an actual power factor is known.

13-4.3.3 The above sizing criteria assume that no single load represents either a large portion of the total load or has a high inrush current. Some static UPS systems have very little overload capability and it is usually not practical or economical to oversize the UPS so that it is capable of satisfying inrush or short-circuit current requirements. On some UPS designs, the output voltage will collapse as the UPS is overloaded.

13-4.3.4 If high inrush starting currents loads can exceed the UPS rating, evaluate the following design options:

- Selective loading of individual loads.
- UPS with guaranteed overload capability sufficient for inrush currents.
- Static switch bypass when starting inrush loads.
- Rotary UPS design to obtain transient load-change capability.

13-4.3.5 The preferred method of establishing the expected UPS loading is to perform a site survey, if a UPS is to be added to an existing system. The UPS should not be sized based on the total connected using nameplate information if a site survey demonstrates that the actual loading is substantially less than this amount. For each load or panel, record the following information to document the actual facility loads. Ensure that measurements capture peak loading periods. Determine future facility load requirements by estimating the following information for each location.

- Reading location, such as a panel or specific load.
- Phase currents (record each phase separately).
- Neutral current.
- Load type.
- Voltage.

- Frequency.

- Total harmonic distortion (voltage and current).

13-4.3.6 UPS systems are available in single-phase and three-phase configurations. In some cases, the load requirements (three-phase versus single phase or magnitude of the loads) will establish a need for a three-phase UPS. With a three-phase system, care must be taken to balance loading and load power factors between phases to minimize the imbalance in the UPS output voltage.

13-4.3.7 Once the UPS has been sized for a given kVA, the next size-related design issue is one of how long the battery must be capable of operating. The battery has to be capable of providing the specified power for the specified duration. Refer to Appendix E for sizing of UPS batteries.

13-4.4 **Selection of a Large UPS System or Multiple Smaller UPS Systems**.

13-4.4.1 Paragraph 13-4.3 provides the recommended approach for UPS sizing. This approach applies regardless of the UPS size in terms of rated kVA. If the total connected load is large, another design selection decision must be made regarding whether to select a single distribution-type UPS system or multiple smaller point-of-use UPS systems. Several smaller UPS systems are preferred over a single large UPS system for the reasons discussed in the following paragraphs.

13-4.4.2 Large UPS systems have one advantage in that they are usually well-designed, include self-monitoring capability, and are well supported by the manufacturer. They are also expensive, require a large dedicated facility space for installation, the battery tends to be very large, and maintenance can require special training. Furthermore, loss of a single large UPS can possibly cause the loss of multiple mission critical functions.

13-4.4.3 Smaller point-of-use UPS systems are often self-contained, require less floor space, and provide additional flexibility for relocation when equipment is moved. Smaller UPS systems are more easily added to the facility without requiring extensive rework of the facility electrical system. Rather than select a single large UPS, the use of smaller 10 kVA to 20 kVA UPS systems is preferred. Ideally, the UPS systems should be designed as multiple identical units that are easily interchangeable and relocated. Such a design arrangement allows UPS systems to be relocated and interchanged as necessary under contingency situations to allow continuation of critical missions.

13-4.4.4 Smaller point-of-use UPS systems require periodic monitoring of the backup power source – the battery. Smaller UPS systems might use lower quality batteries and are often forgotten by the maintenance program until they fail. Manufacturer’s literature for UPS systems rated up to 15 kVA often specify 10-year life valve-regulated lead-acid batteries (and even some larger UPS systems rated at 150 kVA have lower-life batteries). These batteries often fail within 3 years. Smaller UPS systems should have their batteries replaced more frequently than usually suggested by the manufacturer.

13-4.4.5 Very small UPS systems (less than 2 kVA) are sold in an extremely competitive market. Accordingly, the manufacturer often has to design the UPS to be price-competitive rather than highly reliable for a long life. UPS systems are installed because the user determined that uninterrupted power was a design requirement. Very small UPS systems must be included in the facility maintenance program so that they are periodically checked for proper performance and the battery replaced.

13-4.5 **Design Criteria**.

13-4.5.1 UPS systems are widely available from many companies. Although the electronics design and the equipment layout vary widely, the UPS performance requirements are usually very similar for each application. The following summarizes the key UPS design criteria for any application.

13-4.5.2 The UPS system must provide uninterrupted power. Upon loss or improper performance of the normal power source, the UPS system has to provide continuous, uninterrupted power to its loads. Some UPS designs, such as an off-line UPS and possibly a line interactive UPS, include a momentary break in power as the UPS transfers between the normal source and the battery. This type of design might not be a true UPS and should be avoided unless the downstream system performance is confirmed to still be acceptable with a momentary break in power.

13-4.5.3 The UPS system must provide power from its backup source for the required duration. Generally, the stationary battery has to be properly sized and adequately maintained to meet this requirement.

13-4.5.4 The UPS output frequency has to remain stable regardless of changes to the input or to the loads. Each UPS system will have a particular operating frequency—50, 60, 400, or higher Hertz. A common specification is for the UPS to maintain the output frequency within ±0.5 percent.

13-4.5.5 The UPS output waveform should be sinusoidal, with a voltage total harmonic distortion less than 10 percent, with no single harmonic frequency greater than 5 percent of the fundamental frequency. Depending on the UPS design, the output waveform might vary from almost purely sinusoidal to a square wave. This particular attribute requires evaluation during the UPS selection process. Also, the ability of the UPS to supply nonlinear loads must be evaluated. Determine with the UPS supplier if power conditioning or an output load filter is required for the expected harmonic environment.

13-4.5.6 The UPS input voltage range might require adjustment for UPS systems applied in locations where commercial power is subject to larger than normal variations, such as outside the continental United States. In such locations, the UPS adjustable range should be a design consideration.

13-4.5.7 The battery charger might require current limiting characteristics when emergency power, such as an engine generator, provides power to the UPS. Otherwise, the combined load, consisting of the UPS loads and the battery recharge current, could require a larger engine generator design. By limiting the maximum current, a smaller engine generator can be used.

13-4.5.8 Unattended locations might require remote monitoring capability so that other attended locations can respond promptly to UPS failure alarms.

13-4.6 **Site Survey for an Installation**.

13-4.6.1. Perform a site survey as part of a UPS design and installation. The purpose of this survey is to ensure that building environmental and equipment location constraints are understood before equipment is procured.

13-4.6.2 Record the required facility information. Table 13-2 lists typical information to be obtained.

Table 13-2. Building and Room Characteristics Data List

General Building Characteristics	General Room Characteristics
Location	Location
Building designation	Room designation
Obstructions—location and dimensions	Structural—floor and ceiling load requirements and constraints
Environmental—temperature and humidity	Equipment heat dissipation
Access	Wall material
Security	Ceiling material
Comments	Dimensions—height, width, and length
	Obstructions—location and dimensions

13-4.6.3 Determine the existing electrical system capability, including transformer and generator ratings. This information is required to ensure the UPS can be adequately powered by the existing system.

13-5 **AUTOMATIC TRANSFER EQUIPMENT**.

13-5.1 **Introduction**.

13-5.1.1 An automatic transfer switch (ATS) is used to transfer power from one source to another. An ATS often includes controls that detect a power failure and triggers other controls to start the backup power source, such as an engine generator. When the generator reaches the operating voltage and frequency, the ATS transfers the loads from the normal source to the generator. An ATS often includes controls to retransfer power back to the normal source after it has been restored. Thus, the ATS can coordinate the complete sequence of operation, including engine starting, transfer of power to the generator, retransfer back to normal after power is restored, and subsequent engine shutdown.

13-5.1.2 Considering that the ATS can control the entire process of power transfer to the backup source and eventual retransfer to the normal source, the ATS is an important part of a backup power system. If the ATS fails for any reason, backup power cannot be transferred even if it is available, unless a manual option is included with the ATS or if a manual bypass is installed in parallel with the ATS.

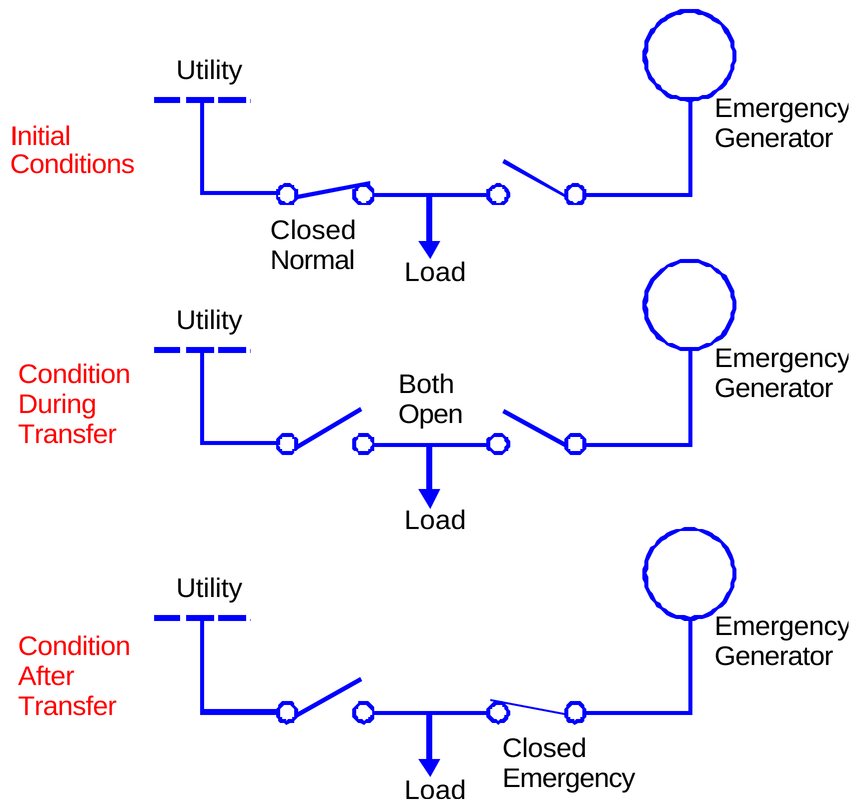
13-5.1.3 Some of the design criteria provided in this section relate to ATS applications in which the choice of power is either the utility (commercial power) or an onsite emergency source. In many ATS applications, the potential for cross-connecting emergency power to the utility supply will not be a design concern because of the location of the ATS in the electrical distribution system.

13-5.2 **Transfer Methods**.

13-5.2.1. **Open Transition Transfer (Break Before Make)**.

13-5.2.1.1 Open transition transfer is a break before make transfer in which the loads are momentarily deenergized during the transfer; the original connection to the source is opened followed by a connection to the alternate source (refer to Figure 13-1). The length of time that the loads are deenergized can vary from a few milliseconds to several seconds or more, depending on the transfer switch design and operating logic.

Figure 13-1. Open Transition Transfer

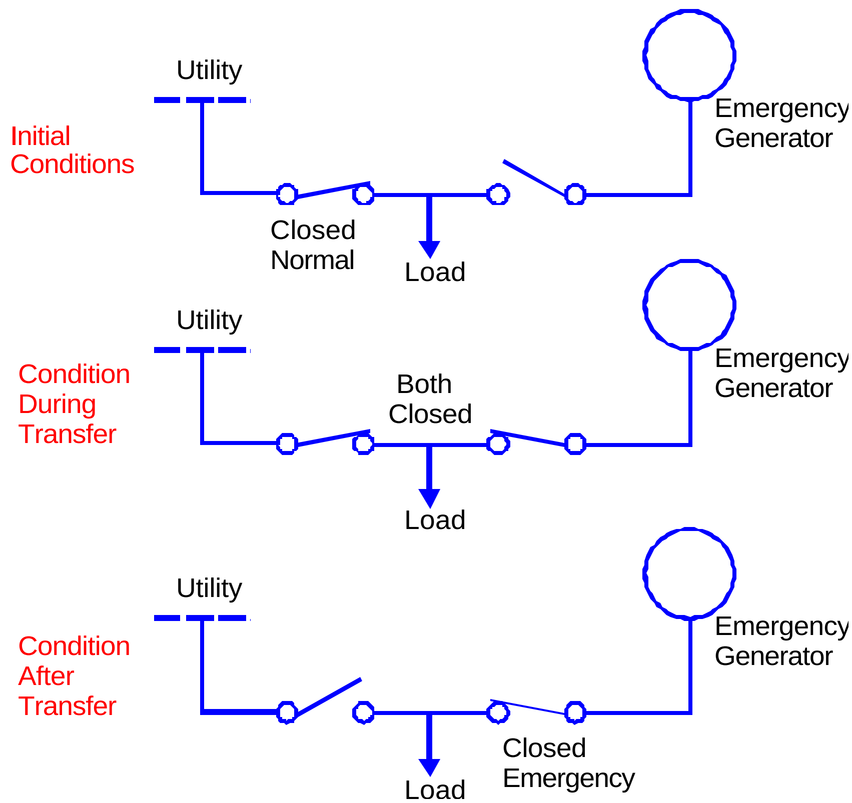


13-5.2.1.2 Open transition transfer is usually used for transfers from normal commercial power to an emergency generator, and back. In this case, open transition transfer avoids issues arising with possibly paralleling, even momentarily, an emergency generator with commercial power.

13-5.2.2 **Closed Transition Transfer (Make Before Break)**.

13-5.2.2.1 Closed transition transfer is a make before break transfer in which the normal source is momentarily paralleled with the alternate source (refer to Figure 13-2). Closed transition transfer is often used on UPS systems to transfer to and from its bypass, and it is also a standard feature on high end rotary UPS systems. Closed transition can be used between an energized normal source and an energized alternate source, including two emergency generators. Note that closed transition transfer is only possible when both the normal and alternate sources are available. Upon loss of the normal source, the transfer switch must operate in open transition transfer mode to the alternate source.

Figure 13-2. Closed Transition Transfer



13-5.2.2.2 Closed transition transfer must be used with care on any transfer scheme that includes commercial power. Because of the problems that can be caused by inappropriate closed transition transfer, the following subsections provide additional information and design criteria if commercial power is involved.

13-5.2.2.3 Closed transition transfer between commercial power and an emergency generator means that the two sources are momentarily operating in parallel. In this case, install all controls and protective functions necessary to operate a generator in parallel with commercial power. Do not use an in-phase monitor to accomplish the transfer. Instead, include synchronization equipment with the transfer switch to actively control the speed and phase angle of the generator relative to the utility. The generator must be properly designed for parallel operation with commercial power, including provisions for load control and power factor control. Note that even with the above features, closed transition transfer will still place the full load on an unloaded generator as an instantaneous load. This block loading of the generator will cause a voltage and frequency excursion that still might exceed the intended power disturbance limits.

13-5.2.2.4 Utility permission is required for all systems paralleled with the utility system. Even if the utility grants permission, it will probably impose additional protective relaying requirements to protect the utility system from transfer switch problems. Some utilities do not allow closed transition transfer with the emergency system under any conditions.

13-5.2.2.5 Regularly scheduled testing of a system with closed transition transfer will usually only transfer the load from an energized source to another energized source. This configuration does not represent the actual system configuration when normal power is lost. When normal power fails, the transfer switch must transfer the deenergized load to the energized emergency side, and all equipment must be capable of handling the subsequent inrush currents. This capability cannot be tested without actually deenergizing the loads and requiring the emergency system to then pick up the loads.

13-5.2.2.6 NEC Article 700.6 (2002 Edition) requires that transfer equipment be designed and installed to prevent the inadvertent interconnection of normal and emergency sources of supply in any operation of the transfer equipment. For closed transition transfer, a switch failure could cause both sources to remain connected to the load.

13-5.2.2.7 The above cautions have been provided because closed transition transfer requires careful design and still might not be accepted by the local utility if commercial power is involved. Instead, a UPS system should be used for those loads that require uninterrupted power. In the case of a UPS, closed transition transfer to and from the bypass is appropriate because the ac power source to the UPS is the same in each case.

13-5.2.3 **Fast Transfer (Break Before Make)**. Fast transfer schemes accomplish a transfer within a few cycles. Typically, an in-phase monitor is used to keep the transfer within some degree of synchronization. This approach has been used as one method of transferring motor loads. Under loss of normal power conditions, even a fast transfer scheme can cause significant stress on electrical equipment; an in-phase monitor cannot fully anticipate or compensate for the complex rate of change of frequency. Fast transfer schemes require careful evaluation.

13-5.3 **Design Considerations**.

13-5.3.1 **Continuous Current Rating**.

13-5.3.1.1 An ATS is usually installed upstream of branch circuits because it is supplying power to a variety of loads. Thus, the ATS must be capable of maintaining power to continuous loads and withstanding different types of abnormal loading or short circuit conditions. An ATS is continuously exposed to system full-load current. During normal operation, current flows through the ATS to supply the operating loads. Upon loss of power, the ATS transfers to a backup source of power, such as an engine generator. This load requirement is different than for other backup power supplies that only have to provide power during the period that normal power is lost.

13-5.3.1.2 The ATS has to do more than provide power 24 hours a day for its expected service life. During this period, load switching, periodic short circuits, or abnormal environmental conditions must not degrade its performance below acceptable levels.

Finally, as an ongoing maintenance consideration, the ATS continuous duty capability should be achievable with minimal maintenance.

13-5.3.1.3 To meet the above continuous duty requirements, the ATS contact temperature rise must be well below that established for an 8-hour rated device. Select an ATS capable of carrying the maximum continuous load current. Momentary inrushes need not be included in the continuous load requirement, provided that the ATS is rated for the inrush. Table 13-3 shows typical ATS continuous current ratings:

Table 13-3. Typical ATS Continuous Current Ratings

Current Ratings (amperes)	
30	600
40	800
70	1000
80	1200
100	1600
150	2000
225	3000
260	4000
400	

13-5.3.1.4 Consider oversizing the ATS to be as large in current carrying capability as its upstream protective device. Although oversizing an ATS will add to the system cost, it ensures that the ATS does not become the limiting component if loads are added to the system.

13-5.3.2 **Fault Current Withstand Rating**.

13-5.3.2.1 An ATS has to be capable of withstanding the stresses and dissipate the heat energy generated during short circuit currents. ATS withstand current ratings vary with switch size and type as shown in Table 13-4. An ATS has to be rated for 1) the available fault current at its location in the electrical system and 2) the expected duration that the fault current will be present before an upstream overcurrent device (or the ATS if it has integral overcurrent protection) clears the fault; both design features are important.

Table 13-4. Typical ATS Fault Current Ratings

Available Symmetrical Amperes RMS Ratings at 480 Volts						
	Long-Time Withstand With Any Overcurrent Protective Device		Rating When Applied With a Rated MCCB	Rating When Applied With Current Limiting Fuses		
ATS Rating (Amperes)	Symmetrical Amperes RMS at 480 Volts	Time (Cycles)	Symmetrical Amperes RMS at 480 Volts	Symmetrical Amperes RMS at 480 Volts	Fuse Size Maximum	Fuse Type
30	10,000	1.5	22,000	100,000	60	J
70, 100	10,000	1.5	22,000	200,000	200	J
150	10,000	1.5	22,000	200,000	200	J
260	35,000	3	42,000	200,000	600	J
400	35,000	3	42,000	200,000	600	J
600, 800	50,000	3	65,000	200,000	1200	L
1000, 2000	65,000	3	85,000	200,000	2000	L
1600, 2000	100,000	3	100,000	200,000	3000	L
3000, 4000	100,000	3	100,000	200,000	6000	L

13-5.3.2.2 An ATS is rated in terms of the available RMS symmetrical current at a specified power factor. The system short circuit study must consider the X/R ratio at the ATS location. Higher than rated X/R ratios allow the fault current to peak higher and be sustained longer than was certified during ATS certification testing. If the system X/R ratio exceeds that of the ATS certification, discuss the available options with the manufacturer. Higher withstand and X/R ratio ATS designs are available.

13-5.3.3 **Arc Interrupt Capability**.

13-5.3.3.1 When a set of contacts open that are carrying power, an arc will be drawn as the contacts separate. The duration of the arc increases with higher voltages and lower power factors. In an ATS, the arc between the opening contacts must be extinguished before the other contacts close. Otherwise, a short circuit can occur between the two sources.

13-5.3.3.2 When an ATS transfers from the normal source to the emergency source, an arc might not occur because the normal source voltage might be zero. But, when the switch retransfers back to the normal source, it will have to interrupt the full voltage of the emergency source. During testing, the switch might have to interrupt full voltage between both sources.

13-5.3.3.3 When evaluating an ATS application, review the manufacturer's test documentation to ensure the ATS is capable of repeated arc interruption during transfer.

13-5.3.4 **Inrush Current Capability**.

13-5.3.4.1 When an ATS transfers to its alternate source, its contacts must be capable of withstanding a substantial inrush current. The amount of current depends on the type of load. Regardless of the load type, the ATS contacts must not weld when closing on loads with high inrush currents. UL 1008, *Standard for Automatic Transfer Switches*, requires that an ATS be capable of withstanding inrush currents of 20 times the continuous current rating. Verify the selected ATS has contacts rated for heavy duty use.

13-5.3.4.2 An ATS is rated for different types of loads, such as the following UL 1008 classifications:

- Resistive load consisting of heating and other noninductive loads.
- Electric discharge lamp load consisting entirely of electric discharge lamps, including fluorescent lamps.
- Incandescent lamp load consisting entirely of incandescent lamps.
- Motor loads.
- Total system load consisting of any combination of motors, electric discharge lamps, resistive heating, and incandescent lamp loads. The incandescent lamp loads cannot exceed 30 percent of the ATS continuous current rating.

13-5.3.5 **Simultaneous Closure of Both ATS Power Sources**. An ATS must be designed to prevent the normal source and the alternate source from being inadvertently connected to the load at the same time. The operating mechanism should be simple, yet ensure that the two sources are interlocked from ever being simultaneously closed.

13-5.3.6 **ATS Power Source**. An ATS should receive its power to transfer from the source to which it is transferring the loads. For example, upon loss of normal power, the power to the ATS must come from the emergency power source to which it transfers. The controls used for ATS operation should ensure reliable switching operation and not allow the transfers to cross through an off position.

13-5.3.7 **Maintainable Design**. In order to accomplish periodic maintenance, the ATS design must be maintainable. Most components should be accessible from the front of the ATS. Also, the ATS must be in a location that allows interior access. A parallel bypass feature should be provided if power to the load cannot be interrupted or if outages cannot be easily scheduled.

13-5.4 **Static Transfer Switches**. Static transfer switches provide digital switching without the use of electromechanical components. This allows very fast transfer times compared to conventional ATS designs. Static transfer switches are commonly provided with UPS systems and are usually provided with an independent certification based on UL 1008. The ATS design criteria apply also to static transfer switches. In particular, inrush and overload capability must be confirmed during the design process.

13-5.5 **Sizing**.

13-5.5.1 Most ATS designs are capable of carrying 100 percent of rated current at an ambient temperature of 40 °C (104 °F). Some designs, including those incorporating integral overcurrent protective devices, might be limited to a continuous load of 80 percent of the ATS rating. Confirm the continuous load rating as part of the sizing and selection process.

13-5.5.2 When sizing an ATS, specify a switch capable of carrying the total current load, including anticipated future load additions. The required ATS rating is calculated by adding the amperes required by all loads. Apply the following guidelines when determining the total load.

13-5.5.2.1 Only a motor's continuous load current has to be considered. Motor inrush current need not be included, provided that the ATS or static transfer switch is rated for inrush capability.

13-5.5.2.2 Resistive loads and incandescent lamp loads are determined from the total wattage.

13-5.5.2.3 Fluorescent, mercury vapor, and sodium vapor lamp currents must be based on the current that each ballast or autotransformer draws, not the total watts of the lamps.

13-5.5.3 In ambient temperatures above 40 °C (104 °F), the ATS might require derating. Consult with the manufacturer for sizing requirements for operation above this temperature.

13-5.5.4 Appendix B provides an ATS sizing example.

13-5.6 **Effect of Motor Loads**.

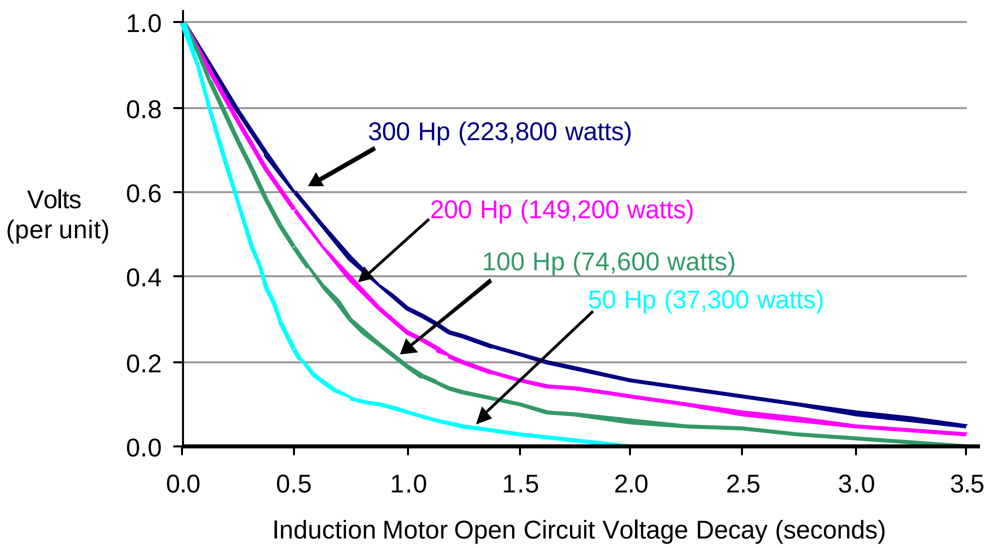
13-5.6.1 Motor loads require two considerations with regard to transferring their power source by an ATS during open transition transfer:

13-5.6.1.1 How to avoid nuisance breaker tripping and possible motor damage when the motor is switched between two unsynchronized energized sources. Motors and related equipment can be damaged when switched between two energized power sources. During a retransfer back to normal power or during a system test, both power sources are at full voltage, which can result in abnormal inrush currents in large motors causing damage to motor windings, insulation, or couplings.

13-5.6.1.2 How to shed motor loads prior to transfer to prevent overloading of the alternate power source. Engine generators are often used as the alternate power source to an ATS. When substantial motor load is present, the resulting inrush current can overload the generator. Engine generators that are intended as an emergency power source are often sized for the expected full-load current plus a limited margin for motor starting. The engine-generator can be overloaded if several motors simultaneously have high inrush currents. In these cases, the loads must be sequenced onto the generator. Time delays are usually used on less critical loads to assure that the most important loads are connected first. Load shedding ASDs with subsequent restart might be necessary to avoid damaging the ASD during the period of ATS power transfer.

13-5.6.2 The standard method used to avoid the potential problems with motor loads is to include a time delay in the transfer circuit to allow the residual motor voltage to decay to a safe level before allowing connection to the alternate source. When a running induction motor is disconnected from its power source, the motor generates residual internal voltage until the stored residual magnetism dissipates due to losses in the iron and as the motor loses speed. Figure 13-3 shows the typical voltage decay rate for different size motors.

Figure 13-3. Induction Motor Open Circuit Voltage Decay



13-5.6.3 The motor voltage should be below 0.25 per unit to allow a safe connection to the transferred source. Although only 1 to 2 seconds is necessary for voltage to decay to this level, the transfer should be delayed by 5 to 10 seconds to be conservative. This provides adequate margin for several motors operating from a common source. If this long of a time delay is not desired because of other loads, the motor loads should be separately disconnected by the automatic transfer equipment and then restarted in a sequenced manner after the transfer has been made.

13-5.6.4 Some transfer switches use a phase angle monitor in an attempt to avoid the motor voltage decay problem. The rate of change of frequency associated with motor loads is complex and varying during transfer. Phase angle monitors should not be used because they are not guaranteed to achieve an in-phase transfer.

13-5.7 **Maintaining Ground Fault Protection**.

13-5.7.1 Refer to NEC Article 250.20 (2002 Edition) for grounding requirements.

13-5.7.2 Ground fault protection requires special consideration with an ATS. The NEC provides the basic requirements for GFP. NEC Article 230.95 (2002 Edition) requires GFP to be provided for solidly grounded, wye electrical services of more than 150 volts to ground, but not exceeding 600 volt phase-to-phase for each service disconnecting means rated 1,000 amperes or higher. FPN No. 3 in NEC Article 230.95 recognizes the inherent difficulty of the above requirement when a transfer switch is used. It states that where GFP is provided for the service entrance disconnect and interconnection is made with another supply system by a transfer device, means or devices might be needed to ensure proper ground fault sensing by the ground fault equipment.

13-5.7.3 The selected design approach depends on whether the generator is a separately derived system. If the generator system is a separately derived system, a 4-pole ATS should be used in which the neutral is also switched.

13-5.8 **Additional System Design Considerations**.

13-5.8.1 If allowed by the facility layout, locate the transfer switch near the load. This increases system reliability by minimizing the length of the run common to both power sources from the transfer switch to the load.

13-5.8.2 Design feeder routing with physical separation between the normal power feeders and the emergency feeders. This minimizes the possibility that both power sources will be simultaneously interrupted by a localized problem within the facility.

13-5.8.3 Where possible, use a greater number of small transfer switches rather than a lesser number of large transfer switches. By this approach, failure of a single transfer switch should not affect the entire facility. NFPA 99 endorses this approach by separating the electrical system into subsystems.

13-5.8.4 Include a fully rated break and load maintenance bypass switch in parallel with a closed transition ATS. It is important that the ATS be designed for maintenance and repair without requiring shutdown of the associated system.

13-5.8.5 Refer to NFPA 99 for any transfer switch applications involving medical facilities.

13-5.9 **Information Sources**. The following references provide additional information regarding automatic transfer switches.

- EGSA *On-Site Power Generation: A Reference Book*—provides a detailed overview of design and application issues.

- EGSA 100S, *Performance Standard for Transfer Switches for Use with Engine Generator Sets*—contains classifications, applications and performance requirements for transfer switches for emergency and standby transfer switches.

- IEEE 446—discusses ATS applications.

- NFPA 99—provides specific electrical requirements for medical facilities and addresses transfer switch requirements in detail.

- NFPA 111—establishes the NFPA requirements for ATS designs.

- UL 1008—establishes ATS certification requirements and is a useful reference source for ATS ratings.

CHAPTER 14

STATIONARY BATTERY SYSTEMS

14-1 STATIONARY BATTERIES.

14-1.1 Selection.

14-1.1.1 To an ever-increasing degree, manufacturers design battery cells for specific applications. A cell designed for reliable, long-life service in one application can fail quickly in another application. The system designer is responsible for selecting the best battery for a given application. The best design balances system technical requirements and goals with cost and ongoing maintenance requirements. When selecting the battery size and type, consider the following factors:

- Application and duty cycle requirements.
- System interface limitations.
- Service environment.
- Initial equipment cost.
- Installation cost.
- Ongoing maintenance cost.
- Periodic replacement cost.

14-1.1.2 Use vented lead acid batteries preferentially for switchgear control power and UPS applications. Batteries for switchgear or backup power applications should be rated for general purpose, switchgear, or utility use. Batteries for UPS applications should be rated for UPS or high-rate use.

