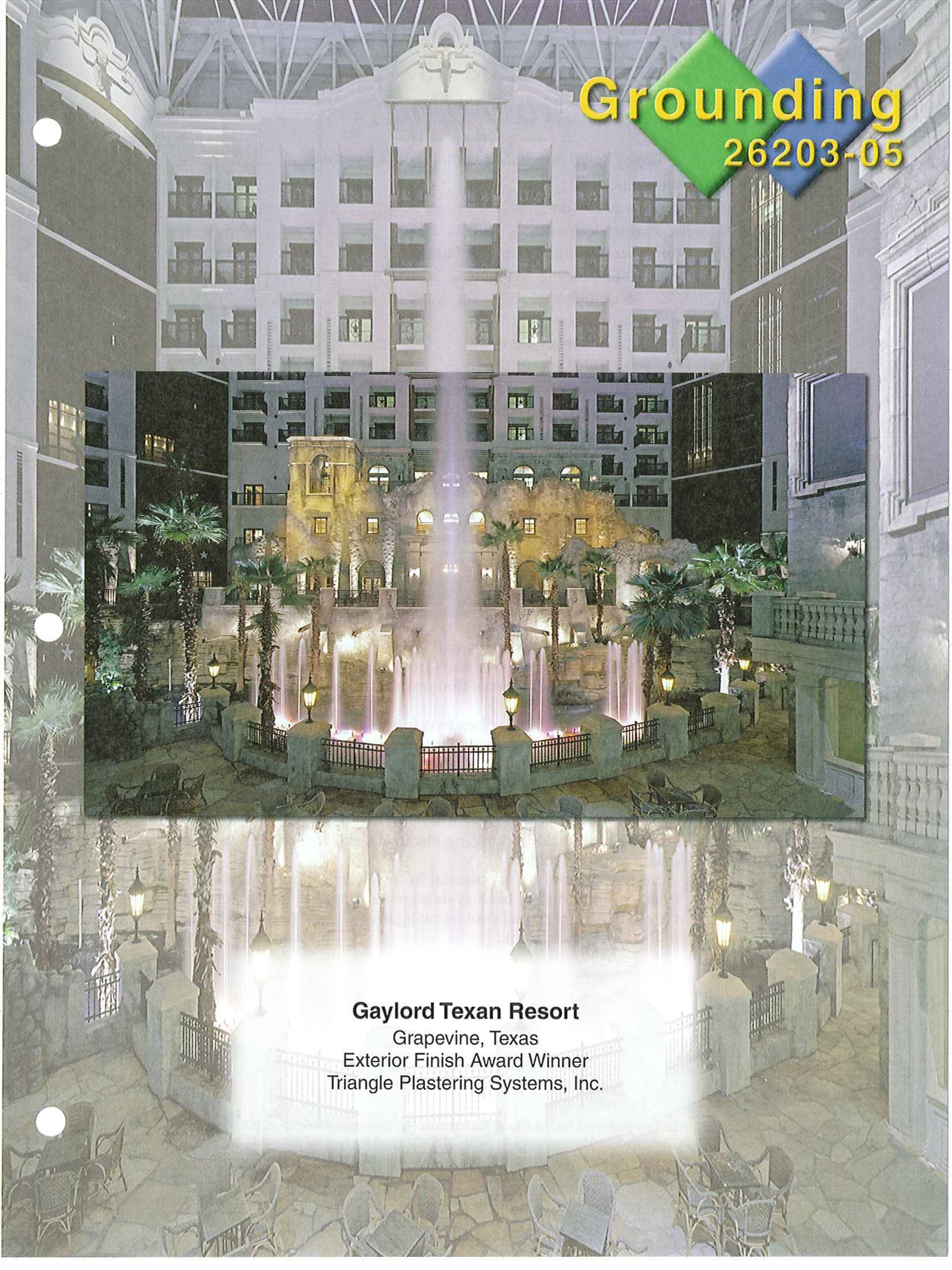
Grounding
26203-05



Gaylord Texan Resort
Grapevine, Texas
Exterior Finish Award Winner
Triangle Plastering Systems, Inc.

26203-05
Grounding

Topics to be presented in this module include:

Overview

One of the most comprehensive articles of the *National Electrical Code*® is *Article 250,* also known as the Grounding Article. It is so comprehensive because of the important role that grounding plays in the safe operation of electrical systems.

NEC Article 250 describes two forms of grounding: system grounding and equipment grounding. System grounding is the intentional connection of one of the current-carrying conductors to a grounding electrode, while equipment grounding is the physical, conducting connection of any noncurrent-carrying metal parts to a grounding electrode. The interconnection of all noncurrent-carrying metal parts to each other is called bonding. Once the bonding system is connected to the grounding electrode, the equipment grounding system is effectively grounded.

System grounding is essential in the electrical operation of some grounded systems. In addition, both system grounding and equipment grounding provide a level of personal protection against electrical shock should a fault occur in the electrical system.

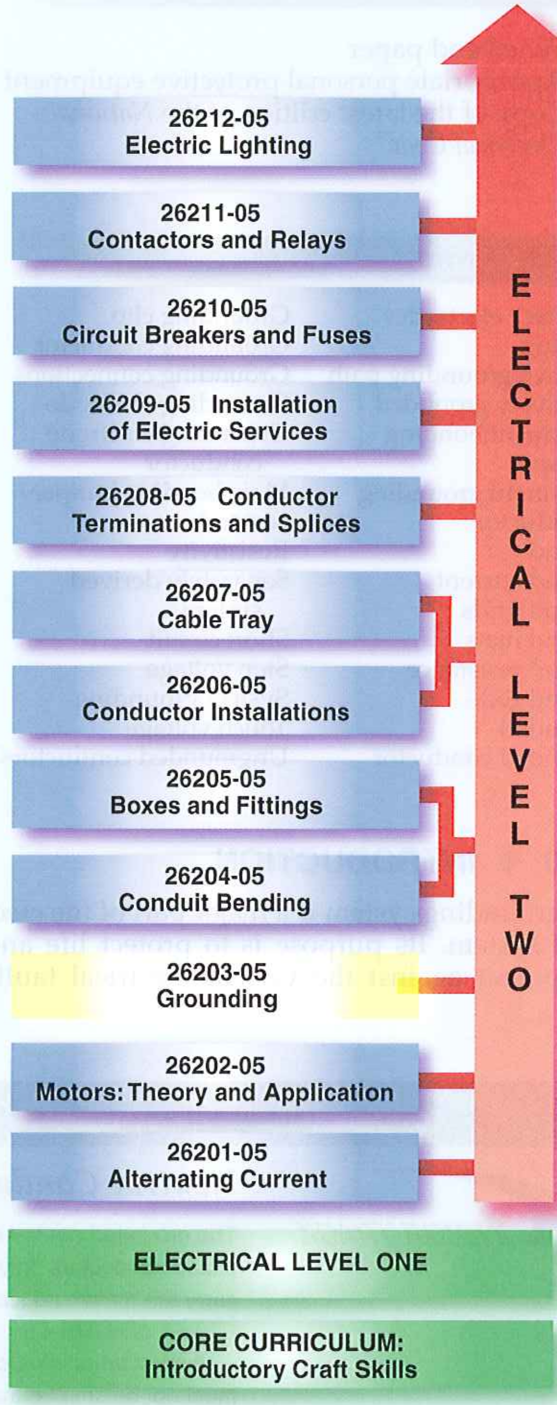
Objectives

When you have completed this module, you will be able to do the following:

1. Explain the purpose of grounding and the scope of *NEC Article 250.*
2. Distinguish between a short circuit and a ground fault.
3. Define the *NEC*® ground-related terms.
4. Distinguish between system grounding and equipment grounding.
5. Use *NEC Table 250.66* to size the grounding electrode conductor for various AC systems.
6. Explain the *NEC*® requirements for the installation and physical protection of grounding electrode conductors.
7. Explain the function of the grounding electrode system and determine which grounding electrodes must be used.
8. Define electrodes and explain the resistance requirements for electrodes using *NEC Section 250.56.*
9. Use *NEC Table 250.122* to size the equipment grounding conductor for raceways and equipment.
10. Explain the function of the main bonding jumper and system bonding jumpers in the grounding system and size the bonding jumpers for various applications.
11. Size the main bonding jumper for a service utilizing multiple service disconnecting means.
12. Explain the *NEC*® requirements for bonding of enclosures and equipment.
13. Explain the *NEC*® requirements for grounding of enclosures and equipment.
14. Explain effectively grounded and its importance in clearing ground faults and short circuits.
15. Explain the purposes of the grounded conductor (neutral) in the operation of overcurrent devices.
16. Explain the *NEC*® requirements for grounding separately derived systems, including transformers and generators.
17. Explain the *NEC*® requirements for grounding at more than one building.
18. Explain the *NEC*® grounding requirements for systems over 600 volts.

Prerequisites

Before you begin this module, it is recommended that you successfully complete *Core Curriculum; Electrical Level One;* and *Electrical Level Two,* Modules 26201-05 and 26202-05.



203CMAP.EPS

This course map shows all of the modules in *Electrical Level Two.* The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map. The local Training Program Sponsor may adjust the training order.

