PDHonline Course E370 (6 PDH)

Electrical Power Distribution and Utilization

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TABLE OF CONTENETS

1. GENERAL POWER SYSTEM CRITERIA

1.1. General Characteristics

1.1.1. Voltage

1.1.1.1. Electrical characteristics of the power system should be selected to provide a safe, efficient, and economical distribution of power, based upon the size and types of loads to be served. Distribution and utilization voltages of the highest level that is practical for the load to be served should be selected. The following guidelines apply:

- 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.
- 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.
- 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, lighting should be designed 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. Dry-type transformers as needed should be utilized to serve smaller 208Y/120 volt loads.
- An economic analysis should be performed for 208 volt systems larger than 300 kVA or serving motors larger than 25 horsepower (18,650 watts).

1.1.1.2. Exceptions to the above guidelines should be justified based on the existing facility design or on unique requirements of the proposed design.

1.1.1.3. The standard available voltages of the host nation should be used for facilities located outside of North America. The highest distribution and utilization voltage level that is practical for the load to be served should be applied. Power conversion equipment should be used as necessary to satisfy voltage requirements of specific equipment.

1.1.1.4. Other voltage levels can be used as necessary to serve specific loads.

1.1.2. Frequency

1.1.2.1. A frequency of 60 Hertz should be used 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.

1.1.2.2. In locations in which the commercially-supplied frequency is other than 60 Hertz, such as 50 Hertz, the available supplied frequency should be used 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.

1.1.3. Power Factor

1.1.3.1. 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.

1.1.3.2. Power factors lower than 0.9 lagging are not as energy efficient as desired. Refer to paragraph 6-6 to see if power factor correction is considered. Power factor correction requires careful coordination with power quality design features. See PDH Course E319 “Electrical Calculation Methods and Examples” for further details.

1.1.4. Neutral Conductor Grounding

1.1.4.1. Except for applications such as continuous processes for industrial systems where shutdown would create a hazard, loss of materials, or equipment damage the neutral conductor of all distribution systems operating at phase-to-phase voltages of 600 volts or less should be solidly grounded. For continuous process applications, the use of a solidly grounded wye system with a backup power supply, or a high-resistance grounded wye system should be evaluated. 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, a ground detection system should be included in the design to alert personnel of an inadvertent ground.

1.2. Normal Power Source

1.2.1. 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 1-1 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. The choice of the main supply service voltage should be based on an economic analysis of the various electrical system options for any particular facility under design. If the total facility load is large, the impact of transformer failure on the facility's mission and the need for dual transformers or backup power should be considered.

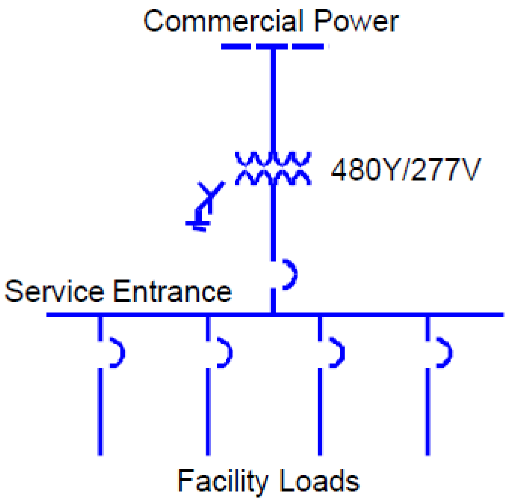


Figure 1-1 Single Power Feed to Facility

1.2.2. Critical facilities requiring reliable power 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 1-2). Double-ended transformer installations should be designed with incoming sections, transformers, and primary bus in the middle, and the secondary distribution sections on the outside to allow for future load growth. Each transformer of a double-ended system should be sized 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.

1.2.3. The two feeds from commercial power should be physically separated from each other, to the degree practical consistent with the overall facility design to minimize the possibility of simultaneous damage to both feeds by lightning, nearby excavation, and/or other reasons.

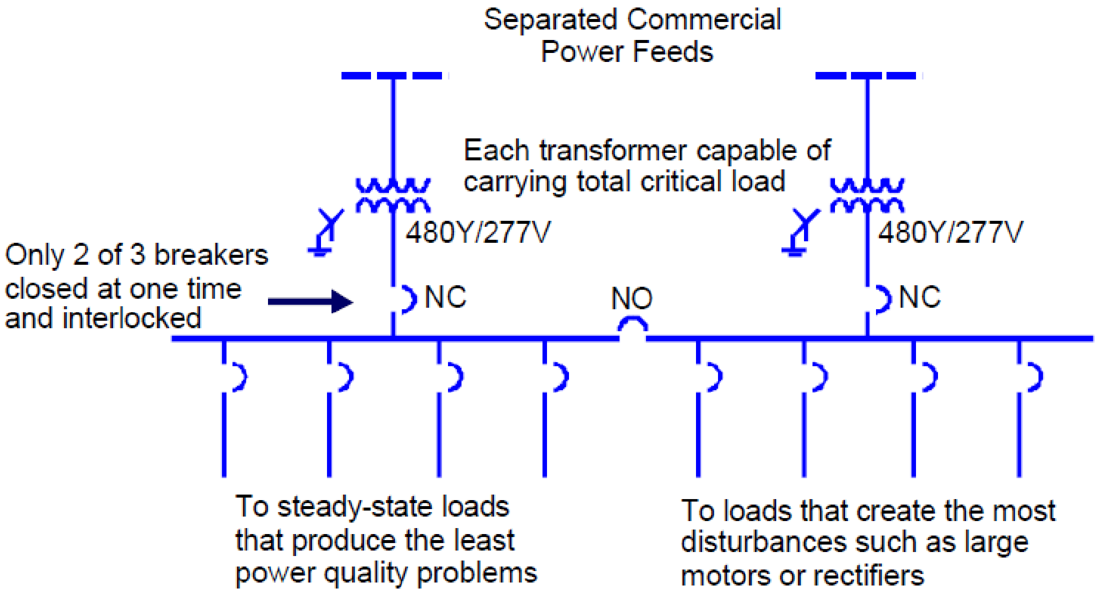


Figure 1-2 Redundant Power Feed to Facility

1.3. Alternate and Backup Power Source

1.3.1. 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.

1.3.2. Loads served by an alternate source normally consist of critical systems and equipment only, unless designated otherwise by specific 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.

1.4. Services

1.4.1. Service entrance equipment should be located in readily accessible spaces to facilitate disconnection of power in case of emergency. The service entrance location should be coordinated with the exterior distribution system to ensure that service and feeder circuit lengths are as short as practical.

1.4.2. 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. The ampacity of service entrance conductors should be calculated in accordance with paragraphs 4-2 and 4-3.

1.4.3. Services greater than 600 volts to structures should be installed underground. Incoming services tapped from aerial distribution circuits should be provided with surge protectors at the service entrance equipment (refer to PDH Course E288 “Surge Protection Systems Performance and Evaluation” for surge protection design criteria). Services exceeding 600 volts should be limited 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.

1.4.4. In general for services greater than 600 volts, metal-enclosed, manually operated, fusible load interrupter switches or power circuit breakers should be used. For services 600 volts and less, molded case breakers, low voltage power circuit breakers, or fusible disconnect switches are preferred. Low voltage power circuit breakers should be selected only where the added cost incurred by their use can be justified by operational considerations. A single disconnecting means should be provided for each facility. Multiple disconnects should be avoided unless major economies can be realized in large capacity services or if multiple service voltage requirements exist. Care has to be taken to make sure that 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.

1.4.5. Energy usage and demand meters should be provided in accordance with paragraph 6-5.

1.4.6. 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. Care has to be taken to make sure that equipment can be removed and replaced without interference with other systems or equipment, and without requiring building modifications. Adequate ventilation should be provided to permit equipment to operate within normal ambient temperature limitations; otherwise, the equipment should be derated for a lower capability and potentially shorter service life. Refer to paragraph 6-1 for additional requirements regarding equipment clearances.

1.4.7. Electrical distribution systems that require high reliability power should be designed 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.

2. TRANSFORMERS

2.1. Ratings

2.1.1. Introduction

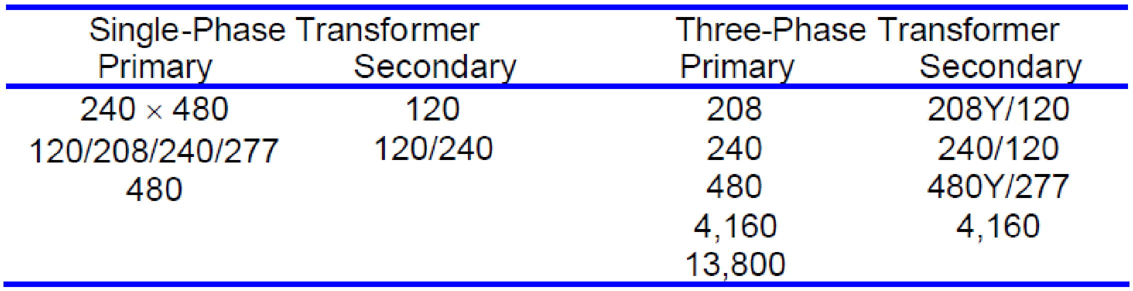
2.1.1.1. The choice of the main supply service voltage should be based on an energy economic analysis of the various electrical system options for any particular facility under design. This is an integral part of determining the transformer primary voltage rating.

2.1.1.2. 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

2.1.2. Voltage and Current

2.1.2.1. The transformer primary voltage rating must be determined by the voltage available to the transformer from the facility electrical distribution system. The transformer secondary voltage should be selected 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.

2.1.2.2. 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 2-1.



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	

Table 2-1. Common Primary and Secondary Transformer Voltages

Note: Table 2-1 does not include all possible combinations of transformer ratios. Refer to Table 3-1 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. The transformer vendor should be contacted for non-standard voltage and frequency ratings.

2.1.3. Temperature and kVA

2.1.3.1. 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. The transformer should be selected based on its kVA capacity and temperature rating.

2.1.3.2. 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 2-1):

- 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.