14-1.1.3 Nickel-cadmium batteries are often more expensive than vented lead-acid batteries and should be considered primarily for extreme temperature environments or engine-starting applications. Nickel-cadmium batteries are preferred for engine starting applications because of their high-rate discharge capability.

14-1.1.4 As a general practice, do not use a valve-regulated lead acid (VRLA) battery if a vented lead-acid battery will satisfy the design requirements. VRLA batteries have exhibited a shorter service life than vented equivalents and have shown a tendency to fail without warning. Refer to AFPAM 32-1186, *Valve-Regulated Lead-Acid Batteries for Stationary Applications*, for additional information regarding VRLA batteries.

14-1.1.5 VRLA batteries are allowed to be used in the following types of applications:

- Installations with small footprints such that a vented battery with adequate power density will not fit within the available space.

- Locations in which the consequences of electrolyte leakage cannot be allowed. For example, some buildings cannot tolerate the consequences of electrolyte leakage into the internal wiring spaces between floors. A vented lead-acid cell can leak its entire electrolyte reserve if the container fails; a VRLA battery will have little or no leakage upon container failure. UPS systems are often located in areas that necessitate the use of a VRLA battery.

14-1.1.6 Just as VRLA batteries have applications in which they will be preferentially used, there are also applications in which their use should be avoided. Do not use VRLA batteries in the following types of applications:

- Unregulated environments that can experience abnormally high and low temperatures.

- Unmonitored locations that seldom receive periodic maintenance checks. VRLA batteries have shown a tendency to fail within only a few years after installation.

- Critical applications, unless the installation location requires the features available only in a VRLA battery.

14-1.1.7 Apply the following service life for life-cycle cost comparisons of stationary batteries:

- Small VRLA batteries – 3 years.

- Large VRLA batteries – 7 years.

- Small vented lead acid batteries – 10 years.

- Large vented lead acid batteries – 15 years.

- Nickel-cadmium batteries – 15 years.

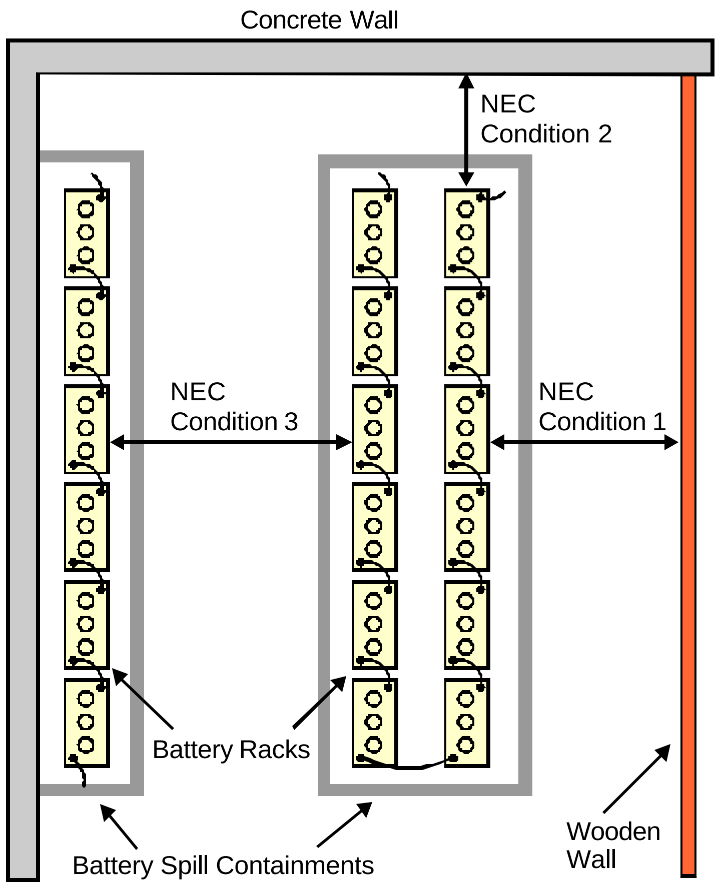
14-1.2 **Battery Areas and Battery Racks**.

14-1.2.1 Locate stationary batteries within a protective enclosure or area accessible only to qualified personnel. A protective enclosure can be a battery room, control building, enclosure, or other equipment that will protect the contained battery and limit the likelihood of inadvertent contact with energized parts.

14-1.2.2 Provide space around batteries to allow safe inspection, maintenance, testing, and cell replacement. When required by the battery size or battery type, provide space above the cells to allow for operation of lifting equipment, addition of water, and taking measurements. Provide working clearances in accordance with NEC

Article 480.9(C) (2002 Edition). Figure 14-1 provides examples of the NEC-required clearances.

Figure 14-1. Battery Room Clearances



14-1.2.3 Select the battery rack to fit within the defined footprint while also satisfying the need for maintenance access. Although this might seem to be an obvious design consideration, many batteries have been installed in a manner such that access to some (or all) cells is severely limited. Examples of actual poor battery installations include:

14-1.2.3.1 Stepped battery racks without consideration of access to the rear row. The worst installations require personnel to reach over two rows to get access to a third row, thereby exposing personnel to the risk of short circuits and electric shock during maintenance. In this case, access should have been provided behind the battery rack to allow access to the last row.

14-1.2.3.2 Vertical two-high arrangements in which the lower row is completely blocked by the upper row. Access to the lower row requires complete disassembly and removal of the upper row. This is an example of a *maintenance-proof* design; because access to the lower row is so difficult, adequate maintenance can not be performed on this battery.

14-1.2.3.3 Sealed battery cubicle inside a UPS with insulated terminal covers in which the battery requires disconnection to gain access. This is another maintenance-proof design; periodic voltage measurements are not even possible. Some UPS enclosures require partial or sometimes almost complete disassembly just to reach the batteries, and thus cannot be inspected while in service.

14-1.2.3.4 VRLA installations that are so tall that a ladder is needed to reach the upper rows.

14-1.2.3.5 Battery installations hidden behind other equipment, which is also a violation of local building codes.

14-1.2.4. Figures 14-2 and 14-3 show typical battery rack configurations for vented cells. Regardless of the design, personnel should think through how they will have ready access to each cell. Larger VRLA cells are often mounted horizontally in a vertical configuration and have plastic safety covers over the terminals.

Figure 14-2. Two-Step Battery Rack Configurations (End View)

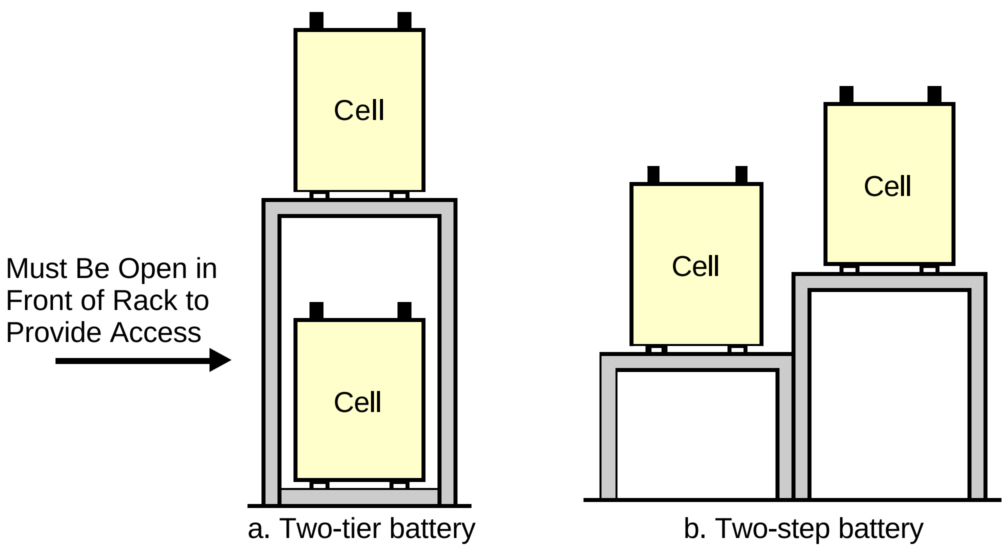
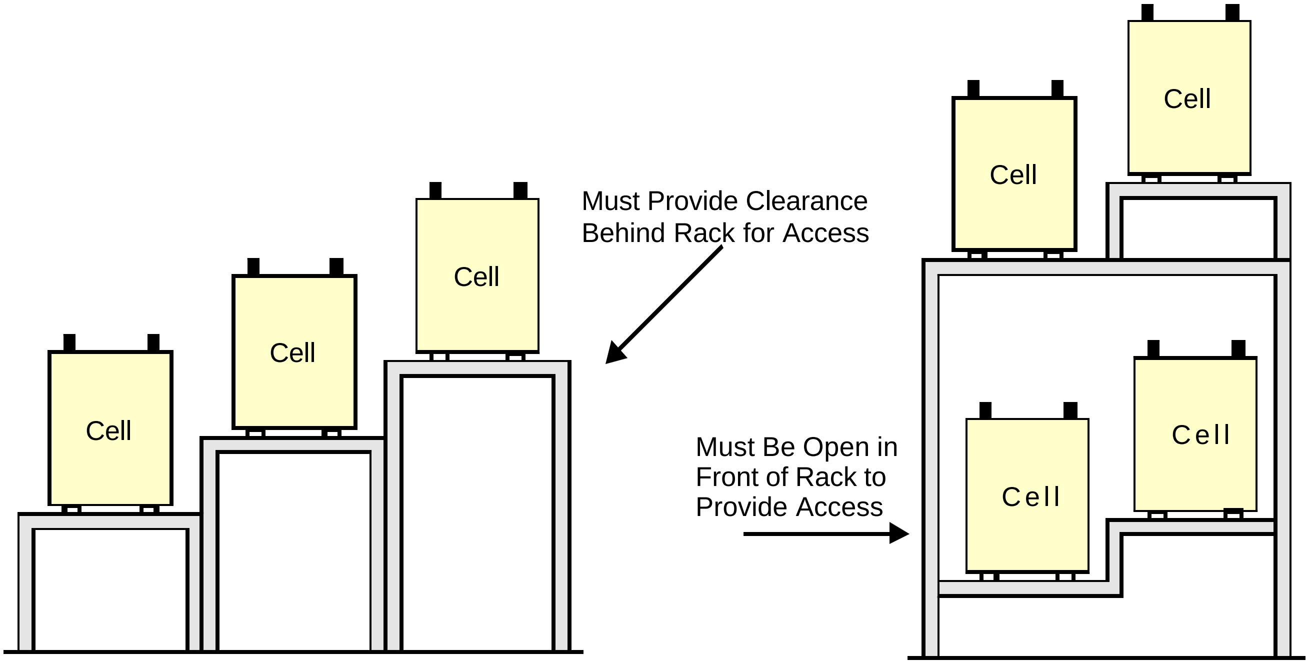


Figure 14-3. Larger Battery Rack Configurations (End View)



a. Three-step battery   b. Two-tier, two-step battery

14-1.2.5 Obtain the battery rack from the same manufacturer that supplies the battery. Other battery racks might not be designed for the particular battery to be installed and can place stress on the cell containers due to inadequate clearances. The eventual consequence of this stress can be container failure and subsequent electrolyte leakage.

14-1.2.6 Select and install battery racks in accordance with International Conference for Building Officials (ICBO) Uniform Building Code (UBC) criteria based on seismic risk zone. Table 14-1 shows the rack requirements based on seismic zone.

Table 14-1. Battery Rack Requirements by Seismic Zone

Seismic Zone	Description
0—earthquakes are unlikely.	Racks do not require cell restraints.
1—distant earthquakes might cause minor motion.	Racks require side restraints.
2-4—local or nearby earthquake.	Racks require heavy-duty construction with side restraints and should have additional floor anchor points.

14-1.2.7 Floors of battery areas should be of an acid-resistive material, or be painted with acid-resistive paint, or be otherwise protected. Provision should be included to contain electrolyte spills from vented lead-acid batteries.

14-1.2.8 Protect lighting fixtures in battery areas from physical damage by guards or isolation. Receptacles and lighting switches should be located outside of the battery area.

14-1.2.9 Batteries with a nominal voltage above 250 volts require special installation considerations as detailed in NEC Article 480.6 (2002 Edition).

14-1.3 **Installation Design Considerations**.

14-1.3.1 **Industry Standards**. The installation of a new battery or the replacement of an existing battery represents a significant effort. Review the following IEEE standards, as applicable for the battery type, prior to the installation:

- ANSI/IEEE 450, *IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications*.
- ANSI/IEEE 484, *IEEE Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications*.
- IEEE 485, *IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications*.
- ANSI/IEEE 1106, *IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications*.
- IEEE 1187, *IEEE Recommended Practice for Installation Design and Installation of Valve Regulated Lead-Acid Batteries for Stationary Applications*.
- IEEE 1188, *IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications*.

14-1.3.2 **Design Requirements**.

14-1.3.2.1 Verify that the selected battery is appropriate for the expected operating environment. Specifically, determine the average ambient temperature for the installation location and evaluate if the battery is expected to perform well in the environment. Temperature has a major impact on the battery's overall performance and service life; ambient temperature extremes must be given careful consideration. If the battery is to be located in an enclosure, the expected ambient temperature extremes inside the enclosure should be determined.

14-1.3.2.2 Verify ventilation is adequate for the new installation. If the battery is to be located in an enclosure (such as a UPS battery), ventilation requirements must be clearly addressed. The battery area must be ventilated, either by natural or powered ventilation system, to limit hydrogen accumulation to less than an explosive mixture. If powered ventilation is required to limit hydrogen buildup, annunciate failure of the ventilation system. The ventilation system must limit hydrogen accumulation to less than 2 percent of the total volume of the battery area and the location should be free of areas that might collect pockets of hydrogen. Maximum hydrogen evolution rate is 1.27 x 10^{-7} cubic meters per second (0.000269 cubic feet per minute) per charging ampere per cell at 25 °C (77 °F) at standard pressure. The worst-case condition occurs when forcing maximum current into a fully charged battery, such as the end of an equalizing charge, and applies to both vented and VRLA batteries.

14-1.3.2.3 Verify that the new battery arrangement will not cause disruptions in airflow that could result in unacceptable cell temperature variations.

14-1.3.2.4 Verify the charger is compatible with the new battery. Consider the following design features: recharge rate, output ripple, and equalizing voltage.

14-1.3.2.5 Confirm that electrical protective device ratings and setpoints are appropriate for the battery size and type.

14-1.3.3 **Installation Requirements**.

14-1.3.3.1 Ensure the maintenance and test requirements of the battery are well understood. Include the cost of maintenance into the battery selection process. The type of battery selected (vented lead-acid, VRLA, or nickel-cadmium) will directly impact maintenance requirements.

14-1.3.3.2 Confirm the footprint of the battery allows for adequate room to perform maintenance and testing.

14-1.3.3.3 Confirm the rack height is appropriate for the room dimensions to allow access to the tops of the cells without undue hazard.

14-1.3.3.4 Verify the rack height, room arrangement, and footprint allow for proper arrangement of rigging equipment.

14-1.3.3.5 Determine if on site spare cells will be needed. If spare cells will be maintained on site permanently, establish where the cells will be stored and how they will be charged.

14-1.3.3.6 Verify existing test equipment is adequate.

14-1.3.3.7 Determine if the installation location allows for convenient connection to load test equipment. A case in point is a battery that was installed in a building basement and the available load bank was too large for the stairs.

14-1.3.3.8 All related local maintenance inspection and test procedures might require revision if the battery type is changed.

14-1.3.3.9 Install safety signs inside and outside of the battery area prohibiting smoking, sparks, or flame.

14-1.3.3.10 Inspect all cells for damage before installation. Verify that the cells were stored in accordance with the manufacturer's recommendations.

14-1.3.3.11 Apply an initial charge in accordance with the manufacturer's recommendations after installation.

14-1.3.3.12 Take a baseline set of intercell and termination resistances and include this information in the annual inspection procedure as future acceptance criteria.

14-1.3.3.13 Baseline internal ohmic measurements should be taken for VRLA batteries in accordance with IEEE 1187.

14-1.3.3.14 An acceptance test, in accordance with IEEE 450, IEEE 1188, or IEEE 1106, as applicable, is recommended as part of the installation if the manufacturer did not perform an acceptance test before shipment.

14-1.3.3.15 If a VRLA battery is installed, all manufacturer's recommendations for the installation and operation of the battery should be closely reviewed. The installed location and configuration must comply with the manufacturer's requirements.

14-2 **BATTERY CHARGERS**.

14-2.1 This section applies to stand-alone battery chargers that are installed for dc systems. UPS systems also contain battery charging capability; however, the charger is designed for operation as part of the UPS power module.

14-2.2 Use single-phase chargers for smaller applications. Rate single-phase battery chargers for 240 volts single phase, unless only 120 volts is available. Three-phase chargers should be used if the charger's dc output current rating will be greater than 75 amperes. Unless the battery has specific requirements to the contrary, all chargers should be of the constant voltage type.

14-2.3 Regardless of the type selected, each charger should at least have the following features:

- Output voltage regulation of ± 0.5 percent.
- Current limiting circuitry.
- Filter circuitry.
- Float and equalize charge adjustment capability with a timer for an equalize charge.
- Input and output circuit breaker protection.

- Ammeter and voltmeter.

- Ground detection lamps.

- Alarm contacts for loss of ac power and low dc voltage.

14-2.4 Unattended locations should have remote monitoring capability. In this case, alarm contacts for loss of ac power and low dc voltage should require the capability to support remote monitoring.

14-3 **BATTERY PROTECTION**.

14-3.1 NEC Article 240.21 (2002 Edition) requires that "Overcurrent protection shall be provided in each ungrounded circuit conductor and shall be located at the point where the conductors receive their supply…". Install a circuit breaker or fused protection device as close to the battery as possible because the battery is the power source during battery discharge. A circuit breaker or fused disconnect switch also allows battery disconnection for maintenance or repair.

14-3.2 Provide overcurrent protection for each string in a parallel battery system.

14-3.3 Refer to IEEE 1375, *Guide for the Protection of Large Stationary Battery Systems*, for additional guidance.

CHAPTER 15

LIGHTING

15-1 **LIGHTING DESIGN CRITERIA**. Because of the importance of lighting and the rate at which lighting technology changes, a separate UFC manual will be developed for lighting design and controls. Until the UFC manual is issued, apply the lighting design criteria provided in Appendix F.

CHAPTER 16

COMMUNICATIONS AND INFORMATION SYSTEMS

16-1 **INTRODUCTION**. Chapter 16 addresses communications and information systems as they relate to interior wiring systems, facility network equipment, desktop instruments and workstations; exterior duct and communications cable to the appropriate service connection point(s); and communications and information system infrastructure upgrade requirements. The design criteria for communications and information systems are covered in other documents and are referenced here for completeness.

16-2 **ARMY DESIGN CRITERIA**. Apply the USACE ETL 1110-3-502, *Telephone and Network Distribution System Design and Implementation Guide* as the basis for design criteria.

16-3 **NAVY DESIGN CRITERIA**. Apply MIL-HDBK-1012/3 as the basis for design criteria.

16-4 **AIR FORCE DESIGN CRITERIA**. The Air Force (JTA-AF) Fixed Base Technical Architecture (FBTA) provides the technical design criteria relating to communications and information systems. Appendix F provides additional information regarding design criteria for Air Force installations.

CHAPTER 17

AUXILIARY AND SUPPORT SYSTEMS

17-1 **FIRE ALARM AND DETECTION SYSTEMS**.

17-1.1 Provide fire alarm and detection systems in accordance with MIL-HDBK-1008C.

17-1.2 Provide auxiliary power support for such systems in accordance with NFPA 72, *Fire Alarm Systems*, except that primary (non-rechargeable) batteries are not authorized for use. If the fire alarm and detection system is installed in a facility equipped with an auxiliary generator for supplying emergency lighting power (such as in a hospital), design this system to also supply auxiliary power for the fire alarm and detection system. If a central stationary battery provides emergency lighting power, this system can supply auxiliary power for the fire alarm and detection system. Design the capacity of the selected auxiliary power source to include the fire alarm and detection system load.

17-2 **SECURITY SYSTEMS**. Guidance for the design and installation of intrusion detection, electronic entry control, and alarm assessment systems, where authorized, is provided by the following sources:

- MIL-HDBK-1013/1A, *Design Guidelines for Physical Security of Facilities*.
- TM 5-853-1, *Designing for Security*.

17-3 **TELEVISION SYSTEMS (TV)**.

17-3.1 TV antenna systems should be provided only when the facility cable TV system does not provide adequate coverage or is not accessible at the new facility.

17-3.2 Install antennas on buildings only when signals are not available from an installation distribution system. Antenna masts must be supported, grounded, and guyed in accordance with the NEC. Coordinate roof penetrations with the architectural plans.

17-3.3 Provide lightning protection for antenna installations in accordance with NEC Article 810 (2002 Edition) and NFPA 780 Article 3-17.

17-3.4 Locate exterior mounted antennas and supports as unobtrusively as possible for minimum aesthetic impact.

17-3.5 For multi-outlet systems, amplifiers and splitters should be utilized to obtain uniform and adequate signal strengths at all outlets. Community antenna television (CATV) or TV outlets should be located in recreation areas, dayrooms, and lounges of barracks. In bachelor officer quarters, outlets should be located in the living rooms of each quarters and, if applicable, in the lobby. Outlets in service clubs should be located in each activity and dining room.

17-4 **CLOCK SYSTEMS**. Clock systems should normally be provided in buildings requiring more than 25 clocks only if authorized and justified by the using agency. Wherever possible, the use of battery-operated clocks is recommended over electric clock systems because of the added facility wiring expense caused by clock systems.

17-5 **ENERGY MANAGEMENT AND CONTROL SYSTEMS (EMCS)**. Refer to TM 5-815-2/AFM 32-1093, *Energy Monitoring And Control Systems (EMCS)*, for design criteria for an EMCS.

CHAPTER 18

FACILITY-SPECIFIC DESIGN CRITERIA

18-1 **MEDICAL FACILITIES**.

18-1.2 Apply the following documents for the interior electrical design effort of medical facilities:

- AFI 32-1023, *Design and Construction Standards and Execution of Facility Construction Projects*.
- Army Engineering Instruction (AEI), *Medical Design Standards*.
- Department of the Army, Volume 1, *Medical Design Guide*.
- MIL-HDBK-1191, *Medical Military Design and Construction Criteria*.
- NFPA 99, *Health Care Facilities*.
- IEEE 602.

18-2 **POWER DISTRIBUTION FOR AIRCRAFT HANGARS (SHELTERS)**.

18-2.1 Refer to NEC Article 513 (2002 Edition) and NFPA 409, *Standard on Aircraft Hangars*, for design criteria for aircraft hangars, which is applicable to maintenance, servicing, and storage hangars; corrosion control hangars; fuel cell repair hangars; depot overhaul facilities; and all types of aircraft shelters. The following hazardous location classifications apply to hangars.

18-2.1.1 Any pit or depression below the level of the hangar floor must be classified as a Class I, Division 1 location, extending up to the floor level.

18-2.1.2 The entire area of the hangar, including any adjacent and communicating areas not suitably isolated from the hangar, must be classified as a Class I, Division 2 location up to a level of 457 millimeters (18 inches) above the floor.

18-2.1.3 The area within 1.5 meters (5 feet) horizontally from aircraft power plants or aircraft fuel tanks must be classified as a Class I, Division 2 location that extends upward from the floor to a level 1.5 meters (5 feet) above the upper surface of wings and of engine enclosures.

18-2.2 Adjacent areas in which flammable liquids or vapors are not likely to be released, such as stock rooms, electrical control rooms, and other similar locations, will not be classified provided they are adequately ventilated or effectively isolated from the hangar by walls or partitions.

18-2.3 Wherever possible, do not locate electrical distribution or utilization equipment in zones classified as hazardous. Locate main distribution panels, metering equipment, and similar electrical equipment in a room separate from the aircraft storage and servicing areas. This electrical equipment room must be protected by a partition having at least a 1-hour fire resistance rating. The partition must not be penetrated except by electrical raceways, which must be protected by approved sealing methods that maintain the same fire resistance as the partition.

18-2.4 Corrosion control hangars are designed to provide space and equipment for the corrosion control processing of aircraft. Functions performed in a corrosion control hangar can include deicing; limited detergent washing and rinsing; paint stripping; corrosion removal; protective coating application and painting; and finish curing and drying. Locate electrical utilization equipment in corrosion control hangars to facilitate the various functions that might be performed. Electrical installations in the hangar area, paint and chemical mixing rooms, paint equipment cleaning room, and paint storage room must meet the requirements specified in NEC Articles 500 and 501 (2002 Edition) for the specific hazardous (classified) location. Apply NFPA 33, *Spray Applications Using Flammable or Combustible Materials*, in hangars where the rate of spray paint application exceeds 0.9464 liters (1 quart) per hour or the cumulative application of more than 3.7854 liters (1 gallon) over an eight-hour period.

18-2.5 Fire protection criteria for hangars are provided in Air Force ETL 98-7, *Fire Protection Engineering Criteria – New Aircraft Facilities*, and ETL 98-8, *Fire Protection Engineering Criteria – Existing Aircraft Facilities*. Wherever deluge sprinkler protection is provided, electrical equipment in the hangar bay must be waterproof to prevent equipment damage in the event of testing or accidental discharge of the deluge system.

18-2.6 Refer to paragraph F-15.5 for lighting design criteria.

18-2.7 Refer to paragraph 6-4 for design criteria for convenience outlets and receptacles. Flexible cords for aircraft energizers, ground support equipment, and mobile servicing equipment must be suitable for the type of service and approved for extra-hard usage, and must include an equipment grounding conductor. All outlets in a Class I, Division 2 location in the aircraft servicing area must be rated for such use.

18-3 **HIGH-ALTITUDE ELECTROMAGNETIC PULSE (HEMP) AND TEMPEST PROTECTION**.

18-3.1 TEMPEST is a program to develop methods of preventing the compromise of government and military information by reducing or eliminating unintended electric or electromagnetic (EM) radiation emanations from electronic equipment. The TEMPEST approach is nearly the opposite of the HEMP event. TEMPEST is the unclassified name for the studies and investigation of compromising emanations. Equipment within the facility can be the source of EM waves and stray currents/voltages with characteristics that are related to the information content of signals being processed. Thus, HEMP and TEMPEST protective measures must each control EM energy, the former protecting system equipment from externally generated signals and the latter containing emissions from internal sources.

18-3.2 Apply the following documents for HEMP and TEMPEST protection:

- MIL-STD-188-125-1, *High-Altitude Electromagnetic Pulse (HEMP) Protection for Ground-Based C^4I Facilities Performing Critical, Time-Urgent Missions*.

- MIL-HDBK-423, *High-Altitude Electromagnetic Pulse (HEMP) Protection for Fixed and Transportable Ground-Based C^4I Facilities*.

- *USAF Handbook for the Design and Construction of HEMP/TEMPEST and Other Shields in Facilities*.

- National Security Telecommunications Information Systems Security Issuances (NSTISSI) 7000, *TEMPEST Countermeasures for Facilities* (refer to the NSTISSI Index for related publications).

- AFSSM 7011, *Emission Security Countermeasures Review*.

18-3.3 The following documents provide additional information regarding shielding of electronic equipment:

- MIL-HDBK-419A

- MIL-HDBK-1195, *Radio Frequency Shielded Enclosures*

18-4 **SEISMICALLY QUALIFIED DESIGNS**. Apply the following documents for seismically-qualified design criteria:

- TI 809-04, *Seismic Design for Buildings*.

- TI 809-05, *Seismic Evaluation and Rehabilitation for Buildings*.

18-5 **TROPICAL ENGINEERING**. Refer to MIL-HDBK-1011/1, *Tropical Engineering*.

18-6 **ARCTIC ENGINEERING**. Refer to TM 5-852-9, *Arctic and Subarctic Construction, Buildings* and TM 5-852-5, *Arctic and Subarctic Construction: Utilities*.

18-7 **GENERAL FACILITY TYPES**. Refer to MIL-HDBK-1000/1A, *Engineering and Design Criteria and Documentation for Navy Facilities*. This MIL-HDBK provides an index to other manuals and handbooks, which includes design criteria for specific facility types.

