AUDEL™

GUIDE TO THE 2011 NATIONAL ELECTRICAL CODE

PAUL ROSENBERG

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All New Edition

Paul Rosenberg

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FOREWORD

I think that almost everyone who has been required to use the *National Electrical Code (NEC)** on a regular basis has often wished that it were easier to understand. Often, it seems that it lacks sufficient clarity and detail; other times, it seems to be overflowing with useless information. The purpose of this book is to help the reader sort through the voluminous code regulations and find the information he or she needs, with a minimum of effort. Perhaps it would help to understand where this code book comes from.

The *National Electrical Code* is one of many codes and standards published by the National Fire Protection Association (NFPA), a not-for-profit corporation. The code is revised every three years in order to keep up with new materials, tools, and methods that are constantly being developed. This work is performed by 21 separate committees, each consisting of approximately 10 to 15 persons, the majority of them engineers, and each of them sponsored by some organization, including manufacturers, industry organizations, and unions. Members of each committee meet several times, discuss all proposed changes, accepting some and rejecting others, and rewrite (as required) the sections of the *Code* that were assigned to their committee. Then, they circulate the changes among the various committees, coordinate the changes, and rewrite again. So, obviously, the updating of the *NEC* is no small chore. But the real difficulty is that it must remain applicable to all types of electrical installations, leaving no gaps. Because of this, it becomes rather difficult to interpret in many instances.

The purpose of this book is to arrange all of the pertinent requirements of the *NEC* in a manner that is user-friendly, allowing the reader to find the needed information painlessly and quickly. The challenge with the *NEC* is that many communities use it as law, and as such, it must be written accordingly. Every possible facet of every type of electrical installation must be covered. Because of this, the *NEC* is full of engineering requirements, installation requirements, and manufacturing requirements—all in engineering lingo and legalese. It's not hard to see why it is such a difficult document to comprehend. In order to make the *NEC* more easily understood and applicable, a number of guides have been written, most of which have a legitimate place. These guides serve to make all parts of the *NEC* understandable. They are written for engineers, designers, installers, and inspectors.

The book you now hold in your hands is substantially different from standard *NEC* guidebooks. Rather than covering everything in the *NEC*, we concentrated only on the requirements for electrical installations. By omitting the engineering and manufacturing requirements, much of the confusion of the *NEC* is eliminated

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in one stroke. This leaves only the rules that actually apply to installing electrical wiring—which is the reason the *Code* is referred to 99 percent of the time.

This book is designed exclusively for the installer of electrical wiring, and is the result of many years of supervising and instructing electricians in the requirements of the *NEC*. Every effort has been made to make this book as easy to use as possible, both for the professional electrician and for the homeowner who wishes to do his or her own electrical work safely and efficiently, avoiding hassles with the local electrical inspector.

For actually installing electrical wiring, this book should be more useful than the standard *NEC* handbooks. For engineering questions, however, the *National Electrical Code* should be consulted.

Throughout this book, you will see substantive changes for the 2011 *NEC* highlighted. Bear in mind that these changes will have the force of law once the 2011 *Code* is adopted in your jurisdiction.

As you go through both this book and the *Code*, you will find numerous references to other codes and standards. These various codes and standards are useful but must always be used in conjunction with the *NEC*, not separate from it. It is critical to remember that codes are generally adopted as law by local municipalities, while standards are not. So codes contain mandatory requirements and standards contain suggested methods.

Finally, please remember that good workmanship and safety consciousness are essential ingredients for any good electrical installation. Like fire, electricity can be the best of friends or the worst of foes. Without careful workmanship and an overriding concern for the safety of the installation and the installer, no electrical installation is worthwhile.

My sincere thanks go to all of the fine people I've worked with down through the years—I have had the good fortune of working with some of the finest people in the industry.

Paul Rosenberg

INTRODUCTION

The *National Electrical Code* is written as a minimum standard for electrical installation for the protection of life and property. It does not necessarily define the best installation methods, merely the minimum safety standards. Many purchasers of electrical installations will want to surpass the code.

When reading and interpreting the *NEC*, there are certain words that you must pay attention to. These key words are:

Shall. Any time you see the word *shall* in the *NEC*, it means that you must do something a certain way. You have no choice at all; either you do it that specific way, or you are in violation of the code.

May. The word *may* gives you an option. You can do it the certain way that is stated, or you can do it another way; it is your choice.

Grounded Conductor. This is almost always the neutral conductor, although not necessarily. Take care not to let the word *grounded* confuse you; *grounded conductor* does not refer to a green wire.

Grounding Conductor. This is the green wire, more correctly called the *equipment grounding conductor*, because it is used to connect equipment to ground.

You will find these ideas expressed in section 90.5 of the *NEC*, discussed below. They are defined as Mandatory Rules (shall), Permissive Rules (may), and Explanatory Material (Fine Print Notes). Special care must also be taken to differentiate between similar terms, such as *grounded conductor* (a neutral wire), and the *grounding conductor* (the green equipment grounding conductor). These terms are almost identical, and if you do not carefully examine each word, you could very easily make a wrong interpretation.

In addition to these terms, there are other, less common terms (*identification, listing, supervised,* etc.) that can also be confusing. Remember that the *NEC* cannot be read casually. In order to make correct interpretations, every word must be considered. This requires extra work and effort.

Before getting to the main body of the *NEC* (starting with Article 100), it is important to cover the section that precedes it: Article 90 explains what the *Code* is and what it applies to.

Article 90—INTRODUCTION

This Article lays the groundwork for the writing and application of the *National Electrical Code*. It begins by stating the purpose of the document, “the practical safeguarding of persons and property from hazards arising from the use of electricity," and goes on to explain that the *NEC* is written to provide safe installations, though not necessarily efficient ones.

Section 90.2 is especially important, as it identifies what sorts of installations are, or are not, covered by the *NEC*. Note that almost all wiring owned by utilities or mines and in boats, aircraft, and automobiles is excluded.

90.1: Purpose

(1) Electricity can be dangerous if not used properly. The *Code* is written to provide a set of rules for the safe installation of electrical wiring.

(2) This *Code's* provisions are those essential for safety, and compliance with these rules may not always result in the most efficient, convenient, or least expensive installations; neither does it necessarily provide for the future expansion of electrical usage. It is, however, essentially free from hazards that may be encountered. Nonconformity to the rules of the *NEC* may result in hazards or overloading of wiring systems. Most of these problems result from not taking into consideration the increasing usages of electricity. If future needs are taken into consideration at the time of the original installation and adequate measures are taken to provide for the increased usage of electricity, these hazards and overloading may be greatly eliminated.