Required Trainee Materials

1. Pencil and paper
2. Appropriate personal protective equipment
3. Copy of the latest edition of the *National Electrical Code®*

Trade Terms

- Auxiliary electrodes
- Bonding
- Effective grounding path
- Effectively grounded
- Equipment bonding jumper
- Equipment grounding conductor
- Ground
- Ground current
- Ground grids
- Ground mats
- Ground resistance
- Ground rod
- Grounded
- Grounded conductor
- Grounding clip
- Grounding conductor
- Grounding connections
- Grounding electrode
- Grounding electrode conductor
- Main bonding jumper
- Neutral
- Resistivity
- Separately derived system
- Short circuit
- Step voltage
- System grounding
- Touch voltage
- Ungrounded conductors

1.0.0 ◆ INTRODUCTION

The grounding system is a major part of the electrical system. Its purpose is to protect life and equipment against the various electrical faults that can occur. It is sometimes possible for higher-than-normal voltages to appear at certain points in an electrical system or in the electrical equipment connected to the system. Proper grounding ensures that the electrical charges that cause these high voltages are channeled to earth or ground before damaging equipment or causing danger to human life. Therefore, a circuit is **grounded** to limit the voltage on the circuit and improve overall operation of the electrical system and continuity of service.

When we refer to **ground,** we are talking about ground potential or earth ground. If a conductor is connected to the earth or to some conducting body that serves in place of the earth, such as a driven **ground rod** (electrode) or cold-water pipe, the conductor is said to be grounded. The **neutral** in a three- or four-wire service, for example, is intentionally grounded and therefore becomes a **grounded conductor.** However, a wire used to connect this neutral conductor to a grounding electrode or electrodes is referred to as a **grounding conductor.** Note the difference in the two meanings; one is grounded, while the other is grounding.

The **equipment grounding conductor** is the conductor used to connect the noncurrent-carrying metal parts of equipment, raceways, and other enclosures to the system grounded conductor, the **grounding electrode conductor,** or both, at the service equipment or at the source of a **separately derived system.** See *Figure 1*.

INSIDE TRACK

Neutral Conductor Size

The grounded neutral conductor is permitted to be smaller than the hot ungrounded phase conductors only when the neutral conductor is properly and adequately sized to carry the maximum load imbalance as computed according to ***NEC Sections 215.2, 220.61, and 230.42.***

It must be pointed out that per ***NEC Section 250.24(C)*** the grounded conductor must not be smaller than the size of the grounding electrode conductor. This is important when you have three-phase services with little or no neutral loads to use as a basis for sizing the grounded conductor.

NEC Section 215.2 (feeders) and ***NEC Section 230.42*** (service-entrance conductors) reference ***NEC Article 220*** for minimum rating and size computation requirements. ***NEC Article 220*** states that the feeder neutral load must be the maximum imbalance of the load, which is the maximum net computed load between the neutral and any one ungrounded conductor.

In summary, both the neutral current, as determined in ***NEC Articles 215, 220, and 230,*** and the minimum grounding electrode size, as determined in ***NEC Article 250,*** must be used to determine the actual neutral wire size.

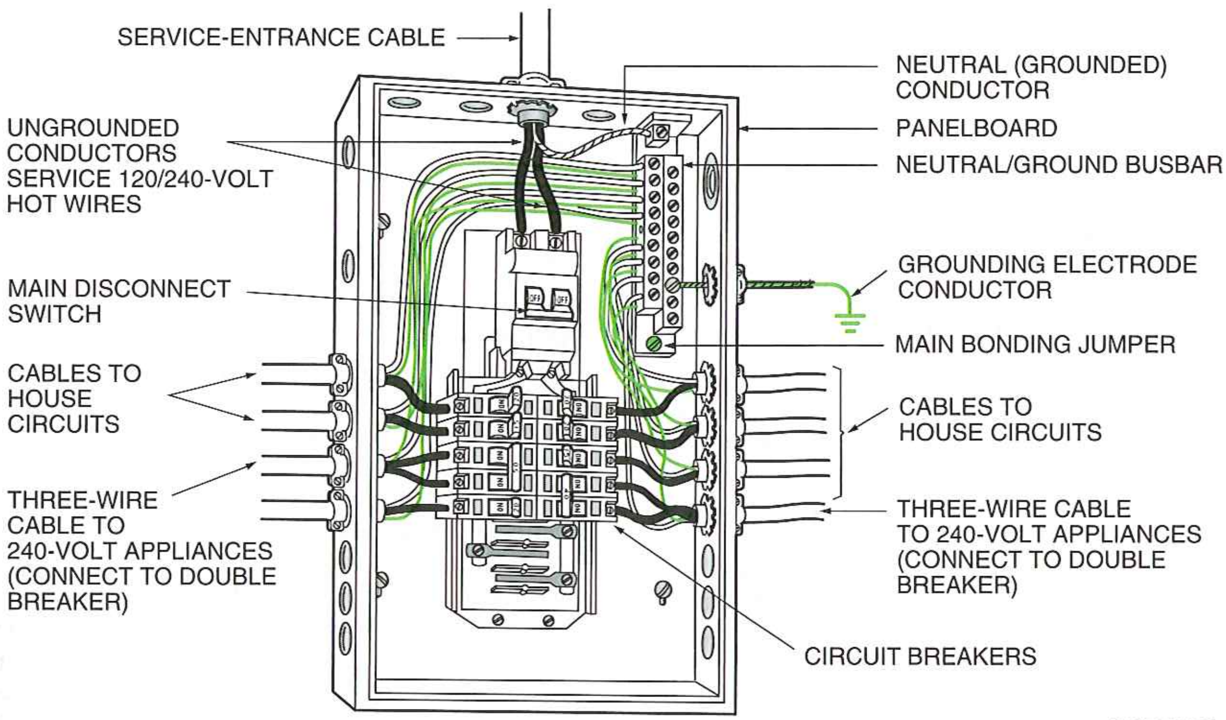


Figure 1 ◆ Panelboard showing grounded and grounding conductors.

This module is designed to explain what a ground is and to teach proper grounding techniques. *NEC®* regulations and the testing of grounding systems will be thoroughly covered. Upon completion of this module, you should have a solid foundation in the principles of grounding, one of the most important aspects of an electrical system for the protection of life and property.

2.0.0 ◆ PURPOSE OF GROUNDING

Systems are solidly grounded to limit the voltage to ground during normal operation and to prevent excessive voltages due to lightning and line surges. They are also grounded to stabilize the voltage to ground during normal operation. Conductive materials enclosing electrical conductors or equipment, or that form a part of the equipment, are grounded. This limits the voltage to ground on these materials. The conductive materials are bonded to facilitate the operation of overcurrent devices under ground fault conditions.

3.0.0 ◆ *NEC®* REQUIREMENTS

NEC Article 250 is the primary governing article for the proper use and installation of grounding and bonding. This article covers general requirements for grounding and bonding of electrical installations. It presents the following specific requirements:

- Systems, circuits, and equipment that are required, permitted, or not permitted to be grounded
- Circuit conductor to be grounded on grounded systems
- Location of grounding connections
- Types and sizes of grounding and bonding conductors and electrodes
- Methods of grounding and bonding
- Conditions under which guards, isolation, or insulation may be substituted for grounding

What's wrong with this picture?

203P0301.EPS

NEC Section 250.4(A)(5) requires that the path to ground from circuits, equipment, and metal enclosures shall:

- Be permanent and continuous
- Have the capacity to safely conduct any fault current likely to be imposed on it
- Have sufficiently low impedance to facilitate the operation of the protective devices in the circuit
- Be capable of safely carrying the maximum ground fault likely to be imposed

Permanent, reliable, and continuous grounding systems are vital to the safety of electrical systems. Intermittent connections are likely to be unpredictable and may result in hazardous situations.

The minimum size (**grounding electrode**) conductor and equipment grounding conductor is necessary to ensure that the proper capacity to protect the system is in place. Methods to determine the proper size of these conductors will be discussed later in this module.

A low-impedance conductor is necessary because the higher the impedance, the more resistance there is to current flow. The current should flow with the least amount of resistance to ensure that personnel and equipment are protected when a fault does occur.

4.0.0 ◆ SHORT CIRCUIT VERSUS GROUND FAULT

Short circuits and ground faults are commonly misunderstood. Both faults stem from a failure of insulation resistance. It is important to have a common language for better understanding of these conditions.

4.1.0 Short Circuit

A short circuit is a conducting connection, whether intentional or accidental, between any of the conductors of an electrical system, whether it is from line-to-line or from line-to-ground. See *Figure 2.*

The failure might occur from one phase conductor to another phase conductor or from one phase conductor to the grounded conductor or neutral. The maximum value of fault current is dependent on the available capacity the system can deliver to the point of fault. The maximum value of short circuit current from line-to-ground will vary depending upon the distance from the source to the fault. The available short circuit current is further limited by the impedance of the arc where one is established, plus the impedance of the conductors to the point of short circuit.

4.2.0 Ground Fault

A ground fault, as defined in *NEC Section 250.2,* is the unintentional electrically conducting connection between an ungrounded conductor of an electrical circuit and the normally noncurrent-carrying conductors, metallic enclosures, metallic raceways, metallic equipment, or earth. While not specified in the *NEC®*, an unintentional electrically conducting connection between a grounded conductor of an electrical circuit and the normally noncurrent-carrying conductors, metallic enclosures, metallic raceways, metallic equipment, or earth would also be considered a ground fault. While the first instance may result in a large amount of fault current to flow in a properly installed grounded system, the latter may result in parallel paths being formed between the grounded conductor and the grounding system. These parallel paths would result in an unwanted current flow on the grounding system. See *Figure 3.*

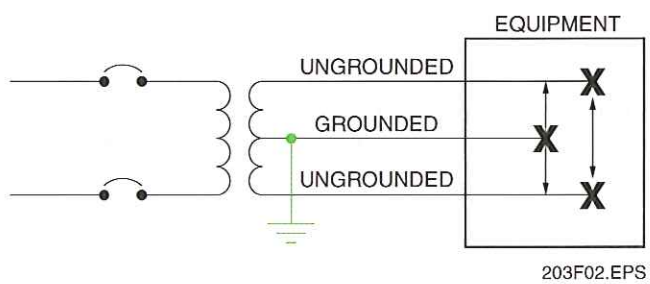


Figure 2 ◆ Short circuit.