GLOSSARY

Abbreviations and Acronyms:

AA—Self-Cooled Transformer

AA/FA—Self-Cooled/Forced-Air Cooled Transformer

ac—Alternating Current

AFA—Forced-Air Cooled Transformer

AFCA—Air Force Communications Agency

AFCEE—Air Force Center for Environmental Excellence

AFCESA—Air Force Civil Engineer Support Agency

AFI—Air Force Instruction

AFJMAN—Air Force Joint Manual

AFMAN—Air Force Manual

AFPAM—Air Force Pamphlet

AHJ—Authority Having Jurisdiction

ANSI—American National Standards Institute

ASD—Adjustable Speed Drive

ASHRAE— American Society of Heating, Refrigerating and Air-Conditioning Engineers

ASTM—American Society for Testing and Materials

ATS—Automatic Transfer Switch

AWG—American Wire Gauge

BCE—Base Civil Engineer

BCP—Base Comprehensive Planning

BICSI—Building Industry Consulting Service International

BIL—Basic Impulse Insulation Level

BITS—Base Information Transport System

C-CS—Communications and Computer Systems

C&I—Communications and Information

C4I—Command, Control, Communication, Computer, and Intelligence

CAD—Computer-Aided Drafting

CATV—Community Antenna Television

CCT—Correlated Color Temperature

CCTV—Closed Circuit Television

CFR—Code of Federal Regulations

CID—Comprehensive Interior Design

CRI—Color Rendering Index

CRT—Cathode Ray Tube

CSIR—C&I Systems Installation Record

CSO—Communications and Information Systems Officer

CSRD—Communications and Information Systems Requirements Document

CT—Current Transformer

CVS—Computer Vision Syndrome

dB—Decibel

dc—Direct Current

DLA—Defense Logistics Agency

DOE—Department of Energy

EGSA—Electrical Generating Systems Association

EI—Engineering Instruction

EIA—Electronics Industries Association

EIG—Engineering Installation Group

EM—Electromagnetic

EMCS—Energy Management and Control System

EMP— Electromagnetic Pulse

EMT—Electrical Metallic Tubing

EO—Executive Order

EPA—Environmental Protection Agency

ER—Engineering Regulation

ETL—Engineering Technical Letter

IEC—International Electrotechnical Commission

FCAN—Full Capacity Above Normal

FCBN—Full Capacity Below Normal

FEMP—Federal Energy Management Program

FIPS—Federal Information Processing Standard

FPN—NEC Fine Print Note

GFCI—Ground Fault Circuit Interrupter

GFP—Ground Fault Protection

HACR—Heating, Air Conditioning, and Refrigeration

HEMP— High-Altitude Electromagnetic Pulse

HID—High-Intensity Discharge

HQ—Headquarters

HVAC—Heating, Ventilating, and Cooling

hp—Horsepower

Hz—Hertz

I^2R—Resistive Heat Loss

I—Amperes

ICBO—International Conference for Building Officials

ICC—Interstate Commerce Commission

IEEE—Institute of Electrical and Electronics Engineers

IESNA—Illuminating Engineering Society of North America

IMC—Intermediate Metal Conduit

JTA-AF—Air Force Joint Technical Architecture

kW—Kilowatts

kWh—Kilowatt Hours

kV—Kilovolts

kVA—Kilovolt-Amperes

kVAR—Kilovolt-Amperes Reactive

LAN—Local Area Network

LDD—Luminaire Dirt Depreciation

LED—Light-Emitting Diode

LLD—Lamp Lumen Depreciation

LVPB—Low Voltage Power Breaker

MAJCOM—Major Command

MCC—Motor Control Center

MCCB—Molded Case Circuit Breaker

MCOV—Maximum Continuous Overvoltage Rating

MCP—Military Construction Program

MCP—Motor Circuit Protector

MDF—Main Distribution Frame

MI—Mineral Insulated

MIL HDBK—Military Handbook

MOV—Metal Oxide Varistor

MTS—Maintenance Testing Specifications

MVA—Megavolts-Ampere

NAVFAC—Naval Facilities

NBC—Nuclear, Biological, Chemical

NEC—National Electrical Code

NECA—National Electrical Contractors Association

NEIS—National Electrical Installation Standards

NEMA—National Electrical Manufacturers Association

NESC—National Electrical Safety Code

NETA—International Electrical Testing Association

NFA—Net Floor Area

NFPA—National Fire Protection Association

NIST—National Institute of Standards and Technology

NSTISSI—National Security Telecommunications Information Systems Security Issuances

O&M—Operations and Maintenance

OEM—Original Equipment Manufacturer

OSHA—Occupational Safety and Health Administration

PCB—Polychlorinated Biphenyl

PCC—Point of Common Coupling

PCCIE—Power Conditioning and Continuation Interfacing Equipment

PDS—Protected Distribution System

PF—Power Factor

POL—Petroleum, Oil, and Lubricant

PSA—Project Support Agreement

PT—Potential Transformer

PUB—Publication

PVC—Polyvinyl Chloride

R—Resistance

RE—Remote

RFI—Radio Frequency Interference

RMS—Root-Mean-Square

RPM—Revolutions Per Minute

SAD—Seasonal Affective Disorder

SAE—Society of Automotive Engineers

SE—Service Entrance

SF—Square Foot

SP—Surge Protector

SPD—Surge Protective Device

STEM—Systems Telecommunications and Engineering Manager

SUPS—Static UPS

SWD—Switching Duty

TB—Technical Bulletin

TBB—Telecommunications Bonding Backbone

TC—Telecommunications Closets

TDD—Total Demand Distortion

TGB—Telecommunications Grounding Busbar

THD—Total Harmonic Distortion

TIA—Telecommunications Industry Association

TM—Technical Manual

TMGB—Telecommunications Main Grounding Busbar

TV—Television

TVSS—Transient Voltage Surge Suppressor

UBC—Uniform Building Code

UF—Underground Feeder

UFGS—Unified Facilities Guide Specifications

UL—Underwriters Laboratories

UPS—Uninterruptible Power Supply

US—United States

USACE—U.S. Army Corps of Engineers

V—Volt

VAC—Volts Alternating Current

VDC—Volts Direct Current

VDT—Video Display Terminal

VFD—Variable Frequency Drive (see ASD)

VRLA—Valve-Regulated Lead Acid

W—Watts

X—Reactance

X/R—Ratio of Reactance to Resistance

Terms:

> *Note: The terms listed here are provided for clarification of the design criteria provided in this manual. Refer to* IEEE 100, IEEE Standard Dictionary of Electrical and Electronics Terms*, for additional electrical-related definitions. Refer to the* IESNA Lighting Handbook *for lighting-related terms.*

AC Contactor—An electrical device designed for the specific purpose of establishing or interrupting an ac power circuit.

Acceptance Test (Stationary Battery)—A constant current or power capacity test made on a new battery to determine whether it meets specifications or manufacturer's ratings.

Accessible—Easily entered or vacated by a physically disabled person.

Accessible Area of Refuge—An area of refuge complying with the accessible route requirements of International Code Council (ICC)/ANSI A117.1, *American National Standard for Accessible and Usable Buildings and Facilities*.

Active Filter—A power electronics device equipped with controls to provide cancellation of harmonic current components caused by nonlinear loads.

Ambient-Compensated Circuit Breaker—A breaker that has the capability to partially or completely counteract the effect of ambient temperature upon the tripping characteristics.

Area of Refuge—A floor or fully sprinklered building that has at least two accessible rooms or spaces separated from each other by smoke partitioning; or a space in a means of egress that is protected from the effects of fire and smoke, either by separation from the other spaces in the same building or by virtue of location, thereby permitting delay in egress travel from any level.

Asymmetrical Current—A current wave that is not symmetrical about the zero axis. The current is offset from the zero axis with the magnitude of current above and below the zero axis unequal.

Automatic Transfer Switch (ATS)—A switch designed to sense the loss of one power source and automatically transfer the load to another source of power.

Auto-Transformer—A transformer having a single continuous winding, portions of which are common for the input and output windings.

Available Short-Circuit Current—The maximum current that the power system can deliver through a given circuit point to any negligible impedance short circuit applied at the given point, or at any other point that will cause the highest current to flow through the given point.

Backup Protection—A form of protection that operates independently of specified components in the primary protective system. It may duplicate the primary protection or may be intended to operate only if the primary protection fails or is temporarily out of service.

Bolted Fault—The highest magnitude short circuit current for a particular fault location. The impedance at the fault location is usually very low or zero for a bolted fault.

Bonding—A reliable connection to assure electrical conductivity. In terms of grounding, the permanent joining of metallic parts to form an electrically conductive path to assure electrical continuity with the capacity to conduct safely any current likely to be imposed.

Bonding Conductor—A conductor used specifically for the purpose of bonding.

Branch Circuit—The circuit conductors and components between the final overcurrent device protecting the circuit and the equipment.

Bypass Transformer—In terms of UPS systems, a transformer that provides ac power to the UPS loads when the UPS equipment fails, is temporarily overloaded, or is out of service for maintenance.

Circuit Breakers Incorporating Ground Fault Protection—Circuit breakers that perform all normal circuit breaker functions and also trip when a current to ground exceeds some predetermined value.

Clearing Time—The total elapsed time between the beginning of an overcurrent and the final interruption of the circuit at rated voltage. For a fuse, the clearing time is considered the sum of the melting time and the arcing time. For a breaker, the clearing time is the elapsed time between the actuation of a release device and the instant of arc extinction on all poles of the primary arcing contacts.

Closed Transition Switch—Transfer switch that provides a momentary paralleling of both power sources during a transfer in either direction. The closed transition is possible only when the sources are properly interfaced and synchronized.

Constant Voltage Transformer—A ferroresonant transformer used for voltage regulation in single-phase circuits.

Current Limiting Circuit Breaker—A circuit breaker that does not utilize a fusible element, and that when operating within its predetermined current-limiting range, limits the let-through I^2t to a value less than the I^2t of one-half cycle of the expected symmetrical current.

Current Limiting Fused Circuit Breaker—A circuit breaker in combination with integral current-limiting fuses that, when it interrupts a current within its specified current limiting range, purposely introduces an impedance so as to reduce the current magnitude and duration.

DC Link—The direct-current power interconnection between rectifier or rectifier/charger and inverter function units.

Delayed Transition—A timed disconnection of the load from the power sources during transfer, primarily to allow for the decay of motor residual voltage.

Earth Ground—An electrical connection to earth obtained by a grounding electrode system.

Electromagnetic Relay—An electromechanical relay that operates principally by action of an electromagnetic element that is energized by the input quantity.

Electromechanical Relay—A relay that operates by physical movement of parts resulting from electromagnetic, electrostatic, or electrothermic forces created by the input quantities.

Emergency Lighting System—A system capable of providing minimum required illumination specified in NFPA 101, *Code for Safety to Life from Fire in Buildings and Structures*, Section 5.9. It includes the lighting units, related backup power source(s), and required connections.

Equipment Grounding Conductor—The conductor used to connect the noncurrent carrying parts of conduits, raceways, and equipment enclosures to the grounded conductor (neutral) and the grounding electrode at the service equipment (main panel) or secondary of a separately derived system, such as an isolation transformer.

Existing Facility—A facility is existing if changes to be made are cosmetic or minor in nature.

Feeder—The circuit conductor and components between the main and the branch protective devices.

Filter—A general term used to describe equipment whose purpose is to reduce harmonic voltage or current distortion flowing in or being impressed upon specific parts of an electrical system.

Fixed Instantaneous Trip—The portion of an overcurrent trip element that contains a nonadjustable means of tripping a breaker instantaneously at or above a predetermined level of current.

Frame—An assembly consisting of all parts of a circuit breaker with the exception of an interchangeable trip unit.

Frame Rating—The maximum continuous current rating for a given frame size.

Frame Size—A classification for a group of MCCBs that are physically interchangeable with one another. Frame size is expressed in amperes and corresponds to the largest ampere rated breaker within the given group.

Ground—A conducting connection, either intentional or accidental, by which an electric circuit or equipment is connected to the earth, or to some conducting body of relatively large extent that serves in place of the earth.

Grounded—An electrical connection that gives a circuit a direct positive path to ground.

Grounded Neutral—A point of an electrical system that is intentionally connected to ground.

Grounded, Solidly—Connected directly through an adequate ground connection in which no impedance has been intentionally inserted.

Harmonic—A sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency.

Horizontal Exit—A passage from one building to an area of refuge and access to a means of egress (per NFPA 101) in another building on approximately the same level; or a passage through or around a fire barrier (2 hour minimum) to an area of refuge with access to a means of egress (per NFPA 101) on approximately the same level in the same building, that affords safety from fire and smoke originating from the area of incidence and communicating areas.

I^2t—Heating caused by current as a function of time.

Inrush Current—The inrush current of a machine or apparatus is the maximum current that flows after being suddenly and fully energized.

Instantaneous—For relays and breakers, a term used to indicate that no delay is purposely introduced in the automatic tripping of the circuit breaker.

Instantaneous Trip Circuit Breaker—A circuit breaker intended to provide short circuit protection with no overload protection.

Integrally Fused Circuit Breaker—A circuit breaker with coordinated fuses connected in series with the trip elements of the circuit breaker that are mounted within the housing of the circuit breaker.

Let-Through Current—The maximum instantaneous or peak current that passes through a protective device.

Linear Load—An electrical load device that presents an essentially constant load impedance to the power source throughout the cycle of applied voltage in steady-state operation.

Listed—Applies to equipment or materials included in a list published by an organization acceptable to the authority having jurisdiction. The organization periodically inspects production and certifies that the items meet appropriate standards or tests as suitable for a specific use.

Low Voltage System—An electrical system having a maximum root-mean-square (rms) voltage of less than 1,000 volts.

Medium Voltage System—An electrical system having a maximum RMS ac voltage of 1,000 volts to 15 kV. Some documents such as ANSI C84.1 define the medium voltage upper limit as 100 kV, but this definition is inappropriate for facility applications.

Molded Case Circuit Breaker—A low voltage circuit breaker assembled as an integral unit in an enclosing housing of insulating material. It is designed to open and close by nonautomatic means, and to open a circuit automatically on a predetermined overcurrent, without damage to itself, when applied properly within its rating.

Molded Case Switch—A device assembled as an integral unit in an enclosing housing of molded insulating material, designed to open and close a circuit by nonautomatic means.

Motor Control Center—A piece of equipment that centralizes motor starters, associated equipment, bus and wiring in one continuous enclosed assembly.

New Construction—A facility is considered new if changes to be made are more than cosmetic or minor, such as major renovations, additions, or new facilities.

Nonlinear Load—A steady state electrical load that draws current discontinuously or has the impedance vary throughout the input ac voltage waveform cycle. Alternatively, a load that draws a nonsinusoidal current when supplied by a sinusoidal voltage source.

Point of Common Coupling (PCC)—The point of interface between two different parts of the power system where the propagation and characteristics of a power quality variation can be evaluated. With respect to evaluation of harmonic voltage and current limits at the supply to an end user, this is the point on the system where another end user can be supplied.

Power Quality—The concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment.

Primary Protection—First-choice relay protection in contrast with backup relay protection.

Radial System—A system in which independent feeders branch out radially from a common source of supply.

Sag—A decrease in RMS voltage or current at the power frequency for a duration of 0.5 cycle to 1 minute.

Selective Opening (Tripping)—The application of switching devices in series such that (of the devices carrying fault current) only the device nearest the fault will open and the devices closer to the source will remain closed and carry the remaining load.

Service Voltage—Voltage at the facility service entrance location.

Short Circuit—An abnormal condition (including an arc) of relatively low impedance, whether made accidentally or intentionally, between two points of different potential.

Surge Protector—A device composed of any combination of linear or nonlinear circuit elements and intended for limiting surge voltages on equipment by diverting or limiting surge current; it prevents continued flow of follow current and is capable of repeating these functions as specified.

Swell—An increase in RMS voltage or current at the power frequency for a duration of 0.5 cycle to 1 minute.

Symmetrical Current—A current wave symmetrical about the zero axis.

Tactile Signs—Signs perceptible by touch that provide critical egress information to the sight-impaired.

Thermal Trip Unit—A bimetal element connected to the breaker trip unit to provide protection with an inverse time characteristic.

Time-Current Curve—A graphical representation of the expected time of a breaker to open in response to overcurrent.

Transfer Switch—A device for transferring one or more load conductor connections from one power source to another.

Uninterruptible Power Supply System—A system that converts unregulated input power to voltage and frequency controlled filtered ac power that continues without interruption even with the deterioration of the input ac power.

Utilization Voltage—The voltage at the line terminals of utilization equipment.

Withstand Current—The specified RMS symmetrical current that a circuit breaker can carry in the closed position for a specified time.

X/R Ratio—The ratio of reactance to resistance in a circuit.

APPENDIX A

REFERENCES

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AFI 32-1065, *Grounding Systems*

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2. American Society of Heating, Ventilating, and Air Conditioning Engineers, 720 Tully Circle, Atlanta, GA 30335
3. BICSI, 8610 Hidden River Parkway, Tampa, FL 33637-1000
4. Illuminating Engineering Society of North America, 345 East 47th Street, New York, NY 10017
5. Institute of Electrical and Electronics Engineers, 345 East 47th Street, New York, NY 10017
6. Insulated Cable Engineers Association, Box P, South Yarmouth, MA 02664
7. International Electrical Testing Association, P.O. Box 687, 231 Red Rock Vista Drive, Morrison, CO 80465
8. National Electrical Manufacturers' Association, 2101 L Street, N.W., Suite 300, Washington, DC 20037
9. National Fire Protection Association, One Batterymarch Park, P.O. Box 9101, Quincy, MA 02269
10. Underwriter's Laboratories, Inc., 333 Pfingston Road, Northbrook, IL 60062

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MIL-HDBK-1012/3, *Telecommunications Premises Distribution Planning, Design, and Estimating*
MIL-HDBK-1013/1A, *Design Guidelines for Physical Security of Facilities*

MIL-HDBK-1191, *Medical Military Design and Construction Criteria*
MIL-HDBK-1195, *Radio Frequency Shielded Enclosures*
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Naval Facilities Engineering Command Planning and Design Policy Statement 98-01, *Design of Sustainable Facilities and Infrastructure*
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Naval Facilities Engineering Command Planning and Design Policy Statement 98-03, *Procurement of Sustainable Facilities and Infrastructure Through Architect-Engineer (A-E) and Related Contracts*
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29 CFR 1926.405, *Wiring Methods, Components and Equipment for General Use—Installation Safety Requirements*

Underwriter's Laboratories

UL 248-1-2000, *Low-Voltage Fuses – Part 1: General Requirements*
UL 248-2-2000, *Low-Voltage Fuses – Part 2: Class C Fuses*
UL 248-4-2000, *Low-Voltage Fuses – Part 4: Class CC Fuses*

UL 248-5-2000, *Low-Voltage Fuses – Part 5: Class G Fuses*
UL 248-6-2000, *Low-Voltage Fuses – Part 6: Class H Non-Renewable Fuses*
UL 248-7-2000, *Low-Voltage Fuses – Part 7: Class H Renewable Fuses*
UL 248-8-2000, *Low-Voltage Fuses – Part 8: Class J Fuses*
UL 248-9-2000, *Low-Voltage Fuses – Part 9: Class K Fuses*
UL 248-10-2000, *Low-Voltage Fuses – Part 10: Class L Fuses*
UL 248-12-2000, *Low-Voltage Fuses – Part 12: Class R Fuses*
UL 248-15-2000, *Low-Voltage Fuses – Part 15: Class T Fuses*
UL 497A-2001, *Standard for Secondary Protectors for Communication Circuits*
UL 497B-1999, *Standard for Protectors for Data Communication and Fire Alarm Circuits*
UL 498-2001, *Attachment Plugs and Receptacles*
UL 508-1999, *Industrial Control Equipment*
UL 1008-1996, *Standard for Automatic Transfer Switches*
UL 1449-1996, *Transient Voltage Surge Suppressors*

Miscellaneous Documents

ASHRAE/IESNA/ANSI 90.1-1999*, Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings*
Building Industry Consulting Service International (BICSI), *Telecommunications Distribution Methods Manual*, 1998
Energy Policy Act of 1992
Executive Order 13123
Federal Information Processing Standards Publication (FIPS PUB) 94*, Guideline on Electrical Power for ADP Installations*, Sept. 21, 1983 (withdrawn July 1997)
Life Cycle Costing Manual (NIST Handbook 135)
NECA/IESNA/ANSI 500-1998, *Recommended Practice for Installation of Commercial Lighting Systems*
NECA/IESNA 502-1999, *Recommended Practice for Installing Industrial Lighting Systems*
NETA ATS-1999, *Acceptance Testing Specifications for Electrical Power Distribution Equipment and Systems*
NETA MTS-1997, *Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems*

APPENDIX B

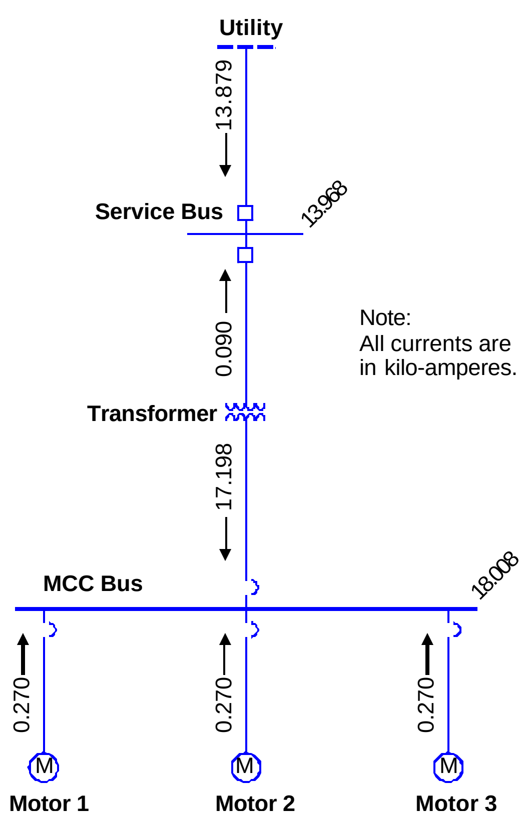
CALCULATION METHODS AND EXAMPLES

B-1 SHORT CIRCUIT CURRENT EFFECTS.

B-1.1 Electrical distribution systems must be designed to withstand the maximum expected fault (short circuit) current until the short circuit current is cleared by a protective device. This is a fundamental electrical requirement. NEC Article 110.9 (2002 Edition) requires that all protective devices intended to interrupt current at fault levels must have an interrupting rating sufficient for the nominal circuit voltage and the current that is available at the line terminals of the equipment. For this reason, the maximum available short circuit current must be determined for all locations throughout the electrical system.

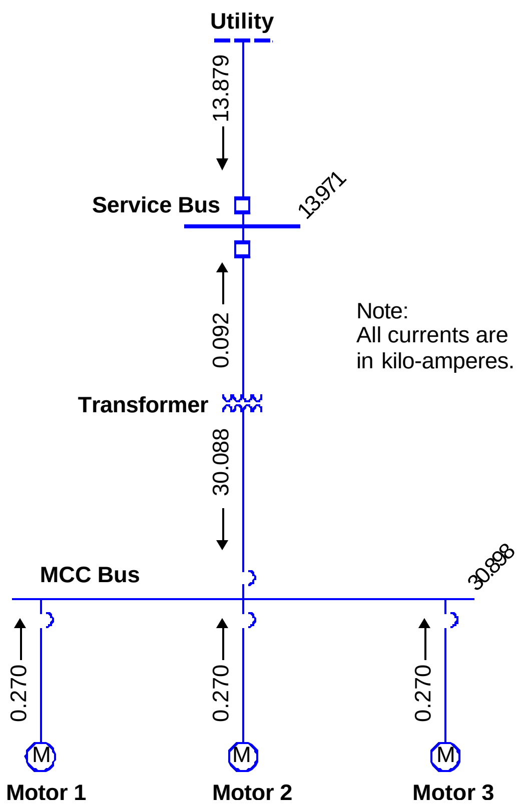
B-1.2 Figure B-1 shows a simplified short circuit study for a small section of an electrical distribution system. The available fault current is shown at the service bus and at an MCC bus. As can be seen, the bulk of the short circuit current is provided by the distribution system through the transformer, with a lesser amount of current provided by each of the motors.

Figure B-1. Sample Short Circuit Results—1 MVA Transformer



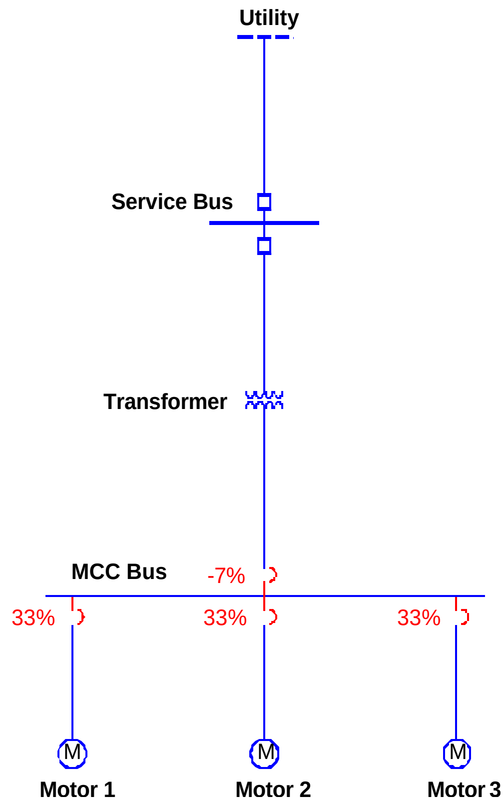
B-1.3 The transformer size has a significant effect on the available short circuit current. Whenever a transformer is replaced with a larger transformer, perform a short circuit study for the larger transformer to verify that all equipment is properly sized for the increased short circuit current. Figure B-2 shows an example of the increase that might be observed as a transformer size is increased from 1 MVA to 2 MVA. Comparing Figure B-1 to Figure B-2, the MCC bus fault current has increased from 18,000 amperes to over 30,000 amperes. Although the system breakers might have been adequately rated for use with the 1 MVA transformer, the larger 2 MVA transformer could allow a short circuit current in excess of the breakers' ratings. This example illustrates the importance of evaluating the entire electrical system whenever a change is made.

Figure B-2. Sample Short Circuit Results—2 MVA Transformer



B-1.4 The computer program used for short circuit analysis should be capable of identifying overduty breakers (breakers in which the short-circuit current, including asymmetric current effects, exceeds the breaker interrupting rating). Figure B-3 shows an example of overduty breakers. The feeder breaker to the MCC bus is 7 percent below its interrupting rating and the downstream load breakers are 33 percent over their interrupting rating.

Figure B-3. Overduty Molded Case Circuit Breakers



B-2 **VOLTAGE DROP**.

B-2.1 Calculate voltage drop by the following equation:

$$Voltage\ \ Drop = I_L \times (R \cos\theta + X \sin\theta)$$

where,

I_L = Line current in amperes

R = Resistance of line in ohms

X = Reactance of line in ohms

? = Phase angle between voltage and current – if phase angle is not known, assume a phase angle of 36.9 degrees corresponding to a power factor of 0.8.

B-2.2 The above equation is simplified, but usually provides acceptable results. In the above equation, obtain the conductor resistance and reactance values as a function of gauge size from NEC Chapter 9, Tables 8 and 9 (2002 Edition). Note that NEC conductor resistance values are based on 75 °C (167 °F) and will usually require correction to the actual expected temperature (refer to NEC Chapter 9, Table 8, or the first example in paragraph B-6.1 for how to convert the resistance to a different temperature). The line current is calculated based on the expected real power requirement and phase angle. The following equations show the calculation of line current:

Single-Phase Circuits

$$I_L = \frac{P}{V \times \cos q}$$

where,

I_L	=	Line current in amperes
P	=	Real power, in kW
V	=	Voltage, RMS—in kV to match power units
?	=	Phase angle between voltage and current

Three-Phase Circuits

$$I_L = \frac{P}{\sqrt{3} \times V_L \times \cos q}$$

where,

I_L	=	Line current in amperes
P	=	Total three-phase real power, in kW
V_L	=	Line voltage, RMS—in kV to match power units
?	=	Phase angle between voltage and current

B-2.3 If comparing voltage drops across different nominal voltages, reference voltage drop calculations to a 120 volt base to allow ready comparison of the voltage drops throughout the system, regardless of the actual voltage level. Use the following expression to convert a voltage drop at some nominal voltage to a 120 volt base:

$$Actual\ Voltage\ Drop\ (120\ V\ Base) = \frac{Actual\ Voltage\ Drop \times 120}{System\ Nominal\ Voltage}$$

B-3 **TRANSFORMER RATED CURRENT**.

B-3.1 Transformer rated secondary current is calculated by dividing the rated kVA capacity by the rated secondary voltage. The following examples illustrate the rated secondary current calculation.

EXAMPLE: What is the rated secondary current of a 30-kVA single-phase transformer with a rated secondary voltage of 240 volts?

$$I_s = \frac{30\,kVA \times 1000}{240\,V} = 125\ amperes$$

EXAMPLE: What is the rated secondary current of a 100-kVA three-phase transformer with a rated secondary voltage of 480 volts?

$$I_s = \frac{100\,kVA \times 1000}{\sqrt{3} \times 480\,V} = 120\ amperes$$

B-3.2 The above examples do not include the effect of any losses; however, the calculations provide approximate values that are usually adequate for use.

B-4 **TRANSFORMER IMPEDANCE EFFECTS**.

B-4.1 For a given kVA rating, a transformer will provide a higher short circuit current as its impedance is lowered. Transformer impedance is usually expressed as a percent. A transformer rated at 10 percent impedance can supply 100%/10% = 10 times its rated secondary current into a short circuit. A transformer rated at 4 percent impedance can supply 100%/4% = 25 times its rated secondary current into a short circuit. Notice that two transformers of equal kVA capacity can have significantly different short circuit currents. This feature must be evaluated as part of the transformer sizing and selection process.

EXAMPLE: Compare the secondary short circuit current of a 500-kVA, 480 volt secondary, three-phase transformer with a 10 percent impedance to an equal capacity transformer with a 2 percent impedance.

First, calculate the rated secondary current:

$$I_{rated} = \frac{500\,kVA \times 1000}{\sqrt{3} \times 480\,V} = 600\ amperes$$

The 10 percent impedance transformer has the following expected short circuit current:

$$I_{sc-10\%} = \frac{100\%}{10\%} \times 600\ amperes = 10 \times 600\ amperes = 6{,}000\ amperes$$

The 2 percent impedance transformer has the following expected short circuit current:

$$I_{sc-2\%} = \frac{100\%}{2\%} \times 600\ amperes = 50 \times 600\ amperes = 30{,}000\ amperes$$

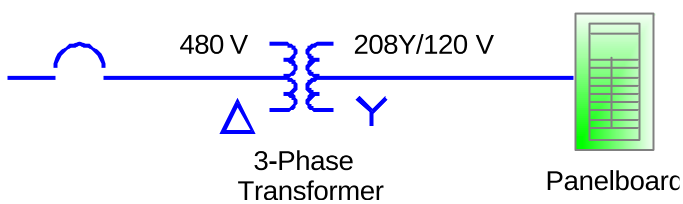
Notice that the 2 percent impedance transformer has 5 times the short circuit current of the 10 percent impedance transformer. The 2 percent impedance transformer might require a complete redesign of downstream electrical equipment to withstand the higher short circuit currents.

B-4.2 Impedance affects transformer regulation. As the impedance increases, the voltage regulation tends to increase. Voltage regulation is defined as the voltage change from no load to full load conditions:

$$Regulation\ (percent) = \frac{V_{no-load} - V_{full-load}}{V_{full-load}} \times 100\%$$

B-5 **TRANSFORMER SIZING**. The following example illustrates the sizing process for a simple transformer installation. Primary and secondary conductor sizes are also determined.

EXAMPLE: A feeder supplies three-phase power to a 480 volt transformer. The transformer steps down to 208Y/120 volts to a lighting panel with a continuous load of 30 amperes on each phase. What is the required transformer kVA capacity, and required amperage on the primary and secondary?



Transformer Size

The transformer required kVA capacity is given by:

$$Required\ kVA = \sqrt{3} \times 208 \times 30 = 10.8\ kVA$$

Transformers are provided in standard sizes. The next larger standard size above 10.8 kVA is 15 kVA. So, choose a 15 kVA transformer for this load. If additional load growth is anticipated, a larger transformer might have been selected instead.

Primary Ampacity

Assume that the transformer will eventually be fully loaded. The required primary amperage is:

$$I_p = \frac{15\ kVA \times 1000}{\sqrt{3} \times 480\ V} = 18\ amperes$$

Referring to NEC Table 310.16 (2002 Edition), a #12 AWG copper conductor would be selected for the primary. A #14 AWG copper conductor would not be selected even though it appears to have adequate current-carrying capacity because the footnote to NEC Table 310.16 requires that overcurrent protection be limited to 15 amperes for a #14 AWG conductor.

The NEC has an additional requirement relating to the transformer primary conductor. NEC Article 215.2(A)(1) (2002 Edition) requires that feeder conductors be sized for the noncontinuous load plus 125 percent of the continuous load. In this case, the primary conductor would be sized for 125 percent of 18 amperes, or 22.5 amperes. Referring again to NEC Table 310.16, a #12 AWG copper conductor is still acceptable for use because it has an ampacity of 25 amperes. Note that the footnote to NEC Table 310.16 requires that overcurrent protection be limited to 20 amperes for a #12 AWG conductor; however, this load limit still exceeds the 18 ampere actual load requirement and is therefore acceptable.