(3) In no manner is this *Code* intended to be used for design specifications or as an instruction manual for untrained persons. The rules of this *Code* will, however, add materially to proper design. It is also adopted as the regulations governing wiring installations by most government agencies. There may be additional requirements by the local agencies, and these should be checked out.

90.2: Scope

(A) Covered. This *Code* covers:

(1) Electric conductors and equipment installed in or on: public or private buildings or other structures, mobile homes and recreational vehicles, floating buildings, and other premises, such as yards, carnivals, parking and other lots, and industrial substations.

Additional information concerning installations in multibuilding complexes or industrial buildings is found in the National Electrical Safety Code, IEEE C2-2007.

(2) The installation of conductors on the exterior of a premises is covered.

(3) The installation of conductors outside of a premises is covered.

(4) The installation of optical fiber cables and raceways. The inclusion of optical fiber cables in the *NEC* is odd, since these cables carry no electricity at all. They are included in the *National Electrical Code* for two primary reasons: (1) because they are usually installed by the same persons who install electrical wiring and (2) because optical fiber systems interact with, and depend upon, electrical and electronic systems.

The code's reference to *optical raceway* refers to special raceways whose use is dedicated to the optical cables they house. These are special inner ducts and possibly tubes associated with air-blown fiber. This is not defined clearly in the code, so check with your local inspector if you have any questions. Also, see 770.6 for details.

(5) Wiring in of offices, warehouses, or other buildings owned by electric utilities but not part a generating facility, substation, or control facility.

(B) Not Covered. This *Code* does not cover:

(1) Ships, watercraft, trains, aircraft, automobiles, or trucks, although mobile homes and recreational vehicles are covered.

(2) Installation of conductors is not covered in the *NEC* for underground mines. This does not exempt the above-ground installation of wiring, although self-propelled surface mining machinery and its trailing cables are excluded.

(3) Railroad generation, transformation, and transmission or distribution, if used only for signaling devices, and railroad trains are not covered in the *NEC*.

(4) Communication equipment located outdoors or indoors, if used exclusively by utilities, is not covered in the *NEC*.

(5) Electric utility wiring exclusively under the utility company's control, used for communication, metering, generation, transformation, and distribution of electricity, whether indoors or outdoors on property owned or leased by the utility, whether out of doors by established rights on private property and public highways, streets, or roads, are not covered by the *NEC*.

(6) Any metering, wiring, buildings, or structures on any premises that is not owned or leased by the utility company is covered by the *NEC*. The *NEC* does cover all wiring other than utility metering equipment ahead of service equipment through building structures or any other place not owned or leased by the utility.

(C) Special Permission. Conditions and usages vary in different localities; therefore, the authority having jurisdiction for the enforcement of the *Code* must be able to grant exemptions for the installation of the wiring system equipment not under the control of the utilities. This occurs whenever utilities are connecting service-entrance conductors of the building or structure that they are serving. If such installations are outside the building or terminate just inside the building, special permission should be granted in writing.

There has been an abundance of work done by utilities, and often the work becomes a part of the *Code*. Should the installation of service laterals, for example, be deemed good engineering practice by utilities and acceptable by the enforcing authority, this practice may, by special permission, be permitted under the *Code*. This special permission does not eliminate the Special Permission under Article 100; it applies only to Section 90.2.

90.3: *Code* Arrangement

The *Code* is divided into an introduction and nine chapters. Chapters 1 through 4 deal with general applications of the *Code* to wiring and installations. Chapters 5, 6, and 7 supplement or amend the first four chapters, and deal with special occupancies and installations that involve special equipment or special conditions. Chapter 8 deals with communication circuits, and with the equipment and installation of radio and television. Chapter 9 deals with tables not included in, but to be used in conjunction with, the first eight chapters. Also included are examples for figuring requirements for installation. These examples are extremely valuable in the understanding of the preceding chapters.

Familiarity with the various *Code* chapters makes it easy to find what you want in the *Code*. Chapters 4 through 9 are special chapters and refer back to the first three chapters.

90.4: Enforcement

The *NEC* is written so that it can be enforced when adopted by agencies having the rights of inspection. The *Code's* enforcement and interpretation is placed in the hands of the enforcing agency or authority. These authorities are the ones who make the final decisions, hopefully using the good judgment that is essential in such interpretations. In many instances, the *Code* puts the entire responsibility of interpretation on the enforcing authority. For example, you will often find the phrase *by special permission*; this means special permission, in writing, by the *Code*-enforcing authority.

The enforcing authority is vested with the right to decide on the approval of equipment and materials. However, listings from the Underwriters' Laboratory (UL), the Canadian Standards Association (CSA), or other independent testing laboratories are used for this purpose in many instances. One of the deterrents to *Code* understanding can be lack of communication between the inspector and the installer. Actually, the inspector is the installer's friend, and all the inspector wants is a good safe job. The best advice to offer in this respect is to get acquainted with your inspector; he or she will be understanding and helpful in most cases.

Many industries have established procedures for installation and maintenance that are very effective and in many cases far more safety oriented than the *Code* installations. This gives the enforcing authority the latitude to okay such installations.

90.5: Mandatory Rules, Permissive Rules, and Explanatory Material

The *Code* includes both mandatory and advisory rules. The mandatory rules are characterized by the word *shall.* This means that the rules must be strictly followed. Any time you see the word *shall* in the *NEC*, it means that you must do something in a certain way. You have no choice at all; either you do it that specific way, or you are in violation of the *Code*. Permissive rules are characterized by the word *may.* The word *may* gives you an option. You can do it the specific way that is stated, or you can do it another way; it is your choice.

Explanatory material in the *NEC* is placed in Informational Notes. These notes are important for you to read, but they are not enforceable.

90.6: Formal Interpretations

An *NEC* committee is set up to render official *Code* interpretations when these are necessary. In the majority of questions arising on the *Code*, the interpretations are under the inspector's jurisdiction, as will be seen in the next section. However, there may be instances when official interpretations are required. No official interpretations will be made unless the Formal Interpretation Procedures outlined in the *Code* are followed.