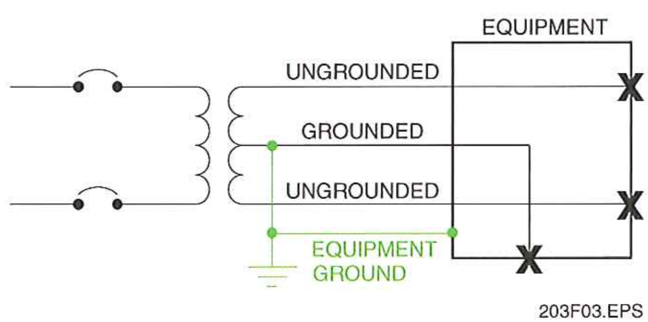


Figure 3 ◆ Ground fault.

5.0.0 ◆ TYPES OF GROUNDING SYSTEMS

The two general classifications of protective grounding are system and equipment grounding.

System grounding and bonding relates to the service-entrance equipment and its interrelated and bonded components. That is, one system conductor is grounded to limit voltages due to lightning, line surges, or unintentional contact with higher voltage lines, as well as to stabilize the voltage to ground during normal operation.

Equipment grounding conductors are used to connect the noncurrent-carrying metal parts of equipment, conduit, outlet boxes, and other enclosures to the system grounded conductor, the grounding electrode conductor, or both, at the service equipment or at the source of a separately derived system. Equipment grounding conductors are bonded to the system grounded conductor to provide a low impedance path for fault current that will facilitate the operation of overcurrent devices under ground fault conditions. *NEC Article 250* covers general requirements for grounding and bonding.

5.1.0 Single-Phase Systems

To better understand a complete grounding system, we will examine a conventional residential or small commercial system beginning at the power company's high-voltage lines and transformer, as shown in *Figure 4*. The pole-mounted transformer is fed with a two-wire 7,200V system that is transformed and stepped down to a three-wire, 120/240V, single-phase electric service suitable for residential use. A wiring diagram of the transformer connections is shown in *Figure 5*. Note that the voltage between Leg A and Leg B is 240V.

However, by connecting a third wire (neutral) on the secondary winding of the transformer between the other two, the 240V splits in half, giving 120V between either Leg A or Leg B and the neutral conductor. Consequently, 240V is available for household appliances such as ranges, hot water heaters, clothes dryers, and the like, while 120V is available for lights, small appliances, televisions, and similar appliances.

Referring again to the diagram in *Figure 5*, conductors A and B are **ungrounded conductors,** while the neutral is a grounded conductor. If only 240V loads were connected, the **neutral or grounded conductor** would carry no current. However, since 120V loads are present, the neutral will carry the unbalanced load and become a current-carrying conductor. For example, if Leg A carries 60A and Leg B carries 50A, the neutral conductor would carry only 10A (60 − 50 = 10). This is why the *NEC®* sometimes allows the neutral conductor in an electric service to be smaller than the ungrounded conductors.

The typical pole-mounted service entrance is normally routed by a grounded (neutral) messenger cable from a point on the pole to a point on the building being served, terminating at the service drop. Service-entrance conductors are routed

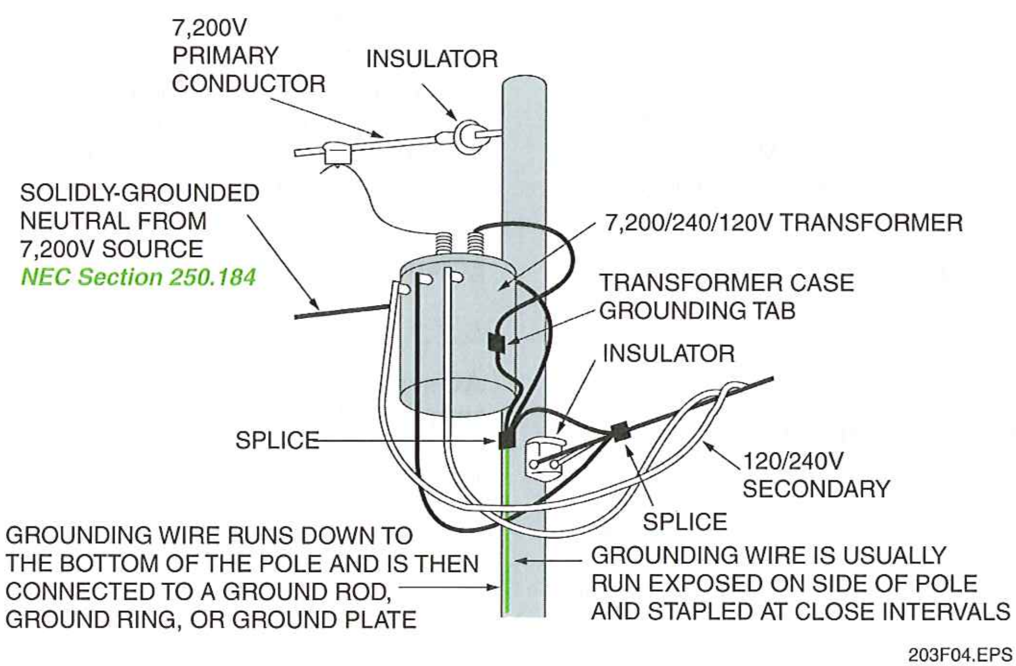


Figure 4 ◆ Pole-mounted transformer.

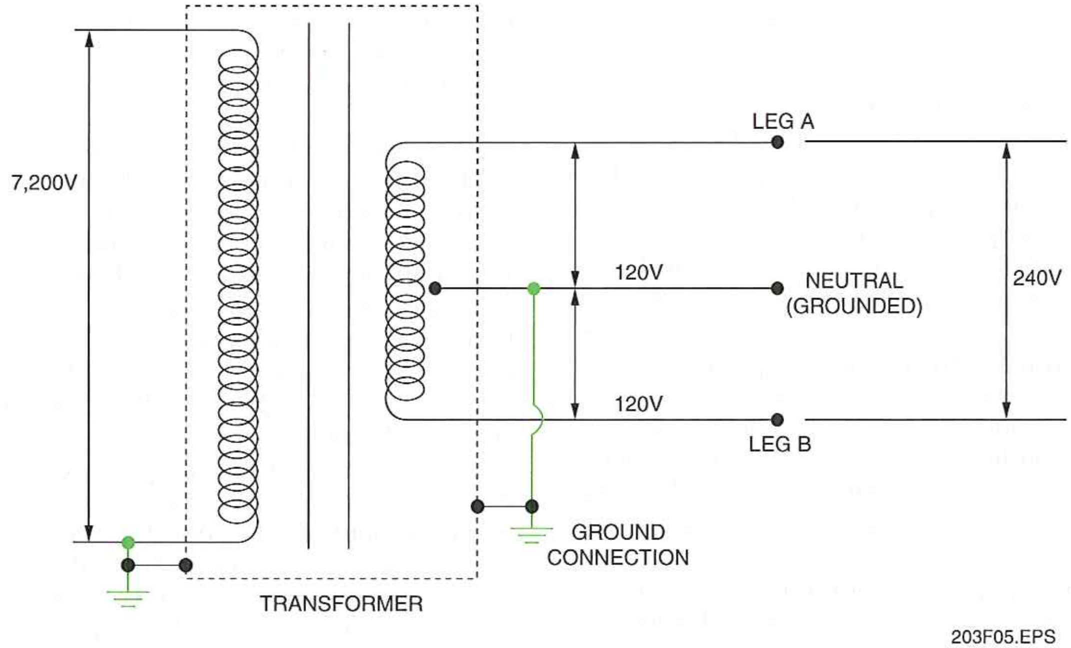


Figure 5 ◆ Wiring diagram of a 7,200V to 120/240V single-phase transformer connection.

between the meter housing and the main service switch or panelboard. This is the point where most systems are grounded—the neutral bus in the main panelboard. See *Figure 6*.

WARNING!
Exercise extreme caution when disconnecting a ground. Never grab a disconnected ground wire with one hand and the grounding electrode with the other. Your body will act as a conductor for any fault current; the results could be fatal.

5.2.0 Grounding Requirements

NEC Sections 250.20 and 250.21 provide the grounding requirements for AC systems. The *NEC*® should always be referenced when working with grounded and ungrounded systems. There are various exceptions to the requirements that will not be covered in detail in this module.

5.2.1 Systems Less Than 50 Volts

Grounding is required:

- Where supplied by transformers if the supply voltage to the transformer exceeds 150V to ground
- Where supplied by transformers if the transformer supply system is ungrounded
- Where installed as overhead conductors outside of the building
- In other circuits and systems provided they comply with the provisions of *NEC Article 250*

Figure 7 shows examples of these requirements.

5.2.2 50-Volt to 1,000-Volt Systems

AC systems of 50V to 1,000V supplying premises wiring and premises wiring systems shall be grounded under any of the following conditions:

- Where the system can be grounded so that the maximum voltage to ground on the ungrounded conductors does not exceed 150 volts
- Where the system is three-phase, four-wire, wye-connected and the neutral is used as a circuit conductor
- Where the system is three-phase, four-wire, delta-connected and the midpoint of one phase winding is used as a circuit conductor
- In other circuits and systems provided they comply with the provisions of *NEC Article 250*

Figure 8 shows examples of 50V to 1,000V grounded applications.

5.2.3 AC Systems 1kV and Over

AC systems over 1,000V must be grounded if they supply mobile or portable equipment as covered in *NEC Section 250.188.* Other AC systems over 1,000V are permitted (but not required) to be grounded.