<u>Secondary Ampacity</u>

The required secondary amperage is:

$$I_p = \frac{15\,kVA \times 1000}{\sqrt{3} \times 208\,V} = 41.6 \ amperes$$

NEC Article 215.2(A)(1) requires that feeders be sized for the noncontinuous load plus 125 percent of the continuous load. In this case, the secondary conductor would be sized for 125 percent of 41.6 amperes, or 52 amperes. Referring to NEC Table 310.16, a #6 AWG copper conductor would be selected.

B-6 **ENERGY SAVINGS WITH OVERSIZED CONDUCTORS**.

B-6.1 Significant energy savings can be realized by installing conductors one size larger than required by the NEC. The following examples illustrate the evaluation process as well as the potential savings that can be realized.

EXAMPLE: A three-phase circuit feeds a 125 horsepower (93,250 watts), 460 volt motor, operating at 75 percent load, 76.2 meters (250 feet) from the load center. Assume that the motor operates only 50 percent of the time (4,380 hours per year). The motor full load current is 156 amperes and 75 percent of this load is 117 amperes.

A #3/0 AWG conductor satisfies the electrical requirements. As shown below, a larger #4/0 AWG conductor pays for itself within 5 years. Thereafter, the installation continues to save energy costs of almost $50 per year compared to the smaller #3/0 AWG conductor.

Input Data	#3/0 AWG	#4/0 AWG
Conduit size	51 mm (2 inch)	51 mm (2 inch)
Conductor resistance (30 °C)	0.0164	0.0130
Estimated power loss (3 phase)	673 W	534 W
Estimated wire cost	$991	$1,232
Estimated conduit cost	$365	$365
Incremental cost		$241
Projected energy savings		609 kWh/year
Cost savings at $0.08 per kWh		$48.72/year
Payback period		5 year

In the above example, the copper conductor resistance was obtained from NEC Chapter 9, Table 8 (2002 Edition), and corrected for use at 30 °C (rather than 75 °C as listed in the table) in accordance with the following expression provided by a footnote in the same table:

$R_2 = R_1 \times [1 + 0.00323 \times (T - 75)]$, where R_1 is the copper conductor resistance at 75 °C.

The estimated power loss was then calculated by:

$$Power \;\; Loss = I^2 \times R$$

EXAMPLE: A single-phase, 15 ampere lighting load operates only 50 hours per week (2,600 hours per year) and is located 30.5 meters (100 feet) from the load center. As shown below, the larger #10 AWG conductor pays for itself in just over 1 year. Thereafter, the installation continues to save energy costs of almost $6 per year compared to the smaller #12 AWG conductor.

Input Data	#12 AWG	#10 AWG
Conduit size	12.7 mm (0.5 inch)	12.7 mm (0.5 inch)
Conductor resistance (30 °C)	0.3384	0.2120
Estimated power loss (1 phase)	76 W	48 W
Estimated wire cost	$12	$19
Estimated conduit cost	$42	$42
Incremental cost		$7
Projected energy savings		73 kWh/year
Cost savings at $0.08 per kWh		$5.8/year
Payback period		1.2 year

EXAMPLE: Even if a larger conduit is required, an acceptable payback can be achievable with a larger wire size. For this example, assume that a three-phase, 40 ampere lighting load operates for only 4,000 hours per year (which is about 11 hours per day) and is located 61 meters (200 feet) from the load center. As shown below, the larger #6 AWG conductor pays for itself in 1.5 years. Thereafter, the installation continues to save energy costs of over $75 per year compared to the smaller #8 AWG conductor.

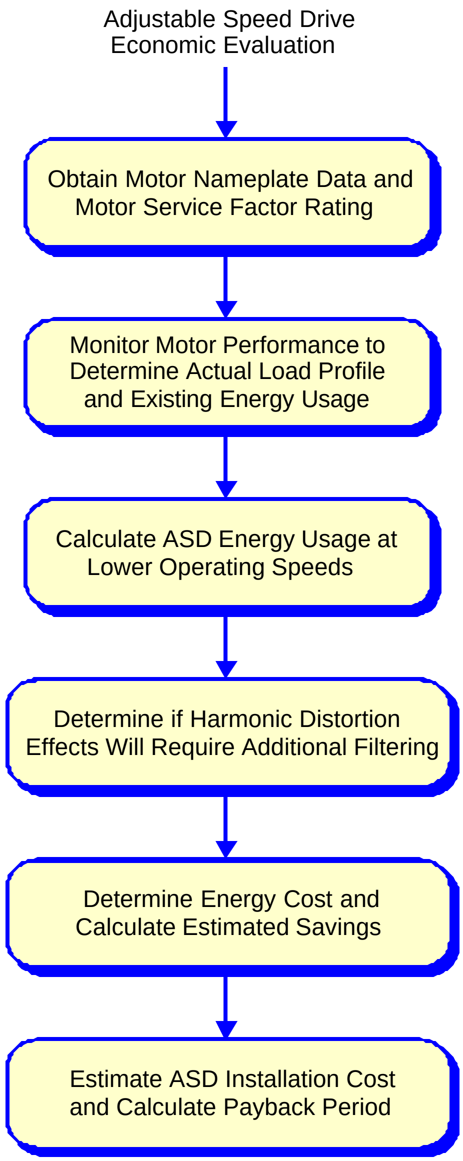
Input Data	#8 AWG	#6 AWG
Conduit size	19.1 mm (0.75 inch)	25.4 mm (1 inch)
Conductor resistance (30 °C)	0.1330	0.0839
Estimated power loss (3 phase)	638 W	403 W
Estimated wire cost	$117	$166
Estimated conduit cost	$128	$192
Incremental cost		$113
Projected energy savings		940 kWh/year
Cost savings at $0.08 per kWh		$75.2/year
Payback period		1.5 year

B-6.2 As the above examples illustrate, a significant energy savings can be realized by increasing the conductor size to the next higher gauge size.

B-7 ADJUSTABLE SPEED DRIVE ECONOMIC EVALUATION.

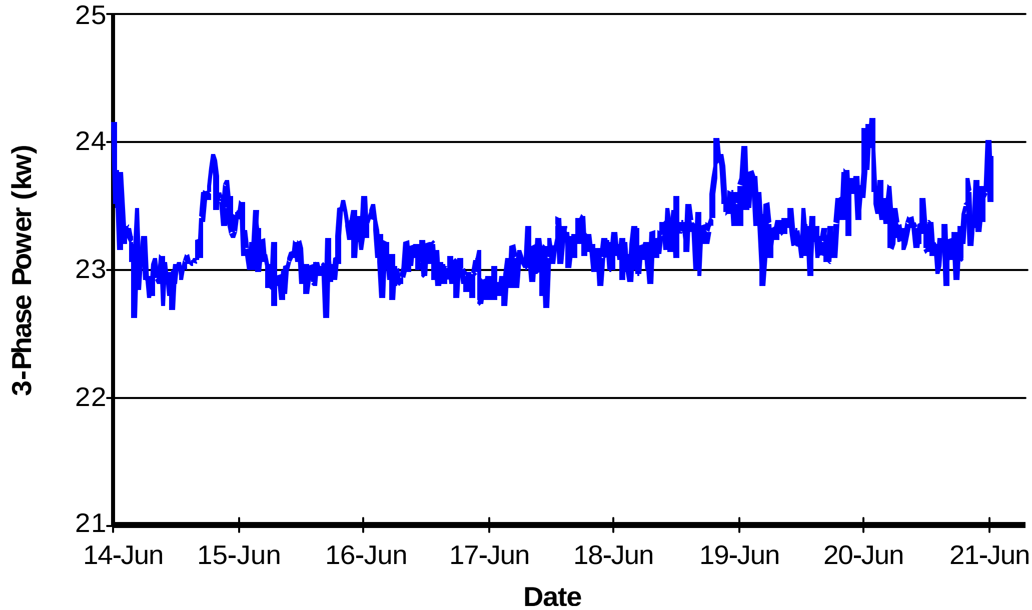
B-7.1 If an ASD installation is considered on the basis of energy efficiency, perform an economic evaluation in accordance with the process shown in Figure B-4.

Figure B-4. Adjustable Speed Drive Economic Evaluation



B-7.2 The key to an economic evaluation is to determine whether or not the motor will be fully loaded under expected operating conditions. If the motor is always loaded at or near 100 percent of rated load, then little if any savings will be realized. Fortunately, it is common to discover that the actual load current is significantly less than rated. For example, Figure B-5 shows a typical case in which a 60 horsepower (44,800 watts) motor normally operates at a load of less than 24 kW. In this case, an ASD can provide substantial savings.

Figure B-5. Typical Motor Load Profile With Motor Operating at Half of Rated Load



B-7.3 Table B-1 provides a sample economic evaluation for an ASD installation for a continuously operating HVAC system motor. This evaluation was for a hospital application in which higher initial ASD costs were expected in order to address harmonic distortion concerns as part of the design. Even so, a payback period of less than 2 years was estimated. As can be seen in Table B-1, an ASD economic evaluation is most sensitive to the following assumptions:

- Total motor operating time per year—unless it is fully loaded, a continuously energized motor will show a faster payback than an intermittently energized motor.

- Estimated actual motor load/speed—for a typical centrifugal fan motor, energy usage is proportional to the $(\text{speed})^3$. For example, if the motor speed can be reduced to 90 percent of rated speed, the energy usage can be reduced to almost 70 percent of its nominal value.

- Cost per kilowatt hour—the local average energy cost should be used.

- ASD equipment and installation cost—for critical locations, the added cost of ensuring acceptable power quality can double the total initial cost.

Table B-1. Example Adjustable Speed Drive Energy Savings Worksheet

Input Data for Existing Application

Motor ID #	HVAC Fan - 1	Comments
Motor Horsepower/Watts	60/44,760	Larger motors provide greater payback.
Motor Efficiency (From Nameplate)	91.7%	Evaluate efficiency at less than full load.
Motor Load Factor	50.0%	Existing energy usage is lower if the motor is operating at less than full load. This value is obtained from metering or monitoring.
Number Hours Operation per Year	8,760	Hours of operation per year is particularly important to energy analysis.
Existing Motor Energy Use (kWh/yr)	213,794	$= [(60 \times 0.746)/0.917] \times 8760 \times 0.5$

Calculation for Adjustable Speed Operation

ASD Efficiency 95.0%

Operating Schedule With ASD	Frequency	Percent Speed	Percent Time	Energy (kWh)
$32,812 = [213,794 \times (0.9)^3 \times 0.2]/.95$	54	90.0%	20.0%	32,812
$40,328 = [213,794 \times (0.8)^3 \times 0.35]/.95$	48	80.0%	35.0%	40,328
$27,017 = [213,794 \times (0.7)^3 \times 0.35]/.95$	42	70.0%	35.0%	27,017
$4,861 = [213,794 \times (0.6)^3 \times 0.1]/.95$	36	60.0%	10.0%	4,861
Estimated Energy Use With ASD			Total:	105,018

Economic Analysis and Payback Calculation

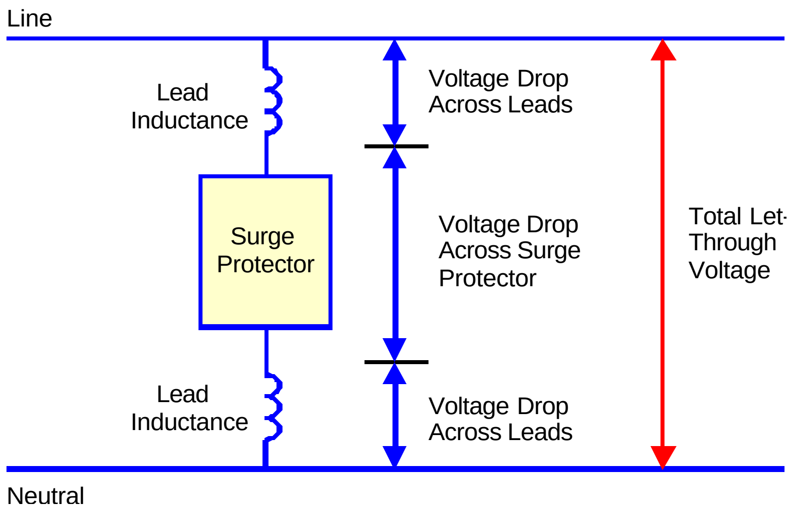
Annual Energy Savings (kWh):	108,776	= (213,794 - 105,018)
Cost per Kilowatt Hour:	$0.06	Based on local commercial power rates.
Annual Cost Savings:	$6,527	$= (108,776 \times \$0.06)$
Estimated Installation Cost Per Motor Horsepower:	$225	Estimate based on ASD operating requirements and features.
Estimated Installation Cost:	$13,500	$= (60 \text{ hp} \times \$225)$
Payback Period (Years)	2.07	= (13,500/6,527)

B-7.4 Payback periods greater than 5 years should not be approved solely on the basis of economic savings; operating system improvements should also be an identified need for these cases.

B-8 SURGE VOLTAGE LET-THROUGH BY EXCESSIVE LEAD LENGTH.

B-8.1 Lead length refers to the length of conductor between the circuit connection and a surge protector, and is the critical installation attribute for parallel-type surge protectors. For typical installations, the lead conductor has negligible resistance, but a significant inductance when subjected to a high frequency surge transient. This inductance can develop a substantial voltage drop under surge conditions, thereby proportionately increasing the let-through voltage. Figure B-6 shows the circuit model for this configuration. Each parallel lead develops a voltage drop in addition to the voltage drop across the surge protector. The total let-through voltage is the sum of the three voltage drops.

Figure B-6. Lead Length Effect on Let-Through Voltage



B-8.2 As the lead length is increased, the added inductance increases the voltage drop in proportion to the lead length, with the result that the let-through voltage increases. For example, a surge protector connected by 305 millimeters (12-inch) leads might allow an additional 200 volts of let-through voltage compared to an equivalent surge protector with 152 millimeters (6-inch) leads. The equation for voltage drop as a function of surge current is given by:

$$V = L\frac{di}{dt} + iR$$

EXAMPLE: At the typical surge current frequency, the inductance per foot is near 0.25 x 10^{-6} henries. The surge current usually has a rise time of 8 x 10^{-6} seconds. In the above equation, the voltage generated by *iR* is negligible compared to the voltage drop across the inductance. Assuming a surge current of 4,000 amperes, the lead length voltage drop per foot is estimated by:

$$V = \left(0.25 \times 10^{-6}\right)\frac{4{,}000}{8 \times 10^{-6}} = 125\, volts\ per\ foot$$

Notice that the voltage drop becomes linearly larger for larger surge currents. The inductance per foot varies with wire gauge size, but this variation is not significant compared to the increase in inductance with length.

B-9 **AUTOMATIC TRANSFER SWITCH SIZING**. The following example illustrates the sizing process for an ATS that is UL listed for *Total System Load* capability.

EXAMPLE: Determine the required size for an ATS rated for *Total System Loads*, for a 208Y/120 volt, three-phase circuit consisting of the following three-phase balanced loads:

1. Resistive heating load: 100 kW or $I = \frac{100\,kW}{\sqrt{3} \times 208\,V} = 278\ amperes$

2. Incandescent lighting load: 50 kW or $I = \frac{50\,kW}{\sqrt{3} \times 208\,V} = 139\ amperes$

3. Motors (4) at 32 amperes each, or 128 amperes continuous load, and each motor has approximately 192 amperes inrush on starting.

The total continuous load requirement is 545 amperes. The incandescent lighting load does not exceed 30 percent of the total load. Select an ATS rated for 600 amperes (the next standard ATS size above 545 amperes). Verify with the manufacturer that the ATS is acceptable for the expected motor inrush currents (although it should be fully capable of this inrush per UL 1008).

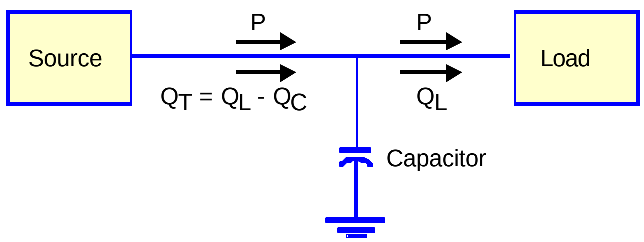
APPENDIX C

CAPACITORS FOR POWER FACTOR CORRECTION

C-1 **PURPOSE**.

C-1.1 Capacitors are normally used to improve power factor. Although power factor correction capacitors are not usually applied to military interior electrical systems, their use is discussed here for completeness. Figure C-1 shows a typical configuration in which a shunt capacitor is added to improve the power factor.

Figure C-1. Capacitor Installation for Power Factor Correction



C-1.2 Power factor correction is usually justified for the following reasons:

- To improve voltage.
- To lower the cost of energy, when the electric utility rates vary with the power factor at the metering point.
- To reduce the energy losses in conductors.
- To utilize the full capacity of transformers, switches, overcurrent devices, buses, and conductors for active power predominantly, thereby lowering the capital investment and annual costs.
- To reduce overload of fully loaded motors.

C-1.3 Capacitor installations can have adverse effects on facility operation. The following effects must be considered as part of the overall design:

- Capacitor switching causes surge voltages, which can necessitate the use of surge protection.
- Capacitors can affect the operation of nonlinear loads.

C-1.4 Although capacitors are commonly used for power factor correction, their use requires careful evaluation of the overall facility design. Without a proper design evaluation, capacitors can introduce other problems that offset the potential benefit of a higher power factor.

C-2 Determining Capacitor Size.

C-2.1 Determine the required capacitor size to improve power factor in accordance with the following expression:

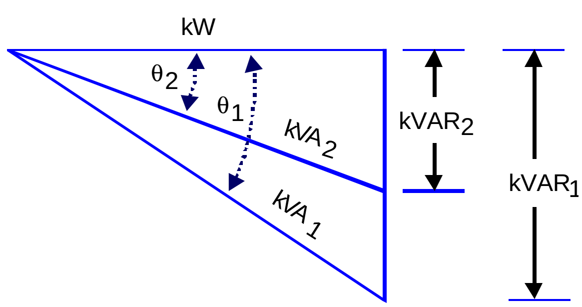
$$kVAR_{cap} = kW \times (\tan q_1 - \tan q_2)$$

where,

$kVAR_{cap}$	=	Required capacitor size in kVARs
kW	=	Active power in circuit
$?_1$	=	Phase angle before applying power factor correction
$?_2$	=	Desired phase angle after power factor correction

C-2.2 Figure C-2 shows the phasor relationship for power factor correction. The addition of kVARs by a shunt capacitor reduces the supplied kVAR.

Figure C-2. Phasor Diagram for Power Factor Correction



EXAMPLE: A three-phase, 460-volt, 50 horsepower (37,300 watts) motor has a power factor of 0.65. What capacitor rating is needed to improve the power factor to 0.95?

First, calculate the power required by the motor at full-load conditions. NEC Table 430.150 (2002 Edition) specifies a typical full-load current of 65 amperes. The load power is then calculated by:

$$P(kW) = \frac{\sqrt{3} \times V \times I \times pf}{1000} = \frac{1.73 \times 460 \times 65 \times 0.65}{1000} = 33.7\, kW$$

For a power factor of 0.65, cos $?_1$ = 0.65, or $?_1$ = 49.46°, and tan $?_1$ = 1.17. The desired power factor is 0.95, or $?_2$ = 18.19°, and tan $?_2$ = 0.33. The required capacitor size is given by:

$$kVAR_{cap} = kW \times (\tan q_1 - \tan q_2) = 33.7 \times (1.17 - 0.33) = 28.3\, kVAR$$

C-2.3 Look-up tables are often used to perform the above calculation. Table C-1 shows a typical table.

EXAMPLE: The previous example determined the required capacitor size for an active power of 33.7 kW with a power factor of 0.65 to obtain a desired power factor is 0.95. Using Table C-1, the applicable correction factor is 0.84 and the required capacitor size is:

33.7 kW x 0.84 = 28.3 kVAR.

Table C-1. Correction Factors for Capacitor Sizing

Original Power Factor	Desired Power Factor							
	0.86	0.87	0.88	0.89	0.90	0.91	0.92	0.93
0.50	1.139	1.165	1.192	1.220	1.248	1.276	1.303	1.337
0.51	1.093	1.119	1.146	1.174	1.202	1.230	1.257	1.291
0.52	1.051	1.077	1.104	1.132	1.160	1.188	1.215	1.249
0.53	1.007	1.033	1.060	1.088	1.116	1.144	1.171	1.205
0.54	0.966	0.992	1.019	1.047	1.075	1.103	1.130	1.164
0.55	0.926	0.952	0.979	1.007	1.035	1.063	1.090	1.124
0.56	0.887	0.913	0.940	0.968	0.996	1.024	1.051	1.085
0.57	0.849	0.875	0.902	0.930	0.958	0.986	1.013	1.047
0.58	0.812	0.838	0.865	0.893	0.921	0.949	0.976	1.010
0.59	0.775	0.801	0.828	0.856	0.884	0.912	0.939	0.973
0.60	0.741	0.767	0.794	0.822	0.849	0.878	0.905	0.939
0.61	0.706	0.732	0.759	0.787	0.815	0.843	0.870	0.904
0.62	0.672	0.698	0.725	0.753	0.781	0.809	0.836	0.870
0.63	0.640	0.666	0.693	0.721	0.749	0.777	0.804	0.838
0.64	0.607	0.633	0.660	0.688	0.716	0.744	0.771	0.805
0.65	0.576	0.602	0.629	0.657	0.685	0.713	0.740	0.774
0.66	0.545	0.571	0.598	0.626	0.654	0.682	0.709	0.743
0.67	0.515	0.541	0.568	0.596	0.624	0.652	0.679	0.713
0.68	0.486	0.512	0.539	0.567	0.595	0.623	0.650	0.684
0.69	0.456	0.482	0.509	0.537	0.565	0.593	0.620	0.654
0.70	0.427	0.453	0.480	0.508	0.536	0.564	0.591	0.625
0.71	0.399	0.425	0.452	0.480	0.508	0.536	0.563	0.597
0.72	0.370	0.396	0.423	0.451	0.479	0.507	0.534	0.568
0.73	0.343	0.369	0.396	0.424	0.452	0.480	0.507	0.541
0.74	0.316	0.342	0.369	0.397	0.425	0.453	0.480	0.514
0.75	0.289	0.315	0.342	0.370	0.398	0.426	0.453	0.487
0.76	0.262	0.288	0.315	0.343	0.371	0.399	0.426	0.460
0.77	0.236	0.262	0.289	0.317	0.345	0.373	0.400	0.434
0.78	0.210	0.236	0.263	0.291	0.319	0.347	0.374	0.408
0.79	0.183	0.209	0.236	0.264	0.292	0.320	0.347	0.381
0.80	0.157	0.183	0.210	0.238	0.266	0.294	0.321	0.355
0.81	0.131	0.157	0.184	0.212	0.240	0.268	0.295	0.329
0.82	0.105	0.131	0.158	0.186	0.214	0.242	0.269	0.303
0.83	0.079	0.105	0.132	0.160	0.188	0.216	0.243	0.277
0.84	0.053	0.079	0.106	0.134	0.162	0.190	0.217	0.251
0.85	0.027	0.053	0.080	0.108	0.136	0.164	0.191	0.225

Table C-1. Correction Factors for Capacitor Sizing, continued

Original Power Factor	Desired Power Factor						
	0.94	0.95	0.96	0.97	0.98	0.99	1.00
0.50	1.369	1.402	1.441	1.481	1.529	1.590	1.732
0.51	1.320	1.357	1.395	1.435	1.483	1.544	1.686
0.52	1.281	1.315	1.353	1.393	1.441	1.502	1.644
0.53	1.237	1.271	1.309	1.349	1.397	1.458	1.600
0.54	1.196	1.230	1.268	1.308	1.356	1.417	1.559
0.55	1.156	1.190	1.228	1.268	1.316	1.377	1.519
0.56	1.117	1.151	1.189	1.229	1.277	1.338	1.480
0.57	1.079	1.113	1.151	1.191	1.239	1.300	1.442
0.58	1.042	1.076	1.114	1.154	1.202	1.263	1.405
0.59	1.005	1.039	1.077	1.117	1.165	1.226	1.368
0.60	0.971	1.005	1.043	1.083	1.131	1.192	1.334
0.61	0.936	0.970	1.008	1.048	1.096	1.157	1.299
0.62	0.902	0.936	0.974	1.014	1.062	1.123	1.265
0.63	0.870	0.904	0.942	0.982	1.030	1.091	1.233
0.64	0.837	0.871	0.909	0.949	0.997	1.058	1.200
0.65	0.806	0.840	0.878	0.918	0.966	1.027	1.169
0.66	0.775	0.809	0.847	0.887	0.935	0.996	1.138
0.67	0.745	0.779	0.817	0.857	0.905	0.966	1.108
0.68	0.716	0.750	0.788	0.828	0.876	0.937	1.079
0.69	0.686	0.720	0.758	0.798	0.840	0.907	1.049
0.70	0.657	0.691	0.729	0.769	0.811	0.878	1.020
0.71	0.629	0.663	0.701	0.741	0.783	0.850	0.992
0.72	0.600	0.634	0.672	0.712	0.754	0.821	0.963
0.73	0.573	0.607	0.645	0.685	0.727	0.794	0.936
0.74	0.546	0.580	0.618	0.658	0.700	0.767	0.909
0.75	0.519	0.553	0.591	0.631	0.673	0.740	0.882
0.76	0.492	0.526	0.564	0.604	0.652	0.713	0.855
0.77	0.466	0.500	0.538	0.578	0.620	0.687	0.829
0.78	0.440	0.474	0.512	0.552	0.594	0.661	0.803
0.79	0.413	0.447	0.485	0.525	0.567	0.634	0.776
0.80	0.387	0.421	0.459	0.499	0.541	0.608	0.750
0.81	0.361	0.395	0.433	0.473	0.515	0.582	0.724
0.82	0.335	0.369	0.407	0.447	0.489	0.556	0.698
0.83	0.309	0.343	0.381	0.421	0.463	0.530	0.672
0.84	0.283	0.317	0.355	0.395	0.437	0.504	0.645
0.85	0.257	0.291	0.329	0.369	0.417	0.478	0.620

C-3 **Capacitor Ratings**.

C-3.1 Capacitors are built to standard sizes as specified by IEEE 18, *IEEE Standard for Shunt Power Capacitors*. Table C-2 shows the capacitor sizes of potential interest to facility interior electrical design.

Table C-2. Common Capacitor Reactive Power Ratings

Voltage Rating (rms)	kVAR Rating	Number of Phases	BIL kV
216	5, 7.5, 131/3, 20, and 25	1 or 3	30
240	2.5, 5, 7.5,10, 25, 20, 25, and 50	1 or 3	30
480	5, 10, 15, 20 25, 35, 50, 60, and 100	1 or 3	30
600	5, 10, 15, 20 25, 35, 50, 60, and 100	1 or 3	30
2,400	50, 100, 150, and 200	1	75
2,770	50, 100, 150, and 200	1	75
4,160	50, 100, 150, and 200	1	75
7,200	50, 100, 150, 200, 300, and 400	1	95
12,470	50, 100, 150, 200, 300, and 400	1	95
13,800	50, 100, 150, 200, 300, and 400	1	95 and 125
Refer to IEEE 18 for ratings at other voltages.			

C-3.2 The calculated capacitor size will rarely exactly match one of the available sizes. The decision of whether to select the next larger or the next smaller size depends on the circuit configuration and the desired power factor. Paragraph C-4 provides specific design criteria regarding capacitor size.

C-3.3 IEEE 18 establishes the required design tolerances for capacitors.

C-4 **Design Criteria**.

C-4.1 Consider requiring power factor correction as part of the facility design. Power factor correction has to be justifiable based upon operational performance improvements or cost-savings, including any potential effects caused by interaction with other devices.

C-4.2 If used, apply capacitors to obtain a power factor range of 0.85 to 0.95. A power factor of 0.85 will satisfy most operational requirements, but the actual minimum value should also be based on any revenue metering penalties established by the local commercial utility for low power factors. Little, if any, economic advantage will usually be realized if attempting to correct above a power factor of 0.95. Ensure that power factor correction will not cause a leading power factor under no-load conditions.

C-4.3 Power factor correction requires particular attention if nonlinear loads are a significant portion of the facility load; this includes electronic equipment, ASDs, UPS systems, and other significant sources of harmonic distortion. Capacitors can resonate with nonlinear loads and cause additional distortion of the electrical system voltage and current. In this case, the capacitor(s) might not improve the power factor at all. Also, resonant conditions can cause capacitor failure. If facilities contain a significant proportion of nonlinear loads, evaluate the application of a synchronous condenser instead. Synchronous condensers are often applied at the service entrance, which might not solve all power factor problems throughout the facility.

C-4.4 For facility applications, continuously energized capacitors are preferred over switching capacitors, even though this might necessitate the addition of a smaller amount of capacitance. If a pre-selected quantity of capacitors cannot be connected and left connected to the line in a constantly energized state, the facility electrical system would probably be better off without them. Each capacitor on-off cycle causes transient voltage surges that are potentially damaging to other equipment over time. Additional design considerations such as soft-start or pre-insertion resistors are necessary if capacitors are routinely switched. Also, apply surge protection for switched capacitors in accordance with the criteria of Chapter 11. Refer to IEEE 141 for additional design considerations for switched capacitors.

C-4.5 Evaluate capacitors installed strictly for motor applications based on the number of motors to have power factor correction. If only a single motor or a small number of motors require power factor correction, the capacitor can be installed at each motor such that it is switched on and off with the motor. If several motors connected to a single bus require power factor correction, install the capacitor(s) at the bus. For new installations, specify the MCC to contain the capacitor(s). For existing installations, determine if spare cubicles can be refurbished to accept the capacitor(s). Refer to NEMA MG 1, IEEE 141 and IEEE 1036, *IEEE Guide for Application of Shunt Power Capacitors*, for additional information.

C-4.6 Do not install capacitors directly onto a motor circuit under the following conditions:

- If solid-state starters are used.
- If open-transition starting is used.
- If the motor is subject to repetitive switching, jogging, inching, or plugging.
- If a multi-speed motor is used.
- If a reversing motor is used.
- If a high-inertia load is connected to the motor.

C-4.7 Size the ampacity of capacitor circuit conductors at least 135 percent of the rated capacitor current in accordance with NEC Article 460.8 (2002 Edition). Provide overcurrent protection and disconnection means as specified by the NEC. IEEE 1036 provides additional guidance for sizing protective devices for the maximum possible inrush current.

C-4.8 Consult with the manufacturer before applying a capacitor under any of the specified abnormal service conditions of IEEE 18.

C-4.9 Liquid dielectrics used in capacitors must be non-PCB mineral oil or other less flammable liquid type. Do not use tetrachloroethylene (perchloroethylene) and 1,2,4, trichlorobenzen fluids.

C-4.10 Provide all capacitors used for power factor correction with an automatic means of draining the stored charge after the capacitor is disconnected from its source of supply.

C-4.11 Power capacitors can fail in such a manner to cause "noise" on communication lines. Ensure that capacitors are not located near communications equipment.