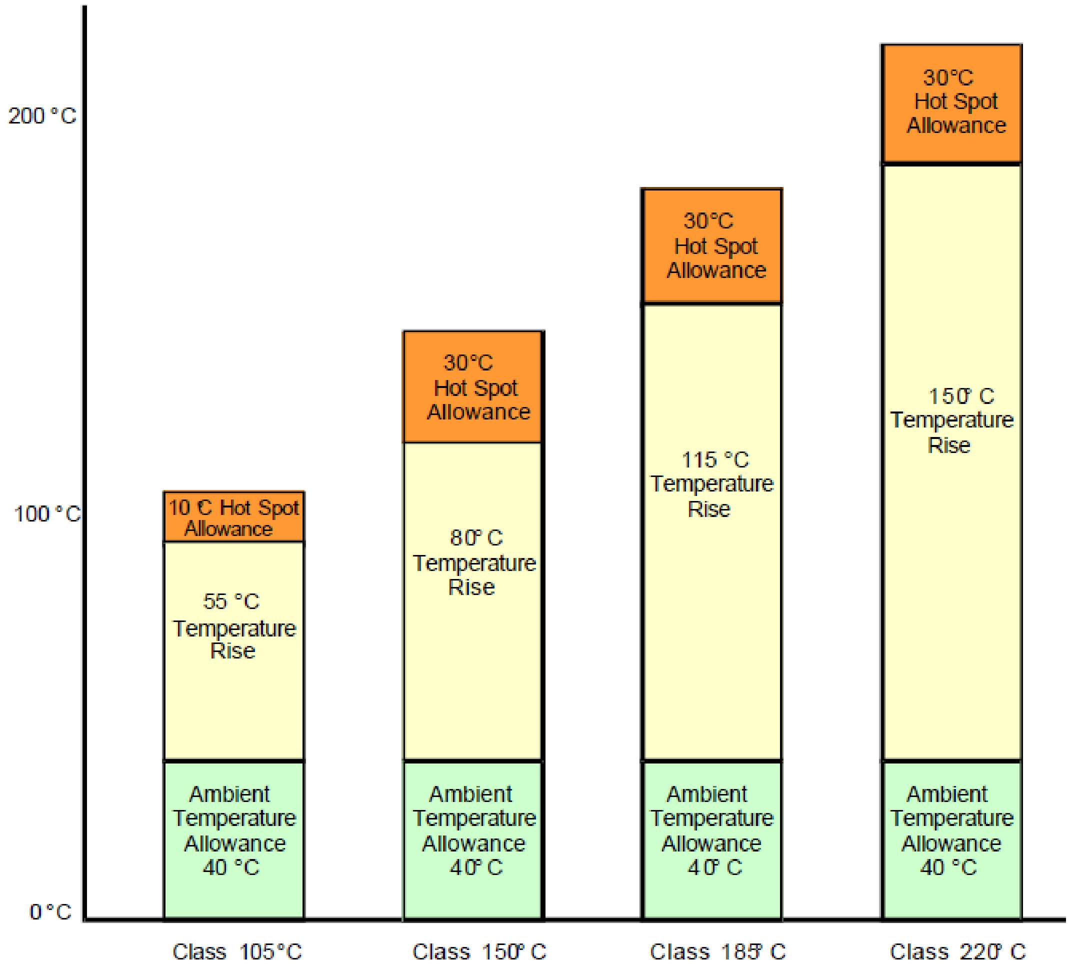


Figure 2-1. Insulation System Ratings

2.1.3.3. The kVA rating and the insulation system rating are related. The desired kVA rating or insulation system should be selected 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, the kVA rating or insulation system class

should be increased to reduce the degree of thermal damage at higher temperatures.

2.1.3.4. 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.

2.1.4. Impedance

2.1.4.1. 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.

2.1.4.2. The selected transformer's impedance rating should be evaluated to ensure that it will not allow a greater short circuit current in its secondary than the downstream protective devices are capable of interrupting.

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

2.1.4.4. 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, the available short circuit current should be calculated to make sure that it does not exceed the interrupting rating of downstream protective devices.

2.1.5. Number of Phases

2.1.5.1. Single-phase transformers should be used on single-phase systems and on single –phase circuits derived from three-phase systems.

2.1.5.2. Either three single-phase transformers or one three-phase transformer should be used 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.

2.1.6. Transformer Taps

2.1.6.1. 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.

2.1.6.2. 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.

2.1.6.3. The tap setting should be selected 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 manufacturer's requirements.

2.1.7. Noise

2.1.7.1. 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. The system designer needs to determine if noise rating is a required design consideration for the intended installation location.

2.1.7.2. 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.

2.1.7.3. In addition to the transformer noise rating, the following actions need to be considered to improve the generated sound level:

- Transformers should be mounted in such a way 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.
- Flexible couplings and conduit should be used to minimize vibration transmission through the connection points.
- transformer should be located 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.

2.1.8. Basic Impulse Insulation Levels (BIL)

2.1.8.1. 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.

2.1.8.2. 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.

2.1.8.3. Lower BIL levels should not be specified solely because surge protection has been installed.

2.2. Low Voltage Transformers

2.2.1. 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. Ventilated dry-type transformers should not be located in environments containing contaminants including dust, excessive moisture, chemicals, corrosive gases, oils, or chemical vapors. Transformers should be designed for floor or wall mounting.

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

2.2.3. 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, an evaluation needs to be performed 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.

2.2.4. 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.

2.2.5. 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, detailed rationale supporting the proposed arrangement should be provided as part of the design analysis.

2.2.6. Generally autotransformers should not be used unless necessary for a special application. Explanation needs to be provided as to why the special application requires an autotransformer as part of the design analysis.

2.2.7. 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.

2.3. Medium Voltage transformers

2.3.1. Medium voltage transformers should be considered 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.

2.3.2. 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 PDH Course M122 “Fire Protection for Facilities Engineering, Design, and Construction”, for guidance regarding installation criteria.

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

2.3.4. A transformer economic analysis, including the rationale supporting the decision, should be provided as part of the design analysis. The 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, should be included in the cost analysis. All transformers and equipment addressed in the analysis should be equal in every electrical respect, including but not limited to capacity, voltage, overload capability, and BIL in order to obtain a fair comparison.

2.3.5. Generally autotransformers should not be used unless necessary for a special application. Explanation needs to be provided as to why the special application requires an autotransformer as part of the design analysis.

2.4. Other Transformers

2.4.1. Isolation Transformers

2.4.1.1. 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.

2.4.1.2. When configured in a delta-wye configuration, the isolation 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.

2.4.1.3. 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 and thereby isolating triple harmonics from being fed back into the source. Refer to PDH Course E290 “Power System Quality” for additional criteria related to power quality and harmonic distortion.

2.4.1.4. 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.

2.4.2. Buck-Boost Transformers

2.4.2.1. 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. Buck-boost transformers should be applied only when required to achieve voltages beyond the capability of the existing utilization equipment.

2.4.2.2. A buck-boost transformer cannot 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 (2008 Edition).

2.4.2.3. Buck-boost transformers should not be used 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.

2.4.2.4. Buck-boost transformers should not be used 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.

2.4.3. K-Factor Transformers

2.4.3.1. 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.

2.4.3.2. The effect of nonlinear loads should be evaluated 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 PDH Course E290 “Power System Quality” to determine if a transformer requires derating.

2.4.3.3. 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.

2.4.3.4. 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.

2.4.3.5. 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.

2.4.3.6. Equipment suppliers can provide bundled power distribution systems that contain k-rated transformers or otherwise address power quality issues. The applicability of this equipment should be evaluated before selecting a k-rated transformer.

2.4.4. Specialty Transformers

2.4.4.1. Specialty transformers include control, industrial control, Class 2, signaling, ignition, and luminous tube transformers. These transformers should be selected using National Electrical Manufacturers Association (NEMA) ST 1, Specialty Transformers (Except General Purpose), as a guide.

2.5. Transformer Installation Criteria

2.5.1. Introduction

2.5.1.1. NEC Article 450 (2008 Edition) provides specific criteria applicable to transformers and transformer installations. The NEC location and installation criteria are applicable as described in this course.

2.5.1.2. For each of the specified criteria in the NEC, exceptions are often provided. As part of any installation design, the NEC should be reviewed to ensure that applicable criteria, including allowed exceptions, are satisfied. Regardless of the location, transformers should have adequate ventilation to avoid overheating. Clearances specified by NEC Articles 110.26 and 110.34 (2008 Edition) should be complied with for installations below 600 volts or above 600 volts, respectively.

2.5.2. Dry-Type Transformers

2.5.2.1. 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.

2.5.2.2. Figure 2-2 shows the installation spacing criteria for transformers rated 112.5 kVA or less. As shown, these transformers should 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 non-ventilating type.

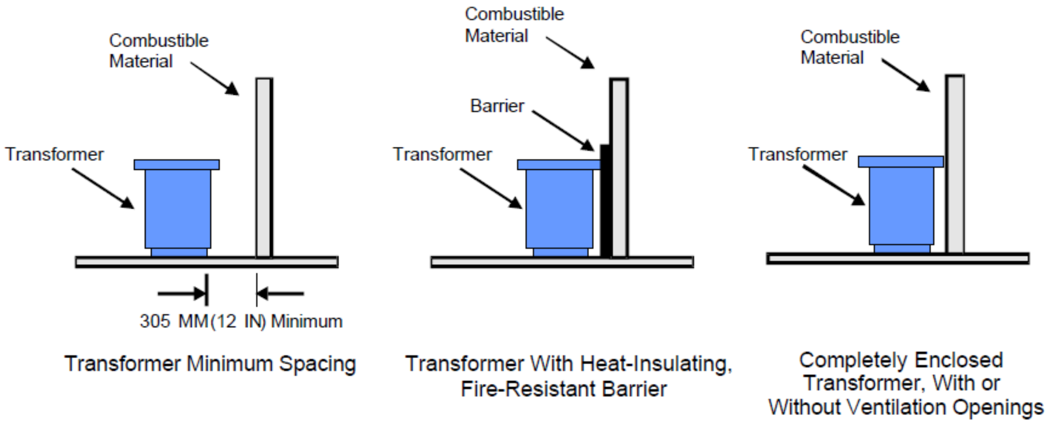


Figure 2-2. Spacing Requirements for Transformers Rated 112.5 kVA or Less

2.5.2.3. Dry-type transformers rated for more than 112.5 kVA have different requirements, depending on the insulation rating as shown in Figure 2-3. 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 2-3 or a fire-resistant, heat insulating barrier.