Other circuits and systems shall be permitted to be grounded. If such systems are grounded, they shall comply with the provisions of *NEC Article 250.*

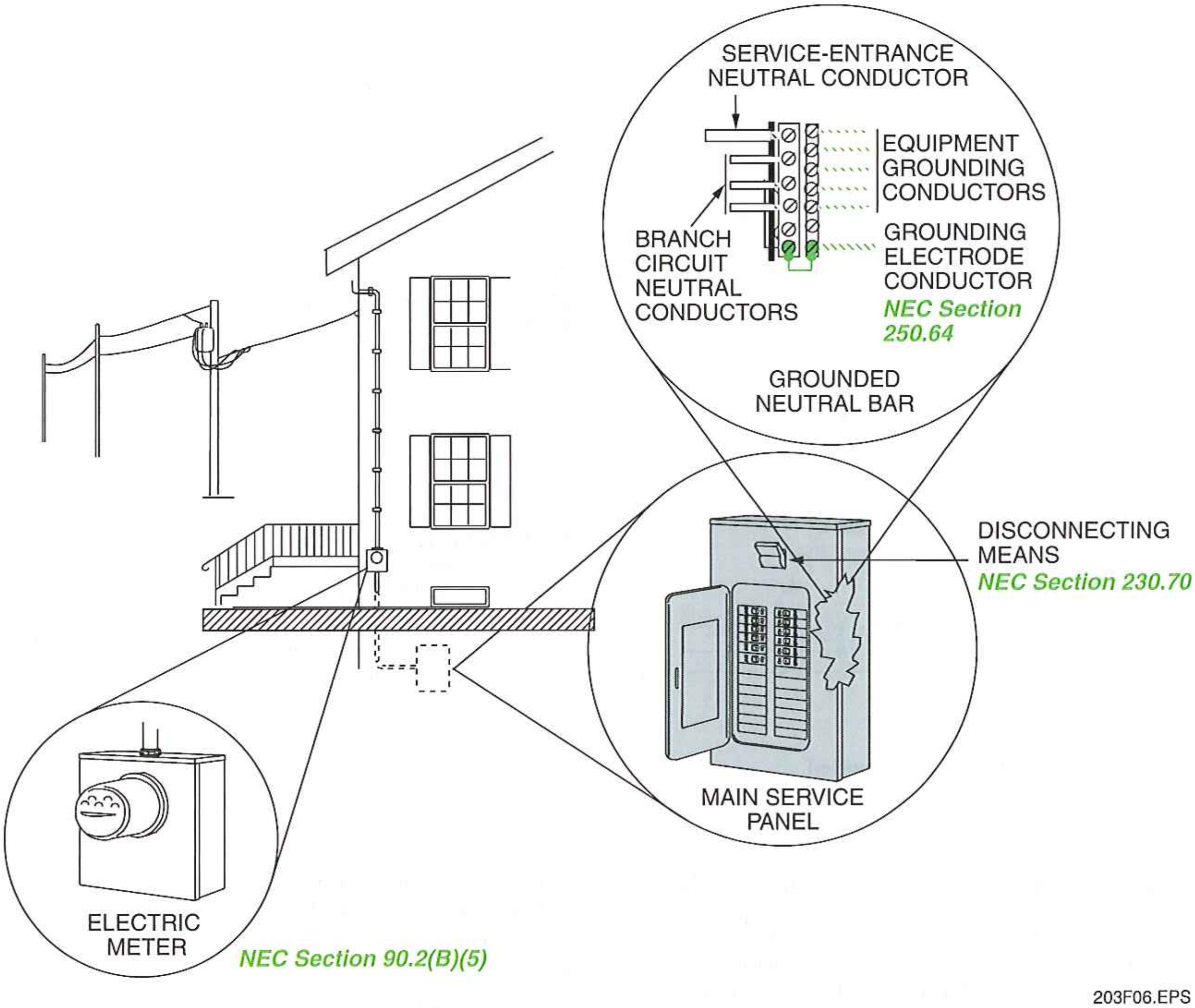


Figure 6 ◆ Typical service entrance and related service equipment.

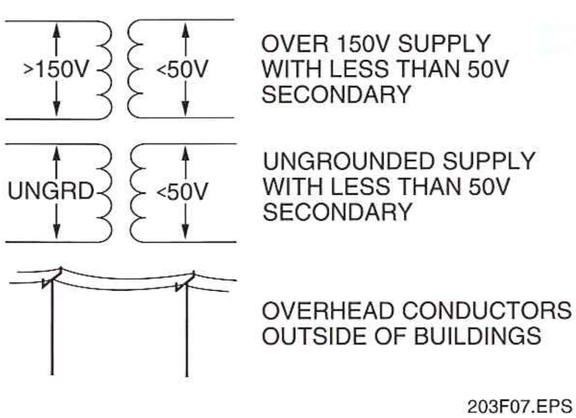


Figure 7 ◆ Systems less than 50V that must be grounded.

5.2.4 Separately Derived Systems

Electrical systems derived from a generator, transformer, or converter windings that have no direct electrical connection to the supply conductors originating in another system must be grounded if the system that is derived complies with the conditions previously described. The separately derived system must then be grounded as specified in *NEC Section 250.30.*

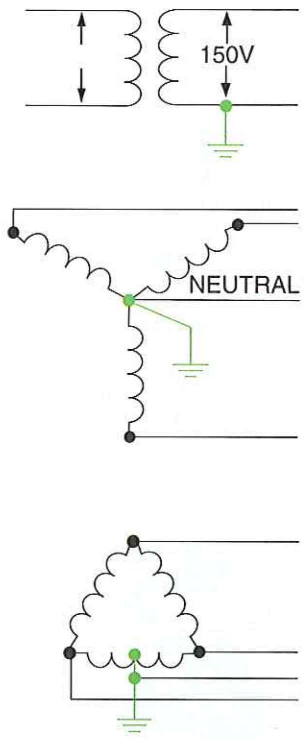


Figure 8 ◆ Systems that must be grounded.

Examples of separately derived systems include:

- Transformers with no direct electrical connection between the primary and secondary
- Generator systems that supply power where the neutral is not connected to the utility system, such as for carnivals, rock crushers, or batch plants
- Generator systems used for emergency, required standby, or optional standby power that have all conductors, including a neutral, isolated from the neutral or grounded conductor of another system (usually via a transfer switch)
- AC or DC systems derived from inverters or rectifiers

5.2.5 Circuits That Cannot Be Grounded

According to *NEC Section 250.22,* only four types of circuits are not permitted to be grounded:

- Circuits for cranes that operate over combustible fibers in Class III locations, as provided in *NEC Section 503.155*
- For healthcare facilities, those isolated power circuits in hazardous (classified) locations as provided in *NEC Section 517.61*
- Circuits for electrolytic cells as provided in *NEC Article 668*
- Secondary circuits on lighting systems as provided in *NEC Article 411.5(A)*

NOTE

Equipment located or used within the electrolytic cell line working zone or associated with the cell line DC power circuits are not required to comply with ***NEC Article 250.***

Figure 9 shows some examples of these circuits.

Systems Permitted to Be Grounded but Not Required to Be Grounded

NEC Section 250.21 states that the following AC systems of 50V to 1,000V shall be permitted to be grounded but shall not be required to be grounded:

- Electric systems used exclusively to supply industrial electric furnaces for melting, refining, tempering, and the like
- Separately derived systems used exclusively for rectifiers that supply only adjustable-speed drives
- Separately derived systems supplied by transformers that have a primary voltage rating of less than 1,000V, provided that all of the conditions listed in *NEC Section 250.21* are met
- Isolated systems as permitted or required in *NEC Articles 517 and 668*
- High-impedance grounded neutral systems as specified in *NEC Section 250.36*

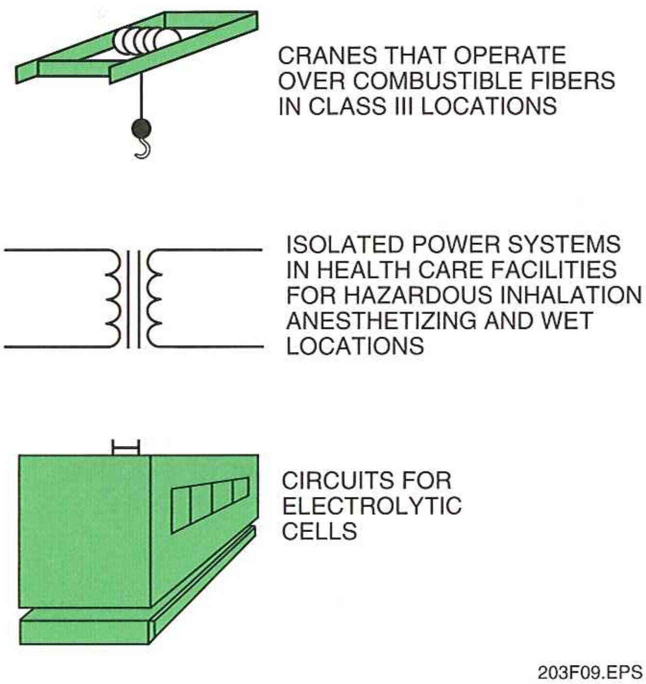


Figure 9 ◆ Circuits that are not permitted to be grounded.

6.0.0 ◆ *NEC®* REQUIREMENTS

The grounding equipment requirements established by Underwriters Laboratories, Inc. (UL) have served as the basis for approval for grounding in the *NEC®*. The *NEC®*, in turn, provides the grounding standard for the Occupational Safety and Health Administration (OSHA).