C-5 **Information Sources**. The following references provide additional information regarding power factor correction:

- IEEE 18—provides information regarding the ratings and testing of capacitors.
- IEEE 141—provides a detailed technical overview of power factor correction.
- IEEE 519—addresses power factor correction in a nonlinear load environment.
- IEEE 1036—provides application guidelines for shunt power capacitors and is intended for 2,400 volts and higher, although the principles apply to lower voltage applications also.
- NEC Article 460—provides marking, installation, protection, and grounding requirements for capacitors.
- NEMA MG 1—provides recommendations regarding the application of capacitors to motor circuits.

APPENDIX D

SURGE PROTECTOR PERFORMANCE AND EVALUATION CRITERIA

D-1 **SUMMARY**.

D-1.1 The most important surge protector performance and evaluation characteristics are:

- Listing in accordance with UL 1449, *Standard for Transient Voltage Surge Suppressors, Second Edition* (paragraph D-2.1).
- UL 1449 surge suppression rating (paragraph D-2.2).
- Maximum continuous overvoltage rating (paragraph D-2.3).
- Maximum surge current rating (paragraph D-2.4).
- Repeated surge current withstand capability (paragraph D-2.5).
- Modes of protection (paragraph D-2.6).
- Internal fusing characteristics (paragraph D-2.7).
- Installation capability (paragraph D-2.8).
- Warranty (paragraph D-2.9).
- Price (paragraph D-2.10).

D-1.2 Paragraphs D-2.1 through D-2.10 discuss each of the above performance attributes. Paragraphs D-3.1 through D-3.5 discuss other commonly advertised performance characteristics that are not as important to consider.

D-2 **IMPORTANT SURGE PROTECTION ATTRIBUTES**.

D-2.1 **UL 1449 Listing**.

D-2.1.1 UL 1449 listing is a fundamental requirement for all procured surge protectors for use in electrical distribution systems.

D-2.1.2 The UL 1449 listing process primarily ensures that the surge protector has passed a variety of safety tests. In particular, the UL 1449 fail-safe requirements are intended to address metal oxide varistor (MOV) degradation modes in which an MOV at end of life can conduct continuously, causing overheating. The surge suppression tests listed in UL 1449 are not necessarily representative of actual surges that might be encountered, but UL 1449 listing ensures the surge protector has passed some basic level of qualification. Figure D-1 shows a typical listed surge protector properly installed adjacent to a panelboard.

Figure D-1. UL 1449 Listed Surge Protector

D-2.1.3 Surge protectors are available on the market that have not been listed to UL 1449. In these cases, the user does not know if the manufacturer's claims can be accepted because there has not been an independent evaluation process. Use of unlisted surge protectors is also a violation of NEC Article 280.4(A) (2002 Edition), which requires that "surge arresters installed on circuits of less than 1000 volts shall be listed for the purpose." Figure D-2 shows an example of an unlisted surge protector. As can be seen, this surge protector consists of two conductors in an insulator with silica sand around the conductors; this is only a simple spark gap.

Figure D-2. Unlisted Surge Protector

D-2.1.4 To summarize, ensure surge protectors have a UL 1449 listing; this is a fundamental design requirement. The UL 1449 listing process does not alone confirm that all other specified capabilities in the manufacturer's literature have been met.

Additional evaluation is necessary for these other features as described in subsequent sections.

D-2.2 **UL 1449 Surge Suppression Rating**.

D-2.2.1 The lowest possible UL 1449 surge suppression rating is 330 volts and the highest possible rating is 6,000 volts. Contrary to intuition, lower ratings are better. A 6,000 volt rating could mean that the surge protector will still allow a 6,000 volt surge to be transmitted to downstream equipment, with little or no attenuation.

D-2.2.2 Table D-1 lists the maximum recommended surge suppression ratings. Considering how the UL 1449 listing process determines these ratings, a good quality surge protector should have no difficulty meeting these limits.

Table D-1. Maximum Allowed UL 1449 Surge Suppression Ratings

AC Power System Voltage	Line-to Neutral Maximum Suppression Rating
Single-Phase	
120	600
120/240	600
Three Phase Wye	
208Y/120	600
480Y/277	1,200

D-2.2.3 Table D-1 specifies the maximum recommended UL 1449 surge suppression ratings. Lower ratings are preferred.

D-2.3 **Maximum Continuous Overvoltage Rating**.

D-2.3.1 The maximum continuous overvoltage rating (MCOV) is the rated continuous voltage that can be applied to the MOV elements without having the surge protector start to operate. If the normal system voltage exceeds the MCOV, the surge protector will conduct continuously and eventually fail. Everything else equal, a higher MCOV is desirable; a lower MCOV rating increases the surge protector's susceptibility to a temporary overvoltage such as a momentary voltage swell.

D-2.3.2 Table D-2 lists the preferred minimum MCOV rating for surge protectors. Lower MCOV ratings can be used provided that the manufacturer provides documentation of the surge protector performance during voltage swell events. Temporary overvoltages cause a large proportion of the total surge protector failures.

Table D-2. Minimum Recommended MCOV Ratings

AC Power System Voltage	Minimum MCOV Rating
Single-Phase	
120	150
120/240	300/150
Three Phase Wye	
208Y/120	300/150
480Y/277	600/320

D-2.4 **Surge Current Rating**.

D-2.4.1 The surge current rating provides a relative measure of the surge protector's ability to withstand surge currents and is an indicator of the peak surge current that the device subassemblies and modules are designed to handle on a one-shot basis without failure. The surge current rating is usually based upon the total summation (or near-total) of internal subassembly or individual MOV ratings on each phase or protection mode.

D-2.4.2 For large surge current ratings (over 100,000 amperes), it is unlikely that the entire surge protector was actually tested to such a high level. Test laboratories are capable of generating an IEEE C62.41 8x20 µsec impulse up to about the 100,000 ampere level. What this means is that surge protectors with surge current ratings in the hundreds of thousands of amperes have most likely not been tested to this level. Furthermore, it is possible that a surge protector with such a high rating would fail if subjected to such a high level; circuit board traces, internal fusing, or connecting wire would probably open under the high transient current. Another point to consider with regard to surge current ratings is that the ratings usually assume equal parallel operation of the MOVs, but the nonlinear behavior of MOVs virtually assures that such precise parallel matching is unachievable.

D-2.4.3 For MOV-based designs, the surge current rating provides a relative measure of the amount of MOV surface area that is available for surge protection. As MOVs are subjected to surge voltages, the MOV grain boundaries degrade with time. By including additional MOVs to obtain a higher surge current rating, the surge protector effectively provides an operating and aging margin. In other words, a higher surge current rating can provide a longer operating life. Surge protectors that are rated for hundreds of thousands of amperes of surge current do not actually expect to experience such a high current level. Instead, the higher rating provides assurance that the surge protector can withstand a number of smaller surges, each of which damages MOV grain boundaries by some amount, without experiencing complete failure of the surge protector. By this approach, the surge protector should have a longer life.

D-2.4.4 Table D-3 provides the minimum allowed surge current ratings per phase or per mode of protection. The surge current ratings have been selected based on ensuring an adequate margin for higher-than-expected surges due to nearby lightning strikes. Higher surge current ratings can be selected provided there is not a significant cost difference.

Table D-3. Minimum Allowed Surge Current Rating

AC Power System Location	Minimum Surge Current Rating Per Phase or Per Mode of Protection
Service Entrance	80,000 amperes
Sub-Panels	40,000 amperes
Critical Loads	40,000 amperes

D-2.4.5 The surge current ratings specified in Table D-3 apply regardless of whether the facility is located in a high, medium, or low exposure area (as defined by IEEE C62.41. The selected minimum surge current values are based on the following rationale:

- The values are high enough to ensure protection in high exposure areas.
- The values are not so high that lower exposure areas are over-protected.
- This approach does not force each designer to decide if a given facility is located in a high, medium, or low exposure environment.

D-2.5 **Repeated Surge Current Withstand Capability**. The specified surge current ratings are intended to provide an adequate allowance for repeated surges over the life of the surge protector. In addition to the specified surge current ratings, verify that the manufacturer has tested representative surge protectors to the following IEEE C62.41 levels, as a minimum:

- A minimum of 1,000 operations at ±500 amperes, 100 kilo-Hertz ring wave.
- A minimum of 1,000 operations at ±3,000 amperes, 8/20 µsec combination wave.
- A minimum of 40 operations at ±10,000 amperes, 8/20 µsec combination wave.
- A minimum of 1 operation at ±20,000 amperes, 8/20 µsec combination wave (one in each polarity).

D-2.6 **Modes of Protection**.

D-2.6.1 UL 1449, Table 34.2, provides the various test configurations to provide different modes of protection. The total possible modes of protection depend on the system design and voltage level, as shown below in Table D-4.

Table D-4. UL 1449 Modes of Protection

Single phase (2-wire + ground)	Single phase (3-wire + ground)	Three phase (4-wire + ground)
L_1 – N	L_1 – N	L_1 – N
L_1 – G	L_2 – N	L_2 – N
N – G	L_1 – G	L_3 – N
	L_2 – G	L_1 – G
	L_1 – L_2	L_2 – G
	N – G	L_3 – G
		L_1 – L_2
		L_1 – L_3
		L_2 – L_3
		N – G

D-2.6.2 **Wye Connections**.

D-2.6.2.1 For single phase and three phase wye connected systems, the following modes of protection are recommended:

- Each phase to neutral (L – N).
- Neutral to ground (N – G).

D-2.6.2.2 Phase to ground (L – G) protection will be important if the grounding system is of poor quality or in other countries where neutral and ground are not connected. By protecting both the neutral and ground paths, any differences in potential between the two points will still be protected against surge events.

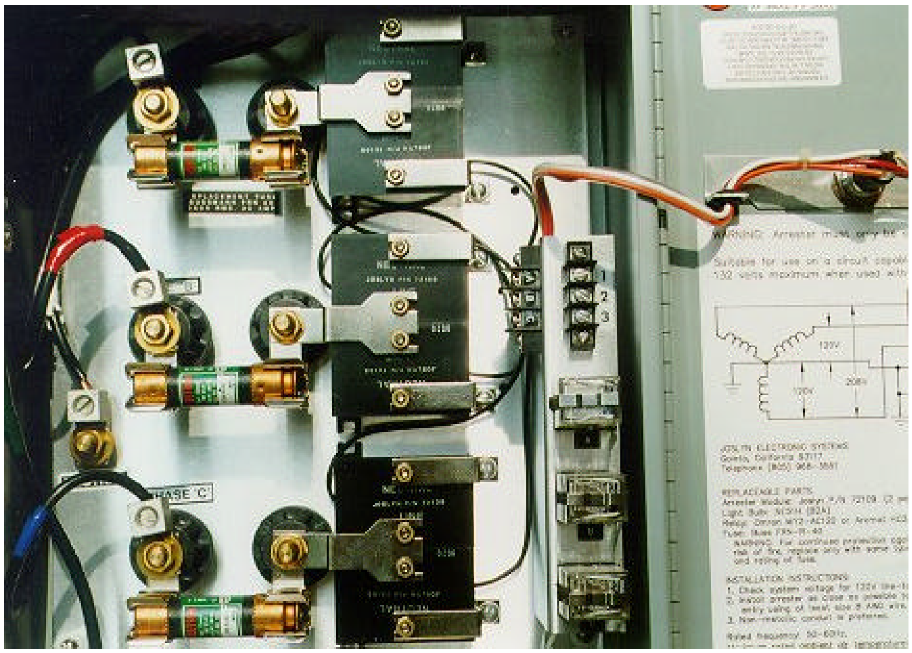
D-2.6.2.3 Phase to phase (L – L) protection is not needed for wye-connected systems provided that the other modes of protection are provided.

D-2.6.3 **Delta Connections**. Provide the following modes of protection:

- Phase to phase (L – L).
- Phase to ground (L – G).

D-2.7 **Internal Fusing**. UL 1449 listing provides assurance that the surge protector can be applied safely. Some older surge protector designs could overheat and catch fire after an MOV degrades to the point that it continuously conducts current. Newer designs often individually fuse each MOV. In addition, a fuse might be installed for each separate mode of protection. Figure D-3 shows an example of fusing for each module. If the selected surge protector has this type of fuse arrangement, verify with the manufacturer the overcurrent characteristics of the fuse when exposed to transient surge currents.

Figure D-3. Example of Internally Fused Surge Protector

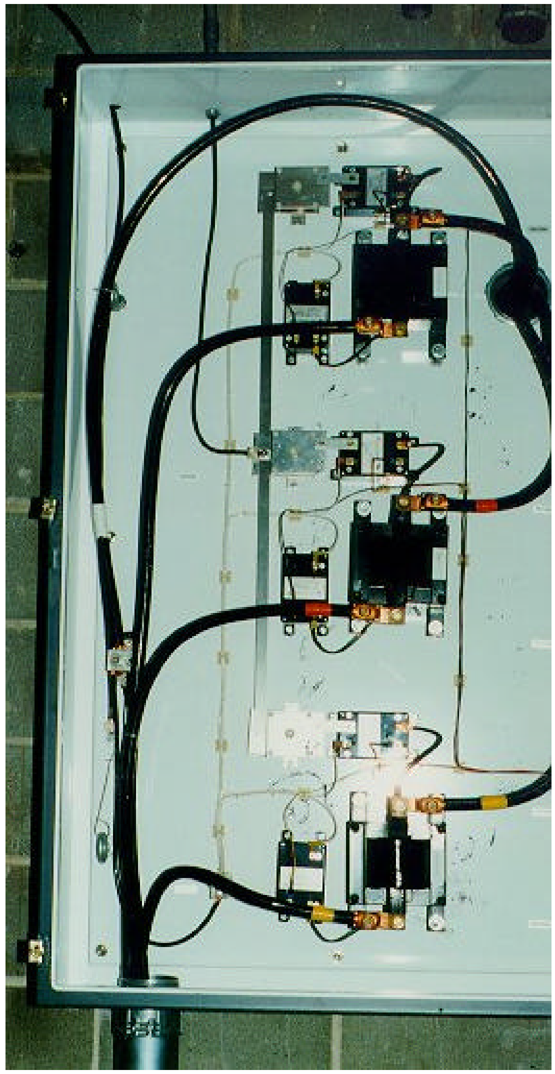


D-2.8 **Installation Capability**.

D-2.8.1 Surge protectors covered by this manual should normally be of the parallel type. The surge protector size and installation method are important evaluation considerations. If the surge protector enclosure is over-sized, it might not fit near the required location, thereby causing the lead length of the connecting conductors to be excessive, which increases the let-through voltage.

D-2.8.2 Figure D-4 shows an example of an unacceptable design; this example has two problems. First, the enclosure size ensures that the connection leads will be long, which increases the let-through voltage. Second, the large enclosure might not fit where it should be installed—near the equipment to be protected—which again ensures excessive lead length.

Figure D-4. Excessive Lead Length Caused by Over-Sized Enclosure



D-2.9 **Warranty**. A minimum 5-year full-replacement warranty is required. Longer warranty intervals are desirable.

D-2.10 **Price**. The previous specification criteria attempt to provide an adequate minimum level of surge protector performance. Given this approach, the low bid can be used provided that the selected supplier confirms the required performance attributes listed in paragraphs D-2.1 through D-2.9.

D-3 PERFORMANCE SPECIFICATIONS THAT ARE NOT IMPORTANT.

D-3.1 **Introduction**. The previous section listed the important surge protection attributes. This section discusses performance attributes that either are less important or are possibly misunderstood because of inconsistent terminology in the industry.

D-3.2 **Clamping Voltage**. Disregard references to clamping voltage unless it can be confirmed that the meaning is equivalent to let-through voltage as defined in this manual. Depending on its use, the clamping voltage can be the voltage at which the surge protector *starts* to operate. In this case, the clamping voltage does not provide adequate information regarding the actual let-through voltage. Manufacturers that provide only a clamping voltage might be disguising poor let-through voltages. UL 1449 listing establishes a standardized suppression voltage rating that can be used for evaluation purposes. Compare the UL 1449 suppression voltage rating to the stated clamping voltage to identify any significant differences. If necessary, request the manufacturer to provide a copy of the UL listing test file to assure that clamping voltage is not inappropriately stated.

D-3.3 **Response Time**. Manufacturers advertise response time but the meaning is not always clear. Response time is not important; let-through voltage is important. If the surge protector response time is slow, the let-through voltage will be high.

D-3.4 **Joules Rating**. The joules rating (sometimes referred to as surge energy capability) is not an important performance attribute and is frequently misunderstood. If the surge protector is listed to UL 1449 and has demonstrated acceptable operational cycling, the surge protector will have an acceptable energy dissipation capability.

D-3.5 **Sine Wave Tracking**. The suppression of the surge voltage throughout the sine wave has been referred to as sine wave tracking and it can provide an added level of protection for sensitive loads. The term sine wave tracking is not used in industry standards, it is not confirmed as an attribute by UL 1449, and its meaning does not appear to have an industry-accepted definition. Sine wave tracking is not considered a design requirement for surge protectors. Manufacturers that market sine wave tracking as a design feature are claiming that the surge protector will provide a certain level of suppression throughout the sine wave. This suppression is usually achieved by installing capacitors. If sine wave tracking is a feature desired by the user, ensure that the manufacturer provides certified test data that demonstrates this capability. The test data should include surge applications at different points on the sine wave.

APPENDIX E

STATIONARY BATTERY AND CHARGER SIZING

E-1 BATTERY SIZING FOR APPLICATIONS WITH A DUTY CYCLE.

E-1.1 The designer of a backup power system has to determine the battery size. The battery can carry more load or perform longer as it is made larger, but a larger battery is also more expensive, requires more floor space, and increases the life cycle cost. For these reasons, provide a technical basis for the battery size.

E-1.2 The classic method of sizing a battery is based on determining the specific load requirements and selecting a battery size capable of supplying that load for the specified time. IEEE 485 is the best industry reference for this type of cell sizing and should be reviewed as part of a battery sizing evaluation. IEEE 1115, *IEEE Recommended Practice for Sizing Nickel-Cadmium Batteries for Stationary Applications*, provides equivalent sizing information for nickel-cadmium batteries.

E-1.3 The battery duty cycle is the load that the battery is expected to supply for a specified period of time. Generally, the duty cycle is described in terms of the worst-case load that the battery is expected to supply. The battery would have to carry all or part of the connected load under any of the following conditions:

- System load exceeds the battery charger capability.
- Battery charger output is lost (could be by charger failure or loss of ac input).
- All ac power is lost in the facility.

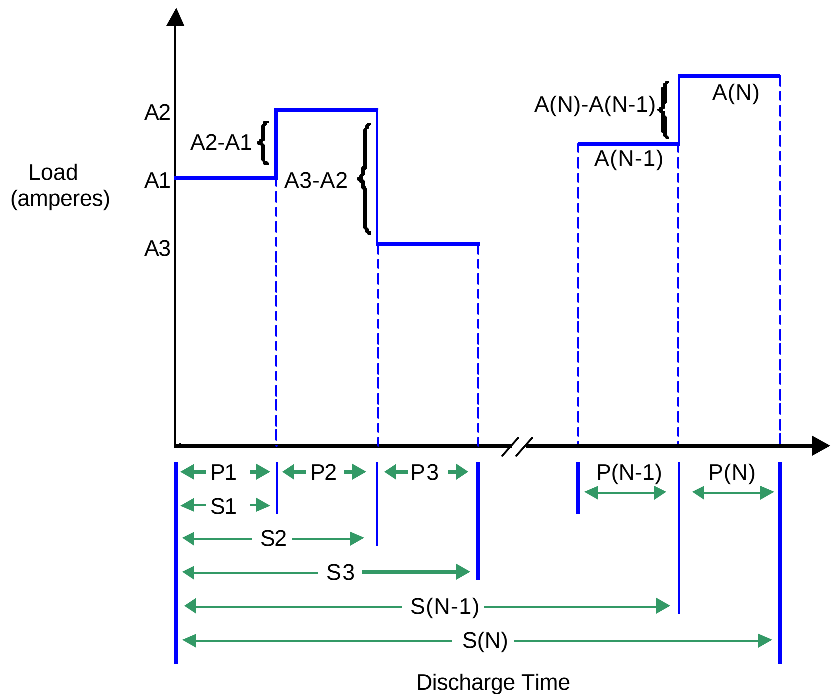
E-1.4 The worst case load usually occurs when all ac power is lost because other emergency loads might be energized in addition to the normally-energized loads. For example, loss of all ac power might require the additional energization of emergency lighting, circuit breaker components such as trip coils or spring charging motors, and emergency diesel engine cranking power. The duty cycle must consider all of these loads.

E-1.5. The following design inputs are needed to determine a battery size:

- Discharge capability of selected battery type.
- Load requirements, including duration.
- Minimum and maximum system voltage limits.
- Temperature, aging, and design margin allowances.

E-1.6 Evaluate the duty cycle, section by section, to determine which section of the duty cycle is limiting in terms of battery size. The cell size is selected based on the most limiting portion of the duty cycle. A generalized representation of a duty cycle is shown in Figure E-1.

Figure E-1. Generalized Duty Cycle



E-1.7 The battery sizing analysis of a duty cycle determines the required cell size for each section. Depending on the load profile, it is not guaranteed that the last section containing all periods will be limiting. For example, the cell size might be established by the first minute of the duty cycle if many loads are energized at once. IEEE 485 provides worksheets to assist with the calculation process. Battery manufacturers provide similar worksheets.

E-1.8 The battery sizing methodology determines the cell size for the defined duty cycle when the battery capacity is 100 percent and at the reference temperature of 25 °C (77 °F). For most batteries, end-of-life occurs when capacity falls to 80 percent of the rated capacity. Also, depending on the installation, the actual battery temperature might be well below 25 °C (77 °F), and battery capacity decreases as temperature decreases. Apply correction factors to the calculated cell size to account for these effects. The net result is that the selected cell size must be larger so that it can meet its design requirements at end-of-life at the design low temperature.

E-1.9 Under ideal conditions, a battery can have 90 percent to over 100 percent capacity when new. As the battery ages, its capacity will eventually fall to 80 percent, which is the commonly accepted point at which the battery should be replaced. Below this capacity, the rate of degradation can increase rapidly. As part of the battery sizing process, size the battery so that it can fulfill the duty cycle requirements at its end of life.

Apply the following correction factor to the calculated cell size; the calculated cell size is made 25 percent larger to ensure that it can supply the required load at end of life:

$$\textit{Aging Correction Factor} = \frac{1}{0.8} = 1.25$$

E-1.10 The manufacturer specifies battery performance at the reference temperature of 25 °C (77 °F). As the battery temperature falls below 25 °C (77 °F), battery capacity decreases. As the battery temperature rises above 25 °C (77 °F), battery capacity increases. If the expected operating temperature will be less than 25 °C (77 °F), adjust the cell size to account for the reduced capacity at the lower temperature. Table E-1 shows the correction factors for different battery temperatures. This table is based on vented lead-acid cells with a nominal 1.215 specific gravity. For a different specific gravity, consult the manufacturer to confirm the applicability of these correction factors. VRLA cells can have a completely different temperature response; consult the manufacturer for the appropriate temperature correction factors. Nickel-cadmium cells also require a manufacturer-provided temperature correction factor for low temperature operation, but the correction factor is not as large as for lead-acid batteries.

Table E-1. Temperature Correction Factors for Vented Lead-Acid Cells (1.215 Specific Gravity)

Electrolyte Temperature (°F)	Electrolyte Temperature (°C)	Cell Size Correction Factor	Electrolyte Temperature (°F)	Electrolyte Temperature (°C)	Cell Size Correction Factor	Electrolyte Temperature (°F)	Electrolyte Temperature (°C)	Cell Size Correction Factor
25	-3.9	1.520	71	21.7	1.034	85	29.4	0.960
30	-1.1	1.430	72	22.2	1.029	86	30.0	0.956
35	1.7	1.350	73	22.8	1.023	87	30.6	0.952
40	4.4	1.300	74	23.4	1.017	88	31.1	0.948
45	7.2	1.250	75	23.9	1.011	89	31.6	0.944
50	10.0	1.190	76	24.5	1.006	90	32.2	0.940
55	12.8	1.150	77	25.0	1.000	95	35.0	0.930
60	15.6	1.110	78	25.6	0.994	100	37.8	0.910
65	18.3	1.080	79	26.1	0.987	105	40.6	0.890
66	18.9	1.072	80	26.7	0.980	110	43.3	0.880
67	19.4	1.064	81	27.2	0.976	115	46.1	0.870
68	20.0	1.056	82	27.8	0.972	120	48.9	0.860
69	20.6	1.048	83	28.3	0.968	125	51.7	0.850
70	21.1	1.040	84	28.9	0.964			

E-1.11 The aging and temperature correction factors account for inevitable aging and temperature effects. The battery is sized for a particular duty cycle and, depending on the facility, load growth can occur over time. A design margin correction factor can be applied to provide additional assurance that the battery will meet its future design requirements. The design margin correction factor also adds a capacity margin to allow for less-than-optimum battery operating conditions due to improper maintenance, recent battery discharge, lower than expected operating temperatures, or other effects. Simply stated, the design margin correction factor is an additional margin to help ensure the battery has adequate capacity to perform its job. A design margin of 10 percent to 15 percent is typical.

> EXAMPLE: Suppose the sizing calculation for a vented lead-acid battery determined that 5 positive plates per cell were required for the specified duty cycle. What size cell is needed to account for aging and an expected low operating temperature of 15.6 °C (60 °F)? Also, the designer would like to add a 10 percent design margin.
>
> The aging correction factor is 1.25 to ensure adequate capacity when the battery is at end of life. From Table E-1, the temperature correction factor is 1.11 for an operating temperature of 15.6 °C (60 °F). The design margin correction factor is 1.10. The required cell size is as follows:
>
> $$\mathit{Corrected\ Cell\ Size} = (5\ \mathit{positive\ plates}) \times 1.25 \times 1.11 \times 1.10 = 7.63\ \mathit{positive\ plates}$$
>
> In this case, round up to 8 positive plates. If the application of design margin causes the calculated cell size to slightly exceed the next size cell, for example, 7.05 positive plates, the designer should, in this case, determine if 7 positive plates are adequate. Rounding up to the next cell size results in a larger and more expensive battery. The battery must be big enough to do its job throughout its service life, but a grossly oversized battery is not desirable either.

E-1.12 In summary, size the battery for the limiting portion of the duty cycle, including corrections for performance at end of battery life and for the minimum expected operating temperature. If needed, include an additional design margin.

E-2 **BATTERY SIZING FOR UPS APPLICATIONS**.

E-2.1 Compared to duty cycle sizing, UPS applications often involve a different approach to battery sizing. If the UPS is the only load placed on the battery (which is common for many UPS systems), the battery can be sized more easily based on the UPS constant power requirements. Battery manufacturers also provide sizing charts based on a constant power discharge. The method of analysis is particularly straightforward, consisting of the following steps:

E-2.1.1 Determine total load (and duration) the UPS will place on the battery. The duration can be the most difficult design factor to specify. If additional backup power such as a diesel generator is not available, the UPS battery has to be large enough for the staff to place the system in a safe state in response to a power outage. If diesel generator backup is available, a 5-minute backup time might be adequate if the diesel system operates properly. If the designer allows for diesel starting difficulties, a backup time of over 30 minutes might be needed.

E-2.1.2 Apply cell sizing correction factors so that the battery can provide the required load at end of life and the design low temperature.

E-2.1.3 Determine the minimum and maximum system voltage. Select the number of cells based on the minimum and maximum voltage limits.

E-2.1.4 Calculate the load on each cell and select a cell size capable of supplying the required load.

E-2.2 As a battery discharges, the battery voltage declines in a predictable manner. For a constant power discharge, the current will increase in direct proportion to the voltage decrease in accordance with the following relationship:

$$Power = Voltage \times Current$$

EXAMPLE: The easiest way to discuss battery sizing for a UPS application is with an example. Assume the UPS specifications applicable to the battery are as follows:

Size: 7.5 kVA @ 0.8 power factor (6.0 kW)
Inverter efficiency: 0.92 at full load
Maximum input dc voltage: 140 volts
Low voltage cutout: 105 volts

The user specifies that the UPS must power critical loads for a minimum of 30 minutes following a loss of normal power. The user believes that the UPS will be almost fully loaded for the entire discharge duration.

First, calculate the total battery load. Assume the UPS is fully loaded at 7.5 kVA. The power required from the battery is the real power produced by the UPS including efficiency losses. The real power produced by the inverter is 6.0 kW (7.5 kVA x 0.8 PF). Thus, the required battery load is:

$$Battery\ Load\ (kW) = \frac{Power}{Efficiency} = \frac{6.0\ kW}{0.92} = 6.52\ kW$$

This is the nominal load that the battery must be capable of providing when the battery has 100 percent capacity at 25 °C (77 °F). As discussed previously, the battery will have less than rated capacity if the temperature is less than 25 °C (77 °F). Also, a lead-acid battery is normally sized to be capable of fulfilling its design load requirements at end of battery life (80 percent capacity). Apply the appropriate correction factors to ensure the battery can meet this load requirement at end of battery life at the lowest expected temperature. The correction factors are as follows:

Aging: 1.25 (corresponding to 80 percent capacity)
Temperature: 1.11 (assume lowest expected temperature is 15.6 °C or 60 °F)

The corrected battery load is:

$$Corrected\ Battery\ Load\ (kW) = \frac{6.0\ kW}{0.92} \times 1.25 \times 1.11 = 9.05\ kW$$

Notice that the designer chose not to add design margin because the UPS is already assumed to be fully loaded.

For this typical example, the duty cycle consists of the above constant load for 30 minutes.

The UPS maximum dc input voltage was specified as 140 volts. This voltage is the maximum allowed voltage on the system. Also, assume that the manufacturer recommends a maximum battery equalize voltage of 2.33 volts per cell. The maximum number of cells is given by:

$$Maximum\ Number\ of\ Cells = \frac{Max\ System\ Voltage}{Equalize\ Voltage} = \frac{140}{2.33} = 60.09\ cells$$

In this case, choose 60 cells. Next, determine the minimum allowed voltage per cell based on the system minimum voltage requirement of 105 volts:

$$Minimum\ Cell\ Voltage = \frac{Minimum\ System\ Voltage}{Number\ of\ Cells} = \frac{105}{60} = 1.75\ volts$$

The designer needs 60 cells capable of providing 9.05 kW for 30 minutes without allowing voltage to drop below 1.75 volts per cell. Each cell must deliver:

$$\frac{9.05\ kW}{60\ cells} = 0.151\ kW\ per\ cell$$

This is the information needed to select a cell from the manufacturer's data sheets. Each cell must be capable of providing 0.151 kW for 30 minutes without individual cell voltage falling below 1.75 volts.

E-2.3 Refer to IEEE 1184, *IEEE Guide for the Selection and Sizing of Batteries for Uninterruptible Power Supply Systems*, for additional information regarding sizing of UPS batteries.

E-3 BATTERY SIZING FOR ENGINE STARTING APPLICATIONS.