90.7: Examination of Equipment for Safety

Most equipment and materials have been tested by electrical testing laboratories such as UL, and carry their label. However, the rates that UL charge equipment makers can be prohibitively high. (They are somewhat of a monopoly.) To work around this problem, some municipalities have experimented with allowing consulting engineers to certify the equipment as being safe. If UL rates remain as high as they are now (or possibly go even higher), this method may become far more common. Extreme care must be taken by any inspection authority or testing service in judging the safety of any equipment, device, or material. Care must also be taken to assure that the equipment, device, and so on, will be used only in the way intended. Section 110.3 and Article 100 cover examination of equipment and the meaning of *listed.*

90.8: Wiring Planning

This section is unusual in that it mentions planning for future expansion, but does not require anything specific. It has long been good trade practice to oversize electrical components. However, this is not required by the *NEC*. Oversizing is a design issue, not an installation issue. Nonetheless, responsible installers should oversize the electrical equipment they are responsible for providing, if at all possible. Conduits should not be filled to capacity, and distribution equipment should have plenty of empty space.

In the design of electrical systems by installers, contractors, or electrical engineers, ample provision should be made in the raceways for adequate wiring, as well as distribution and load centers, which should be laid out in practical locations, keeping in mind their accessibility. The number of wires in enclosures and boxes should adhere to *Code* requirements in order to avoid fires and breakdowns and the inconveniences that accompany such troubles.

In reaching the goal of good wiring and installation, there is one requirement—good workmanship. Insulation damage, too many wires, and overfusing are points that must be carefully watched. Regardless of how good the design of the installation, cutting corners will defeat the intended product.

(A) Future Expansion and Convenience. Since the invention of the electric light, the amounts of electricity used in both home and industry have continually increased. Therefore, in designing wiring systems consideration should be given to large enough raceways and, in some cases, spare raceways to accommodate the changes—future uses of electricity or expansion of operations—that are certain to come. During the design phase, it would be a good idea to review Sections 110.16 and 240.24, which describe the necessary clearance distances and accessibility for future additions.

(B) Number of Circuits in Enclosure. You will find later in the *NEC* that there is a maximum number of conductors and circuits that you can put in a single enclosure such as raceways, boxes, and so on. These limitations for single raceways and boxes will reduce problems with short circuits and ground faults in a circuit.

Severe damage could be done to conductor insulation by pulling too many conductors into raceways, or by pulling around too many bends. There are even times, when pulling large sizes of conductors, that the 360 degrees in total bends between pull boxes and the like could be too many. Since the *Code* is not intended to be a design manual, it is up to the designer and the inspection authority to watch for these things. The *Code* has taken into account (derated), as you will find in Article 310, certain numbers of current-carrying conductors in raceways to avoid overheating of conductors and raceways.

90.9: Units of Measurement

Metric units, together with our own units of measurement, are used in the *NEC*. In the 2011 edition, metric units are set in standard text, and English units are contained in parentheses. Horsepower, wire sizes, box sizes, and conduit sizes are generally set primarily in English units.

1

GENERAL

Article 100—DEFINITIONS

The *National Electrical Code (NEC)* contains a great number of definitions, which are very important for interpreting the *Code*. If you have any doubt as to the exact meaning of a general term, refer to Article 100 and verify that meaning. You will also find that the definitions in this section are arranged in two categories—"General" and "Over 600 Volts."

But if you need the definition of a more specific term, you may have to find it in the article where it would be dealt with most directly. As you continue through the *Code*, you will find additional definitions scattered throughout other articles. These definitions are usually specific to that article and are therefore included with that article and not in Article 100.

The following figures are useful in understanding the definitions. For a branch circuit, see Figure 100-1. For a multiwire branch circuit, see Figure 100-2. For an illustration of service drop, see Figure 100-3. Service-lateral and service-entrance equipment are illustrated in Figures 100-4 and 100-5, respectively.

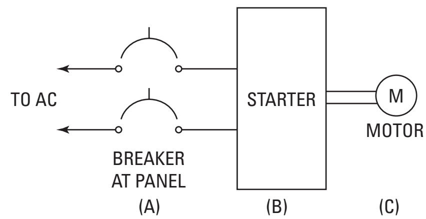

FIGURE 100-1 A motor circuit. The branch circuit extends from point A to point C.

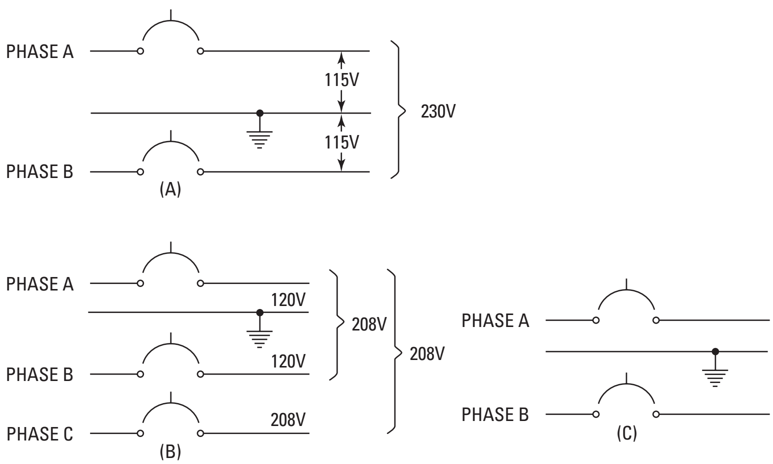

FIGURE 100-2 Variations of a multiwire branch circuit. Circuit C is not a multiwire branch circuit because it utilizes two wires from the same phase in conjunction with the neutral conductor.

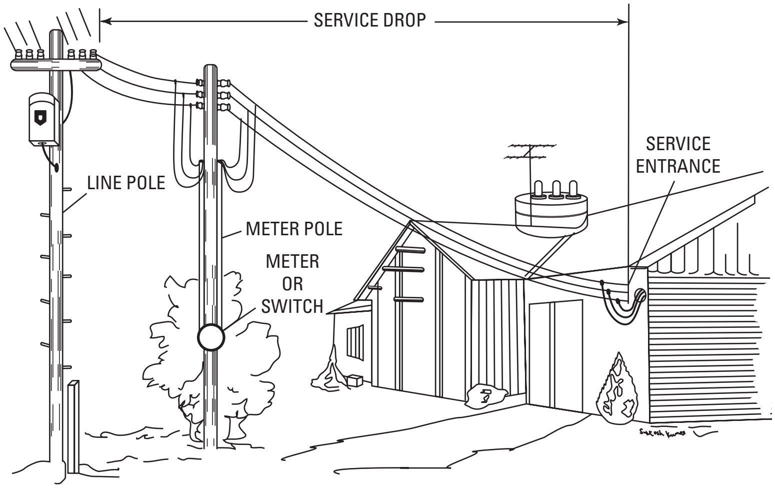

FIGURE 100-3 Illustrating the service drop attached to a building or other structure.