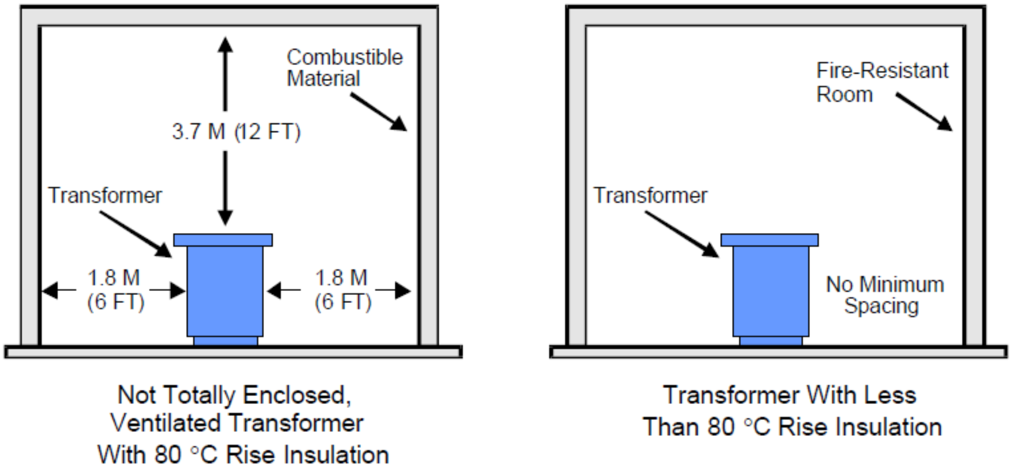


Figure 2-3. Spacing Requirements for Transformers Rated Over 112.5 kVA

2.5.2.4. Dry-type transformers rated for over 35,000 volts should be installed in a vault as shown in Figure 2-4.

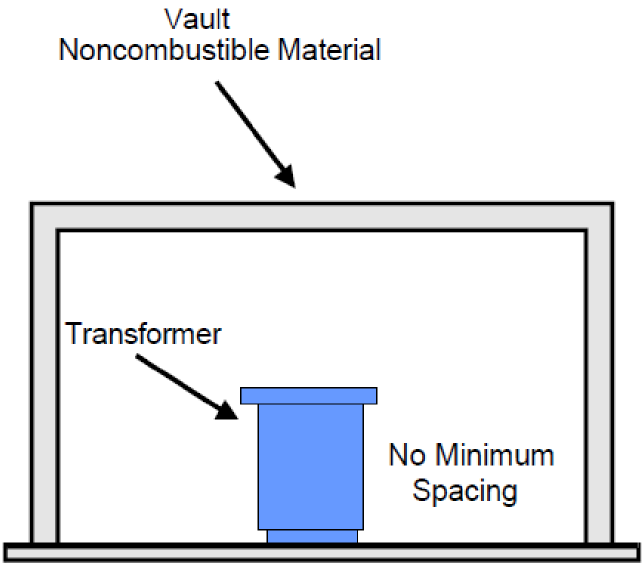


Figure 2-4. Installation Requirements for Transformers Rated Over 35,000 Volts

2.5.3. Less-Flammable, Liquid-Insulated, and Oil-Insulated Transformers

2.5.3.1. Dry-type transformers should be used wherever possible for interior applications.

2.5.3.2. 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 PDH Course E213 "Transformer Fire Protection "for guidance regarding installation criteria.

2.6. Transformer Sizing

2.6.1. Transformers should be sized to have adequate kVA capacity. The associated transformer conductors should be sized to accommodate the rated kVA capacity in accordance with NEC criteria. The transformer conductor sizing establishes the overcurrent protection requirements for the system.

2.6.2. PDH Course E319 "Electrical Calculation Methods and Examples" provides examples for transformer and associated conductor sizing.

2.6.3. 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. This practice should not be followed for interior installations; instead, transformers should be sized assuming 100 percent of rated capacity and the overload capacity will provide future margin, if necessary.

2.6.4. Transformers should not be sized to have significant spare capacity unless load growth in the system is expected. Most transformers in service are lightly loaded.

2.7. **Information Sources**

2.7.1. 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. The following ANSI and IEEE standards, as well as other documents listed below, should be reviewed as appropriate for any transformer application:

- 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.
- 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.
- 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.
- 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.
- 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.

- 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
- 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.
- C57.12.70, *Terminal Markings and Connections for Distribution and Power Transformers*—provides terminal marking layouts and requirements for C57-type transformers.
- 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.
- C57.110—provides transformer sizing criteria for transformers supplying nonsinusoidal loads.
- IEEE 141, *IEEE Recommended Practice for Electric Power Distribution for Industrial Plants* (IEEE Red Book)—provides general considerations for transformer applications.
- IEEE 241—provides general considerations for transformer applications.
- NEMA ST 1—provides design requirements for control, industrial control, Class 2, signaling, ignition, and luminous tube transformers.
- NEMA ST 20—provides design requirements for general purpose dry type transformers.
- TM 5-686, *Power Transformer Maintenance and Acceptance Testing*.

3. SWITCHGEAR, LOAD CENTERS, AND BREAKERS

3.1. Service Entrance

3.1.1. Service equipment should be located at the service entrance point.

3.1.2. The equipment should be 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, the following options need to be evaluated:

- **Current Limiting Fuses.** This is usually the most cost-effective method of reducing downstream fault currents. Downstream equipment ratings should be based 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.
- **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, this option needs to be discussed with the manufacturer to ensure that the current-limiting capability is understood completely. Series-combination ratings for MCCBs are not allowed.
- **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.
- **High Impedance Busway.** This option is not recommended.
- **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.

3.1.3. A single disconnecting means should be provided for each facility. multiple disconnects should be avoided unless major economies can be realized in large capacity services or if multiple service voltage requirements exist.

3.1.4. NEC Article 230.95 (2008 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. The service entrance GFP should be set high enough to allow coordination with downstream devices.

3.1.5. The equipment ampacities should be 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.

3.1.6. Service equipment should be installed 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, adequate space should be reserved for the electrical equipment, including provisions for future modifications. Piping, ducts, and other equipment unrelated to the electrical equipment should not pass through or over the space reserved for electrical equipment. When fluid systems are located near electrical equipment, the equipment should be furnished with splash-shields and water-resistant enclosures.

3.1.7. The electrical system should be designed with the capability to disconnect all ungrounded conductors in a building or other structure from the service-entrance conductors. The disconnecting means should plainly indicate whether it is in the open or closed position and should be installed 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.

3.1.8. All circuit disconnect devices, including switches and breakers, should be clearly and permanently marked to show the purpose of each disconnect.

3.1.9. Barriers should be placed 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.

3.1.10. Depending on the facility design, consideration should be given to 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.

3.2. Switchgear and Switchboards General Criteria

3.2.1. In general switchgear and switchboards should be 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. Switchboards should be 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.

3.2.2. Switchgear should be secured in accordance with the manufacturer's instructions. Cable routed to the switchgear need to be supported to minimize forces applied to conductor terminals.

3.2.3. Piping containing liquids, corrosive gases, or hazardous gases should not be routed in the vicinity of switchgear unless suitable barriers are installed to protect the switchgear from damage in the event of a pipe failure. Switchgear should not be located where foreign flammable or corrosive gases routinely and normally are discharged.

3.2.4. Switchgear enclosure surfaces should not be used as physical support for any item unless specifically designed for that purpose. Enclosure interiors should not be used as storage areas unless specifically designed for that purpose.

3.2.5. All metal instrument cases need to be grounded.

3.2.6. A safety sign should be placed on any cubicles containing more than one voltage source.

3.2.7. Switchgear should be installed with clearances stated in paragraph 6-1. 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.

3.2.8. Switchboards that have any exposed live parts should be located in permanently dry locations and accessible only to qualified persons.

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

3.2.10. 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.

3.2.11. All circuit breakers should be clearly and permanently marked to show the purpose of each breaker.

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

3.2.13. Switchboards should be placed as close as possible to the center of the loads to be served.

3.3. High Voltage Switchgear

3.3.1. 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 course, high voltage refers to any application rated above 15 kV.

3.4. Medium Voltage Switchgear

3.4.1. Ratings

3.4.1.1. **Switchgear.** Need to be specified as metal-enclosed, manually operated, fusible load interrupter switches or power circuit breakers with copper bus. Table 3 -1 indicates the most commonly used voltages; the standard voltages shown without parentheses are preferred.

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

Table 3-1. Medium Voltage Switchgear Voltage Ratings

3.4.1.2. **Standards.** 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*, should be applied in the selection of circuit breakers.

3.4.1.3. **Voltage Rating.** Voltage rating should be determined in terms of three-phase, line - to-line voltage, including the following considerations:

- Maximum nominal system voltage for which the breaker is intended.
- Maximum operating voltage at which the breaker will be used, taking into consideration line voltage regulation, machine over-excitation and overspeed, and shunt capacitance

3.4.1.4. **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:

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

3.4.1.5. **Continuous Current.** The maximum current flow through the breaker need to be calculated by computing the current flow under normal and contingency conditions. Allowances should be provided for future load growth, if required.

3.4.1.6. **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. The following criteria should be used:

- Allowances should be provided 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.*
- If the operating voltage of the circuit differs from the rated voltage of the circuit breaker, the final values need to be corrected to correspond with the rated values given in the manufacturer’s circuit breaker rating tables.
- The asymmetrical requirements should be determined based on the breaker contact parting time.
- The actual operating duty and interruption time of the breaker should be determined from the relay setting calculations.

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

3.4.1.8. **Ambient Temperature.** Circuit breakers need to be derated in environments with ambient temperatures higher than +40 °C (104 °F) or lower than -30 °C (-22 °F) in accordance with IEEE C37.010.

3.4.1.9. **Breaker Selection. Breakers should be selected using the following criteria:**

- **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.
- **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. Use of sulfur hexafluoride circuit breakers should be considered.

3.4.2. Low Voltage Conductors in Medium Voltage Switchgear.

3.4.2.1. Low voltage cables or conductors, except those to be connected to equipment within the compartment, should not be routed through medium or high voltage divisions of switchgear unless installed in rigid metal conduit or isolated by rigid metal barriers. Conductors entering switchgear should be insulated for the higher operating voltage in that compartment or they should be separated from insulated conductors of other ratings.

3.4.2.2. 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.