All electrical systems must be grounded and bonded in a manner prescribed by the *NEC®* to protect personnel and equipment. To be totally effective, a grounding system must limit the voltage on the electrical system and protect it from:

- Lightning
- Voltage surges higher than that for which the circuit is designed
- An increase in maximum potential to ground due to abnormal voltages

6.1.0 Grounding Methods

The requirements for grounding of services are found in *NEC Sections 250.24(A), (B), and (C).* Methods of grounding an electric service are covered in *NEC Article 250, Part III.* In general, all of the following electrodes (if present) must be bonded together to form the grounding electrode system:

- An underground metal water pipe in direct contact with the earth for no less than 10'
- The metal frame of a building where **effectively grounded** per *NEC Section 250.52(A)(2)*
- An electrode encased by at least 2" of concrete, located within and near the bottom of a concrete foundation or footing that is in direct contact with the earth

NOTE

This electrode must be at least 20' long and must be made of electrically conductive coated steel reinforcing bars or rods of not less than ½" in diameter, or consisting of at least 20' of bare copper conductor not smaller than No. 4 AWG wire size.

- A ground ring encircling the building or structure, in direct contact with the earth at a depth not less than 2.5' below grade
- Rod, pipe, or plate electrodes
- Other local metal underground systems or structures

NOTE

This ring must consist of at least 20' of bare copper conductor not smaller than No. 2 AWG wire size. See *Figure 10*.

Grounding systems used in industrial buildings will frequently use all of the methods shown in *Figure 10*, and the methods used will often surpass the *NEC*®, depending upon the manufacturing process and the calculated requirements made by plant engineers.

Figure 11 shows a floor plan of a typical industrial grounding system.

The building in *Figure 12* has a metal underground water pipe that is in direct contact with the earth for more than 10', so this is one valid grounding source. The building also has a metal underground gas piping system, but this may not be used as a grounding electrode [*NEC Section 250.52(B)*].

NEC Section 250.53(D)(2) further states that the underground water pipe must be supplemented by an additional electrode of a type specified in *NEC Section 250.52(A)(2)*. Since a grounded metal building frame, concrete-encased electrode, or

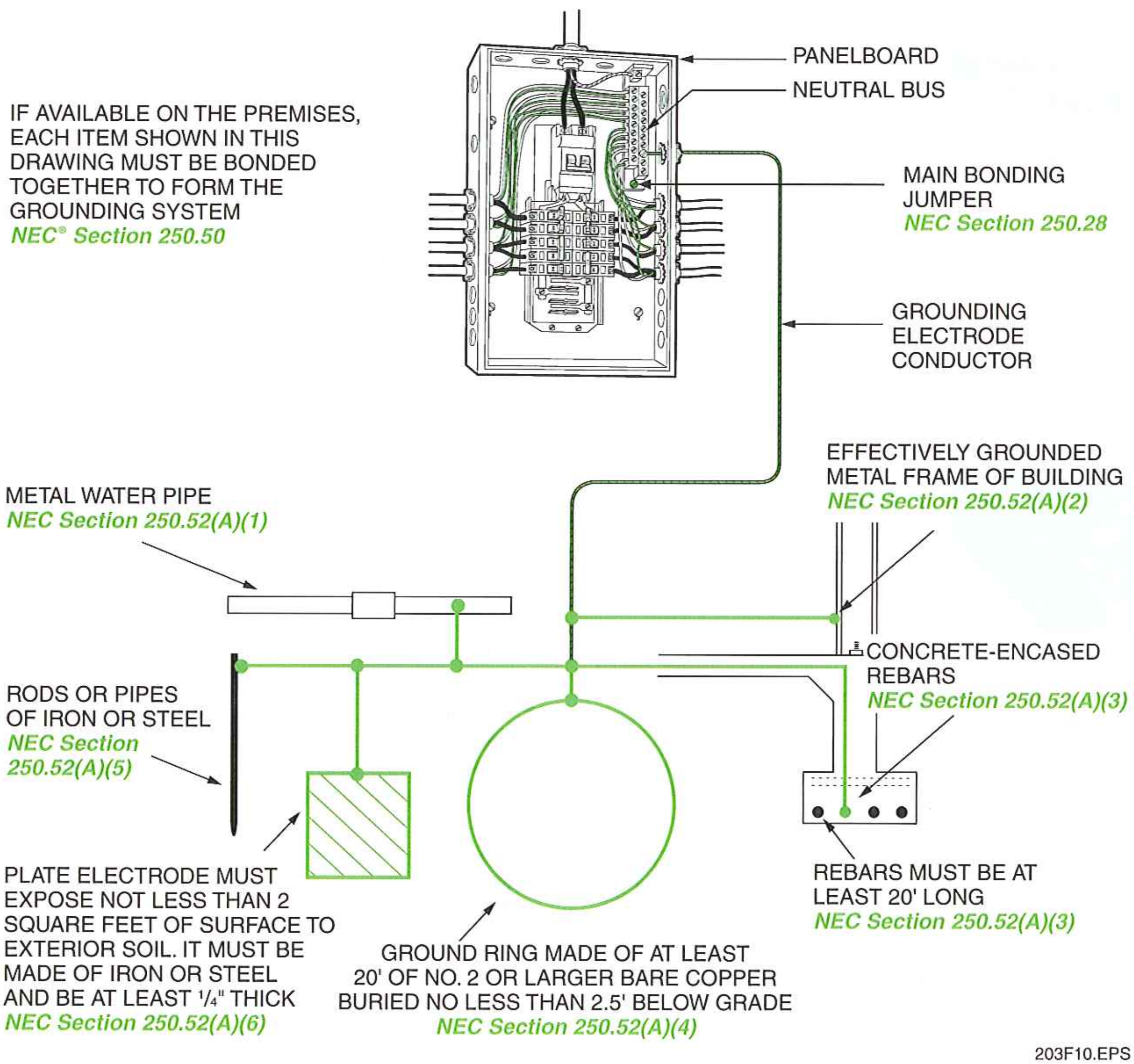


Figure 10 ◆ *NEC*®-approved grounding electrodes.

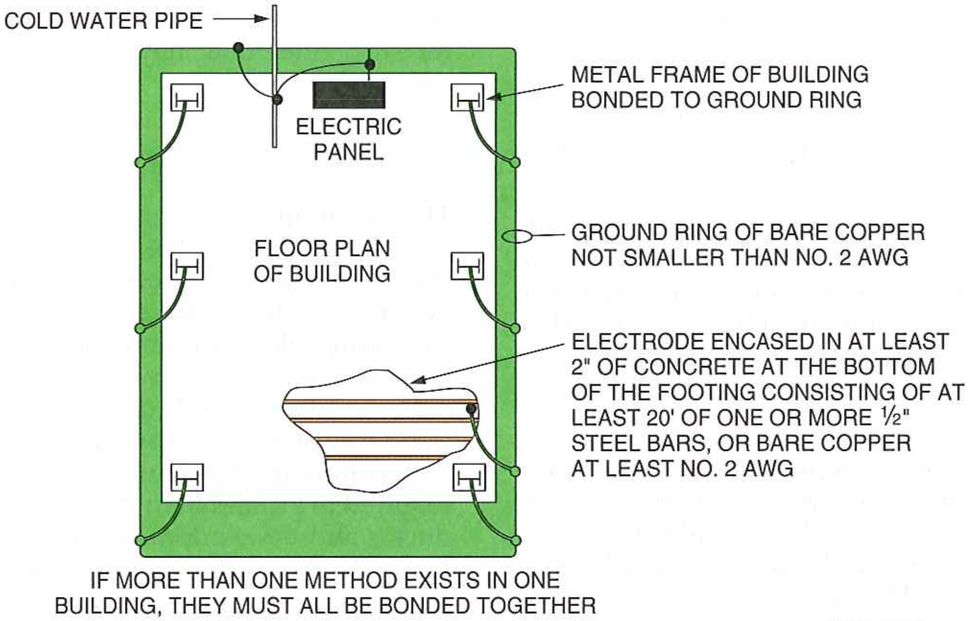


Figure 11 ◆ Floor plan of the grounding system for an industrial building.