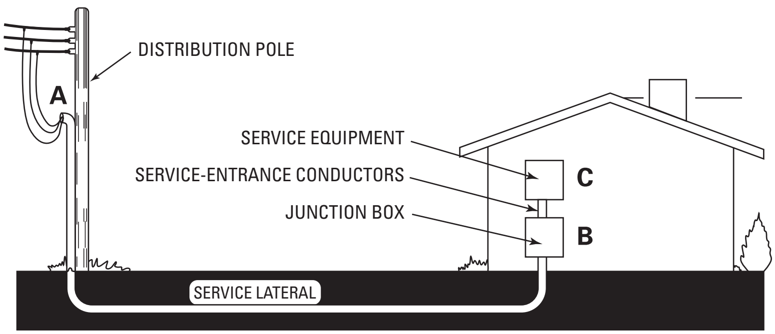

FIGURE 100-4 Illustrating the service lateral extending from point A to point B. The service entrance is from point B to point C.

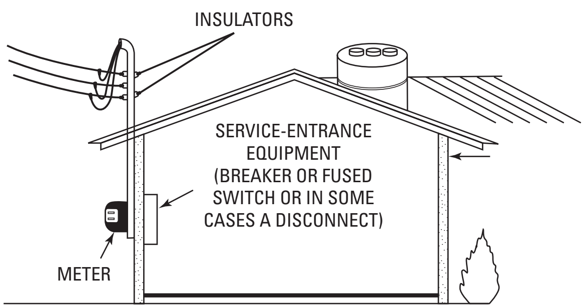

FIGURE 100-5 Showing the service-entrance equipment that will serve as the electrical disconnect.

Article 110—REQUIREMENTS FOR ELECTRICAL INSTALLATIONS

Article 110 is bypassed in the study of the *Code* more often than any other article. It is short, but it is actually the foundation upon which the *Code* is written, as it contains provisions that are used throughout the entire *Code*.

I. General

110.2: Approval

See definition of *approved* under Article 100.

110.3: Examination, Identification, Installation, and Use of Equipment

(A) Examination. Observe the following considerations for the evaluation of equipment:

- **(1)** Wiring devices and equipment that are suitable for use must be provided with identification of the product and of the use intended, including special conditions. The identification, in most cases, is by labeling on the equipment.

  If the preceding information is not available, it becomes the responsibility of the authority having jurisdiction to decide the suitability of the equipment.
- **(2)** The wiring material and equipment must have their parts properly designed so that the enclosure will protect other equipment.
- **(3)** Adequate splice-wire bending is required. The exact measurements are found in Tables 312.6(A) and (B) of the *NEC*.
- **(4)** Electrical insulation may be checked.
- **(5)** Heating effects must be taken into consideration on conductors. In Article 310, there are tables for reducing the ampacity of a conductor as ambient temperatures rise. The author finds that few are familiar with high-altitude rating of motors, which starts at 3500 feet above sea level. In higher altitudes, the air is thinner and therefore has less cooling effect on the motor. For instance, a 5-horsepower motor at a high altitude can't be expected to carry as much load as the same 5-horsepower motor at sea level.
- **(6)** The equipment must be designed for minimal arcing.
- **(7)** The use of voltages and currents must be taken into consideration.
- **(8)** Other factors that affect safety to persons that will have occasion to come in contact with this equipment must be considered.

(B) Installation and Use. Labeling or listing will be effective only if the precautions noted on the installation and use instructions included with the labeling or listing service are followed. Alteration of equipment in the field voids any labeling or listing.

110.4: Voltages

The voltages referred to in the *Code* are the supply voltages, regardless of their source. The supply may be a battery, generator, transformer, rectifier, or a thermopile. When considering AC voltages, the voltage is the root mean square (RMS) voltage as explained in Article 100. There are really three general classifications of voltages in the *Code*—0 to 50 volts, 50 to 600 volts, and voltages that exceed 600 volts. Each is dealt with in separate parts of the *Code*. If wires having different voltages are run in the same raceway, there are specific rules to be followed. See Section 300.3(C).

No electrical equipment may be connected to a circuit that has a voltage higher than the equipment's rating.

110.5: Conductors

Unless the material of which the conductor is made is specifically identified, it is assumed to be copper. Any other material of which a conductor may be made, such as aluminum, shall be identified as such.

Copper and aluminum conductors have different ampacities and are covered in Article 310. Copper-clad aluminum conductors have the same ampacity as aluminum conductors.

110.6: Conductor Sizes

In dealing with wire sizes, the *Code* always refers to the American Wire Gage (AWG). At one time, this was known as the B&S (Brown and Sharpe) Gage. Sizes of conductors larger than 4/0 are measured in circular mils. (A mil is one thousandth of an inch: 0.001 inch.)

The common circular mils measurement abbreviation is *kcmil*, meaning "thousand circular mils." In old editions of the *NEC*, this was specified as *MCM*, which carried the same meaning: "thousand circular mils."

110.7: Insulation Integrity

All wiring shall be installed free of shorts and grounds. This does not cover purposefully grounded conductors, as are covered in Article 250.

Shorts or grounds may be located before energizing circuits by the use of a megohm-type tester (available from several manufacturers).

Conductors of the same circuit and in the same raceway must be insulated with the same type of material. Therefore, insulation-resistance tests on each conductor should produce similar values. Here is an example of the importance of this rule: Six 500-kcmil thermoplastic high-heat-resistant nylon-coated (THHN) conductors in the same conduit read approximately 1500 megohms on four conductors, and in the vicinity of 300 megohms on the other two conductors. While 300 megohms would have been a good value, the difference in the readings indicated problems. The low-reading cables were pulled out, and it was found that the insulation had been cut in many places. With time and condensation moisture, a fault would have occurred.

110.8: Wiring Method

Only recognized and suitable wiring methods are included in the *Code*. Basically, Chapter 3 covers approved wiring methods; Chapters 5 through 8 cover specific conditions and occupancies.

110.9: Interrupting Rating

Interrupting capacity is far different from the rating of the amperes that are required by a load. We are faced with what is known as *fault currents.* A fault current is the amount of current that might develop under a dead-short condition. This level of current is dependent on the utility system supplying the current, the impedance of the system, and any fuses that may be up-line. At one time, this was not much of a problem, but with increased electrical usage and larger generating and distribution capacities, the problem of fault currents has increased. This is taken more into consideration now than in the past, and may become an increasingly important factor. If a piece of equipment is rated at *X* number of amperes, this does not necessarily mean that it can be disconnected under load or a fault condition without damage. Equipment is rated in carrying capacity as well as interrupting capacity. Sections 110.9 and 110.10 together require that all equipment be coordinated and protected from fault currents, not just from overcurrents. This requires the installer to get the cooperation of the utility company to verify available fault currents at the point of service.