3.5. Low Voltage Breakers And Panels

3.5.1. Circuit Breakers

3.5.1.1. The following types of circuit breakers can be used for low voltage applications:

- Molded case circuit breakers (MCCB) should be used 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.
- 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.
- Low voltage power circuit breakers should be selected only where the added cost incurred by their use can be justified by operational considerations. Low voltage power circuit breakers in enclosures should be applied in accordance with IEEE C37.13, *Low-Voltage AC Power Circuit Breakers Used in Enclosures.*
- Insulated-case circuit breakers are rated in a manner similar to MCCBs and can be used instead of low voltage power circuit breakers.
- 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.

3.5.1.2. Series-combination rated breakers should not be used at all. 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.

3.5.1.3. 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.

3.5.1.4. Circuit breakers used as switches in 120 volt and 277 volt lighting circuits should be listed for the purpose and should be marked “SWD” or “HID” (switching duty or high-intensity discharge lighting) in accordance with NEC Article 240.83(D) (2008 Edition).

3.5.1.5. Circuit breakers intended to protect multiple motor and combination load installations associated with heating, air conditioning, and refrigeration equipment are should be marked “Listed HACR Type” in accordance with

NEC Article 430.53(C) (2008 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.

3.5.1.6. Arc-fault circuit interrupter protection should be provided in accordance with NEC Article 210.12 (2008 Edition). This requirement applies to all branch circuits supplying 125 volt, single-phase, 15- and 20- ampere outlets installed in dwelling unit bedrooms.

3.5.2. **Panelboards**

3.5.2.1. 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:

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

  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.

3.5.2.2. Distribution panelboards should be specified as 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.

3.5.2.3. Overcurrent protection of panelboards should be provided in accordance with NEC Article 408.36 (2008 Edition) as follows:

- Each lighting and appliance branch circuit panelboard on the supply side should be protected 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.
- 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 should be protected by an overcurrent protective device having a rating not greater than that of the panelboard.
- Overcurrent protection not in excess of 200 amperes should be provided for panelboards equipped with snap switches rated at 30 amperes or less.
- 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.
- Where a panelboard is supplied through a transformer, the overcurrent protection should be provided on the secondary side of the transformer.

3.5.2.4. Circuit breakers should clearly indicate whether they are in the open (off) or closed (on) position.

3.5.2.5. Panelboard circuit directories should be filled-out clearly.

3.5.2.6. Panelboards should have hinged fronts to allow easier maintenance access.

3.5.2.7. Panelboards should be placed as close as possible to the center of the loads to be served.

3.6. Motor Control Centers

3.6.1. 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.

3.6.2. MCC’s 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 5-2 for motor control criteria.

3.6.3. 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.

3.7. Disconnect Switches

3.7.1. Fusible disconnect switches should be used where special consideration 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.

3.7.2. 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.

3.7.3. 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.

3.7.4. All disconnect switches must be lockable.

3.7.5. Disconnect switches for motor applications should be rated for the horsepower rating of the associated motor.

3.8. Circuit Lockout Requirements

3.8.1. 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 tag-out 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.

3.9. Information Sources.

3.9.1. The following references provide additional information regarding circuit breaker selection and sizing:

- ANSI C37 Series—provides several standards related to switchgear and circuit breakers and should be used as a reference source when preparing specifications.
- IEEE 141—provides an application overview of switchgear, breakers, and other switching devices.
- IEEE 241—provides an application overview of switchgear, breakers, and other switching devices.
- 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.
- 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.
- NFPA 70, National Electrical Code—provides specific requirements related to the sizing and application of circuit breakers.
- OSHA 29 CFR—provides the requirements for circuit disconnection and lockout. Refer to Appendix A for a listing of applicable OSHA regulations.
- EM 385-1-1—provides additional requirements for circuit disconnection and lockout.

4. RACEWAY CRITERIA AND WIRING

4.1. Raceway Criteria

4.1.1. All raceways design used for interior wiring systems shall 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.

4.1.2. Rigid aluminum conduit should not be used unless justified by the application and documented in the design package. For example, aluminum conduit is preferred for 400 Hertz applications. Aluminum conduit should not be imbedded in concrete or masonry, buried in earth, or used to penetrate vertical or horizontal firewalls. If conduit runs penetrate firewalls, steel conduit should be used for a minimum of 0.9 meters (3 feet) on each side. Metal types if should not be mixed if possible.

4.1.3. 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. NEC criteria should be followed for the application of nonmetallic conduit.

4.1.4. Flexible metal conduit is not intended as a general-purpose raceway for long distances. Liquid-tight flexible metal conduit should be used 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.

4.1.5. Surface metal raceways or multi-outlet assemblies should only be used 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.

4.1.6. 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.

4.1.7. 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.

4.1.8. 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. Conduit or cable should not be supported from or attached to the underside of cable tray.

4.1.9. 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.

4.1.10. 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.

4.1.11. 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, cable connections and terminations should be made in accordance with the manufacturer’s recommendations to assure a proper connection.

4.1.12. 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. Surface boxes with nail holes or openings that can admit insects are not recommended.

4.1.13. Conductors entering boxes, cabinets, or fittings should be protected from abrasion. Openings through which conductors enter need to be closed. All unused openings in cabinets, boxes, and fittings must be closed.

4.1.14. All pull boxes, junction boxes, and fittings should be provided with covers approved for the purpose. All metal covers if they are used need to be grounded. In completed installations, a cover, faceplate, or fixture canopy on should be installed on each outlet box. Covers of outlet boxes having holes through which flexible cord pendants pass should be provided with bushings designed for the purpose or should be furnished with smooth, well-rounded surfaces on which the cords can bear.

4.1.15. Pull and junction boxes for systems over 600 volts should provide a complete enclosure for the contained conductors or cables. Boxes should be closed by suitable covers securely fastened in place. This requirement also applies to underground box covers that weigh over 45.5 kilograms (100 pounds). Covers for boxes should be permanently marked with "DANGER—HIGH VOLTAGE. KEEP OUT." The marking should be installed on the outside of the box cover, and should be readily visible and legible.

4.1.16. Wiring systems in hazardous locations must conform to the NEC for the particular hazard encountered. The extent of each hazardous location should be outlined 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 6-3 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:

- Sealing fittings should to be shown on the drawings where needed to ensure compliance with NEC criteria.
- Electrical equipment should be located as much as possible 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.

4.2. Wiring System Criteria

4.2.1. 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. Raceways and cables should be concealed in finished spaces wherever possible.

4.2.2. Conductors should be sized to satisfy the electrical requirements of the system. As a minimum, conductors should be sized 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.

4.2.3. NEC Article 310.10 (2008 Edition) prohibits applying conductors in a manner that will exceed the temperature rating for its insulation. An acceptable temperature rating should be ensured as follows:

- Determine the current required by the loads.
- Select the conductor size in accordance with NEC Article 310.15 (2008 Edition) for a given temperature rating.
- 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.
- Refer to paragraph 4-2.13 for the minimum rating requirements.

4.2.4. 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.

4.2.5. Power conductor insulation should be suitable for the installation and conforming to NEC requirements for each application. Heat-resistant insulation should be selected for conductors #6 AWG and larger.

4.2.6. Feeders should have an ampacity adequate for the loads to be served. Demand factors should be should be selected in accordance with NEC Article 220 (2008 Edition).

4.2.7. Branch circuits should be rated 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, #12 AWG conductors should be used wherever #14 AWG wiring is authorized by the NEC to ensure a better overall design.

4.2.8. If the transformer providing service is located within the facility the combined voltage drop on feeders and branch circuits should not be more than 5 percent. If the transformer is located exterior to the facility, the combined voltage drop for service conductors, feeders, and branch circuits should be limited 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) (2008 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.

4.2.9. 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 (2008 Edition). The conductors should be arranged and terminated 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.

4.2.10. 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.

4.2.11. Receptacle branch circuits feeding predominantly nonlinear loads should be provided with fully sized neutral conductors. The phase and neutral conductors should be labeled in a manner that associates these conductors together for each circuit.

4.2.12. 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, separate panel boards fed from separate feeders back to the service entrance should be provided.

4.2.13. Branch circuit and feeder sizes should be based 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 (2008 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 (2008 Edition) should be used for conductors larger than 100 amperes.

4.2.14. All conductors should be terminated properly in accordance with the manufacturer's recommended procedures. Ensure that the proper crimping tools are available for each type of termination, as applicable.

4.2.15. The use of splices is discouraged unless required for a specific application. If splices are used, conductors should be spliced or joined together with splicing devices suitable for the use. All splices and joints and the free ends of conductors should be covered with an insulation equivalent to that of 150 percent of the conductors or with an insulating device suitable for the purpose. Conductors of dissimilar metals should not be intermixed 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 (2008 Edition). Splices should be installed 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.

4.2.16. 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 (2008 Edition) . The cable should be protected from physical damage where necessary by one or more of the methods allowed by NEC Article 334 (2008 Edition).

4.3. Sizing Wiring Systems for Energy Savings

4.3.1. Paragraph 4-2 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.

4.3.2. 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. PDH Course E319 “Electrical Calculations Methods and Examples” provides example calculations.

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

4.4. Convenience Outlets and Receptacles

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

4.4.2. The grounding pole should be incorporated 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.

4.4.3. A separate conductor (green wire or bare copper) should be used to ground all grounding type outlets and receptacles.

4.4.4. A separate single-branch circuit should be provided 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.

4.4.5. Computer-related circuits and receptacles should be separated from motor load circuits. If required by the manufacturer to minimize noise, a separate grounding conductor back to the branch circuit breaker, should be provided for each circuit, consistent with NEC grounding criteria.

4.4.6. Ground fault circuit interrupters (GFCI) should be provided for personnel protection and GFP for equipment protection in accordance with NEC requirements.

4.4.7. Receptacles used in medical facilities must comply with NFPA 99, Health Care Facilities, and NEC Article 517 (2008 Edition). Hospital grade receptacles listed for this purpose should be used. Receptacles fed from the emergency system should be indentified and the panelboard and circuit number supplying them should be indicated.

4.4.8. 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.

4.4.9. Three-phase power receptacles installed in hangars, aprons, and ramps for supply of electrical energy to aircraft support equipment should be designed to fit the plug used as the standard on the support equipment.