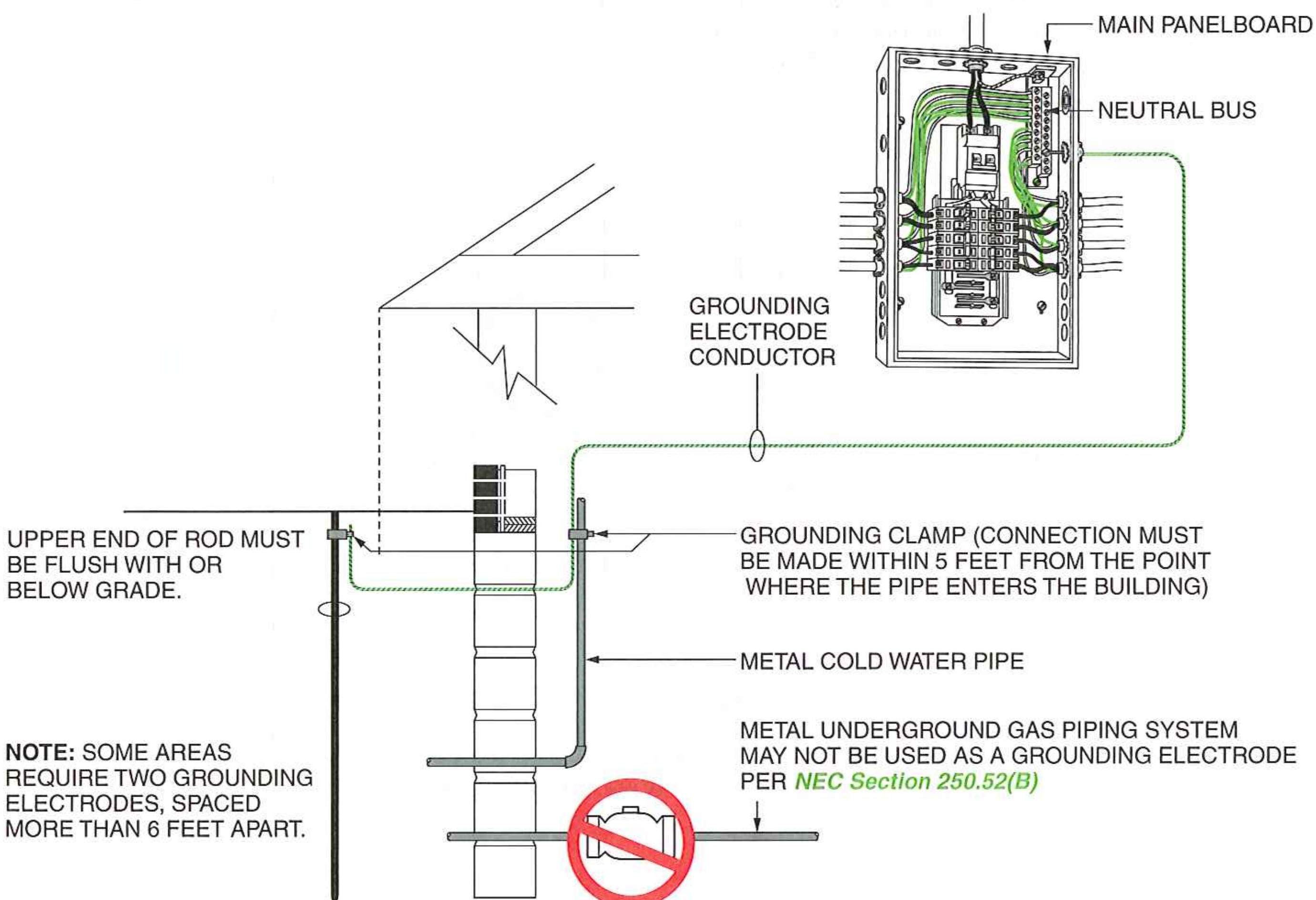


Figure 12 ◆ Grounding requirements for non-industrial buildings.

ground ring is not available in this application, *NEC Section 250.50* must be used in determining the supplemental electrode. In most cases, this supplemental electrode will consist of either a driven rod (*Figure 13*) or pipe electrode, the specifications for which are as follows:

- Withstand and dissipate repeated surge circuits
- Provide corrosion resistance to various soil chemistries to ensure continuous performance for the life of the equipment being protected
- Provide rugged mechanical properties for easy driving with minimum effort and rod damage

An alternate method to the pipe or rod method is a plate electrode. Each plate electrode must expose not less than two square feet of surface to the surrounding earth. Plates made of iron or steel must be at least ¼" thick, while plates of nonferrous metal like copper need only be .06" thick.

Rod, pipe, and plate electrodes must have a resistance to ground of 25 ohms (Ω) or less. If not, they must be augmented by an additional electrode spaced not less than 6' from the first. Many locations require two electrodes regardless of the resistance to ground. This is not an *NEC*® requirement, but is required by some power companies and local ordinances in some cities and counties. Always check with the local inspection authority for such rules that may go beyond the requirements of the *NEC*®.

6.2.0 Grounding Electrode Conductor

The grounding electrode conductor is the sole connection between the grounding electrode and the grounded system conductor for a grounded system, or the sole connection between the grounding electrode and the service equipment enclosure for an ungrounded system. See *NEC Section 250.64,* which describes grounding electrode conductor installation.

A common grounding electrode conductor is required to ground both the circuit grounded conductor and the equipment grounding conductor. *Figure 14* shows the common connection for this system.

6.2.1 Sizing

The grounding electrode conductor must be sized in accordance with *NEC Table 250.66.* The size of this conductor is based on the size of the service-entrance conductor.

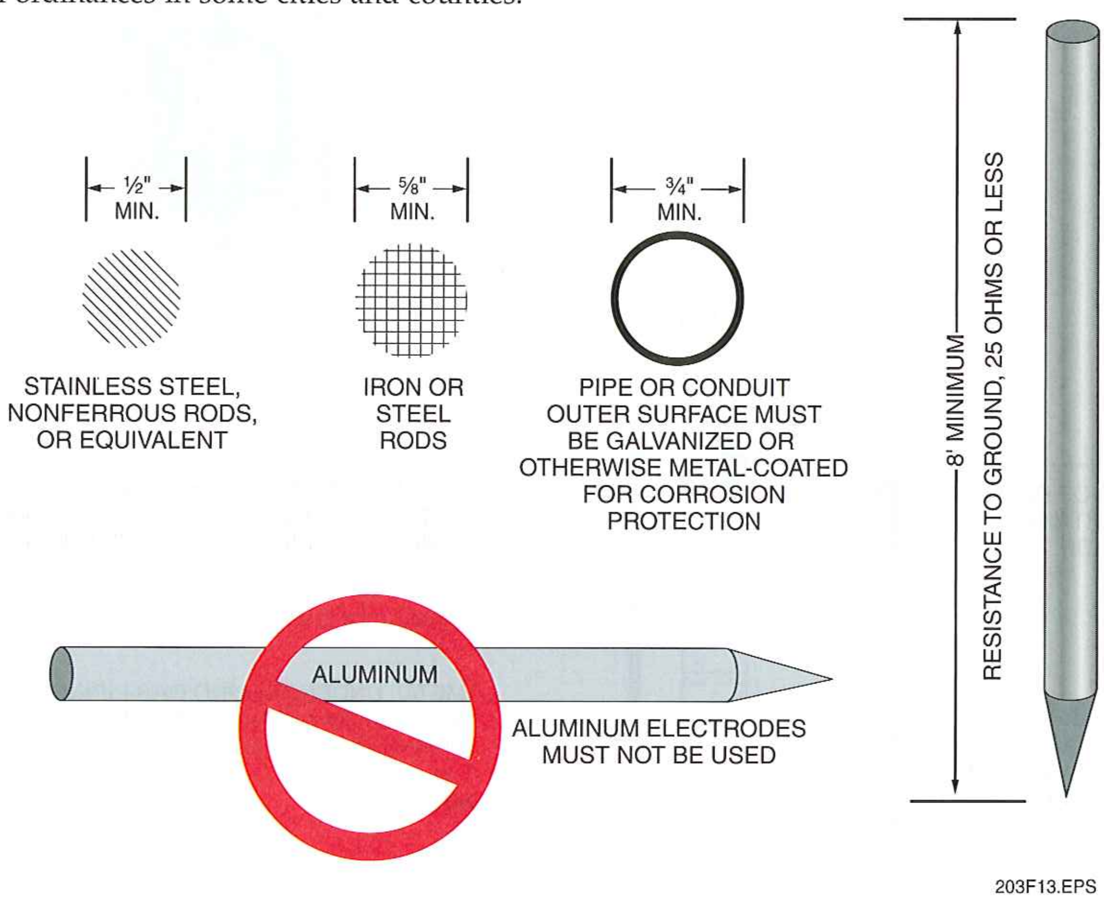


Figure 13 ◆ Requirements for ground rods.

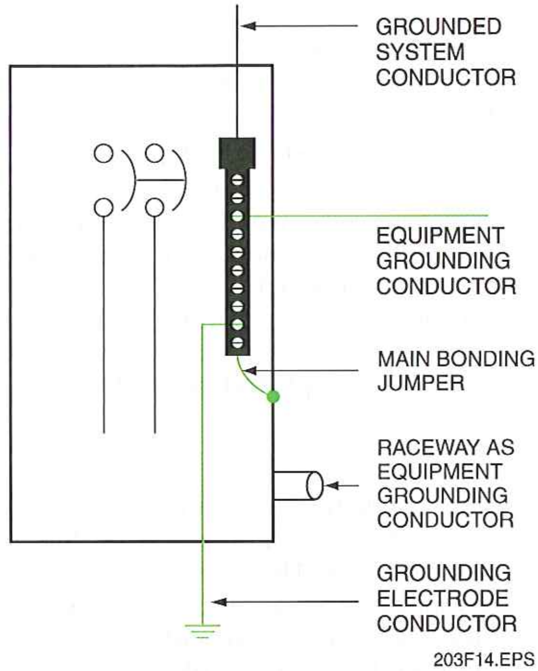


Figure 14 ◆ Grounding electrode connection for grounded system.

The size of the service-entrance conductor is determined from the ampacity of that system. *NEC Table 310.16* is used to determine the size of the service conductor from the ampacity.

The majority of applications use 75°C copper conductors. This information is necessary when using *NEC Table 310.16.* For a 100A service application, the size of the service conductor is No. 3 AWG copper.

Now that the size of the service conductors is known, the size of the grounding electrode conductor can be determined from *NEC Table 250.66.*

Using the No. 3 AWG from the 100A service example, it can be determined from the table that a No. 8 AWG copper grounding electrode conductor is required.

Another example that is fairly common would be to determine the size of the grounding electrode conductor for a 200A, 208V, three-phase system.

Step 1 Determine the size of the service conductor from *NEC Table 310.16.* It is 3/0 AWG.

Step 2 Go down the left column of *NEC Table 250.66* and find 3/0.

Step 3 Go across to find the size of the grounding conductor. It is a No. 4 AWG conductor.

NOTE

Remember, it is the total size of the service conductor that determines the size of the grounding electrode conductor.

6.2.2 Installation and Protection

NEC Section 250.64(B) requires the grounding electrode conductor or its enclosure to be securely fastened to the surface on which it is carried.

No. 4 AWG or larger conductors require protection where exposed to severe physical damage. No. 6 AWG conductors may be run along the surface of the building and be securely fastened. Otherwise, the conductor must be protected by installation in rigid or intermediate metal conduit, rigid nonmetallic conduit, EMT, or cable armor. Smaller conductors shall be protected in conduit or armor.