110.10: Circuit Impedance, Short Circuit Ratings, and Other Characteristics

The fault currents are limited only by the capacity of the electrical supply, the impedance of the supplying circuits, and the wiring. For example, the fault current will be much larger in circuits supplied from a large-capacity transformer supplying a heavily loaded city block than the fault current from a transformer serving a 5-horsepower irrigation pump in a rural area. The impedance of the supply to the 5-horsepower motor will be high in comparison to the impedance of the supply to the city block.

It is necessary to understand all coordinate fault currents, circuit impedances, and component short-circuit withstanding ratings. Fuse and circuit breaker manufacturers produce literature on fault currents and impedances, making it simple to check whether their equipment will withstand available fault currents.

It is also necessary to consider equipment that is connected to these circuits. In many cases, a wiring fault could spread its damage to these devices. This must be prevented. It is also important to understand that the requirements of the *Code*, especially in this section, will provide for a minimum level of safety; they don't guarantee that the equipment will not be damaged. Even with appropriately sized fault protection, damage to the equipment is possible, albeit without causing damage to other equipment or persons.

110.11: Deteriorating Agent

Environmental factors, such as wetness, dampness, fumes, vapors, gases, liquids, temperatures, and any other deteriorating effects, must also be noted; conductors and equipment used must be approved for the specific conditions of operation. The inspection authority is often faced with the responsibility of deciding in which category the installation belongs; it most certainly is beyond the scope of the *Code* to define and specify for every possible condition that will have to be met. The *NFPA National Fire Codes* will be of great value in this respect.

Protection shall be given to equipment, such as control equipment, utilization equipment, and busways, during construction if this equipment is approved for dry locations only. It shouldn't be permanently damaged by weather during the building construction. Section 300.6 further discusses protection from corrosion.

110.12: Mechanical Execution of Work

Electrical installers are required to install all electrical systems in a neat and workmanlike manner. Thus, the *Code* specifies that not just materials are important, but that workmanship is also extremely important.

This "neat and workmanlike manner" rule is actually one of the broadest in the *Code*. It can be applied to conduit bending, the trimming of panels, or to almost any aspect of an installation of electrical wiring. This gives the authorities having jurisdiction some discretion; they can invoke rulings based on workmanship, which can be interpreted many ways. In actual practice, this rule can be applied either well or poorly, but is probably necessary. As expansive as the *Code* document is, human action is far more expansive, and no rule book is able to address every possibility. This rule gives an inspector some latitude. The author has never seen it used in an overtly malicious fashion, though that does remain a possibility.

(A) Unused Openings. All openings in boxes, equipment, or enclosures of any kind must be effectively closed and must provide protection equal to that of the equipment or enclosure itself.

(B) Subsurface Enclosures. Conductors in underground enclosures (such as manholes) must be racked. This is necessary to provide for safe and easy access.

(C) Integrity of Electrical Equipment and Connections. All parts of electrical equipment must be kept free of paint, plaster, cleaners, and any other type of foreign material. This has long been a problem on construction sites, where plaster and paint end up in electrical panels and other items. All such contamination must be avoided.

110.13: Mounting and Cooling of Equipment

(A) Mounting. Mounting of equipment is an item directly related to workmanship. Wooden plugs driven into holes in masonry, plaster, concrete, and so on, will shrink and rot, thereby allowing the equipment to become loose. Thus, only approved methods of mounting and special anchoring devices may be used.

(B) Cooling. Electricity produces heat. Electrical equipment must be installed in such a way that circulation of air and convection methods of cooling are not hindered. Mounting equipment too close to walls, ceilings, floors, or other items will interfere with the electric equipment's designed means of cooling. Ventilation openings in the electric equipment must be kept free to permit natural circulation.

One should also watch the amount of total space in the room where the equipment is mounted. If it is inadequate to permit a low enough ambient temperature, means must be taken to permit the lowering of high ambient temperatures by natural or other means.

110.14: Electrical Connections

Because values of electrolysis (chemical decomposition caused by an electrical current) vary among metals, and because we are using copper or aluminum conductors, copper, being the more noble on the electrolysis series, will corrode the aluminum away. Therefore, you must be sure when making splices of terminations that the lugs or connectors are listed for the purpose for which you are using them. When using solder fluxes or inhibitors, make sure they are listed for the job you are doing. Wherever values for tightening torques are given, they must be adhered to.

The author has found very little available information on torquing values. Therefore, it might be appropriate to insert some torquing values in this book. Many breakdowns and possible fires might result from not adhering to proper torquing values, so Tables 110-1 through 110-3 are presented as guidelines for tightening connections. It might also be mentioned that dies on compression tools do wear, and to avoid breakdowns, testing with a low-resistance ohmeter can prevent this problem.

You will find additional torquing pressures in mechanical engineering handbooks. Loose connections can be a hazard, causing breakdowns and possibly fires. If the authority having jurisdiction so wishes, it may require torquing tests during inspections.

(A) Terminals. Connections to terminals must ensure a good electrical and mechanical contact without injury to the conductors; connection must be by approved pressure connectors, solder lugs, or splices to flexible wires. The

Table 110-1 Tightening Torque in Pound-Feet Screw Fit

Wire Size, AWG	Driver	Bolt	Other
18–16	1.67	6.25	4.2
14–8	1.67	6.25	6.125
6–4	3.0	12.5	8.0
3–1	3.2	21.00	10.40
0–2/0	4.22	29	12.5
AWG 200 kcmil	—	37.5	17.0
250–300	—	50.0	21.0
400	—	62.5	21.0
500	—	62.5	25.0
600–750	—	75.0	25.0
800–1000	—	83.25	33.0
1250–2000	—	83.26	42.0

Table 110-2 Screws

Screw Size, Inches Across Hex Flats	Torque, Pound-Feet
1/8	4.2
5/32	8.3
3/16	15
7/32	23.25
1/4	42

Table 110-3 Bolts

Size	Duronze	Steel	Aluminum
	Standard, Unlubricated		
3/8	20	15	16
1/2	40	25	35
5/8	70	50	50
3/4	100	90	70
	Standard, Lubricated		
3/8	15	10	13
1/2	30	20	25
5/8	50	40	40

exception to the regulation is that No. 10 or smaller stranded conductors can be connected by means of clamps or screws with terminal plates having upturned lugs (Figure 110-1). Terminals for more than one conductor must be of the approved type for this purpose. When permitted to place a wire under a terminal screw, wrap it in such a direction that when you tighten the screw, the wire will not be squeezed out from under the head of the screw. On the smaller sizes of conductors, especially cord conductors, it is best to twist the conductor strands and apply some solder to them.