4.4.10. Receptacles in a floor or apron flush-mounted with an adjacent concrete pad should be installed slightly mounded and slotted to permit drainage. The slots in pavement should be oriented to avoid snowplow blades.

- The receptacle enclosure should be utilized for the pull or junction box. No other opening or hand hole for this purpose can be constructed in the floor or apron.
- The contactor for the circuit, control relay, and control devices should be mounted 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.

4.4.11. 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.

4.5. Wiring for Temporary Power and Lighting

4.5.1. 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, all other criteria for permanent wiring to applies temporary wiring installations.

4.5.2. 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.

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

4.5.4. Feeders for temporary wiring should be originated from a distribution center approved for this purpose. 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.

4.5.5. Branch circuits for temporary wiring should be originated from an approved power outlet or panelboard. Conductors should be multiconductor cord or cable assemblies or open conductors. If run as open conductors, they should be fastened 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.

4.5.6. 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. GFCI protection should be provided in accordance with NEC Article 590.6 (2008 Edition).

4.5.7. No bare conductors or earth returns can be used for the wiring of any temporary circuit.

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

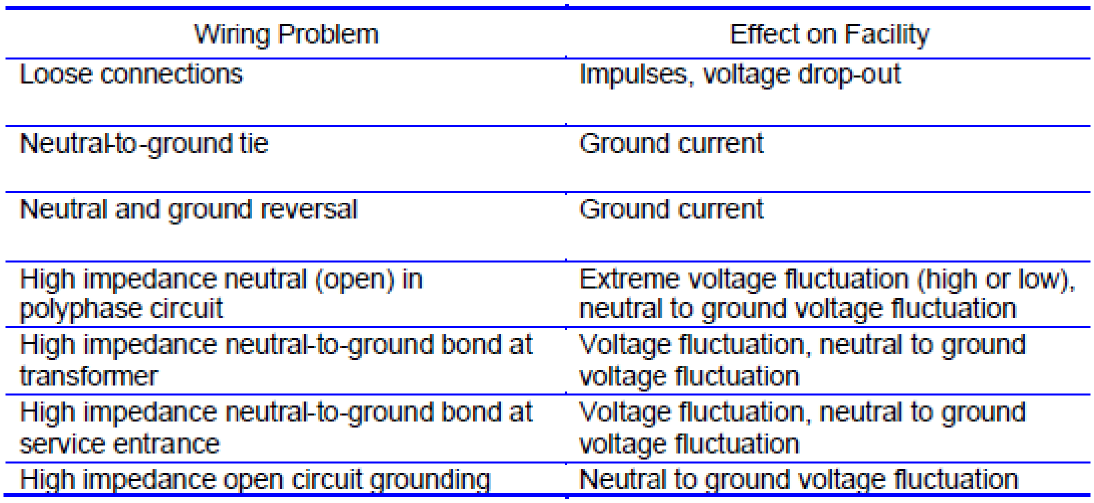
4.5.9. Lamps for general illumination should be protected from accidental contact or breakage. Protection should be provided by elevation of at least 2.1 meters (7 feet) from the normal working surface or by a suitable fixture or lampholder with a guard.

4.5.10. Flexible cords and cables should be protected from accidental damage. Sharp corners and projections should be avoided. Where passing through doorways or other pinch points flexible cords and cables should be provided with appropriate protection to avoid damage.

4.5.11. Aluminum foil or other conductive material should not be wrapped around fuses to keep temporary loads, such as Christmas lights on with fuses blown.

4.6. Acceptance Testing of Wiring Systems

4.6.1. The facility electrical acceptance process should include a detailed inspection of the wiring system from the service entrance to the loads. Table 4-1 shows typical wiring-related problems that can be encountered.



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

Table 4-1. Electrical System Problems Caused by Improper Wiring

4.6.2. If infrared scanning equipment is available, an infrared scan of connections should be performed 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.

5. MOTORS & MOTOR CONTROL CIRCUITS

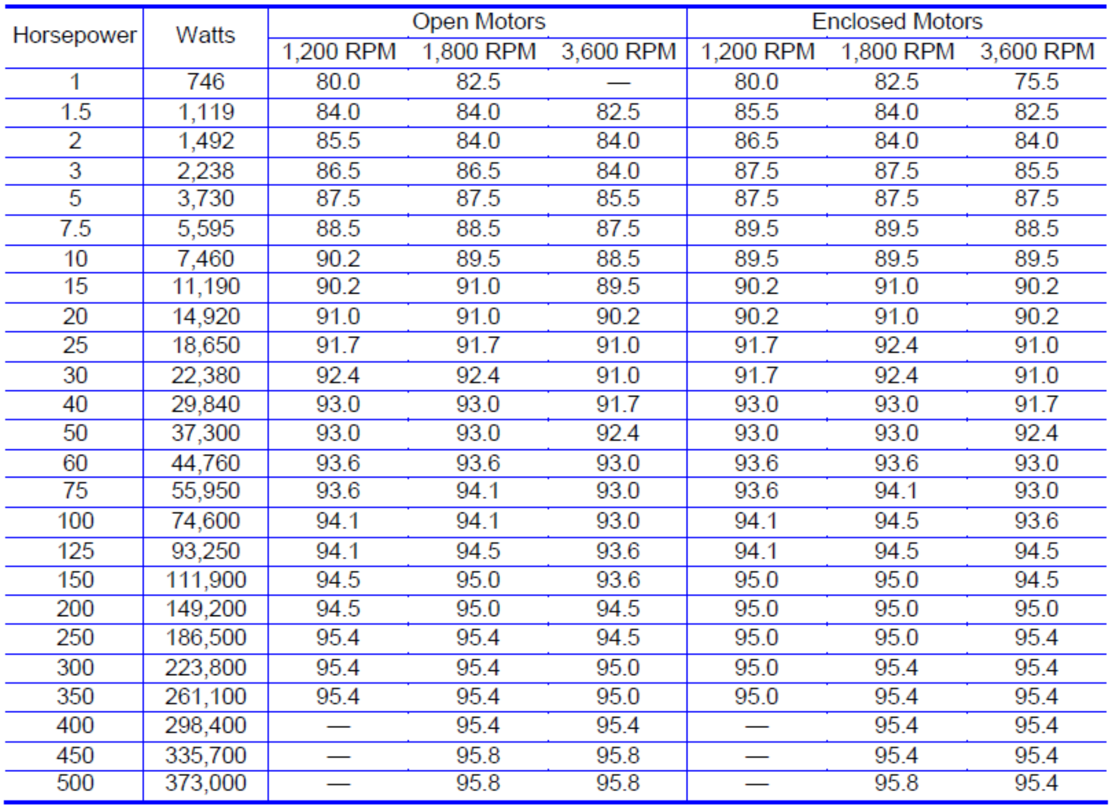
5.1. Basic Motor Criteria

5.1.1. Motors should 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, three-phase motors should be selected if more than 0.5 horsepower (373 watts) rating when such service is available. If three-phase service is not available, motors 0.5 horsepower (373 watts) and larger should operate 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.

5.1.2. 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, the next larger standard size should be selected.

5.1.3. The motor voltage ratings should be suitable for the voltage supplied. 230 volt motors should not be used 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).

5.1.4. Three-phase motors of 1 horsepower (746 watts) or more should meet the minimum full-load efficiencies as indicated in Table 5-1. 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.

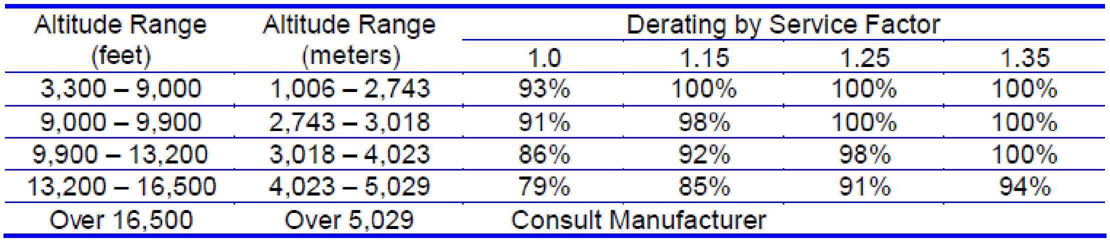


Horsepower	Watts	Open Motors			Enclosed Motors		
		1,200 RPM	1,800 RPM	3,600 RPM	1,200 RPM	1,800 RPM	3,600 RPM
1	746	80.0	82.5	—	80.0	82.5	75.5
1.5	1,119	84.0	84.0	82.5	85.5	84.0	82.5
2	1,492	85.5	84.0	84.0	86.5	84.0	84.0
3	2,238	86.5	86.5	84.0	87.5	87.5	85.5
5	3,730	87.5	87.5	85.5	87.5	87.5	87.5
7.5	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

Table 5-1 Minimum Full-Load Efficiencies

5.1.5. Motors should be selected 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 5-2 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.



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			

Table 5-2 Motor Altitude Derating Factors

5.1.6. The manufacturer should be consulted 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.

5.2. Motor Control Circuits

5.2.1. Motors larger than 0.125 horsepower (93.25 watts) need to be provided with motor controllers (starters) and need to comply with the design criteria 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.

5.2.2. 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.

5.2.3. 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 one of the following methods for motor starting need to be applied:

- **Reduced Voltage Starters.** Several different designs are available, including primary resistor, autotransformer, part winding, wye delta, and solid-state.
- **Adjustable Speed Drives.** If an ASD is required for other reasons, it can also address motor starting current design needs. Refer to paragraph 5-3 for additional information regarding these devices.

5.2.4. 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. Control circuit voltage should be limited to 150 volts to ground.

5.2.5. If designed for direct control, control devices—such as thermostats, float switches, or pressure switches—should be used 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, a magnetic starter actuated by the automatic control device should be used. The wiring requirements and control scheme for complex direct digital control circuit should be thoroughly reviewed during the design phase of the project; these systems typically require more attention in the design phase to ensure the system operates as desired.

5.2.6. 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, the power or control circuit should be designed in such a way that it can be positively locked open.

5.2.7. 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 re-energization after a power supply interruption of sufficient duration for moving equipment to become stationary. The motor control circuit should be designed in such a way 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.

5.2.8. This requirement does not apply to motors with an emergency function where opening of the circuit could cause less safe conditions. Motors that can automatically start should be identified with a caution tag stating, “CAUTION. MOTOR WILL AUTOMATICALLY START.”