E-3.1 Depending on the design, a diesel engine might be started by an air system or an electric motor (starting motor). Electric starting is the most convenient to use, is usually the least expensive, and is the most adaptable method for remote control and automation. The ambient temperature and lubricating oil viscosity affect the starting ability of a diesel engine. The diesel relies on the heat generated by compression to ignite the fuel. When first starting, this compression and heat is created by the diesel cranking (starting) process, which is a function of the cranking speed and cranking time. When the engine is cold, longer cranking periods are required to develop ignition temperatures. The battery powers an electric starting motor to accomplish this cranking process. Lubricating oil imposes the greatest load on the cranking motor; oil viscosity varies with oil type and temperature. For example, Society of Automotive Engineers (SAE) 30 oil viscosity approaches that of grease below 0 °C (32 °F).

E-3.2 Either lead-acid or nickel-cadmium batteries can be used for engine starting. The nickel-cadmium type is often used so that the battery can be located very near the engine, which is usually a higher ambient temperature environment. Also, nickel-cadmium batteries are capable of very high-rate discharges for the few seconds needed for an engine cranking application.

E-3.3 In many cases, the associated battery's only purpose is to provide cranking power to start the diesel engine. In these cases, battery sizing is performed differently than described in the previous sections. The primary considerations for sizing a diesel engine battery are:

- The lowest temperature at which the engine might be cranked. Oil viscosity increases with decreasing temperature and affects how long the starter motor must turn before fuel ignition temperature is reached. Note also that lower temperatures affect the battery's capacity. At lower temperatures, the battery's capacity requires adjustment for both oil viscosity and decreased battery capacity. For very cold applications, consider engine heaters or glow plugs to minimize the battery size requirements.

- How many start attempts will be allowed. Select a battery that can provide at least four 30 second cranking periods (total of 2 minutes of cranking). Engines are often rated for up to 30 seconds of cranking before the starter motors begin to overheat. Confirm the starter motor limitations with the manufacturer.

E-3.4 EGSA 100B provides guidance for sizing a diesel engine starting battery. This performance standard should be used for battery sizing; it recommends providing the following information to the battery manufacturer as part of a battery sizing evaluation:

- Nominal volts needed for the starter motor.

- Starting current of starter motor.
- Engine model and make.
- Cubic inches displacement. Some battery manufacturers have sizing guidelines based on the cubic inches displacement.
- Number of cranks and possible duration of each crank.
- Rest period for battery recovery, if needed.
- Worst case low battery temperature.
- Worst case low engine temperature and oil viscosity.
- Battery type and desired life.
- Seismic or vibration requirements.

E-3.5 As part of the sizing process for a diesel engine battery, consider voltage drop between the battery and the starter motor. The starter motor usually draws significant current from the battery. For this reason, batteries are often located very near the diesel engine to minimize the voltage drop caused by the high current. Typical connecting devices between the battery and the starter motor include:

- Cable—resistance varies with cable size and length.
- Contactors (relays, solenoid, switches)—resistance less than 0.002 ohms is typical.
- Connections—each connection resistance less than 0.001 ohms is typical.

E-3.6 The diesel engine manufacturer usually specifies the minimum system requirements, including the maximum connection resistance between the battery and the starter motor. Ensure these minimum requirements are met by the installation.

E-4 **CHARGER SIZING**.

E-4.1 Size each battery charger to be large enough to power the normal system loads while recharging a discharged battery within a reasonable amount of time. Manufacturers recommend a recharge time of 8 to 12 hours. Shorter recharge times require larger battery chargers and might result in excessive current flow into the battery during the recharge process. For this reason, 8 hours is usually the minimum recharge time for a discharged battery. On the high end, 12 hours is often recommended for an upper limit; however, this recharge time is somewhat arbitrary and 14 hours or 16 hours might be acceptable, depending on the application and how the recharge is controlled. The primary consideration is that the charger should be sized to recharge the battery within a reasonable amount of time.

E-4.2 Size the charger to be large enough to supply the normal continuous loads while also recharging the battery within a reasonable time period. The charger sizing formula is as follows:

$$A = \frac{kC}{H} + L_c$$

where

- A = Output rating of the charger in amperes.
- k = Efficiency factor to return 100 percent of ampere-hours removed. Use 1.1 for lead-acid batteries and 1.4 for nickel-cadmium batteries.
- C = Calculated number of ampere-hours discharged from the battery (calculated based on duty cycle).
- H = Recharge time to approximately 95 percent of capacity in hours. A recharge time of 8 to 12 hours is usually recommended.
- L_c = Continuous load (amperes).

E-4.3 The above sizing method is recommended, but tends to provide an optimistic recharge time. The actual recharge time is usually longer than indicated above because the charging current tends to decrease as the battery voltage increases during recharge.

EXAMPLE: Determine the charger rating if a) the continuous load is 100 amperes, b) 300 ampere-hours are discharged from a lead-acid battery, and c) the battery is to be recharged within 10 hours.

$$A = \frac{1.1 \times 300}{10} + 100 = 133\ amperes$$

EXAMPLE: Suppose that the above system has 50 amperes of noncontinuous loads that can be energized at any time. In this case, the total charger load is the sum of the continuous and noncontinuous load before consideration of battery recharge requirements. At any time, the charger load can be as high as:

$$A = L_c + L_n = 100 + 50 = 150\ amperes$$

If the charger in the previous example was selected to have a capacity of 133 amperes, the battery would have to supply the additional load whenever the noncontinuous load is energized. So, the charger should instead be sized to provide the expected system loads, or 150 amperes in this example. Note that this assumes the noncontinuous loads will not be energized for long periods when the battery is being recharged.

APPENDIX F

INTERIOR LIGHTING

F-1 INTRODUCTION.

F-1.1 Lighting design is one of the fastest changing areas of interior electrical design. Because of the many recent advances in lighting technology, including the industry's understanding of lighting needs for optimal human performance, this appendix has been developed as a stand-alone document for lighting requirements.

F-1.2 Lighting systems are not static devices and require maintenance over time to maintain light levels at acceptable minimums. A key objective is to predict how much extra light is needed to account for non-recoverable losses over the life of the system and recoverable losses between maintenance cycles. Another important objective is to understand how light will be distributed across various tasks and adjacent surfaces. These are some of the reasons why lighting concepts often require mathematical modeling to predict their validity.

F-1.3 Good lighting begins with concepts that meet specific needs. Specific needs for lighting will be different depending on the relative importance of appearance, task, safety, security, maintenance, and energy issues. Although energy is important, the quality or purpose of the lighting design should not be a compromise for the purpose of pure energy savings. If retrofitting an existing project to reduce energy consumption, verify that the lighting design requirements will still be met.

F-1.4 Currently, electric lighting is responsible for about 25 percent of the electrical energy use in North America. By using sound lighting design practices and new equipment technologies, there are significant opportunities for additional power conservation. This appendix has been developed to ensure compliance with the Energy Policy Act of 1992 and Executive Order (EO) 13123, *Greening the Government Through Efficient Energy Management*, which regulate or restrict lighting applications and their energy use in both new and existing Federal buildings.

F-1.5 Federal policy requires the use of life cycle costing to properly evaluate the true cost of lighting. In many instances, lower first costs do not reflect the most cost-effective long-term solutions. Specific requirements of this manual, such as the use of T-8 fluorescent lamps, are considered *de facto* compliant with applicable efficiency and cost effectiveness provisions of Federal law and serves as the minimum standard for comparison purposes.

F-1.6 There is no substitute for practical experience in lighting design. In many ways, lighting design is an art and in others ways it is a science. Some lighting solutions are simple because they are easy to define based on previous experience. Complex spaces with complex needs will require the assistance of a Certified Lighting Designer.

F-2 APPLICABLE DOCUMENTS AND STANDARDS.

F-2.1 The recommendations and requirements in this manual are intended to be consistent with the standards of the Illuminating Engineering Society of North America (IESNA). Other documents are also important to the proper application of lighting. The following documents have been used in the development of this manual and should be available to the designer.

- *IESNA Lighting Handbook*—an extensive compilation of information including the physics, fundamental concepts, calculation methods, standard tables and charts, and application recommendations for indoor and outdoor illumination.

- *IESNA Recommended Practices*—various publications, each covering the illumination applications for a specific building type. Certain publications are especially useful concerning particular building types, and are individually cited in paragraphs F-15.1 through F-15.4.

- American Society of Heating, Refrigerating and Air-Conditioning Engineers ASHRAE/IESNA/ANSI 90.1-1999*, Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings*—this standard, available through ASHRAE, serves as the basis of Federal Energy Policy in new buildings.

- National Electrical Code (NEC)—requirements for lighting are listed throughout the code, and Articles 410 and 411 are directly applicable.

- National Fire Protection Association (NFPA) Standard 101, *Life Safety Code*—identifies illumination levels for emergency egress lighting.

- National Electrical Contractors Association (NECA)/IESNA National Electrical Installation Standards (NEIS), including NECA/IESNA/ANSI 500, *Recommended Practice for Installation of Commercial Lighting Systems*, and NECA/IESNA 502, *Recommended Practice for Installing Industrial Lighting Systems*—provides specific guidance to contractors for the installation of lighting systems.

- Corp of Engineers Technical Instructions TI 811-16, *Lighting Design*—provides additional information regarding lighting design principles.

- Air Force Interior Design Guides, Chapter 10, *Light and Lighting*—provides additional information regarding lighting design principles and is available at http://www.afcee.brooks.af.mil/dc/dcd/interior/intdespu.asp.

F-2.2 The publications referenced here are the current documents as of the writing of this manual; however, most of these documents are periodically revised and reissued. The most recent issue should be used.

F-3 DETERMINING LIGHT QUANTITY REQUIREMENTS.

F-3.1 **Basic Requirement**. Verify the quantity of illumination meets the requirements of the visual tasks being performed, or other requirements stated in this manual. Unless specifically stated otherwise, determine the appropriate illumination according to the IESNA Illuminance Selection Procedure from the IESNA Lighting Handbook.

F-3.2 **Measurement of Illumination**. Unless specifically stated otherwise, the illumination requirements defined in this section are for horizontal illumination measured in the horizontal plane at the task, or for general illumination in a plane 762 millimeters (30 inches) above the floor.

F-3.3 **Lighting Level at the Task**. The IESNA Lighting Handbook lists appropriate illumination levels in footcandles and lux for various visual tasks. Design lighting to provide illumination within this range at each task. Light levels that are higher might be acceptable, but consistent or significant overlighting is not efficient and should be avoided. In this manual, specific light levels are specified for particular applications and take precedence over IESNA recommendations.

F-3.4 **General or Ambient Illumination**. Illumination levels in the area surrounding the task can be as high as the task light levels or as low as 1/3 of the task light levels. Significantly higher ambient to task light levels (>1/1) can create too much contrast, which can cause discomfort and use energy unnecessarily. Lower ambient to task light levels (<1/3) can also create uncomfortable contrast.

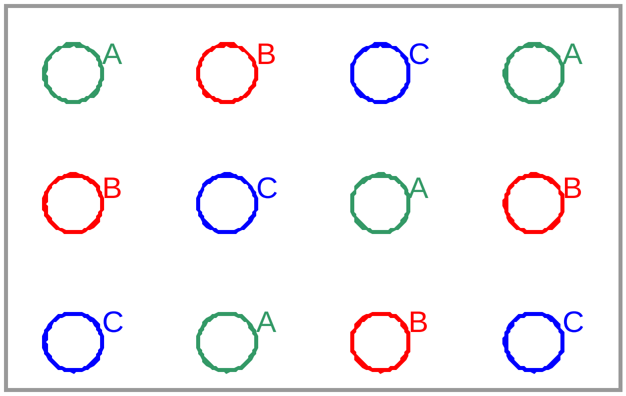
F-3.5 **Illumination in Adjacent Areas**. As part of the selection of illumination levels, take into account the light in adjacent spaces to minimize *transient adaptation*, which is the process of the human eye adjusting to differences in light levels when moving from one space to another. Typical transient adaptation situations that cause visual difficulties include entering a very dark room when coming from a brightly lit environment such as daylight. When the difference is greater than 1,000:1, the eye will be momentarily blinded. If the difference is 10,000:1, such as entering a darkened theater from outdoors, the eye will be blinded for several minutes while the eye adjusts. Adjustments of 100:1 or less do not cause significant temporary blindness.

F-4 DETERMINING LIGHT QUALITY REQUIREMENTS.

F-4.1 Flicker and Stroboscopy.

F-4.1.1 For indoor lighting, minimize light source flicker. This can be accomplished using electronic high frequency ballasts for fluorescent and compact fluorescent lamps, and through the three-phase rotation of high-intensity discharge (HID) light sources (refer to Figure F-1).

Figure F-1. Lighting Plan Showing Phase Rotated HID Luminaires



F-4.1.2 Where rotating machinery is present, minimize or eliminate light source stroboscopy in an appropriate manner. This can be accomplished by the use of the above methods. When using HID lamps, supplemental task light using incandescent or electronically-ballasted fluorescent sources should be added at the rotating equipment task location. In some cases, specialized lighting might be required for safety, and will be usually identified by the equipment manufacturer, operating manual, or by observation of operating conditions.

F-4.2 **Source Color (Chromaticity)**.

F-4.2.1 Select the *correlated color temperature (CCT)* of electric lamps to be appropriate for the application. If possible, select all light sources within the same space with similar color temperature. Appropriate color temperatures are listed in Table F-1, but can be different depending upon specific application situations.

F-4.2.2 People tend to prefer higher color temperature of light with higher light levels. The acceptable CCT is a range, and not an exact value. Table F-1 serves as a guide.

Table F-1. Light Source Applications According to Source Color

CCT (Kelvin)	Typical Light Sources	Appearance	Appropriate Applications
2,000 – 2,500	High pressure sodium	Very warm, similar to candlelight.	Few. Refer to paragraph F-6.6 regarding the use of high pressure sodium lamps.
2,700	Incandescent Fluorescent Compact fluorescent	Warm, similar to incandescent light.	Living quarters Dining rooms Lobbies and waiting rooms Formal meeting spaces Formal offices
3,000	Tungsten halogen Fluorescent Compact fluorescent Metal halide	Warm, but crisp when compared to incandescent. Also, referred to as "Warm White".	Living quarters Dining rooms and cafeterias Lobbies and waiting rooms Formal meeting spaces Formal offices Retail sales and display
3,500	Fluorescent Compact fluorescent	Neither cool nor warm. Also, referred to as "White" and "Natural".	General lighting in a wide variety of applications.
4,100	Fluorescent Compact fluorescent Metal halide	Cool. Also, referred to as "Cool White".	General lighting in work areas.
5,000	Fluorescent Compact fluorescent Special metal halide	Very cool, bluish. Entering typical daylight color temperature range.	Task lighting for precision color tasks
6,500	Fluorescent	Very cool, bluish.	Task lighting for precision color tasks
7,500	Fluorescent	Very cool, very bluish.	Task lighting for precision color tasks
10,000	Fluorescent	Very cool, very bluish.	Task lighting for precision color tasks

F-4.3 **Source Color Quality**. Select the *color rendering index (CRI)* of electric lamps appropriate for the application. Appropriate CRI values are listed in Table F-2.

Table F-2. Appropriate Color Rendering Indices

Color Rendering Index	Typical Sources	Appearance	Applications
0 – 40	High pressure sodium and low pressure sodium	Colors are severely distorted, some colors not even visible.	Warehousing and other gross tasks. Refer to paragraph F-6.6 regarding high-pressure sodium lamps.
40 – 50	Mercury vapor	Colors are distorted, some hardly visible.	Warehousing and other gross tasks. Refer to paragraph F-6.4 regarding mercury vapor lamps.
50 – 65	Traditional fluorescent lamps like “cool white”, “lite white”, “warm white”, “white” and “daylight”.	Colors are distorted, generally with a distinct tint. For example, cool white has a green tint and warm white has an orange tint.	Some work areas.
65 – 80	Fluorescent T-8 lamps Metal halide lamps	Colors are slightly distorted, but reasonable distinction is possible and lighting appears fairly natural.	General lighting in most applications.
80 – 90	Fluorescent lamps Compact fluorescent lamps Certain metal halide lamps	Colors are fairly natural in appearance, and color distinction is very good.	Where color distinction and/or discrimination are important, such as health care treatment and retail sales.
90 – 100	Incandescent and halogen lamps Certain fluorescent lamps	Colors are almost perfectly natural in appearance, and color distinction and discrimination are excellent.	Where color distinction and/or discrimination are important, such as technical color evaluation, graphic arts, and museums.

F-4.4 **Glare Control**.

F-4.4.1 There are two principal types of glare—*discomfort glare* and *disability glare.* Both types can be minimized or eliminated through proper design practices, including the use of luminaires with appropriate characteristics, proper source location, and other means.

F-4.4.1.1 *Disability glare* is caused by light sources that obscure visual tasks or make them hard to see. The reflection of a bright light or window in a computer screen is a type of disability glare. Similarly, a bare lamp adjacent to a task can make it harder, rather than easier to see. Disability glare might not be associated with a sense of discomfort. Because disability glare affects visual performance, attention to potential problems should be considered essential.

F-4.4.1.2 *Discomfort glare* occurs when a bright light source makes viewing uncomfortable, even when a task is not being performed. Natural daylight, if not properly controlled, can be a common source of discomfort glare. Other sources include many types of common electric lights. While not as critical for visual performance, discomfort glare is a cause of eye fatigue and affects long-term worker productivity.

F-4.4.2 Glare control usually involves source shielding from important viewing angles. For this reason, many luminaires employ shielding methods such as lenses, louvers or baffles which obscure the light source from direct view up to about 45 degrees. This permits light to be focused by the luminaire to the visual task below it, but shields a heads-up view from direct viewing of the light source.

F-5 **HUMAN FACTORS**.

F-5.1 **Adaptation**.

F-5.1.1 The process of the eye's adjustment is called *adaptation*. The eye can adjust fairly rapidly over a 100:1 range mostly through the dilation or contraction of the pupil. But the wider the range, the longer the adjustment period. It can take 5 minutes to fully adapt to starlight (0.01 footcandle) when coming from a room lighted to only 10 footcandles, an adjustment range of 1,000:1. The widest adjustment range for the eye, from 10,000 footcandles (full noon sun) to starlight (1,000,000:1) can take over an hour. Adaptation also takes longer with age.

F-5.1.2 Because military operations can involve rapid deployment of personnel into night and low light level activities, consideration for rapid adaptation might be necessary. Usually, this involves reduction of light levels in interior spaces and the use of light sources of appropriate spectrum and shielding. Because this is specialized technology, professional design assistance should be used.

F-5.2 **Computer Vision Syndrome (CVS)**.

F-5.2.1 CVS involves both performance and comfort problems concerning work involving computer screens, especially cathode ray tube (CRT) screens. Lighting problems associated with CVS are usually caused by forms of disability and discomfort glare, too much or too little illumination, and flicker. Because of the importance of computers in most operations, design lighting systems for spaces involving computer work to comply with the recommendations of the IESNA contained in IESNA/ANSI RP-1-93, *Office Lighting*, as it relates to computer work area illumination.

F-5.2.2 For areas where computer work is constant, comply with IESNA “preferred” recommendations. This requires the use of either very low brightness direct luminaires, indirect lighting, or direct/indirect lighting with a very low brightness direct component. Lay out the lighting systems in strict conformance with ceiling brightness, luminance cut off, and other characteristics identified by the IESNA.

F-5.3 **Other Human Factors**.

F-5.3.1 Studies have shown that light can be used effectively to treat several common problems. These include:

F-5.3.1.1 Seasonal affective disorder (SAD), commonly called winter depression. SAD afflicts some people during the winter months with the effects increasing as latitude approaches the poles.

F-5.3.1.2 Sleep disorders, especially for personnel who work at night and sleep by day. Light therapy can be especially effective for personnel assigned to underground stations. Experiments in shift-work cycle acclimation have been performed successfully in nuclear power plants and other locations where worker attentiveness is crucial during midnight shift operations.

F-5.3.1.3 Aid in rapid recovery from jet lag.

F-5.3.2 Light therapies are an evolving area of medical research, and design implications are just beginning to be understood. When project requirements dictate, professional design assistance should be used.

F-6 **LIGHT SOURCE SELECTION**.

F-6.1 **Incandescent Lamps**.

F-6.1.1 Incandescent lamps include incandescent, tungsten halogen, halogen infrared reflecting, xenon incandescent, and low voltage lamps.

F-6.1.2 Lighting systems using incandescent lamps should be avoided due to the inefficiency and short lamp life. It is permissible to employ incandescent in applications where short operating hours or the need for immediate on-off light is required. In addition, the following specific applications can utilize incandescent lamps:

- Special purpose incandescent lamps.
- Retail-type display lighting systems employing track lighting and equipped with tungsten halogen or halogen infrared reflecting lamps.
- Table and floor lamps and decorative chandeliers in living quarters, food service facilities, and residential commons facilities.

- Emergency lighting.

F-6.2 **Full Size and U-Bent Fluorescent Lamps**.

F-6.2.1 Full size and U-bent fluorescent lamps include most straight and U-bent lamps from 152 millimeters (6 inches) in length through 2.4 meters (8 feet).

F-6.2.2 Lighting systems employing full size and U-bent fluorescent lamps should be considered acceptable choices in the majority of interior applications. Wherever possible, designs should utilize 32-watt T8 lamps with a minimum CRI of 70 and a minimum output of 2,800 lumens. Specific lamp color should be determined in accordance with paragraphs F-4.2 through F-4.3. Secondary preference should be given to F96T8, F25T8 and F17T8 straight lamps, and to F32T8 U-bent lamps. T12 lamps should not be used in major lighting system applications.

F-6.2.3 Fluorescent lamp ballasts should be electronic, high frequency type. Ballasts should be selected with consideration for ballast factor, harmonic distortion, and other parameters. Designs should employ multi-lamp standard ballast factor ballasts with total current harmonic distortion less than 20 percent. Various ballast factors, dimming capabilities, and low harmonic distortion ballasts might be required for specific applications.

F-6.2.4 In cold temperature installations, fluorescent lights can be slow to start and will produce less light output.

F-6.3 **Compact Fluorescent Lamps**.

F-6.3.1 Compact fluorescent lamps include most twin tube, quad (double-twin) tube, hex (triple twin tube), helical, double-D, and similar forms of fluorescent lamps. Compact fluorescent lamps are further subdivided into those with plug or pin bases, and those with medium bases.

F-6.3.2 Lighting systems employing plug- and pin-based compact fluorescent lamps should be considered acceptable choices in a number of interior applications. Newer twist-type sockets simplify replacement. Wherever possible, designs should utilize 13-watt twin and 26-, 32-, or 42-watt hex lamps with a minimum CRI of 80. Specific lamp color should be determined in accordance with paragraphs F-4.2 through F-4.3. Secondary preference should be given to other wattages and shapes. In no event should medium based (screw-in) compact fluorescent lamps be used in major lighting system applications.

F-6.3.3 Compact fluorescent lamp ballasts for 13-watt lamps can be magnetic or electronic. Ballasts for 26 to 42 watt lamps should be electronic, high frequency type. Ballasts should be selected with consideration for ballast factor, harmonic distortion, and other parameters. Designs should employ standard ballast factor ballasts with total current harmonic distortion less than 20 percent. Various ballast factors, dimming capabilities, and lower harmonic distortion ballasts might be required for specific applications. Consider ballast end-of-life sensing circuitry for the application.

F-6.3.4 Lamps with medium bases indicate that the ballast is self-contained. If used, these lamps should be of the type that permits lamp replacement without ballast disposal. Applications of this technology should be limited to energy efficiency conversions of existing facilities, including table lamps, floor lamps, and other portable lighting.

F-6.4 **Mercury Vapor Lamps**.

F-6.4.1 Mercury vapor lamps are a type of high intensity discharge lamp whose most common applications include roadway lighting, flood lighting, and other forms of outdoor and industrial lighting.

F-6.4.2 Because mercury vapor lamps are inefficient compared to metal halide and high-pressure sodium lamps, their use in new designs should be avoided. In existing installations, consider retrofitting with sources that are more efficient.

F-6.5 **Metal Halide Lamps**.

F-6.5.1 Metal halide lamps are a type of high intensity discharge lamp whose most common applications include roadway lighting, flood lighting, and other forms of outdoor and industrial lighting. In addition, low wattage (150 watts and less) versions are used for a wide variety of indoor and exterior applications.

F-6.5.2 Lighting systems employing metal halide lamps should be considered acceptable choices in the majority of interior applications. Wherever possible, designs should utilize pulse-start lamps with a minimum CRI of 65. Lamp color options are limited and specific lamp color should be determined in accordance with paragraphs F-4.2 through F-4.3. Secondary preference should be given to standard metal halide lamps in 175-, 250-, 400-, and 1000-watt sizes. Lamp warm-up and restrike times should be taken into consideration, and appropriate instant-starting emergency lights should be provided. Metal halide lamps should be the pulse-start type because of improved life and higher lumen output capability.

F-6.5.3 Newer ceramic metal halide lamps offer improved color resolution (up to 85 CRI) and reduced color shift, and are appropriate light sources in many interior applications.

F-6.5.4 Because of rapidly changing technology in metal halide lamps, specific designs should consider employing evolving technology designed to increase lamp life or increase energy efficiency. Electronic ballasts can be considered, particularly in ballasts for lamps 100 watts and less, provided adequate warranty coverage is included.

F-6.6 **High Pressure Sodium Lamps**.

F-6.6.1 High-pressure sodium lamps are a type of high intensity discharge lamp whose most common applications include roadway lighting, flood lighting, and other forms of outdoor and industrial lighting. In addition, low wattage (150 watts and less) versions are used for a variety of indoor and exterior applications.

F-6.6.2 Lighting systems employing high-pressure sodium lamps should be avoided in the majority of applications. Recent research findings have determined human vision difficulties under sodium based lamps. Appropriate locations for high-pressure sodium luminaires include warehousing and similar situations where neither detailed nor close-up visual work occurs. Lamp warm-up and restrike times should be taken into consideration, and appropriate instant-starting emergency lights should be provided.

F-6.7 **Low Pressure Sodium Lamps**.

F-6.7.1 Low-pressure sodium lamps are a type of high intensity discharge lamp whose most common applications include roadway lighting, and other forms of outdoor and industrial lighting.

F-6.7.2 Lighting systems employing low-pressure sodium lamps should be avoided in the majority of applications. Recent research findings have determined human vision difficulties under sodium based lamps. Appropriate locations for low-pressure sodium luminaires include outdoor storage areas and similar situations where security and surveillance is provided principally by cameras tuned to respond to the monochromatic radiation of these lamps. Lamp warm-up and restrike times should be taken into consideration, and appropriate instant-starting emergency lights should be provided.

F-6.8 **Sulfur Lamps**.

F-6.8.1 Sulfur lamps are an evolving type of high intensity discharge lamp. Sulfur lamps are compact point sources excited by a microwave generator. Commercial products have limited availability, but growth in the product area is expected.

F-6.8.2 Lighting systems employing sulfur lamps can be considered in special or unique applications where the energy efficiency and long lamp life can be realized without adverse effects. Appropriate locations for sulfur luminaires might include area lighting and similar situations where a high wattage, point source may be suitable. Lamp warm-up and restrike times should be taken into consideration, and appropriate instant-starting emergency lights should be provided.

F-6.9 **Cold Cathode and Neon Low Pressure Lamps**. Neon and cold cathode lamps are custom-made low pressure lamps similar to fluorescent lamps in shape, size, and method of operation. Because of their custom nature, neon and cold cathode lamps should be avoided except for unique and specialized applications such as signs, special effects, and shapes such as curves or non-standard lengths.

F-6.10 **High Pressure Xenon and Carbon Arc Lamps**. High-pressure xenon and carbon-arc lamps are technologies optimized for searchlights and similar applications. These sources should only be used in these specialized and unique applications.

F-7 SETTING ENVIRONMENTAL AND INSTALLATION REQUIREMENTS.

F-7.1 **Wetness**. Determine whether "dry", "damp", or "wet" conditions apply. Refer to NEC Article 100 (I) for the definition of damp, dry, and wet locations.

F-7.2 **Environmental Conditions**. Determine whether any special environmental conditions apply, such as a corrosive or explosive atmosphere, extremely cold or hot locations, marine/salt water atmosphere, clean room, food preparation area, or other unusual requirements.

F-7.3 **Structural Support**. Determine the supporting means for the lighting systems, including specific considerations for seismic reinforcement and other conditions.

F-7.4 **Ceiling System**. When lighting systems are intended to be recessed into or mounted onto ceilings, determine the ceiling system type and capacity for lighting, including plenum height and other factors. Determine whether the ceiling is fire rated.

F-7.5 **Power System**. Determine the available voltages, frequency, and capacity of power sources for lighting.

F-7.6 **Maintainability**. Evaluate the ability to perform future maintenance in the installed location. For example, lighting in atriums, tall lobbies, and banister lighting can be very hard to maintain. Determine if the selected design will require a lift or scaffolding just to replace lights. In cases of poor or limited access, evaluate lighting quality and luminaire life as part of the design.

F-7.7 **Accessibility**. Facility users are usually responsible for lamp replacements at and below 3 meters (10 feet). Evaluate the lighting system design to confirm that users will be able to periodically replace the installed lamps.

F-8 SELECTING LUMINAIRES.

F-8.1 Light Distribution.

F-8.1.1 Select luminaires to distribute light in a manner appropriate for the application. The following luminaire distributions should be considered for each application.

F-8.1.1.1 *Direct luminaires* emit light downward, and include most types of recessed lighting, such as downlights and troffers, as well as most types of industrial low and high-bay luminaires. Most office and retail lighting systems use direct luminaires, which tend to be more efficient, distributing light directly onto the task area. But direct lighting can be glaring and often creates dark ceilings and upper walls, which, although dramatic, are uncomfortable due to high contrast.

F-8.1.1.2 *Indirect luminaires* emit light upward, in turn bouncing light from the ceiling into the space. These include many styles of suspended luminaires, sconces, and some portable lamps, generally suited for offices and other clean interior spaces. Indirect luminaires tend to create comfortable low-contrast soft light that psychologically enlarges space. Indirect lighting is less efficient for general and task lighting. Indirect lighting can be used but it must be applied carefully as an ambient light source.

F-8.1.1.3 *Diffuse luminaires* emit light in all directions uniformly, and include most types of bare lamps, strips, globes, chandeliers, and some table and floor lamps. Diffuse luminaires tend to create broad general light that often is considered glaring due to lack of side shielding. They are usually chosen for ornamental reasons or for utilitarian applications.

F-8.1.1.4 *Direct/indirect luminaires* emit light upward and downward but not to the side. These include many types of suspended luminaires, as well as some table and floor lamps. Note that direct/indirect luminaires can be mostly direct or mostly indirect according to the proportions of up and down light. Direct/indirect luminaires are often a compromise between the efficiency of direct lighting and the comfort of indirect lighting.

F-8.1.1.5 *Asymmetric and adjustable luminaires* are designed for special applications. Wallwashers are a form of asymmetric direct luminaire with stronger distribution to one side to illuminate a wall. Adjustable luminaires, including track lights, floodlights, and accent lights are generally direct luminaires that can be adjusted to throw light in directions other than down.