Compression-type connections are extremely good if the proper compression tool is used and it is in good shape. No. 10 or smaller conductors can be used for screws, studs, or nuts that have upturned lugs or equal design to keep the wire connection in place.

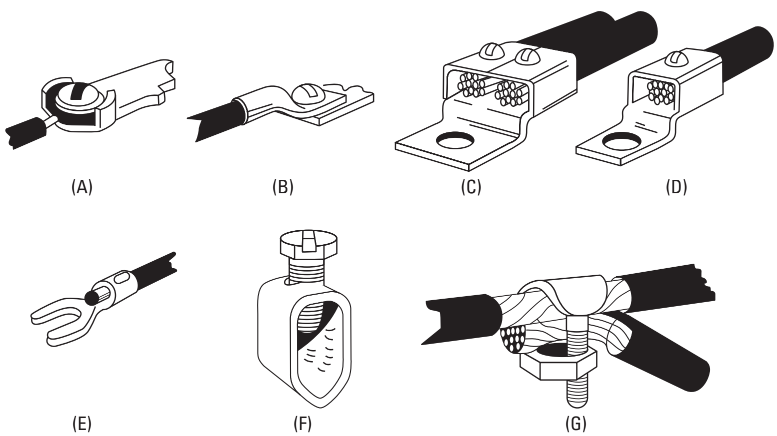

FIGURE 110-1 Various types of approved pressure connectors: (A) terminal plate; (B) soldered lug; (C) double pressure–type lug; (D) single pressure–type lug; (E) open-end crimp-type lug; (F) pressure-type connector; (G) split-bolt clamp.

Any terminal or lug intended for use with aluminum must be so marked.

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Terminals that are used for finely stranded wire must be identified for the purpose. You may encounter fine-stranded conductors in large sound systems, photovoltaic systems, or for dock wiring. Putting fine-stranded wire into a standard lug may result in overheating.

(B) Splices. Splices in wires are permissible in the proper places. When making a splice, the wires must be clean and a good electrical and mechanical connection must be made. The wires may then be soldered, provided a suitable solder and flux are used. The soldering temperature should be carefully controlled, because a cold solder joint is of no value; also, if the wires become too hot, the heat will damage the insulation. Remember that soldering is not permitted on conductors used for grounding. Approved connectors may also be used for splices, making sure the wires are clean and free from corrosion. After splicing, insulation at least equivalent to that on the wire must be applied to the splice. In general, this applies to all splices, but on high-voltage splicing, the specifications supplied with the high-voltage cables should be followed. When wire connectors are to be used on splices directly buried in the ground, they must be made with a type that is listed for that use.

This is extremely important. Many electrical connections fail because they are improperly made. Many troubles have been due to electrolysis between different metals, that is, the more noble metal depleting the less noble metal. Also, the oxidation of aluminum conductors (and this oxidation occurs practically instantly) creates a layer that has a very high resistance.

Another problem is the coefficient of expansion of different metals, creeping, and the difference in deformation of different metals. Be certain that you use connectors approved for use with this new product.

Inhibitors for use with aluminum are very important. Don't rely on the inhibitor alone, but thoroughly brush the aluminum conductor to remove the oxide film, and then immediately apply the inhibitor to prevent the recurrence of the oxide film.

(C) Temperature Limitations. The general principle of temperature limitations is that the operating temperatures of all circuit components (conductors, terminals, and equipment) must be coordinated so that no component is operated above its temperature rating. This section provides temperature limits for the termination of conductors. Terminations for circuits that are rated 100 amps or less and that use conductors from No. 14 through (and including) No. 1 are limited to 60°C. Conductors that have higher temperature ratings (such as the most common THHN conductors) can be used for these circuits, but the ampacity of such conductors must be determined by the "60°C" columns of Tables 310-16 through 310-19.

If the termination devices for the circuits mentioned above are listed for operation at higher temperatures, the conductors may also have their ampacity calculated at the higher temperatures.

Terminations for circuits that are rated over 100 amps, and that use conductors larger than No. 1, are limited to 75°C. Conductors that have higher temperature ratings (such as the most common THHN conductors) can be used for these circuits, but the ampacity of such conductors must be determined by the "75°C" columns of Tables 310-16 through 310-19.

Separately installed pressure connectors (such as a wire nut used between the termination points) must have temperature ratings equal to the temperature at which the conductor's ampacity was calculated. For example, if you are calculating the ampacity of a No. 8 conductor at 75°C, any splicing connector (such as a wire nut) that you use on those conductors must have a temperature rating of at least 75°C.

Design type B, C, D, or E motors are permitted to be terminated with conductors rated 75°C or higher, so long as the ampacity of the conductors will not heat them beyond 75°C. Remember in these situations that the supply source for the conductors must also be rated for the conductors.

110.15: High-Leg Marking

There are many four-wire, delta-connected systems, the fourth wire being the tap of one phase to ground. In Figure 110-2, you can see that two ungrounded conductors of the delta system will give 120 volts to ground, but notice that the third ungrounded conductor gives us a voltage of 208 volts to ground. In the field, this may be referred to as the wild leg, the high leg, or the stinger. This leg of the delta must have some kind of clear and permanent identification. The conductor can be orange in color, tagged, or permanently and effectively colored orange at any point where it could be used with the neutral. This identification shall be placed at any point where there might be connection made to the neutral or grounded conductor when it is present.

Figure 110-2 shows the voltage relationships on a grounded, four-wire wye system. On this system, 120 volts to neutral can be obtained from any ungrounded conductor and neutral.

110.16: Flash Protection

Signs or markings must be field-installed in nonresidential panelboards, switchboards, control centers, and so on, warning of possible arc-flash hazards.

110.18: Arcing Parts

Making and breaking of contacts usually causes sparking or arcing. Also, the white-hot filament of a lightbulb broken while in operation takes a little time to cool. Any parts that normally cause arcing or sparking are to be enclosed unless they are isolated or separated from combustible material. Lightbulbs are mentioned, but additional information is given in the articles covering hazardous areas, along with the specific requirements for switches, outlets, and other devices in hazardous locations.

Hazardous areas are covered in Sections 500 through 517.

110.19: Light and Power from Railway Conductors

It is not permissible to connect any circuits for light or power to any trolley wires that use a ground return signal.