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

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

5.2.11. When making connections to the above selector switches, only the normal automatic control devices are allowed to be bypassed when the switch is in the manual position. All safety control devices, such as low- or high-pressure cutouts, high-temperature cutouts, and motor overload protective devices, should remain connected in the motor control circuit in both the manual and automatic positions.

5.2.12. All motors should be provided 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. Each motor of 0.125 horsepower (93.25 watts) or larger should be provided with thermal overload protection. Three phase motors should be provided 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. If the ambient temperature varies by more than 10 °C (18 °F) an ambient temperature-compensated overload protection should be provided.

5.3. Adjustable Speed Drives

5.3.1. 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.

5.3.2. 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.

5.3.3. 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.

5.3.4. 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.

5.3.5. Motors for ASD applications should have a minimum 1.15 service factor or be rated well above the actual load it will be carry. Motor manufacturer should be contacted to make sure 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.

5.3.6. The final installation should 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; 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 will be powered 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.

5.3.7. Voltage sags can cause nuisance tripping; the ASD needs to have either a minimum of 3-cycle ride-through capability or automatic reset circuitry.

5.3.8. Nearby capacitor switching can cause transient overvoltages, resulting in nuisance tripping; the ASD needs to have either input filtering to reduce the overvoltage or automatic reset circuitry.

5.3.9. Critical applications should include bypass operation capability to allow motor operation independent of the ASD.

5.3.10. Refer to PDH Course E319 "Electrical Calculations Methods and Examples" for additional information regarding an energy efficiency economic evaluation associated with ASDs.

6. OTHER DESIGN CRITERIA

6.1. Electrical Equipment Clearances and Guards

6.1.1. Background

6.1.1.1. 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 (Electrical Safety in the Workplace), NESC (National Electrical Safety Code), and OSHA.

6.1.1.2. Figure 6-1 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 6-1 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.

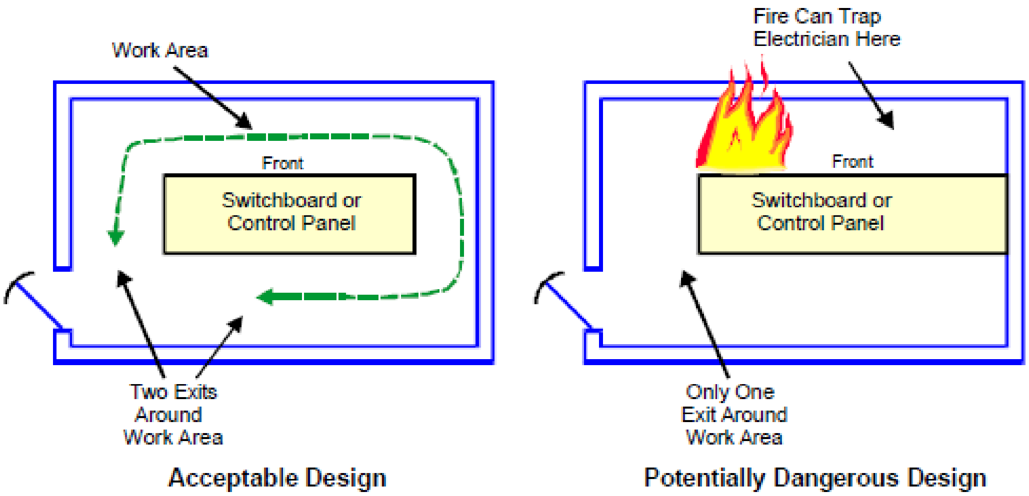


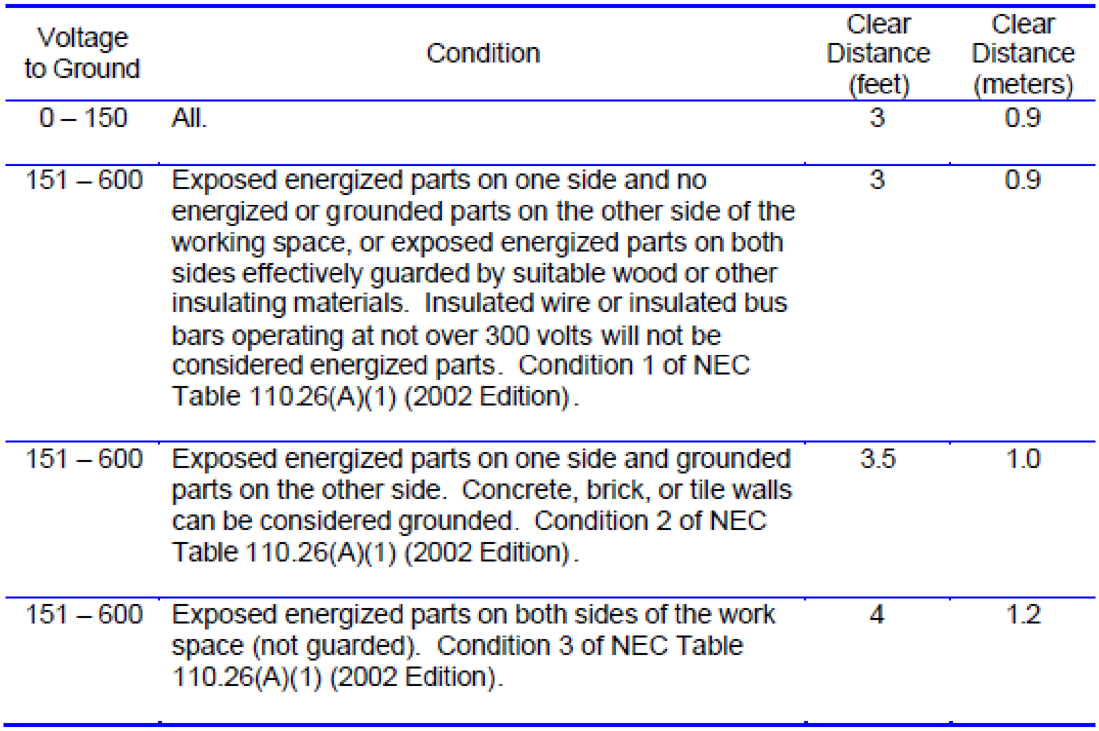
Figure 6-1 Equipment Positioning to Allow Escape Around Equipment

6.1.2. Equipment Rated 600 Volts and Lower.

6.1.2.1. **Basic Requirement.** Power distribution and utilization equipment should be designed and installed in such a manner as to provide adequate clearance for safe operation and maintenance of the equipment.

6.1.2.2. **Access and Entrance to Working Space.** At least one entrance should be provided to give access to the working space about electric equipment.

6.1.2.3. **Working Space.** Working space not less than indicated in Table 6-1should be provided 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 6-1, 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 should be provided. Distances should be measured 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.



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

Table 6-1 Working Space Clearances 600 Volts and Below

6.1.2.4. **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), minimum headroom not less than the height of the equipment should be provided.

6.1.2.5. **Clearance of Other Equipment.** Within the headroom working space height requirement of paragraph 6-1.2.4, 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 6-2). 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.

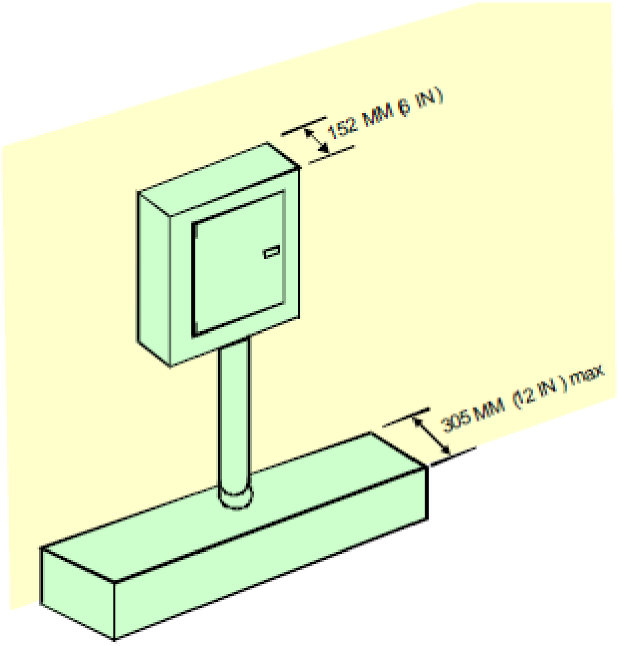


Figure 6-2 Associated Equipment Maximum Extension into Work Space

6.1.2.6. **Front Working Space.** In all cases where there are energized parts normally exposed on the front of switchboards or MCCs, 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 should be provided. This exceeds the minimum space required by the NEC.

6.1.2.7. **Clear Spaces.** Working space required for equipment operation and maintenance should not be used for storage or blocked otherwise. The working space when normally enclosed energized parts are exposed for inspection or servicing, should be guarded if in a passageway or general open space.

6.1.2.8. **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. Dedicated space for switchboards, panelboards, and MCCs should be provided in accordance with NEC Article 110.26(F) (2008 Edition). Summarizing the NEC, 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, should be dedicated to the electrical installation (refer to Figure 6-3). Piping, ducts, or equipment foreign to the electrical installation should not be located in this zone. NEC-specified exceptions regarding protection for foreign systems are allowed.

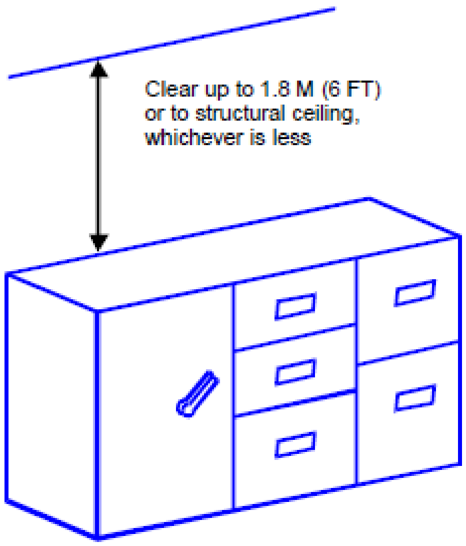


Figure 6-3. Dedicated Clear Space Above Equipment

6.1.2.9. **Illumination.** Adequate illumination for all working spaces about service equipment, switchboards, panelboards, and MCCs installed indoors should be provided.