THINK ABOUT IT

Ground Rods

Suppose you are driving an 8' rod electrode into the ground and you hit a rock after it has been driven to a depth of 6'. Further effort to drive the rod deeper is of no avail. What are your options?

Sizing Electrode Conductors

NEC Table 310.16 shows that the service conductor size (copper wire at 75°C) for a 150A service is 1/0 AWG. Which of the three AWG copper electrode conductor sizes listed below would be used with this service?

No. 4
No. 6
No. 8

6.3.0 Grounding Electrode Conductors

Both the grounding electrode conductor, which connects the grounded conductor and the panelboard neutral bus to ground, and the grounding electrodes must be of either copper, aluminum, or copper-clad aluminum. Furthermore, the material selected must be resistant to any corrosive condition existing at the installation, or it must be suitably protected against corrosion. The conductor may be either solid or stranded, and covered or bare, but it must be in one continuous length without a splice or joint, except for the following conditions:

- Splices in busbars are permitted.
- Where a service consists of more than one single enclosure, it is permissible to connect taps to the grounding electrode conductor.
- Bonding jumper(s) from grounding electrode(s) and GECs shall be permitted to be connected to an aluminum or copper busbar not less than ¼" × 2". See *NEC Section 250.64(C).*

> **WARNING!**
> Exothermic welding is a hazardous process that should only be performed by qualified personnel. Refer to your company's safety procedures and the manufacturer's recommendations before using exothermic welding equipment.

- Per *NEC Section 250.64,* grounding electrode conductors may be spliced at any location by means of irreversible compression-type connectors listed for the purpose or using the exothermic welding process (*Figure 15*).

The size of grounding electrode conductors depends on service-entrance size; that is, the size of the largest service-entrance conductor or equivalent for parallel conductors. *NEC Table 250.66* gives the proper sizes of grounding electrode conductors for various sizes of electric services. *Figure 16* shows the various protection guidelines.

6.4.0 Other Electrodes

When an electrode that meets the requirements of *NEC Section 250.50* is not present, other electrodes may be used. These may be the rod and pipe electrodes discussed earlier, plate electrodes, or other local metal underground systems such as piping and underground tanks. *NEC Sections 250.52(A)(5), 250.52(A)(6), and 250.52(A)(7)* provide information and requirements for these electrodes. *Figure 17* shows other electrodes.

The specific requirements for other electrodes are:

- *Local systems* – Local metallic underground systems such as piping, tanks, etc.
- *Pipe electrodes* – Pipe or conduit electrodes shall be not less than 8' in length nor smaller than ¾"

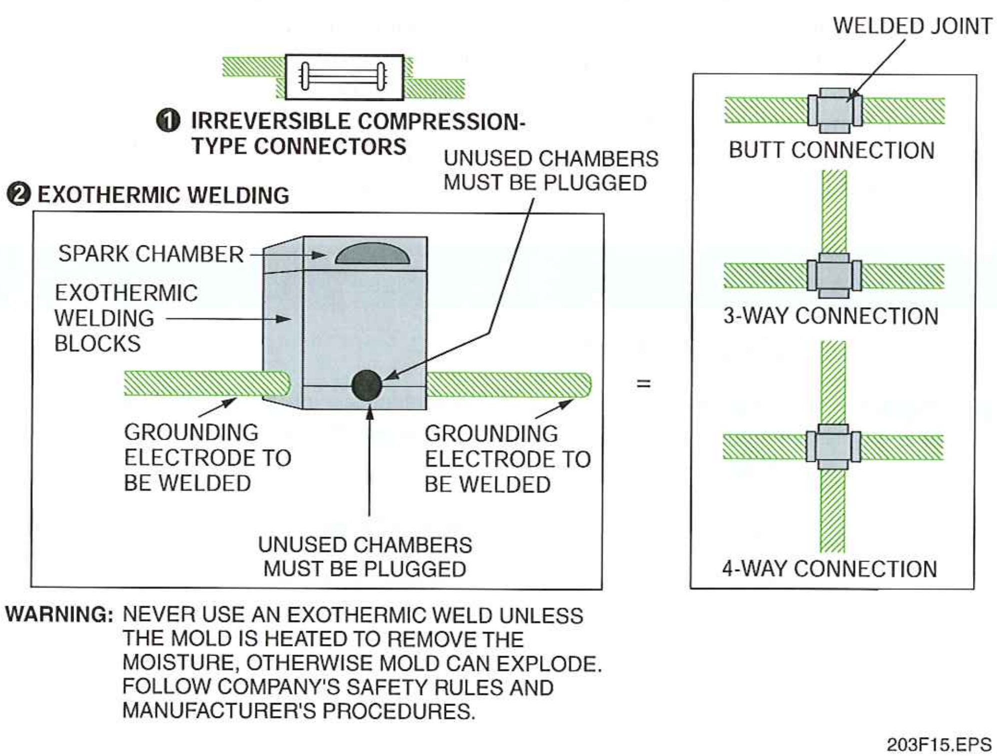


Figure 15 ◆ Methods of splicing grounding conductors.

Protection of Grounding Electrode Conductors

Grounding electrode conductor or enclosure must be securely fastened to the surface.

No. 4 or larger – If exposed to severe physical damage.

No. 6 – Run along surface, securely fastened or protected.

Smaller than No. 6 – Must be protected from damage (must be enclosed in rigid metal conduit).

Bare aluminum – Not allowed in contact with masonry, where subject to corrosive conditions, or within 18 inches of the earth.

203F16.EPS

Figure 16 ◆ Protection of grounding electrode conductors.

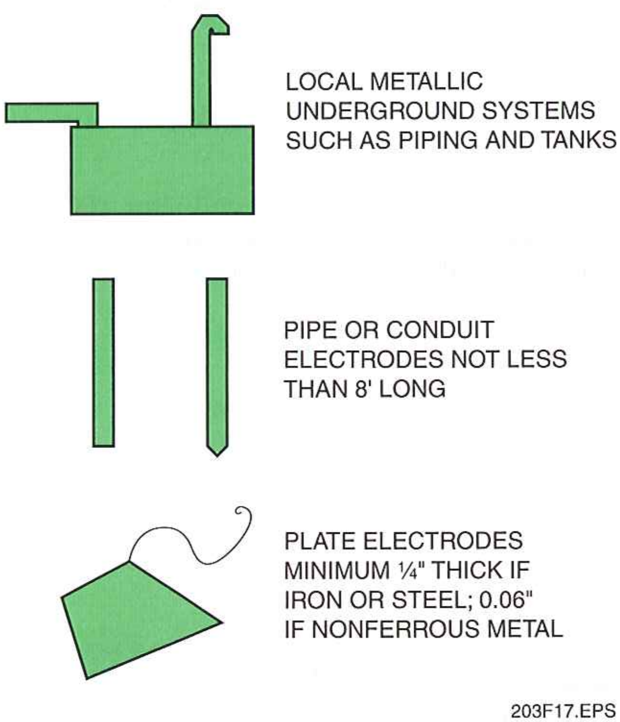


Figure 17 ◆ Other electrodes.

trade size, and if of iron or steel, shall be galvanized or metal-coated for corrosion protection.

- *Rod and pipe electrodes* – Electrodes of steel or iron shall be at least ⅝" in diameter. Rods of nonferrous metal or stainless steel that are less than ⅝" in diameter shall be listed and must be at least ½" in diameter.
- *Plate electrodes* – Electrodes shall have at least two square feet of surface in contact with exterior soil. If of iron or steel, the plate shall be at least ¼" thick. If of nonferrous metal, it shall be at least 0.06" thick.

NOTE

Underground metal gas piping systems are not permitted to be used as grounding electrodes. However, this does not eliminate the requirement that metal gas piping systems be bonded.

INSIDE TRACK

Exothermic Welding

Normally, the connections made by exothermic welding are permanent. They perform better than any crimped or bolted connection because the copper-to-copper or copper-to-steel bond is molecular, eliminating the risk of loosening or corrosion. Exothermic welded connections will carry more current than the conductor, resist repeated fault currents, and will not deteriorate with age.

Plate Electrodes

THINK ABOUT IT

Why does the *NEC*® require that 2' square electrode plates made of iron or steel be at least ¼" (0.25") thick, while 2' square electrode plates made of copper (a nonferrous metal) need only be 0.06" thick?

6.4.1 Installation of Rod, Pipe, and Plate Electrodes

Rod and pipe electrodes must be installed so at least 8' are in contact with the soil. Rods must be driven vertically unless rock obstruction is encountered. If an obstruction is encountered, the rod may be driven at not more than a 45° angle to clear the rock. The other possibility is for the rod to be buried in a trench that is at least 2.5' deep.

The upper end of the rod must be at or below surface level. The rod may be above ground, but at least 8' of rod must be beneath the surface.

7.0.0 ◆ EQUIPMENT GROUNDING

Figure 18 summarizes the equipment grounding rules for most types of equipment required to be grounded. These general *NEC*® regulations apply to all installations except for specific equipment (special applications) as indicated in the code. The *NEC*® also lists specific equipment that is to be grounded regardless of voltage.

In all occupancies, major appliances and many hand-held appliances and tools are required to be grounded. The appliances include refrigerators, freezers, air conditioners, clothes dryers, washing machines, dishwashing machines, sump pumps, and electrical aquarium equipment. Other tools likely to be used outdoors and in wet or damp locations must be grounded or have a system of double insulation.