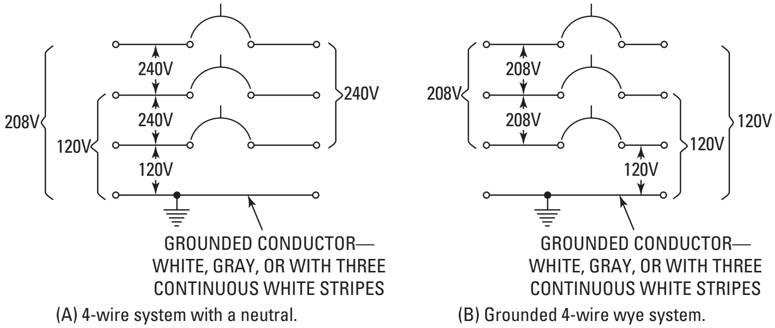

FIGURE 110-2 Voltage relationship on grounded four-wire systems.

The exceptions to this include car houses or any other freight station, and so on, that operate with electric railways.

110.21: Marking

All electrical equipment must be marked, showing the manufacturer's name and the electrical characteristics.

110.22: Identification of Disconnecting Means

It is essential that disconnecting means for appliances, motors, feeders, and branch circuits be properly identified as to what the disconnect serves. If overcurrent devices that have a series combination rating are used, they must be clearly marked to that effect. Such markings must be legible and durable. Panels usually have a card with the circuit numbers marked, which should be filled out in its entirety as a permanent record. This is one of the most frequent violations of the *Code*.

110.24: Available Fault Current

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Available fault current is the amount of current that would be available at a given location in the event of a dead short circuit. For example, at a 200-amp service drop, the utility line feeding the service may actually be able to produce 5000 amps. It is crucial that the main circuit break is capable of interrupting a 5000-amp surge. Finding the available fault current requires coordination with utility engineers, and this is required by the *NEC*, but not in residential locations.

(A) Field Marking. The available fault current for electrical services must be clearly marked at the service equipment. This is not required for dwelling units.

(B) Modifications. When an existing system is modified in a way that changes the available fault current, new calculations must be made, including for downstream overcurrent protective devices, and new markings must be placed.

II. 600 Volts, Nominal or Less

110.26: Working Space about Electric Equipment (600 Volts, Nominal or Less, to Ground)

Adequate space for safety must be maintained for easy maintenance of equipment. When equipment is located in locked rooms, it may still be considered accessible if the room is accessible to qualified personnel.

(A) Working Clearances. For working clearances, refer to Table 110.26(A)(1) in the *NEC.* Where enclosures are installed on each side of a work space (whether or not either has live exposed parts), the amount of clear distance must be determined by Condition 3 in Table 110.26(A)(1).

In addition, the free space in front of electrical equipment must be at least 30 inches (762 mm) wide. This clear space must continue from the floor to the height specified in Section 110.26(E). Doors or panels on all electrical equipment must be capable of opening to at least a 90-degree angle. No equipment is permitted to extend more than 6 inches in front of another piece of equipment; for example, a large transformer may not be placed in front of a panelboard, even when the top of the transformer is lower than the bottom of the panel.

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The minimum ceiling height above the various pieces of equipment covered in this article is 6½ feet (1.98 m), except for residential service equipment or panelboards in existing dwellings rated 200 amps or less. (The requirements for equipment operating at higher voltages are given in Article 490.)

Condition 1: In this portion, insulated wire and bus bars are not considered live parts. If there are any exposed energized parts and parts that are grounded on the opposite side of the working space, or if there are exposed live parts on both sides of the equipment, suitable insulating materials must be installed for protection of only the live parts described above.

From this, we might conclude that a panel of this kind that will have to be worked on from time to time falls under Condition 1, and give a minimum 3 feet of clearance. This will also apply to bus bars and conductors.

Condition 2: In Condition 1, the panel was used as an example, but since the panel is usually contained in a metal enclosure, we must also look at Condition 2, which we find might be used under certain conditions.

Condition 3: Condition 1 might be an electrical closet, where panels are on two walls, in which case 3- and 4-foot conditions would prevail.

EXCEPTION

(a) If there are no renewable or replaceable parts on the back side of switchboards or motor control centers, and all parts of the unit are accessible from its front, working space is not required.

(b) The inspection authority has the right to make exceptions for smaller spaces where it seems appropriate. These judgments are applicable if the particular arrangement of the installation shows that it will provide sufficient accessibility or if no insulated parts carry more than 30 volts RMS, 42 volts peak, or 60 volts DC.

Concrete, brick, or tile walls should very definitely be considered grounds.

(c) Condition 2 working clearances are permitted between pieces of dead-front equipment that are located across an aisle from each other. However, this applies only in cases where written procedures ensure that pieces of equipment located across from one another will never be open at the same time. Also, this must be done in areas that are accessible to authorized personnel only.

(B) Clear Spaces. Clear spaces required around equipment can't be used for storage. If live parts are exposed, they must be guarded.

(C) Access and Entrance to Working Space. This portion is very important for persons working in the area discussed above. There shall be at least one entrance that is large enough to give adequate working space to the electrical equipment therein. Where switchboards and control panels are located with a rating of 1200 amperes or more and are 6 feet or more in width, it is required that one entrance be at least 24 inches in width and 6.5 feet in height at each end. Thus, in cases such as this, at least two entrances are required.

EXCEPTION

(a) This allows for a continuous unobstructed way of exit wherever switchboards or panelboards are located.

(b) Only one entrance is required if the working space around the various pieces of equipment in the room is doubled.

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(D) Illumination. The equipment described in this article must be provided with a source of illumination **and may not be controlled by automatic systems only. Automatic control is allowed, but a switch or other method of controlling the light locally must be provided.**

(E) Dedicated Equipment Space. Motor control centers and other equipment covered by Article 408 must be located in dedicated and protected spaces. An exception is made for control wiring that must be located adjacent to or near specific pieces of equipment.

For indoor locations, this dedicated space is required to be equal to the width and depth of the equipment from the floor up to a 6-foot level, or up to a structural ceiling if it is lower than 6 feet. (Suspended ceilings are not considered to be structural ceilings.) No piping or nonelectrical equipment may be located in this space. Sprinkler systems may be installed for these spaces so long as they are fitted with drip pans or other suitable protection.

Equipment located outdoors must be installed in enclosures that are adequate to the conditions, and must be protected from vehicles and accidental contact by unqualified persons. No other equipment is permitted in the dedicated space.

110.27: Guarding of Live Parts

This section applies to parts supplied with 600 volts or less.