6.1.3. Guarding

6.1.3.1. Live parts of electric equipment operating at 50 volts or more should be guarded 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. Any openings in such partitions or screens should be sized and located 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.

6.1.3.2. 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.

6.1.3.3. Entrances to rooms and other guarded locations containing exposed live parts should be marked with conspicuous warning signs forbidding unqualified persons to enter.

6.1.4. **Equipment Rated Above 600 Volts.** Equipment rated above 600 volts should be provided with clearances for safe operation and maintenance in accordance with OSHA Standard 29 CFR 1910.303, Section h, and the NESC, Section 12.

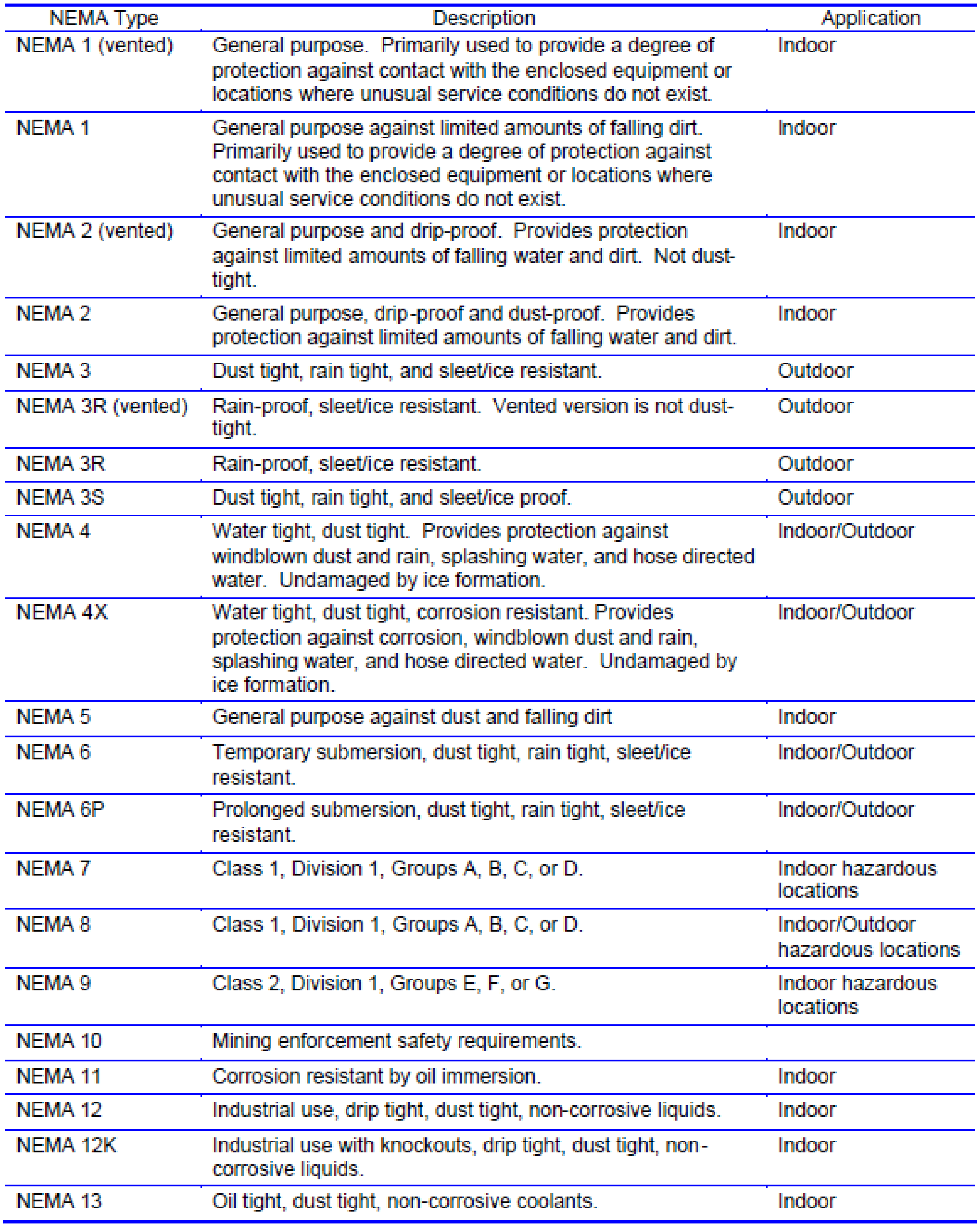
6.2. Enclosures

6.2.1. Equipment enclosures should be selected to provide the following:

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

6.2.2. NEMA classifies enclosures based on the degree of protection provided by the enclosure and the environmental conditions to which the enclosure will be exposed.

6.2.3. Table 6-2 summarizes the NEMA enclosure types. For additional information, NEMA 250, Enclosures for Electrical Equipment (1000 Volts Maximum) should be referred to. If needed, the enclosure manufacturer should be contacted to determine the closest International Electrotechnical Commission (IEC) equivalent designation (NEMA 250, Appendix A, also provides limited information).



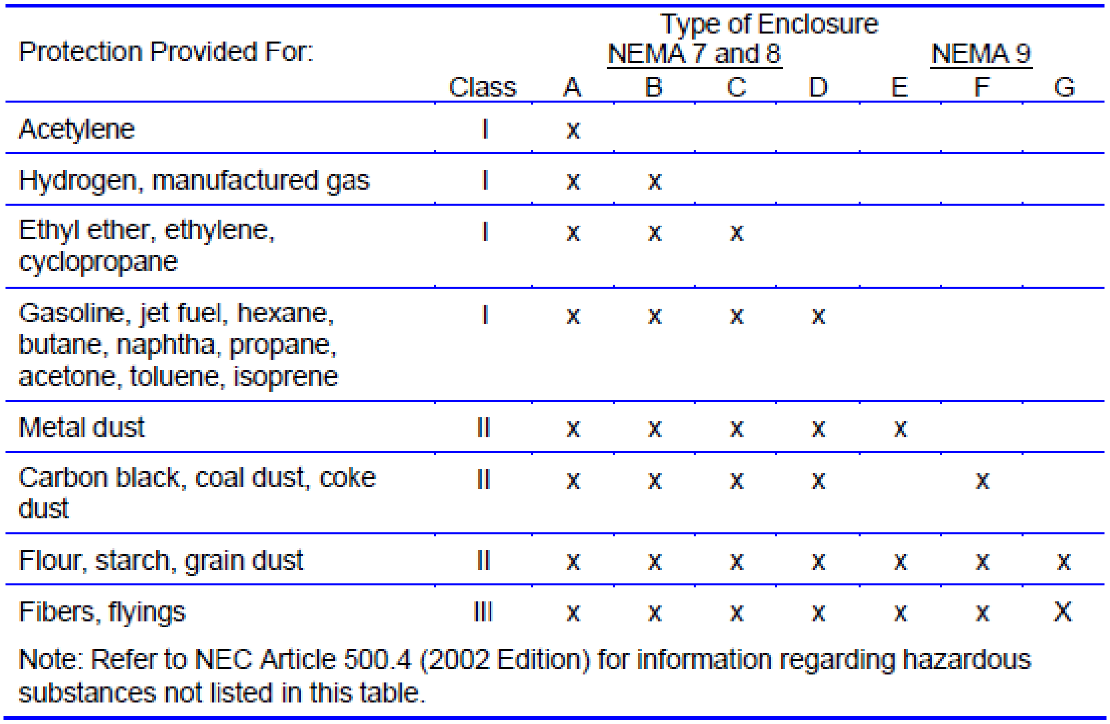
NEMA Type	Description	Application
NEMA 1 (vented)	General purpose. Primarily used to provide a degree of protection against contact with the enclosed equipment or locations where unusual service conditions do not exist.	Indoor
NEMA 1	General purpose against limited amounts of falling dirt. Primarily 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

Table 6-2 NEMA Enclosure Types

6.2.4. Enclosures for indoor applications should be selected in accordance with the conditions specified in Tables 6-3 and 6-4 for non-hazardous and hazardous locations, respectively. Paragraph 6-3 and NEC Article 500 (2008 Edition) should be referred to for the definition of various hazardous locations. The equipment manufacturer should be contacted for assistance with hazardous environment applications.

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 6-3 Indoor Nonhazardous Locations



Protection Provided For:		Type of Enclosure						
		NEMA 7 and 8				NEMA 9		
	Class	A	B	C	D	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

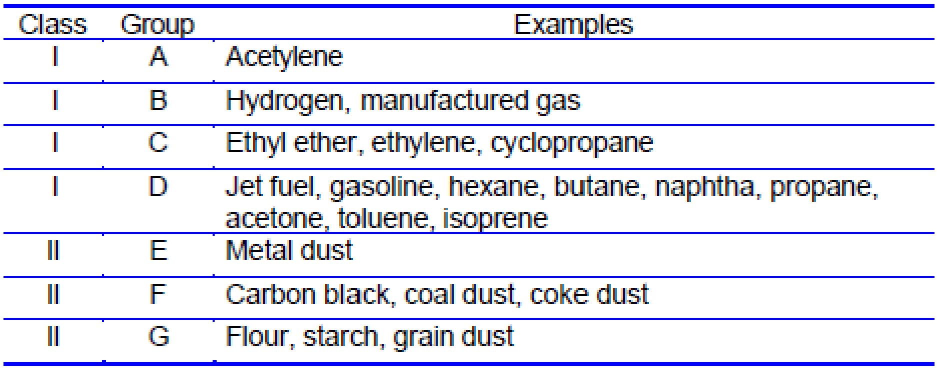
Note: Refer to NEC Article 500.4 (2002 Edition) for information regarding hazardous substances not listed in this table.

Table 6-4 Indoor Hazardous Applications

6.2.5. Evaluate the enclosure temperature rise should be evaluated to 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.

6.3. Hazardous Locations

6.3.1. NEC Article 500 (2008 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 6-5 lists the various hazardous location classifications; refer to NEC Article 500 (2008 Edition) for the definition of each location.



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

Table 6-5 Hazardous Location Classifications

6.3.2. 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.

6.3.3. In accordance with NEC Article 500.5 (2008 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.

6.3.4. In accordance with NEC Article 500.5 (2008 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.

6.3.5. Each location should be evaluated for a possible classification as a hazardous area. All hazardous areas must comply with the design criteria specified in NEC Articles 500 and 501 (2008 Edition). NEC Article 504 (2008 Edition) should be referred to for the design criteria for intrinsically safe systems.