F-8.1.2 **Standard Lighting Systems**. Insofar as possible, select standard commercial or industrial type luminaires intended for use in the application. For most lighting applications, there are specific types of luminaires that have been developed for the application.

F-8.2 **Fluorescent Lighting Systems**.

F-8.2.1 **Strip Lights**. Strip lights or “channels” are the most basic of fluorescent luminaires, but have a surprising number of uses. Like bare incandescent lamps, a strip light can be used to produce cheap general illumination, so long as efficiency and glare control are not important. But often, the strip light is used in unique situations, such as inside cabinets or cases, in coves or valances, behind Plexiglas sign panels, or other applications where a “line of light” is needed.

F-8.2.2 **Troffers**. Troffers are simple steel-trough fluorescent fixtures with a lensed face (in the case of lensed troffers) or louver face (in the case of parabolic troffers). Most troffers are designed to fit in an opening in an acoustic tile ceiling, and are usually 0.6 meters by 1.2 meters (2 feet by 4 feet) in nominal dimensions. Troffers are placed in a pattern to create general lighting throughout the room. Typically, a two-lamp recessed troffer every 6 square meters in a 2.4 meters by 2.4 meters grid (64 square feet in an 8 feet by 8 feet grid) or a three-lamp recessed troffer every 7.4 square meters in a 2.4 meters by 3 meters grid (80 square feet in a 8 feet by 10 feet grid) provides an average of 40 to 60 footcandles maintained. These systems can produce the necessary illumination for many typical interior spaces at about 0.95 watts 0.1 square meter (per square foot). In new luminaires, there is little need for specular silver or aluminum reflectors. The increase in efficiency is only a couple of percent, and the cost is usually not warranted. Do not use silver or polished reflectors in parabolics as they create glare. Paragraphs F-15.1 through F-15.1.3 provide additional guidance regarding the selection of troffer systems.

F-8.2.3 **Wraparounds**. Wraparounds are relatively low cost fluorescents designed to have a finished appearance whether surface mounted or suspended by pendants. The luminaire is essentially a strip light with a U-shaped diffuser or lens surrounding the lamp on three sides, producing some uplight as well as widely distributed downlight. One and two lamp “wraps” are used in corridors, stairs, and a variety of general lighting and utility applications. Four-lamp wraps are often used for the office and retail lighting, as well as some types of “clean” industrial lighting.

F-8.2.4 **Industrial Fluorescents**. Industrial fluorescent luminaires can be used in a variety of shops, service facilities, and other work and utility areas. They can be surface mounted, suspended from stems or on chains, or strapped to the bottom of building structural members. The reflector increases downward light as compared to a strip light, making industrial fluorescent luminaires more efficient for illuminating work surfaces.

F-8.2.5 **Watertight Fluorescents**. These are a form of fluorescent luminaire that permit use in wet environments and allow hose-down cleaning. Watertight fluorescents can be specified with non-metallic housings for corrosion resistance.

F-8.3 **HID Lighting Systems**.

F-8.3.1 **Industrial HID Luminaires**. HID luminaires have been optimized for typical industrial and work area applications. The optics of these luminaires are optimized for various distributions and mounting heights. *High bay* luminaires are designed for mounting heights over 6.1 to 7.6 meters (20 to 25 feet); *low bay* luminaires are designed for mounting less than 7.6 meters (25 feet) above the floor or work plane. Some luminaires are mostly direct, with uplight of 5 to 20 percent to improve visual comfort.

F-8.3.2 **Floodlights**. These are HID luminaires designed for exterior floodlighting. Most general-purpose floodlights are designed for very wide distribution, but in some cases floodlights with specific distribution patterns might be required.

F-8.3.3 **Roadway, Parking Lot, and Outdoor Area Lighting**. HID luminaires are preferred for outdoor drive and lot lighting. The most common luminaire types used in these applications are *cobra head* general-purpose luminaires and *shoebox* cutoff luminaires. Cutoff luminaires are preferred to minimize light pollution and light trespass.

F-8.4 **Considerations for Incandescent, HID, or Compact Fluorescent Lamps**.

F-8.4.1 Downlights are a common lighting system for illumination of lobbies, corridors, and many other space types. In most applications, compact fluorescent or HID lamps should be used, but in some cases, such as residences and dining rooms, incandescent lamps can be used, subject to approval by the Authority Having Jurisdiction. Related types include wallwashers and accent lights.

F-8.4.2 Luminaires that are mounted in exterior and some interior applications are often selected for resistance to physical damage as well as long term durability. Vandal resistant designs are also used in utility areas for protection against breaking.

F-8.4.3 Vaportight luminaires, also called *jelly jars*, are commonly used in a variety of industrial and commercial utility applications. Compact fluorescent and HID lamps make these luminaires efficient choices in a number of applications.

F-8.4.4 Track lighting is a versatile lighting system especially effective for retail display lighting, museum and gallery lighting, and other situations where spotlighting of objects is desired. In some cases, track can be used for general lighting because it is easily installed from a single electric feed point.

F-9 **APPEARANCE AND AESTHETICS**.

F-9.1 Evaluate the importance of lighting appearance and aesthetics for each space being designed. As a minimum, utilize luminaires intended for the application and in an appropriate manner consistent with the manufacturer's recommendations.

F-9.2 When called for in the selection of a specific luminaire, include consideration for the appearance of the luminaire (including surface brightness), the quality of the luminaire, and the resulting lighting appearance.

F-10 **COST EFFECTIVENESS**.

F-10.1 Life cycle cost methods are required for Federal projects to the extent that these measures minimize life cycle costs and are cost effective. Standardized assumptions must be used**,** including discount rates, energy inflation, and analysis period. This process is described in the *Life Cycle Costing Manual (NIST Handbook 135)***,** and its *Annual Supplements*, available from the National Institute of Standards and Technology (NIST) at www.nist.gov.

F-10.2 Federal life cycle costing is based on discounting all costs back to their present value. All of these costs are then summed. The summed present value of all costs for different projects can then be compared. The Federal Energy Management Program also requires that alternative projects be ranked by their savings to investment ratio.

F-11 **LIGHTING CALCULATIONS**.

F-11.1 **Basic Terms**.

F-11.1.1 **Illumination**. The primary calculation is to determine illumination at the task in the horizontal plane. The default height of the task plane is 762 millimeters (30 inches) above the floor indoors, and on the surface of the ground outdoors. Illumination is measured in footcandles (lumens per square foot) or lux (lumens per square meter). A secondary calculation involves determining the illumination occurring in the vertical plane, also measured in footcandles or lux.

F-11.1.2 **Exitance**. Exitance calculations are a secondary calculation that can be performed to determine the reflected light emitted by a surface. Because exitance calculations presume Lambertian (diffuse) distribution, they should only be used to assess surfaces with these characteristics.

F-11.1.3 **Luminance**. Luminance calculations are a secondary calculation type that can be performed to assess the brightness of surfaces or sources, and in particular with respect to each other. Luminance calculations are especially useful for determining visibility and relative brightness for visual comfort.

F-11.1.4 **Light Loss Factors**. Ensure calculations account for light loss according to IESNA recommendations. Assume average or longer-than-average maintenance cycles for recoverable loss factors, including luminaire dirt depreciation (LDD) and lamp lumen depreciation (LLD).

F-11.2 **Calculations of Lighting for Interior Spaces**. For each interior space, perform a calculation employing one of the following methods to determine luminaire quantity and layout.

F-11.2.1 **Lumen Method**. The lumen method is a calculation procedure that can be performed by hand or by simple, spreadsheet formulas. It determines the average illumination in a space, and is reliable only for spaces with a regular and uniform "grid" of luminaires in which general lighting, providing task light levels everywhere, is appropriate. The lumen method also can be used for determination of "ambient" illumination in rooms in which localized "task lights" are used strictly for task light. Refer to the IESNA Lighting Handbook for additional information.

F-11.2.2 **Point Calculations Using Flux Transfer Calculations**. Commercially available computer programs that assume Lambertian (matte or flat) room surfaces can perform point calculations. These calculations indicate illumination at specific points and are capable of exitance and luminance calculations as well. Some programs can incorporate objects in space to assess the lighting in a non-empty room. Many programs generate perspective views of illuminated rooms, although due to the lack of specular reflectivity these rooms appear unnatural.

F-11.2.3 **Point Calculations Using Radiosity Calculations**. Commercially available computer programs that allow for diffuse and/or specular room surfaces can perform point calculations. These calculations indicate illumination at specific points and are capable of exitance and luminance calculations as well. Some programs can incorporate objects in space to assess the lighting in a non-empty room. Many programs generate perspective views of illuminated rooms, which in some cases can be realistic.

F-11.2.4 **Daylighting Calculations**. Refer to the IESNA Lighting Handbook. Daylight availability can be estimated using these methods. In addition, some commercially available computer programs will determine the contribution of daylight at a specific time and date and under specific weather conditions. Daylight calculations are only required when the intent of a specific building design is to provide lighting during the day primarily by daylight.

F-11.3 **Calculations of Lighting for Exterior Areas**.

F-11.3.1 **Point Calculations for Flood and Spot Lighting**. Point calculations are a calculation procedure that can be performed by hand or in simple, spreadsheet formulas. They determine the illumination at a point in either the horizontal or the vertical plane, and are reliable only for single luminaires. Manufacturers often provide photometric data in “isocandle” form, which permits rapid assessment of the performance of a single luminaire.

F-11.3.2 **Automated Calculations for Exteriors**. Point-by-point calculations are performed by commercially available computer programs. These programs permit multiple luminaires and can take buildings and other obstacles into account. Most programs generate computer aided drafting compatible site isolux plots and analytical statistics related to illumination and uniformity.

F-11.4 **Task Lighting Calculations**. Due to near-field photometric effects, the illumination patterns created by task lights are presently not accurately calculable. Task lights should be evaluated on the basis of measured results.

F-11.5 **Energy Efficiency Calculations**. Perform energy efficiency calculations in the manner and using the forms described in the ASHRAE/IESNA/ANSI 90.1.

F-12 **CONTROL REQUIREMENTS FOR ELECTRIC LIGHTING**.

F-12.1 **Basic Principles**.

F-12.1.1 Limiting the hours of operation or the light output of a lighting system can save energy. This can be accomplished through a variety of control strategies ranging from manual switches and dimmers to timers, and motion and light sensors. Manual switching is the absolute minimum control and relies on personnel to manage their own use of lighting energy. Energy codes also require that there be at least one wall switch in each room. A simple manual dimmer, which reduces the light level from a source relative to ordinary operation, is estimated to save 5 percent to 10 percent of lighting energy as compared to a non-dimmed system. Most lighting systems can be switched or dimmed, although some systems work better than others (refer to Table F-3).

Table F-3. Control Considerations for Various Light Sources

Light Source	Switching Considerations	Dimming Considerations
Incandescent and tungsten halogen lamps	Inexpensive. No operating issues.	Low cost and simple. Will extend lamp life. Dimming is full range and appealing. Some energy savings.
Full size and U-bent fluorescent lamps	Inexpensive. Frequent switching can shorten lamp life.	Requires electronic dimming ballast and matching controls. Dimming can not decrease light below a minimum point without flicker. Some color shift when dimmed. Properly matched systems can dim lights smoothly and effectively to 10 percent.
Compact fluorescent lamps	Inexpensive. Frequent switching can shorten lamp life.	Requires electronic dimming ballast and matching controls. Dimming can not decrease light below a minimum point without flicker. Some color shift when dimmed. Properly matched systems can dim lights smoothly and effectively to 5 percent.
HID lamps	Inexpensive. Due to warm up and recycle times, access to switches should be limited.	Requires special ballasts and control systems. Dimming can not decrease light below a minimum point. Energy efficiency of source diminishes with dimming. Undesirable color shift and lamp life problems are likely.

F-12.1.2 Scheduling controls determine the time that lights turn on and off. *Time scheduling* systems include simple time clocks, package programmable relay panels, and complete building automation systems. It is estimated that, compared to manual switches, time scheduling saves about 10 percent to 20 percent of lighting energy.

F-12.1.3 Motion sensors are scheduling controls activated by the movement of people. Wallbox sensors are best suited for small rooms, such as private offices, and can be used in place of a standard wall switch. Ceiling and high wall/corner sensors are more generally applicable and tend to work better. Multiple detectors can control the same lights, covering a large area. It is estimated that motion sensors save around 15 percent of lighting energy in a large room and up to 30 percent in smaller rooms.

F-12.1.4 Photoswitches turn lights off when sufficient daylight is present. This method is usually used for outdoor lighting but can be used in indoor applications where lights must be turned on at night.

F-12.1.5 Photosensors develop a signal proportional to the light in a room and dim lights as daylight levels increase. The energy saved can be 20 percent to 30 percent of the lighting energy without daylighting control.

F-12.1.6 Many lighting controls systems are compatible with one another. Table F-4 identifies factors that can be used for estimating energy savings impacts of combining controls.

Table F-4. Energy Savings when Combining Controls

Basic Strategy	Combined with	Yields (average)
Motion sensing	Daylighting	40% – 45% savings
Motion sensing	Daylighting and dimming or tuning	45% – 50% savings
Daylighting	Dimming or tuning	30% – 35% savings
Daylighting	Dimming or tuning and scheduling	35% – 40% savings

Note: Energy saving yields are as compared to manual switching.

F-12.2 **Minimum Requirements**.

F-12.2.1 Provide the minimum lighting controls as specified by ASHRAE/IESNA/ANSI 90.1-1999. They require lighting control for each space, with a minimum requirement for automatic controls to shut off lights when not needed. Exceptions are made for facilities in which inadvertent or careless lighting switching could cause a hazard. The requirements are not specific as to which type of control device, such as wall switch or motion sensor, is to be used in specific applications. Exceptions can be made for 24-hour operation facilities.

F-12.3 **Motion Sensors**.

F-12.3.1 Motion sensors should be used as a primary means of lighting control in appropriate applications. Be certain that the sensor is designed for the ambient temperature, room geometry, and other conditions.

F-12.3.2 Motion sensors mounted into wallboxes in place of a standard switch can be used in offices and other enclosed rooms up to 23.2 square meters (250 square feet). Sensors should be passive infrared or ultrasonic and include a means for rapidly relighting a space if the sensor should fail. Infrared-only sensors should be not be used in applications where motion cannot be easily sensed in all locations, such as toilets.

F-12.3.3 Sensors designed for ceiling and upper wall mounting usually work better and cover a larger area than wallbox sensors. Most ceiling and upper wall sensors consist of a detector head and a remote power pack (usually a transformer-relay). Ceiling and upper wall sensors should be used in most sensor applications, with multiple sensors for large rooms.

F-12.3.4 In areas where motion sensor failure or operation can cause safety concerns, consider leaving some portion of the lighting uncontrolled by the motion sensors. This includes areas such as toilets, filing and storage rooms, and other areas that can have tripping hazards.

F-12.3.5 The most common application problems with motion sensors are caused by improper mounting of sensor units or using inappropriate sensor sensitivity patterns for the application. Studies have shown that occupants will disable offending lighting controls, thereby defeating the energy-savings goals. In most applications, sensor types, sensitivity patterns, mounting heights, and locations should be based on the manufacturer's recommendations.

F-12.3.6 Do not use motion sensors in applications in which lamp restrike times are a concern.

F-12.4 **Dimming Controls**.

F-12.4.1 Recent developments and reduced costs of fluorescent dimming ballasts permit the use of dimming for many applications.

F-12.4.2 There are several methods of dimming electric lights, including:

- Two-wire forward phase control, which uses a solid-state dimmer and is compatible with incandescent lamps, certain electronic ballasts for fluorescent and compact fluorescent lamps.

- Two-wire forward phase control, which uses a solid-state dimmer and is compatible with incandescent lamps and inductive loads such as transformers for low voltage lighting and high voltage neon and cold cathode lighting.

- Two-wire reverse phase control, which uses a solid-state dimmer and is compatible with incandescent lamps and "electronic transformers" for low voltage incandescent lighting and certain electronic ballasts for fluorescent and compact fluorescent lamps.

- Two wire autotransformer dimming, which uses a power autotransformer to vary ac voltage and is compatible with incandescent lamps, inductive loads such as transformers for low voltage lighting and high voltage neon and cold cathode lighting, and some other loads.

- Three-wire forward phase control, which uses a solid-state dimmer and is compatible with magnetic dimming ballasts for fluorescent lamps and certain electronic ballasts for fluorescent and compact fluorescent lamps.

- Four wire dimming in which a remote control device generates a 0 to 10 volt dc signal and is compatible with certain electronic ballasts for fluorescent and compact fluorescent lamps, and for dimming incandescent lamps, inductive loads, and some other light sources through solid-state dimming within theatrical-style dimming equipment.

- Proprietary control systems that are designed for specific loads, the most common being digital controls that send encoded signals to specific electronic ballasts for fluorescent lamps, and analog systems designed to dim HID lamps.

F-12.4.3 Dimming systems can be controlled by manual stations or hand-held controllers, or automatically by photosensors, motion sensors, building automation systems or other devices.

F-12.4.4 The specific combination of dimmer, lamp and ballast or transformer is critical for the proper performance of any dimming system. When dimming is to be employed, systems should be designed with close attention to the various components and specifications for luminaires should be very exacting in calling out those parts that depend on the specific dimming system.

F-12.4.5 Consider dimming systems for specific applications as follows:

- Architectural Dimming. For applications in which dimming is required to adjust lighting for different times of the day, such as in a dining room, or for different uses of a space, such as a conference room with audio-visual capabilities.

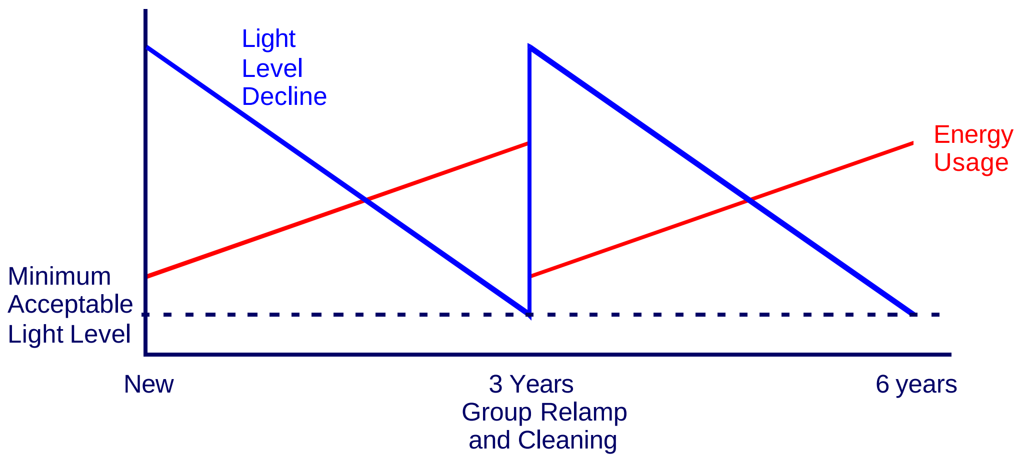
- Daylighting. Where dimming is controlled by a photosensor to save energy in interior spaces where adequate natural illumination is available during occupancy.

- Lumen Maintenance. Where dimming is controlled by a photosensor to save energy in interior spaces by compensating for recoverable light loss. Lumen maintenance is usually applied to lower light levels when lamps are new, but the light levels (and energy usage) are gradually increased as needed to maintain proper light levels throughout the maintenance cycle (refer to Figure F-2).

- Demand Profile Management. Where dimming is controlled by a system designed to reduce peak electrical demand.

- Tuning. Where dimming is used to tune interior lighting levels to save energy by better matching individual spaces and worker needs.

Figure F-2. Lumen Maintenance



F-12.4.6 Because dimming is more costly than switching, justification is required. Dimming must be based on room use or program. Justification can be based on a life cycle cost advantage.

F-12.5 **Multiple Lighting Level Controls**. Include multiple lighting level control if required by the tasks performed in the work area. An example of areas in which lighting levels can vary are dining facilities in which light levels required for cleanup are higher than that required for dining. Aircraft shelters also can require varying ambient light levels depending on the tasks performed.

F-12.6 **Time of Day Controls**.

F-12.6.1 Time of day controls, or time scheduling systems, can be effective at reducing energy usage only if the following two conditions are met:

- The occupancy patterns in the space are relatively predictable.
- There are some hours when the lights can be off (or at low level) without adversely affecting productivity, safety, or security.

F-12.6.2 In spaces not employing motion sensors, automatic time controls with programmable start and stop times can be provided. Programmable time controls should be electronic with different schedules for each work day, programmable holidays, and astronomical features. Automatic adjustment for daylight savings time should be included. Provide battery backup to ensure that the programming is not lost in the event of a power outage. Provide manual override switches at readily accessible locations.

F-12.6.3 Time of day controls are most effectively implemented as part of an energy management and control system. If a separate system is used, ensure that the selected system is relatively easy to reprogram and provide adequate training to personnel responsible for maintaining the system.

F-12.7 **Photoelectric Switching Controls**. Photoelectric switches should be provided for exterior dusk-to-dawn lighting, and for interior lighting in daylighted spaces and not equipped with dimming systems. Use interior detectors that are specifically designed for the application.

F-12.8 **Building Automation and Energy Management Control of Lighting**. Building automation systems that provide for the control requirements given above can be used instead of systems dedicated to lighting control only.

F-13 **DAYLIGHTING**.

F-13.1 **Basic Principles**.

F-13.1.1 Daylighting is defined as the combination of properly designed fenestration (windows, skylights, or other openings) and the control of electric light to permit interior illumination from natural light whenever possible.

F-13.1.2 Natural light ("daylight") entering through fenestration is controlled and limited to provide reasonably even illumination without glare and a minimum of solar heat gain as compared to no fenestration at all. This requires a carefully designed combination of building siting, orientation, massing, fenestration design, and glazing material. In some cases, mechanical daylighting controls might also be needed.

F-13.1.3 The amount and uniformity of natural light is critical in daylighting. Interior lighting levels must be free of extreme "hot spots" caused by direct sunlight. The average natural illumination should not be more than 300 percent of the interior lighting design levels set forth in this document, with the exception of light levels measured immediately adjacent to the fenestration. Excessive interior daylight illumination can cause solar heat gain, which can require more cooling energy than the electric energy saved from lower artificial light levels.

F-13.2 **Design Criteria**.

F-13.2.1 **Buildings Designed for Daylighting**. Analyze the performance of any proposed daylighting system by a point-by-point interior lighting program with daylight capabilities, and a building energy analysis program. The proposed building design must provide the following:

- Interior illumination in the majority of the space achieving a minimum of 50 percent and a maximum of 300 percent of the required illumination on a clear summer day.
- Lower energy consumption than the same building with ordinary fenestration and electric lights operating at full power.
- A life cycle cost benefit considering the differential costs of the daylighting systems, including fenestration, mechanical shading controls, and electric dimming controls.

F-13.2.2 **Ordinary Buildings**. There are many spaces where electric lighting controls can save energy using similar principles. These include spaces like offices and classrooms with windows. Automatic controls of electric lighting should be used in fenestrated spaces when a life cycle cost benefit can be demonstrated.

F-13.3 **Control of Electric Lighting**. Include electronic dimming ballasts for fluorescent or compact fluorescent lamps; photosensors; and other related control devices. Dimming of HID lamps can be expensive and does not always work well; step-lighting controls are preferred for HID systems. Daylighting systems require careful installation and testing to achieve the desired results.

F-14 **EMERGENCY AND EXIT LIGHTING**.

F-14.1 **Background**.

F-14.1.1 The purpose of emergency lighting is to ensure the continuation of illumination along the path of egress from a building and provide adequate light for the orderly cessation of activities in the building. The purpose of exit lights is to identify the path of egress. Both types of lighting are to be powered from both a normal power source and an emergency source, with automatic switching from one to the other.

F-14.1.2 In some specific situations, emergency lighting might be required for specific spaces or work areas that are not on the path of egress. There are often areas where work of a critical nature must continue regardless of loss of normal power, such as a computer mainframe room.

F-14.1.3 In health care facilities, including hospitals, skilled nursing homes, and residential custodial care facilities, lighting for the path of egress (including exit signs) and elevator cabs is considered “life safety” lighting and must be connected to the life safety branch of the facility’s emergency power system. Task illumination at anesthetizing locations, patient care areas, laboratories, intensive care units, recovery rooms, and other locations as required by NEC Article 517 (2002 Edition) are considered “critical” lighting and must be powered from the critical power branch of the facility’s emergency power system.

F-14.1.4 Emergency lighting and exit sign requirements are related, but separate. Note that the installation of exit signs does not automatically satisfy the emergency lighting requirements of NFPA 101. Regardless of the exit sign design, ensure that the emergency lighting requirements are also met. In summary, provide emergency illumination for a period of 1.5 hours in the event of failure of normal lighting. Arrange emergency lighting facilities to provide initial illumination that is not less than an average of 10 lux (1 footcandle) and a minimum at any point of 1 lux (0.1 footcandle) measured along the path of egress at floor level. Illumination levels are permitted to decline to 6 lux (0.6 footcandle) average and a minimum at any point of 0.6 lux (0.06 footcandle) at the end of the emergency lighting time duration. Do not exceed a maximum-to-minimum illumination uniformity ratio of 40 to 1.

F-14.2 **Emergency Lighting Requirements**.

F-14.2.1 Provide emergency lighting in accordance with NFPA 101, Section 5-9.

F-14.2.2 Emergency lighting is required only for designated stairs, aisles, corridors, ramps, escalators, and passageways leading to an exit. Interior rooms and windowless rooms usually do not require emergency lighting unless they qualify as a windowless structure or an underground structure as defined in NFPA 101, Section 32-7. Mechanical rooms, telephone equipment rooms, toilets, and similar utility spaces usually do not require emergency lighting. Although an elevator is not considered a component in the required means of egress, all elevators must provide lighting in accordance with ANSI A17.1, *Safety Code for Elevators and Escalators*, or ANSI A17.3, *Safety Code for Existing Elevators and Escalators*, as applicable.

F-14.2.3 Where emergency lighting is required, arrange the system so that the failure of any individual lighting element, such as the burning out of a light bulb, cannot leave any space in total darkness.

F-14.2.4 The following are acceptable emergency lighting systems.

- Fixtures connected to a permanently installed facility electrical generator. Any generator used for this purpose must be installed, maintained, and tested in accordance with NFPA 110, *Emergency and Standby Power Systems*.

- Fixtures with internal battery packs that are part of a drop-in light system. The system must be installed, maintained, and tested in accordance with NFPA 111, *Stored Electrical Energy Emergency and Standby Power Systems*.

- Fixtures with remote battery packs. The system must be installed, maintained, and tested in accordance with NFPA 111, *Stored Electrical Energy Emergency and Standby Power Systems*.

- Normal lighting system designs. Emergency lighting fixtures can be either separate from or designed as integral parts of the normal lighting system; some luminaires are provided with normal and emergency lighting within the same enclosure.

F-14.2.5 The following are prohibited emergency lighting systems.

- New construction—do not use fixtures with wall-mounted battery packs.

- Existing construction—remove existing fixtures equipped with wall-mounted battery packs wherever such fixtures are not required by NFPA 101. Do not remove fixtures for the sole purpose of eliminating wall-mounted battery packs if the emergency lighting is required by NFPA 101 and the fixtures meet minimum NFPA 101 requirements.

F-14.2.6 In applications where the loss of light, even momentary, would endanger personnel or risk other loss or damage, provide lighting systems to maintain constant illumination through the use of a UPS of sufficient capacity to permit an orderly cessation of activity. This lighting is in addition to path-of-egress lighting.

F-14.3 **Exit Marking Requirements**.

F-14.3.1 **Acceptable Exit Signs**.

F-14.3.1.1 Use LED exit signs with illuminated letters displayed on an opaque background.

F-14.3.1.2 Lettering on all exit signs for an installation must be one uniform color. Each base should establish either red or green as the standard lettering color. Installations in or near jurisdictions with established exit sign lettering colors should adopt similar red or green standards. Do not replace existing exit signs meeting NFPA 101 requirements simply to standardize sign colors. When signs must be replaced for other reasons, use the installation color.

F-14.3.1.3 Installations overseas can use different colors, pictorials, or bilingual lettering as necessary to comply with local national standards. All exit signs must be immediately obvious as an exit marking to a recently transferred or visiting U.S. citizen, or accompanied by a marking complying with NFPA 101, Section 5-10. At a minimum, locate exit markings in accordance with NFPA 101, Section 5-10. Additional markings are permitted to comply with host nation standards.

F-14.3.1.4 If an area of refuge or accessible area of refuge requires an illuminated exit sign, identify the area with an illuminated LED sign stating "AREA OF REFUGE" and displaying the international pictograph for accessibility in accordance with ICC/ANSI A117.1, *American National Standard for Accessible and Usable Buildings and Facilities*.

F-14.3.2 **Prohibited Exit Signs**.

F-14.3.2.1 **Radioluminous**. All existing signs were previously required to be replaced.

F-14.3.2.2 **Incandescent**. Do not use signs lit by incandescent bulbs in new construction. Existing incandescent signs can remain in service. When replacement is dictated by maintenance or construction requirements, replace the signs with LED exit signs, or refit them with LED conversion units.

F-14.3.3 **Locating Illuminated Exit Signs**. Locate exit signs and floor proximity signs in accordance with NFPA 101, Section 5-10. Do not install exit signs on main entrance/exit doors that are clearly identifiable as exits. Do not install exit signs on other exit doors that are clearly identifiable as exits, with the exception of assembly and mercantile occupancies.

F-14.3.4 **Tactile Signage**.

F-14.3.4.1 **Exits**. Tactile signs are required at each door to a stair enclosure and at each exit, including horizontal exits, in accordance with NFPA 101, Section 5-10, and ICC/ANSI A117.1. Signs must have raised or recessed lettering and pictographs (where applicable) in contrasting colors. The sign content must be in Braille. Locate tactile signs on the latch side of the door, centered at 1524 millimeters (60 inches) above the finished floor.

F-14.3.4.2 **Areas of Refuge**. Tactile signs displaying “AREA OF REFUGE” and the international pictograph for accessibility are also required to identify areas of refuge and accessible areas of refuge in accordance with ICC/ANSI A117.1.

F-14.3.4.3 **Stair Enclosures**. Use tactile signs to identify:

- Floor level.
- Terminuses at the top and bottom of the stair enclosure.
- Floor level of and direction to the exit discharge, including other identifying information (such as “East” or “West”).

F-14.4 **Testing of Emergency Lighting Equipment**.

F-14.4.1 NFPA 101, Section 31-1, requires that emergency lighting equipment be tested periodically. A functional test is required at 30-day intervals for a minimum of 30 seconds. Perform an annual test for the 1.5 hour duration. Ensure equipment is fully operational for the duration of the test.

F-14.4.2 Because of the periodic testing requirements, accessibility of equipment is an important design consideration. Ensure that emergency lighting equipment is installed in conspicuous and accessible locations to facilitate the periodic testing requirements.