(A) Live Parts Guarded Against Accidental Contact. This section covers the guarding or protecting of live parts of electrical equipment that are operated at 50 volts or more, so as to prevent accidental contact with them. Approved cabinets or enclosures shall be used, according to the requirements in other portions of the *Code*. The following are the means by which this shall be accomplished:

- **(1)** Many references are made to only qualified persons having access to rooms, vaults, and so on. It is recommended that the reader refer to Article 100 and review the definition of qualified persons.
- **(2)** So that only qualified persons may have access to live parts, suitable partitions or screens must be installed to keep away unqualified persons. Openings to live parts shall be of such a size that unqualified persons will be kept from accidentally contacting live parts. Again, qualified persons are mentioned. Their safety is thought of in making the equipment accessible without obstruction and in giving attention to the contact of conducting materials such as conduit or pipes.
- **(3)** Balconies, galleries, or platforms must have sufficient elevations and be arranged such that unqualified persons have no access to live parts.
- **(4)** Any live parts of equipment that are elevated a minimum of 8 feet or more above the floor or other accessible places are considered accessible to qualified persons only.

(B) Prevent Physical Damage. Many times, electrical equipment is located in a work area where the activity around it might damage the equipment. In such a case, the enclosures or guards shall be of such strength as to prevent any damage to the electrical equipment.

(C) Warning Signs. Warning signs shall be posted at entrances to rooms or other guarded locations giving warning that only qualified personnel are permitted to enter. Although not specifically covered here, posting of dangers that might exist in any situation is always good safety practice.

Motors are covered in Sections 430.132 and 420.133, and parts supplied with over 600 volts are covered in Section 110.34.

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110.28: Enclosure Types

Enclosures for switchboards, panelboards, motor control centers, meter bases, and the like must be marked to show their enclosure type (NEMA 1, NEMA 4x, and so on). Table 110.28 is to be used to determine the right enclosure for each location.

Table 110.28 Enclosure Selection

Provides a Degree of Protection Against the Following Environmental Conditions	For Outdoor Use — Enclosure-Type Number									
	3	**3R**	**3S**	**3X**	**3RX**	**3SX**	**4**	**4X**	**6**	**6P**
Incidental contact with the enclosed equipment	X	X	X	X	X	X	X	X	X	X
Rain, snow, and sleet	X	X	X	X	X	X	X	X	X	X
Sleet*	—	—	X	—	—	X	—	—	—	—
Windblown dust	X	—	X	X	—	X	X	X	X	X
Hosedown	—	—	—	—	—	—	X	X	X	X
Corrosive agents	—	—	—	X	X	X	—	X	—	X
Temporary submersion	—	—	—	—	—	—	—	—	X	X
Prolonged submersion	—	—	—	—	—	—	—	—	—	X
Provides a Degree of Protection Against the Following Environmental Conditions	**For Indoor Use — Enclosure-Type Number**									
	1	**2**	**4**	**4X**	**5**	**6**	**6P**	**12**	**12K**	**13**
Incidental contact with the enclosed equipment	X	X	X	X	X	X	X	X	X	X
Falling dirt	X	X	X	X	X	X	X	X	X	X
Failing liquids and light splashing	—	X	X	X	X	X	X	X	X	X
Circulating dust, lint, fibers, and flyings	—	—	X	X	—	X	X	X	X	X
Settling airborne dust, lint flibers, and flyings	—	—	X	X	X	X	X	X	X	X
Hosedown and splashing water	—	—	X	X	—	X	X	—	—	—
Oil and coolant seepage	—	—	—	—	—	—	—	X	X	X
Oil or coolant spraying and splashing	—	—	—	—	—	—	—	—	—	X
Corrosive agents	—	—	—	X	—	—	X	—	—	—
Temporary submersion	—	—	—	—	—	X	X	—	—	—
Prolonged submersion	—	—	—	—	—	—	X	—	—	—

*Mechanism shall be operable when ice covered.

Informational Note: The term *raintight* is typically used in conjunction with Enclosure Types 3, 3Sr, 3SX, 3X, 4, 4X, 6, and 6P. The term *rainproof* is typically used in conjunction with Enclosure Types 3R, and 3RX. The term *watertight* is typically used in conjunction wish Enclosure Types 4, 4X, 6, 6P. The term *driptight* is typically used in conjunction with Enclosure Types 2, 5, 12, 12K, and 13. The term *dusttight* is typically used in conjunction with Enclosure Types 3, 3S, 3SX, 3X, 5, 12, 12K, and 13.

III. Over 600 Volts, Nominal

110.30: General

Since 1975, additions have been made at the end of various articles of the *Code* to cover over 600 volts, nominal. It is the intent that conductors and equipment used on volts higher than 600 volts, nominal, comply with this article and with all applicable articles. It is not intended that provisions of this article apply to equipment on the supply side of the service conductors.

110.31: Enclosure for Electrical Installations

Areas where access is controlled by lock-and-key or other approved means, shall be considered accessible to qualified persons only. Examples of these areas include vault installations, room or closet installations, and areas surrounded by walls, screens, or fences.

The design and construction of enclosures shall be suitable to the nature and degree of hazard involved.

Any wall or fence less than 7 feet in height is not considered as preventing access. A 7-foot fence or wall is considered to be adequate. Fences or walls of lower height must have additional protection to the 7-foot limit. A fence made of no less than 6 feet of fence fabric and a 1-foot or greater extension, using three or more strands of barbed wire, is acceptable.

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(A) Electrical Vaults. Walls, roofs, floors, and doorways of vaults containing conductors operating at 600 volts or more must be fire-rated for a minimum of three hours. Equipment must also be marked with warning signs. Openings in equipment must be designed so that foreign objects inserted through such openings are deflected away from energized parts. **Simple stud-and-drywall walls are not acceptable. Floors must be a minimum 4 inches of concrete. Doors and locks must be designed and installed to match the fire-rating, and transformer installations must comply with Part III of Article 450.**

(B) Indoor Installations.

(1) In Places Accessible to Unqualified Persons. This section covers indoor installations to which unqualified persons might have access. The equipment shall be made with metal enclosures or a vault that is accessible only by lock and key.

Unit substations and any pull boxes or other means of connection associated with the equipment must be permanently marked with caution signs. Dry-type transformers must be ventilated so that they have openings in the equipment, but they shall be designed in such a manner that foreign objects inserted through the ventilating holes will have something to deflect them from the live parts.

(2) In Places Accessible to Qualified Persons Only. Section 110.34 and Article 490, Part III, are to be used for compliance when indoor electrical installations are considered accessible to qualified persons.