6.3.6. The Zone classification system described in NEC Article 505 (2008 Edition) can be applied as an alternative to the Class and Division designations.

6.3.7. NEC Article 511 (2008 Edition) should be referred to for design criteria for commercial-type garages in which service or repair operations are performed on all or all types of self-propelled vehicles.

6.3.8. NEC Article 514 (2008 Edition) should be referred to 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.

6.3.9. NEC Article 515 (2008 Edition) should be refereed to 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.

6.3.10. Wherever possible, electrical distribution or utilization equipment should not be located in areas or zones classified as hazardous.

6.4. 400-Hertz Distribution Systems

6.4.1. 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.

6.4.2. 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.

6.5. Metering.

6.5.1. If revenue-metering is required; it should be installed ahead of the main disconnecting device at the service entrance.

6.5.2. Watthour meters conforming to ANSI C12.1, Code for Electricity Metering should be used. In general, electronic meters are preferred.

6.5.3. If electromechanical meters are used, ANSI C12.10, Electromechanical Watthour Meters, should be applied, except that the numbered terminal wiring sequence and case size can be the manufacturer’s standard. Watthour meters can be the draw-out 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.

6.5.4. Where required, submetering provisions for energy-consuming mechanical and electrical systems such as lighting, large motor, or HVAC systems should be provided.

6.5.5. Meters should not be used as the principal method of service disconnection. Paragraph 3-1 provides the disconnect requirements for service connections.

6.6. Power Factor Correction.

6.6.1. Power factor correction is not routinely applied to interior electrical systems.

6.6.2. Capacitors are normally used to improve power factor. Although power factor correction capacitors are not usually applied to interior electrical systems, their use is discussed here for completeness. Figure 6-4 shows a typical configuration in which a shunt capacitor is added to improve the power factor.

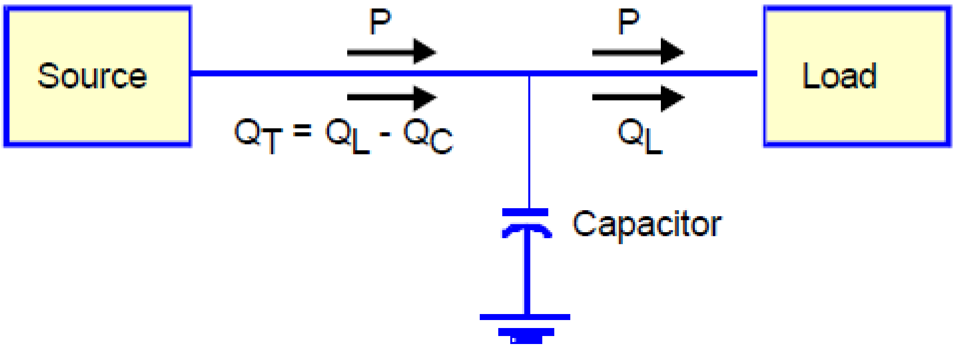


Figure 6-4. Capacitor Installation for Power Factor Correction

6.6.3. 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.

6.6.4. 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.

6.6.5. 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. Refer to PDH Course E 319 “Electrical Calculation Methods and Examples” for further details.

7. GROUNDING, BONDING, AND LIGHTNING PROTECTION

6.7. Introduction

6.7.1. 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.

6.7.2. The electric interconnection of conductive parts to maintain a common electric potential is referred to as bonding.

6.7.3. In the context of this course, lightning protection consists of the facility design features intended to withstand direct lightning strikes and then channel the lightning surge to ground.

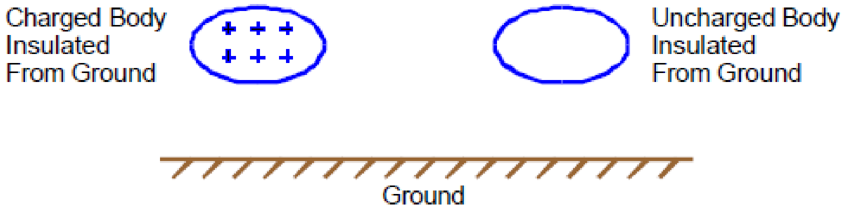
6.7.4. The term surge refers to a voltage or current transient wave, typically lasting less than a few milliseconds. Protection against surges is referred to as surge protection. PDH Course E288 “Surge Protection Systems Performance and Evaluations” provides surge protection design criteria.

6.8. NEC Grounding and Bonding Requirements.

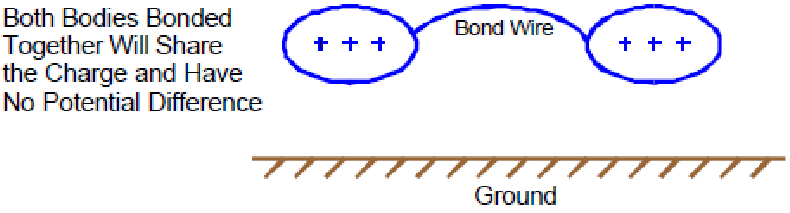
6.8.1. Electrical systems and circuit conductors are grounded to limit voltages during lightning and to facilitate overcurrent device operation in case of a ground fault. NEC Article 250 (2008 Edition) allows the system neutral to be grounded and limits the location of this neutral to earth connection to the source side of the service entrance disconnect or at a separately derived system.

6.9. Static Protection.

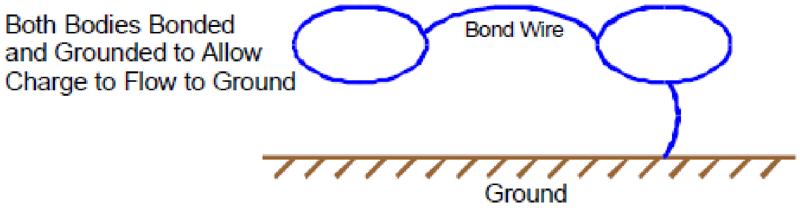
6.9.1. A static ground is a connection between a piece of equipment and earth to drain off static electricity charges before they reach a sparking potential. Figure 7-1 shows an example of static protection. Typically, static grounding involves connecting large metal objects such as fuel tanks or an aircraft to earth through a ground rod. Static grounds are not part of an electrical power system, but usually if an equipment grounding conductor is adequate for power circuits, it is also adequate for static grounding.



A. Charged and uncharged bodies insulated from ground



B. Both insulated bodies share the same charge



C. Both bodies are grounded and have no charge

Figure 10-1. Purpose of Static Grounding

6.10. Communications Systems Grounding And Bonding.

6.10.1. Introduction.

6.10.1.1. Most discussion of grounding relates to compliance with the NEC. The NEC' purpose is to establish safety requirements related to grounding. Communication 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.

6.10.1.2. 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.

6.10.1.3. Communications system grounding and bonding is intended to accomplish its purpose by the following methods:

- 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.
- 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.
- 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.

6.11. Connection to the Grounding Electrode.

6.11.1. 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 800.93 (2008 Edition) establishes the grounding requirements.

6.11.2. Separate grounding electrodes are not normally necessary for the communications systems. NEC Article 800.93 (2008 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.

6.12. Commercial Building Grounding and Bonding Requirements for Telecommunications.

6.12.1. 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.

6.12.2. ANSI/TIA/EIA-607 should be applied 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.

6.12.3. ANSI/TIA/EIA-607 should be considered in conjunction with 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, an analysis should be performed to determine the cost of the application of ANSI/TIA/EIA-607. Upgrades are permitted where the cost-benefit is considered acceptable.

6.12.4. The following summarizes the principal ANSI/TIA/EIA-607 design criteria:

- A permanent telecommunications grounding and bonding system should be installed independent of the telecommunications cabling. Approved components should be used and bonding connections should be installed in accessible locations.
- A telecommunications bonding backbone (TBB) should be installed 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. Each TBB and TGB should be visibly labeled.

- Each telecommunications main grounding busbar (TMGB) should be bonded to the electrical service ground. All TBBs should terminate at this busbar. Generally, each TBB should be a continuous conductor from the TMGB to the farthest TGB. Intermediate TGBs should be spliced to the TBB with a short bonding conductor.
- Each TGB should be bonded to building structural steel or other permanent metallic systems, if close and accessible.
- A communications surge protector should be installed 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.

6.12.5. Building Industry Consulting Service International (BICSI) Telecommunications Distribution Methods Manual, Chapter 20, Grounding, Bonding, and Electrical Protection, should be referred to for background information on the subject of communications bonding and grounding.

6.13. Lightning Protection.

6.13.1. In the context of this course, lightning protection consists of the facility design features intended to withstand direct lightning strikes and then channel the lightning surge to ground.

6.13.2. NFPA 780, Standard for the Installation of Lightning Protection Systems, contains the criteria for lightning protection systems.

6.13.3. 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 PDH Course E288 “Surge Protection Systems Performance and Evaluations” for further guidance.

6.14. Information Sources.

6.14.1. The following references provide additional information on the subject of grounding.

- 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.
- NFPA 77—provides NFPA requirements related to static grounding and bonding requirements.
- NFPA 780—provides NFPA requirements for lightning protection systems. This is the industry standard for lightning protection.
- 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.
- 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.
- 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.
- 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.
- BICSI Telecommunications Distribution Methods Manual—explains in detail the ANSI/TIA/EIA-607 grounding requirements.

7. AUXILIARY AND SUPPORT SYSTEMS

7.1. Fire Alarm and Detection Systems.

7.1.1. Fire alarm and detection systems should be provided in accordance with NFPA 72, Fire Alarm Systems.

7.1.2. Auxiliary power support for such systems should be provided in accordance with NFPA 72, 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), this system should be designed 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. The capacity of the selected auxiliary power source should be designed to include the fire alarm and detection system load.

7.2. Television Systems (TV).

7.2.1. 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.

7.2.2. Antennas should be installed 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. Roof penetrations should be coordinated with the architectural plans.

7.2.3. Lightning protection for antenna installations should be provided in accordance with NEC Article 810 (2008 Edition) and NFPA 780.

7.2.4. Exterior mounted antennas and supports should be located as unobtrusively as possible for minimum aesthetic impact.

7.3. Clock Systems.

7.3.1. 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.