F-14.4.3 If the installation location does not facilitate accessibility for periodic testing, self-testing/self-diagnostic should be installed. NFPA 101 exempts the 30-day functional test from manual testing by the following exemption: *Exception: Self-testing/self-diagnostic, battery-operated emergency lighting equipment that automatically performs a minimum 30-second test and diagnostic routine at least once every 30 days and indicates failures by a status indicator can be exempt from the 30-day functional test, provided a visual inspection is performed at 30-day intervals*. Emergency lighting equipment is also available in which both the functional and annual tests can be initiated remotely by the user, and should also be considered for any location in which accessibility is a concern.

F-15 **CRITERIA FOR SPECIFIC FACILITIES**.

F-15.1 **Offices**.

F-15.1.1 **Lighting System Selection**. Refer to IESNA/ANSI RP-1. The choice of appropriate lighting systems for offices varies according to need and budget. Recessed troffer systems offer value and get the job done at lowest cost; suspended lighting systems improve comfort and visual quality. At the same time, all interior lighting for an office building should not exceed 1.2 watts per 0.1 square meter or (1 square foot) (task lights not included), with a minimum of about 0.8 watts per 0.1 square meter (1 square foot) under ideal conditions. Unless a project has unusual requirements, such as considerable engineering or medical labs, expect most projects to fall within this power allowance.

F-15.1.2 **Direct Lighting Systems**.

F-15.1.2.1 Parabolic troffers are common office lighting systems, with about the same energy efficiency and layout considerations as for lensed luminaires. Standard 3-inch louver luminaires cost more than lens troffers but improve performance in larger rooms with respect to computers. Because most office spaces involve the use of computer work stations, parabolic troffers should be the first choice for a direct lighting system. Parabolic troffers also provide a more attractive office appearance than lensed troffers. Take care when using parabolic troffers that vertical surfaces in the room are adequately lighted; otherwise, the room can have a dark appearance. Louvers should have a plastic cover that is removed after installation or have an organic finish that will not show fingerprints. Plastic louvers should not be used.

F-15.1.2.2 While not suited for computer work in large open areas, lens troffer lighting systems work for most other office building lighting situations. A typical layout employs 3 lamp luminaires on 2.4 by 3.1 meters (8 feet by 10 feet) centers and can produce appropriate lighting levels at around 0.95 to 1.15 watts per 0.1 square meter (1 square foot). A better layout employs 2-lamp luminaires on 2.4 by 2.4 meter (8 feet by 8 feet) spacing with improved uniformity of light distribution. Existing lighting systems of this type can be retrofitted with modern T-8 lamp/electronic ballast technology to equal the performance of new systems.

F-15.1.3 **Suspended Lighting Systems**.

F-15.1.3.1 Lighting systems that hang down from the ceiling—fluorescent indirect and direct/indirect systems—are considered an important upgrade in visual comfort and the appearance of the space.

F-15.1.3.2 Indirect lighting systems cost very little more overall than parabolic troffers. These systems tend to be simple in design and appearance.

F-15.1.3.3 Styled, high performance indirect and direct/indirect lighting systems perform especially well in computer workspace in addition to making an architectural statement.

F-15.1.3.4 Expect indirect lighting systems to require about 1.0 watts per square foot or 0.1 square meter, and to require supplementary task lighting. Direct/indirect systems might require 1.0 to 1.2 watts per square foot or 0.1 square meter but will minimize or eliminate the need for separate task lighting.

F-15.1.4 **Special Considerations for Computer Intensive Workspaces**. Most lensed troffers, wraparounds and some parabolic lighting systems are not suited for computer workspaces. Consider whether a "computer-friendly" parabolic lighting system, indirect lighting system, or one of several high performance luminaires optimized for computer workspace is best. "Computer-friendly" parabolics and specialized direct/indirect visual display terminal (VDT) luminaires are distinctive in that they have specular (mirror-like) louvers. VDT luminaires are more expensive and less efficient, so choose them only for work areas with intensive computer work.

F-15.1.5 **Controls**. Motion sensors should be used for all private offices, conference rooms, and other spaces with irregular use or occupancy. Open office areas, lobbies, atria, and other common spaces should employ time scheduling controls with manual overrides. Consider individual workstation dimming controls for open office areas employing parabolics. In locations with high utility rates, consider daylighting controls and other more advanced lighting controls to realize additional demand savings, especially at peak load periods.

F-15.2 **Classrooms**.

F-15.2.1 Refer to IESNA/ANSI RP-3, *Guide for Educational Facilities Lighting* for specific guidance.

F-15.2.2 For schools, an approach similar to offices should be followed. If the classrooms do not utilize computers, direct/indirect lighting systems (50 percent up/50 percent down) and mostly direct lighting systems (15 percent up/85 percent down) are perhaps better choices than high performance systems. Industrial styled lighting systems are often chosen for schools due to their durability, excellent efficiency, and reasonable cost.

F-15.3 **Warehouses and Light Industrial Facilities**.

F-15.3.1 Refer to IESNA DG-2, *Design Guide for Warehouse Lighting*, and IESNA/ANSI RP-7, I*ndustrial Lighting Facilities*.

F-15.3.2 Wherever possible, warehouse and light industrial buildings should be designed to utilize daylight for general illumination. Basic skylights will be acceptable in most cases, although more advanced daylighting methods such as clerestories should be considered when feasible. A supplemental electric lighting system using controls to realize energy savings should also be provided.

F-15.3.3 For strictly warehousing facilities, high-pressure sodium light sources controlled by a high-low system or photoelectric dimming system will generally be acceptable. In any space where light industrial activity such as assembly, packaging, sorting, or shop work is required, provide a minimum CRI of 65, such as metal halide, fluorescent or compact fluorescent lamps. Use of fluorescent task lights and a general lighting system employing high-pressure sodium lamps is acceptable provided more than 50 percent of the task illumination is provided by the task light.

F-15.4 **Health Care Facilities**.

F-15.4.1 Refer to IESNA/ANSI RP-29, *Health Facilities Lighting*. This Recommended Practice provides specific guidance for health care facilities.

F-15.4.2 Although there are numerous different space types in health care facilities, lighting should be designed to minimize lamp stock and luminaire types without sacrificing quality or utility. Preference should be given to the use of electronic ballasts and T-8 fluorescent lamps, preferably 5,000 Kelvin minimum, with compact fluorescent lamps at 5,000 Kelvin minimum and electronic ballasts for appropriate luminaires. The higher correlated color temperature of 5,000 Kelvin is based on obtaining a high degree of color rendering for hospital applications. General purpose areas in which no diagnosis is performed can be designed with 3,500 Kelvin or 4,1000 Kelvin correlated color temperature luminaires.

F-15.4.3 Daylight is presently being considered a health and healing benefit and should be included in the design of health care facilities whenever possible.

F-15.5 **Aircraft Hangars and Shelters**.

F-15.5.1 Lighting systems must comply with NEC Article 513 (2002 Edition).

F-15.5.2 Provide aircraft hangars and shelters with a combination of overhead, side, and portable lighting. The overhead lighting is intended to provide general area lighting. The side lighting is intended to ensure adequate lighting in areas obstructed from the overhead lighting. Portable lighting is selected and used as necessary for task lighting applications. Overall, contrasts must be managed by ensuring that ambient light levels are adequate.

F-15.5.3 Design overhead and side lighting to provide a minimum of 150 lux (15 footcandles). Refer to the IESNA *Lighting Handbook* for additional guidance.

F-15.5.4 Include separate switches for side lighting to allow turning these lights on and off independent of the overhead lighting. This is intended to allow workers to avoid blinding situations during task-specific work activities.

F-15.5.5 Contrast and ambient light levels can be improved by repainting vertical surfaces. Evaluate the need for painting as part of any lighting upgrade.

F-15.5.6 Sodium lamps should not be used. Refer to paragraphs F-6.6 through F-6.8.2 for additional information.

F-15.6 **Lighting in Cold Temperature Applications**. Special ballasts might be required for operation in low temperatures. Electronic ballasts tends to work properly even in cold temperatures. Verify with the manufacturer that the selected lighting equipment is suitable for cold temperature operation.

F-15.7 **Airfield Lighting**. Refer to UFC 32-1187, *Design Standards for Visual Air Navigation Facilities*, for airfield lighting requirements.

F-16 **RETROFITTING**.

F-16.1 **General**.

F-16.1.1 Many existing lighting systems can be retrofitted with new technology to provide appropriate lighting. Luminaires in good condition, whether relocated or salvaged, should be considered an alternative to new lighting equipment when retrofitted with efficient technology.

F-16.1.2 Retrofitting requires appropriate design analysis to ensure that acceptable results will be achieved. Redistribution of light should only be accomplished based upon sound design principles. Specular reflectors and parabolic retrofits should only be used after testing and system design is accomplished. The following sections provide typical retrofit possibilities; however, it is stressed that lighting design changes require proper evaluation.

F-16.2 **Existing Troffer Systems**.

F-16.2.1 **Typical Installations**. Convert T-12 lighting systems to T-8 lamps and electronic high frequency ballasts. In most cases, delamp 4-lamp luminaires to either 2 or 3 lamps. Silver or polished aluminum reflectors can be installed in older lensed troffers, and white painted reflectors should be installed in older parabolic troffers. Install new lenses in lensed troffers if existing lenses are more than 7 years old.

F-16.2.2 **Special Considerations for Computer Intensive Workspace**. Most lensed troffers are not suited for computer workspaces. For existing lensed luminaires, remove the lens and install a silver reflector and small-cell paracube louver. Alternatively, use a parabolic louver conversion kit.

F-16.2.3 **Retrofits**. In some cases, consider a new indirect lighting system designed to retrofit an existing troffer installation.

F-16.3 **Existing Downlights**.

F-16.3.1 **Typical Installations**. Remove the incandescent lamp and socket, and install a hardwired compact fluorescent adapter using a standard plug-based compact fluorescent lamp. In many cases, replacement of the reflector is also required to efficiently utilize the compact fluorescent lamp. Verify that the lamp length is compatible with the can depth. Compact fluorescent lamp watts should be about 25 percent to 30 percent of original incandescent lamp watts to achieve similar light levels.

F-16.3.2 **Atypical Installations**. In some cases, hardwired conversions can be difficult or not cost effective. Use a medium based adapter with integral ballast and replaceable lamp. Compact fluorescent lamp watts should be about 25 percent to 30 percent of original incandescent lamp watts to achieve similar light levels.

F-16.4 **Existing Fluorescent Industrial Luminaires, Wraparounds, and Strip Lights**.

F-16.4.1 Replace F40T12, and F48T12 lamps and magnetic ballasts with T-8 lamps and electronic high frequency ballasts. Consider employing reflectors and low ballast factor ballasts to achieve further energy reductions.

F-16.4.2 For lighting systems employing F96T12 slimline and F96T12/HO lamps, consider all of the following:

- Retrofitting with electronic high frequency ballasts and continuing to use existing lamps.
- Replacing 2.4 meter (8 foot) lamps with 1.2 meter (4 foot) T-8 lamps, possibly including high light output ballasts and/or high output T-8 lamps when replacing T12/HO lamps.
- Replacing 2.4 meter (8 foot) lamps with T-8 2.4 meter (8 foot) lamps and electronic high frequency ballasts.

F-16.5 **Existing HID Industrials, Floodlights, Downlights and Other Luminaires**.

F-16.5.1 Replace mercury vapor lighting systems with one of the following approaches:

- Replace mercury vapor lamps with compatible metal halide or high-pressure sodium lamps, especially if increased light levels are required.
- Retrofit with metal halide ballasts and lamps for work spaces and other spaces where color rendering is important. The metal halide lamp should be about 60 percent of the original mercury vapor watts.
- Retrofit with high-pressure sodium ballasts and lamps for storage spaces and other spaces where color rendering is not important. The high-pressure sodium lamp should be about 50 percent of the original mercury vapor watts.
- Replace with a compact fluorescent luminaire of similar type, especially for low wattage mercury vapor lamps (up to 100 watts). This replacement is especially

appropriate for applications where switching could be encouraged to save energy. The fluorescent lamp should be about 60 percent of the original mercury vapor watts.

F-16.6 **Existing Exit Signs**.

F-16.6.1 Incandescent exit signs should be retrofitted to either compact fluorescent or LED, depending on the importance of a downlight component for exit pathway illumination.

F-16.6.2 Consider replacing exit signs with all new LED signs.

F-16.7 **Periodic Relamping**.

F-16.7.1 Spot relamping should be performed as necessary for appearance and safety.

F-16.7.2 Group relamping should be the principal method of periodically replacing lights in a given area. The group relamping frequency should be based on ensuring intended lighting levels are maintained above minimum levels. Spot relamping is not recommended in this regard because lighting levels will tend to eventually fall below intended levels. The group relamping interval should consider the lamp mortality curve (provided by the manufacturer for each type of lamp) so that spot relamping does not become an excessive maintenance burden. Any group relamping activity should include fixture cleaning to obtain optimal results.

F-17 **HARMONIC DISTORTION CAUSED BY LIGHTING SYSTEMS**.

F-17.1 Electronic ballasts increase lamp efficacy by converting 60 Hertz power into high-frequency (20 kilo-Hertz to 40 kilo-Hertz alternating current). This conversion process adds to the harmonic distortion on the electrical system. In extreme conditions, the harmonic distortion can overload neutral conductors and affect electronic equipment. In almost all cases, the contribution of lighting system-induced to the electrical system harmonic distortion will not be significant. Table F-5 provides typical total harmonic distortion (THD) generated by various electrical and electronic equipment. Notice that high efficiency magnetic ballasts can generate as much harmonic distortion as electronic ballasts. Newer electronic ballasts tend to produce even lower levels of harmonic distortion. Notice also that certain electronic ballast compact fluorescents tend to cause the greatest harmonic distortion.

Table F-5. THD of Various Devices

Device	Typical THD
Standard electronic ballast	20% or less
Low harmonic electronic ballast	10% or less
Magnetic energy saving ballast, 2-F40	15 – 20%
Magnetic energy saving ballast, 2-F96	25 – 30%
Screw-in electronic ballast compact fluorescent	125 – 175%
Dimming of magnetic ballast	40 – >100%
Personal computers and peripherals	100 – 150%
Adjustable speed drives	>100%

F-17.2 Generally, a facility will have other offending sources of harmonic distortion if lighting-induced harmonic distortion creates problems. If excessive harmonic distortion is suspected, perform power quality monitoring in accordance with Chapter 12 to characterize the facility. Based on the results of the monitoring, determine first if the lighting is the principal cause. For example, a small number of ASDs can easily produce greater levels of harmonic distortion than the entire lighting system. Ensure that monitoring also checks the neutral currents of representative circuits.

F-17.3 Harmonic distortion solutions should be addressed at the facility level. If necessary and after confirming that lighting is the principal cause of problems, select and install electronic ballasts and other lighting equipment of a style designed to produce lower levels of harmonic distortion.

F-17.4 Although unrelated to harmonic distortion, the use of electronic ballasts has in the past interfered with other electronic equipment. For example, consumer grade remote controls and older professional remotes operate by ultrasonically modulated infrared radiation. Electronic ballasts operate lamps at ultrasonic frequencies and the lamps emit visible, ultraviolet, and infrared radiation. The relatively high level of infrared modulation, when modulated at a frequency close to the modulation frequency of the remote control device, can create an unacceptably small signal to noise ratio. The operating frequency of most consumer remotes is around 28 to 40 kilo-Hertz. To minimize the potential for interaction, ballasts are being designed to operate closer to 100 kilo-Hertz. Newer audio-visual systems tend to use 900 mega-Hertz or 2.4 giga-Hertz. Although problems have been observed in the past, lighting manufacturers have tended to correct this problem as described above. Contact the manufacturer for guidance if additional shielding is required for especially sensitive equipment.

APPENDIX G

AIR FORCE COMMUNICATIONS AND INFORMATION SYSTEMS

G-1 **INTRODUCTION**. This appendix provides an overview of communications and information systems design requirements for Air Force installations. Refer to the JTA-AF FBTA for specific design criteria.

G-2 **REFERENCE DOCUMENTS**. Review the following documents, as applicable, to ensure that communications and information-related requirements are satisfied as part of project design activities.

G-2.1 AFI 21-404, *Developing and Maintaining Communications and Information Systems Installation Records (CSIRs)*. CSIRs are drawings and specifications used for planning, programming, and supporting communications and information operations, maintenance, integration, and engineering and installation (EI) efforts. Paragraph 4.4 of AFI 21-404 identifies BCE responsibilities, including the use of CSIR data for base comprehensive planning (BCP) and providing as-installed communications and information system records.

G-2.2 AFI 33-101, *Communications and Information Management Guidance and Responsibilities*. This AFI provides management procedures to ensure availability, interoperability, and maintainability of communications and information systems. It covers general guidance and responsibilities for effective and efficient management of systems throughout their life cycle. Paragraphs 1.14 and 1.15 of AFI 33-101 cover the Communications and Information Systems Officer's (CSO) and System Telecommunications and Engineering Manager (STEM) respective roles in the BCP and military construction program (MCP) processes. Paragraph 2.11 of AFI 33-101 addresses the Communications and Information Systems Blueprint and Paragraph 3.4 addresses communications and information prewiring needed to support construction projects.

G-2.3 AFI 33-103, *Communications and Information Requirements Development and Processing*. Generally, this document outlines related key processes (e.g., documenting requirements, development of technical solutions, approval, resource allocation, and implementation). These processes should be transparent and synchronized with BCE planning and implementation of construction projects. AFI 33-101, paragraphs 4 and 5, also outlines these processes.

G-2.4 AFI 33-104, *Communications and Information Base-Level Planning and Implementation*. This document covers the requirements definition, approval, and implementation processes for command, control, communication, and computer (C4) systems and the base-level infrastructure. It also covers the Communications and Information Systems Blueprint, and BCE support and coordination.

G-2.5 AFI 32-6002, *Family Housing Planning, Programming, Design, and Construction*. This document provides guidance on prewiring family housing.

G-2.6 AFI 65-106, *Appropriated Fund Support of Morale, Welfare, and Recreation and Nonappropriated Fund Instrumentalities*. This document provides guidance on who funds prewiring in nonappropriated fund facilities.

G-2.7 AFI 33-105, *Communications and Information Engineering and Installation Services*. This document covers the format and use of the Communications and Information Systems Blueprint. It also addresses the 38^{th} Engineering Installation Group (38 EIG) engineering and installation processes, MCP requirements, content of project packages, Project Support Agreement (PSA) processing actions, and contract and specialized engineering services.

G-2.8 JTA-AF, Fixed Base Domain, Volume 6: Building Wiring Architecture. This volume is a consolidation of two documents that pertain to building wiring, facility design, and communications systems residing inside of buildings: the 38 EIG Base Information Transport System (BITS) Architecture and Air Force Communications Agency (HQ AFCA) Technical Bulletin (TB) 95-03, *Building Communications Cabling and Distribution Systems*. Since this Volume specifically concerns intra-building communications wiring technologies and methodologies and facility design, it is not intended to be a stand-alone document. Information conveyed in this Volume is used in concert with other Volumes of the JTA-AF FBTA. (Review Volume 1 of this document for more detailed information regarding these relationships.)

G-2.9 AFCA TB 95-03, *Building Communications Cabling and Distribution Systems*. This document provides guidance on prewiring design criteria and general information on several areas regarding building and associated hardware contained in wiring closets. In addition, it also contains many illustrations, wiring pin outs, and technical order references.

G-3 **AIR FORCE DESIGN CRITERIA**.

G-3.1 **Design Criteria**.

G-3.1.1 The JTA-AF FBTA provides the technical design criteria relating to communications and information systems and architecture. Refer to this document for specific design-related criteria.

G-3.1.2 The following section provides an overview of communications and information systems design requirements. Refer to the JTA-AF FBTA for specific design criteria.

G-3.2 **Overview of Design Criteria for Prewiring and Other Communications and Information Systems Requirements**.

G-3.2.1 **General**. The facility design should provide concealment of the wiring/cabling systems, adequate space for installation and maintenance of communications and information systems equipment and wiring, flexibility of office layout in administrative areas, and standardization of common user requirements. Select the most practical cable/wire distribution system, consistent with facility size and function, current and projected communications and information systems requirements, the Comprehensive Interior Design (CID) concept, and the need for flexibility to accommodate future additions or rearrangement. The selection should consider not only the communications and information systems wiring systems, but also wiring to accommodate electrical convenience outlets. Consideration will be given to overhead and in-floor systems including infinite access/raised floors. On-floor (under-carpet) systems can be considered only in facility alteration projects and will not be used in new facility construction.

Note: Cabling carrying classified data through an uncontrolled access area is usually required to be visible unless some other protection method, such as encryption, is used.

G-3.2.2 **Communications Systems**. The building communications systems must support the user's current and future voice, data and video requirements. The communications and information end equipment will include local area networks, secure voice and data systems, network management and control, packet and circuit switching, and premise and sensor equipment, desktop instruments and workstations, as well as communications cabling duct, and equipment rooms and closets which must be sized and engineered to support this equipment. Cables can be optical fiber, coaxial, or twisted-pair, and are considered part of the building assets. In administrative areas, provide numbered outlet jacks for voice and data service, using category 5 wire or better. Provide outlets as required, except in administrative areas exceeding 93 square meters (1,000 square feet) of contiguous net office area (usable office space excluding administrative support area). In such areas, provide an outlet with two jacks, one for telephone and one for data service, for every 4.5 square meters (48 square feet) of net floor area (usable office space including administrative support space). Consider providing dual ports, one for voice and one for data, for every category 5 drop. The Wing can approve requirements for additional outlets and jacks (such as secure voice, or non-administrative data). Jacks and connector terminations must be consistent with the wiring. Ensure adequate equipment grounds. Cable television (CATV) needs should be addressed as part of prewiring in accordance with AFI 64-101, *Cable Television on Air Force Bases*.

G-3.2.3 **Communications Equipment Rooms (CER) and Telecommunications Closets (TC)**:

G-3.2.3.1 Each building [>465 square meters (5,000 square feet) of gross floor area] should have a CER. Ground floors greater than 1,022 square meters (11,000 square feet) of net floor area (NFA) should also have a TC per 929 square meters (10,000 square feet). Each floor greater than 929 square meters (10,000 square feet) should have a TC. Large floors should have a TC for every 929 square meters (10,000 square feet).

G-3.2.3.2 ANSI/TIA/EIA-569 requires one telecommunications closet/intermediate distribution field per floor for up to 1,022 square meters (11,000 square feet). TIA/EIA-

568B requires a distance of the outlet to the endpoint device must be less than 3 meters (10 feet), maximum distance from the telecommunications closet to the outlet is 90 meters (295 feet), and 7 meters (23 feet) cable length is allowed in the closet.

G-3.2.3.3 A facility that has significant communications and computer systems (C-CS) requirements needs a CER. Unoccupied facilities and small facilities (<465 square meters or <5,000 square feet) such as guardhouses, utility control buildings, storage bunkers, etc. will normally not require a CER. The CER normally serves as the entrance facility for all incoming C-CS ducts and service and as the main location for C-CS equipment such as electronic key systems and main local area network hubs/routers/servers.

G-3.2.3.4 The CER should be located on first floor with an exterior wall and be provided with double doors (recommended door size: 1.8 meters wide by 2.4 meters high [6 feet by 8 feet]) without a center support to ensure that large equipment can easily be moved into the room. Due to the sensitivity of newer communications equipment to electromagnetic interference, do not collocate CERs and TCs with utility services for other facilities, such as HVAC, generators, or transformers. Table G-1 provides the CER size requirements.

Table G-1. CER Size Requirements

Building Usable Square Meters (Square Footage)	CER Size (square feet)	CER Size (square meters)	Number of Entrance Conduits
<1,858 (20,000)	400	37.2	2
1,858 to 9,290 (20,000 to 100,000)	500	46.5	4
9,290 to 18,580 (100,000 to 200,000)	900	83.6	5
Every additional 18,580 (200,000)	+600	+55.7	+1
Note: Not less than 2:1 ratio length to width.			

G-3.2.3.5 A TC is required for each floor with 929 square meters (10,000 square feet) of usable building footage in a facility. A TC serves as the interface from the CER to the individual voice/data outlets in the facility and as a location for wiring hubs. Note that the CER can also function as a TC for the area in the facility where it is located.

G-3.2.3.6 Locate the TC close to the center of the area to be served. It is critical that the installed length of distribution cables (horizontal cables) from the TC to user outlets comply with distance requirements.

G-3.2.3.7 Minimum size for a TC is 3.1 meters by 2.1 meters (10 feet by 7 feet). TIA/EIA-569, Chapter 7 discusses a TC's size, location, coverage area, horizontal distances to work areas, floor loading (static and dynamic), excluded items and equipment, lighting, wall coverings, door size, security, closet penetrations, fire safety, and environmental considerations.

G-3.2.3.8 The minimum power requirement for each CER and TC is two 20 ampere dedicated branch circuits. Each room should also have normal 120 volt convenience outlets spaced every 1.5 meters (5 feet) on all walls. The CER must have adequate power to support the C-CS equipment and power requirements can be greater depending on the equipment planned for the room. The planning engineer should coordinate power requirements with the base communications and information personnel and/or the project engineer.

G-3.2.3.9 As a minimum requirement, the CER and TC should have plywood backboards on all walls, from no greater than 0.31 meters (1 foot) above the finished floor level to no less than 2.1 meters (7 feet) above the finished floor level. In the CER, depending on the C-CS requirements, a floor mounted main distribution frame (MDF) might be required to support cable terminations.

G-3.2.3.10 Ground connections in the CER and TC must meet the appropriate NEC requirements and practices. As a minimum, provide a single-point ground for all communications-electronics equipment for the building within the CER. A copper ground plate (bus bar with minimum 152 millimeters high by 610 millimeters in length [6 inches by 24 inches]) must be provided in the CER. Install the ground plate 2.1 meters (7 feet) above ground level on a wall (preferably an outside wall) within the CER. The ground riser must be a No. 1 or larger wire directly connected to the ground plate with no taps. The resistance of the ground riser must be 5 ohms or less measured from the main building ground point. All connections of wire-to-wire and/or wire-to-ground rod must be cadwelded. As a minimum in the TC, provide a No. 6 ground wire or larger connected with a direct home run to the ground plate in the CER. The grounding must be 10 ohms or less measured at the grounding point. Refer to ANSI/TIA/EIA-607.

G-3.2.3.11 Environmental requirements are as follows. If a CER or TC will house electronic equipment, the environmental limits are 5 °C to 40 °C (40 °F to 104 °F) and 20 percent to 70 percent non-condensing humidity. Normal operating ranges should be 10 °C to 30 °C (50 °F to 86 °F) with changes of not more than 12 °C per hour, and 30 percent to 55 percent humidity.

G-3.2.4 **Modular/Movable Equipment and Construction Items**. Communications and information systems wiring systems in areas with equipment or construction items that can be easily moved, such as prewired workstations, systems furniture and modular walls/offices, should provide sufficient flexibility and connectivity to enable rearrangement without modifications to the permanent communications and information systems wiring system in the facility. Suitable connectors must be provided; permanent splices/connections must not be made. Communications and information systems wiring in prewired workstations, portable walls and offices where the outlets are integrally mounted or the wiring is permanently installed must be funded as a part of the workstation, wall or office.

G-3.2.5 **CSIR**. Provide design drawings and records, which form the basis of cable records, to the base CSIR manager, according to AFI 33-104 and AFI 21-404, *Developing and Maintaining Communications and Computer Systems Installation*

Records. Information should include interior dimensions, rack and duct placement, manhole orientation, sump location for manholes, and number, size, configuration, usage, and type of ducts.

G-3.3 **Communications and Information Engineering Management**. EI for communications and information systems is centrally managed by 38 Engineering Installation Wing (EIW), Tinker Air Force Base, Oklahoma. The 38 EIW provides these services with a mixture of active duty engineering and installation units, Department of Air Force civilian personnel, and contract vehicles. These E&I resources do not preclude MAJCOM and host base communications and information systems activities/units from developing local contracts for these services.

Table G-2. Project Book Reminders for Communications and Information Systems

Reminder Items	Included	Not Included
1. **General** Type of building and location		
Number of people		
Telephone system switching equipment space, power, and HVAC requirements (electronic key system, T-carrier, modems, multiplexers, etc.)		
Data requirements		
Red/black requirements		
Number of phones		
Number of computer terminals		
Telephone/data outlet density/locations		
Engineering/administrative considerations		
Communications requirements documentation		
Incremental construction		
Other MCP construction and adjacent area requirements		
Future expansion capability of the facility		
C-CS CSIRs—location for review		
Exterior fiber, copper, wireless connectivity issues (direct burial, underground, or aerial)		
Cable fire protection requirements		
Connectivity to base communications and information systems		

Reminder Items	Included	Not Included
2. **Information Systems** LAN (administrative)		
LAN (secure)		
Secure voice		
Crew alert circuits		
Public address system		
Standard base-level computer and other mainframes		
Pay phones/unofficial (contracted phones)		
In-house cable distribution		
Network services (private lines)		
Base cable plant (commercial lease of government owned)		
Long-haul circuits		
Commercial telephone company interface		
Other C-CS requirements		
Command post (what is included)		
Contingency space/support shelters		
Entry control systems		
Hot lines—special security		
Classified vault requirements, or open storage of classified material		
3. **Miscellaneous Systems** Master antenna		
Duress alarms		
Security alarms		
Fire alarms		
Fire detection/suppression systems		
EMCS system		
4. **Electronic/Electrical Support**		
Filtering		

Reminder Items	Included	Not Included
Mainframe computer connectivity		
Shielding, security, TEMPEST/emission security		
Grounding		
Circuit protection		
Power (primary, backup, PCCIE), battery		
Redundancy—diverse cable routing		
Demarcation point		
Protected distribution system (PDS)		
Waveguide and coaxial cable ingress/egress bulkheads for facilities with external antennas		
5. **Building Support** CER size		
Equipment/cross-connect closet size, density (location)		
Cable riser system		
Equipment access doors		
Cable distribution system type (raised floor, ducts, overhead, under carpet)		
Cable entranceways		
Equipment room/cross-connect closet wall requirements		
HVAC		
Outside plant manhole/duct systems, including protected distribution system		
Cable vault		
Electrical outlets (configuration, location, rating)		
Exterior communications cable/fiber		
Structure for satellite communication, microwave, or other radio antennas		
Electromagnetic pulse (EMP) protection		
Nuclear/biological/chemical (NBC) protection		
Systems furniture		
Explosive environment		

Reminder Items	Included	Not Included
Corrosive environment		
Lighting levels in equipment rooms and cross-connect		
6. **Administrative Planning** LAN—user requirements/operations concept		
Environmental impact statement—outside plant		
AF Form 103, Base Civil Engineering Work Clearance Request		
Teleco lease of right-of-ways/easements/building space		
Revocable license agreements		
Engineering transmission traffic analysis		
Relocation or protection of existing communications and information cables or facilities		
C-CS CSIRs records		
Layout plans and specifications		