7.1.0 Equipment Grounding Conductor

The equipment grounding conductor (EGC) is the conductor used to connect the noncurrent-carrying metal parts of equipment, raceways, and

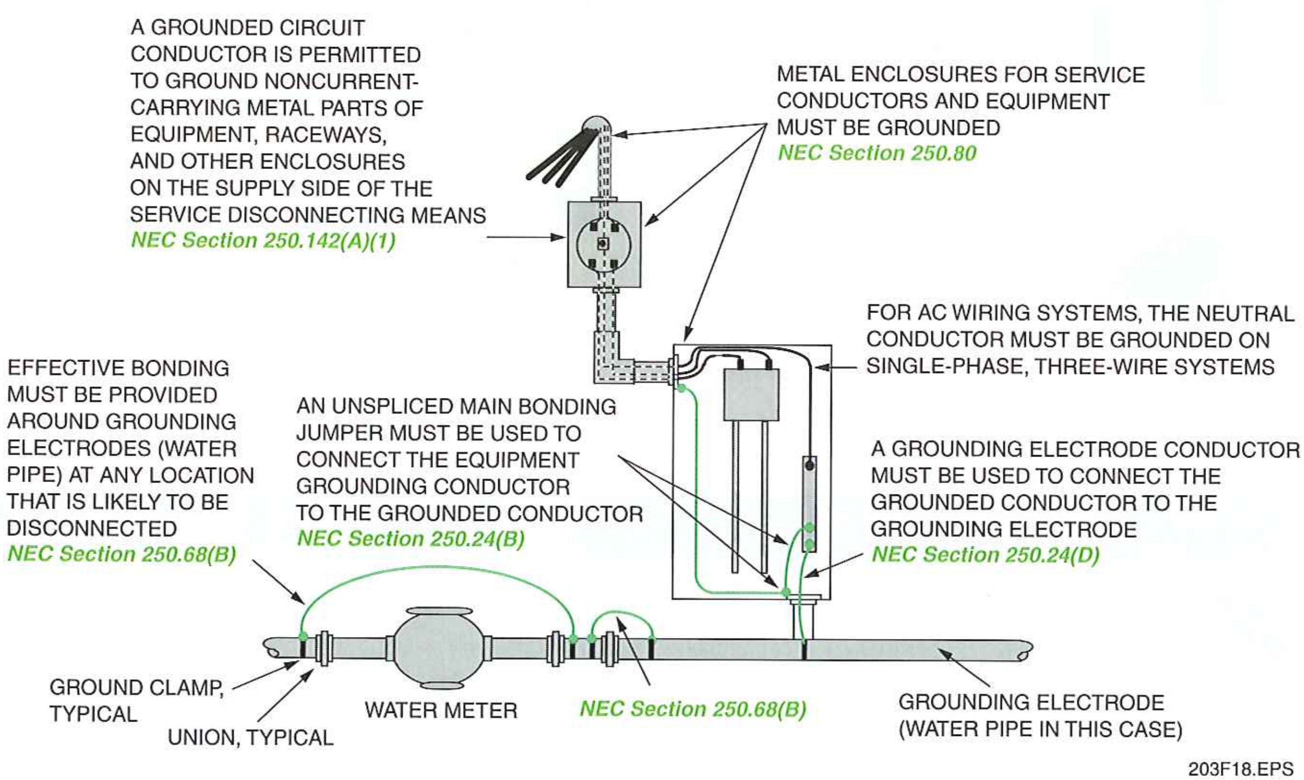


Figure 18 ◆ Equipment grounding summary.

other enclosures to the system grounded conductor and/or the grounding electrode conductor at the service equipment or at the source of a separately derived system.

7.1.1 Grounded and Ungrounded Systems

The EGC or path must extend from the farthest point on the circuit to the service equipment where it is connected to the grounded conductor. *Figure 19* shows an EGC and its path to ground when a ground fault occurs.

7.1.2 Sizing an EGC

EGCs carry fault current from the load to the grounded terminal bar of the service equipment. The size of the EGC is determined from the size of the overcurrent device that is protecting that particular system. *NEC Table 250.122* is used to determine the size of the EGC.

For example, if the ampacity is 400A, the overcurrent device is set at 400A. Use *NEC Table 250.122* and go down the left column until the desired ampacity or the next highest ampacity is found. For the 400A system, the size of the EGC is No. 3 copper wire or No. 1 aluminum or copper-clad wire.

NOTE

The size of the EGC is determined by the overcurrent protective device.

Determine the size of the EGC for a flexible metal conduit connection to a motor supplied with a 30A circuit.

Step 1 Using *NEC Section 348.60,* verify that an EGC is needed.

Step 2 Since this is an installation that requires flexibility, an EGC is required.

Step 3 The 30A circuit will have a 30A overcurrent protective device feeding the circuit.

Step 4 Find 30A in *NEC Table 250.122.*

Step 5 A No. 10 copper or No. 8 aluminum or copper-clad EGC is required for 30A.

Figure 20 shows the requirements for using flexible metal conduit as an equipment ground.

Another example to analyze would be a liquid-tight flexible metal conduit connection to a machine supplied by a 100A circuit.

CASE HISTORY

Mechanical Grounds

A technician was electrocuted recently while servicing a refrigeration unit for a walk-in cooler. The insulation on one of the power conductors inside the flexible metal conduit was damaged, resulting in electrical arcing to a conduit connector on the unit starter box. The conduit connection from the unit to the starter box was loose, thereby effectively disconnecting the mechanical ground from the unit. As the technician was servicing the unit, the thermostat caused the starter to close, energizing the surfaces of the unit and fatally shocking the technician.

The Bottom Line: This accident might have been prevented if one or more of the following procedures had been implemented:

- Proper preventive maintenance checks of all wiring and connections
- Proper lockout/tagout procedures
- Equipment grounding conductor provided along with the power feed conductors

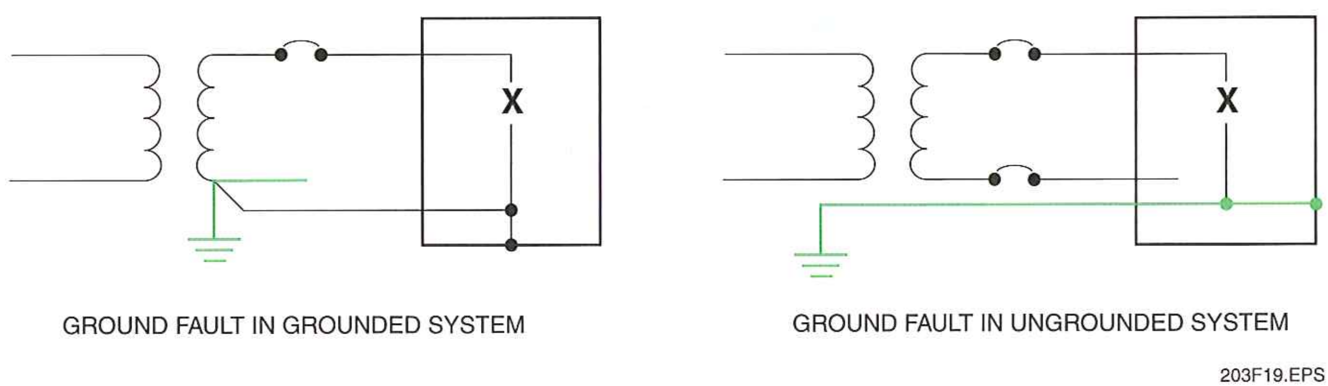


Figure 19 ◆ Ground faults.

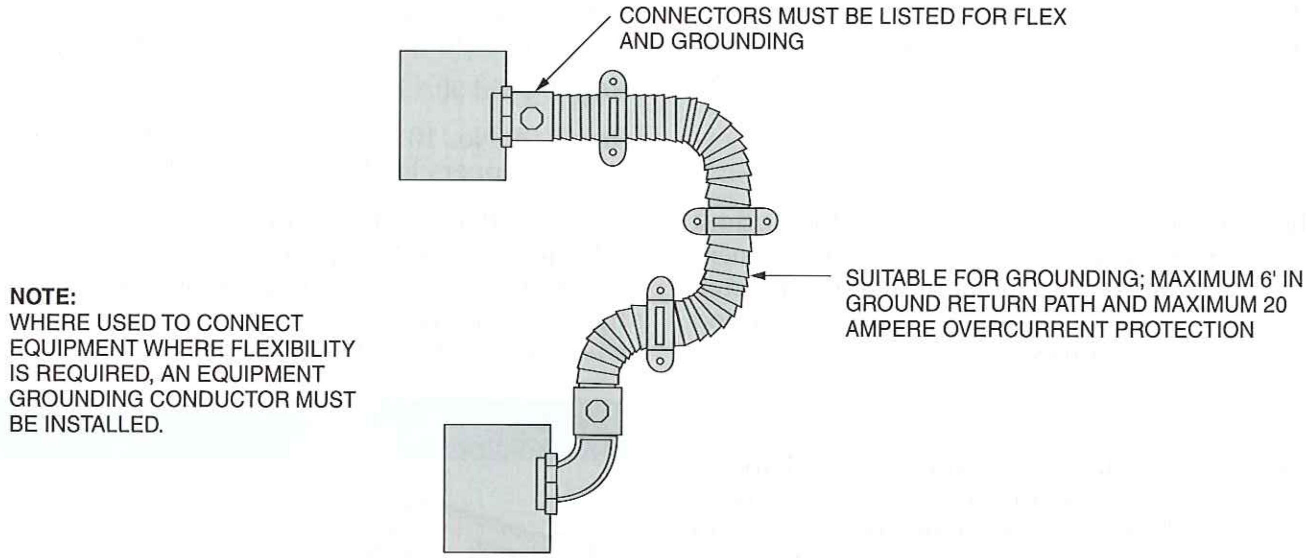


Figure 20 ◆ Installation requirements for flexible metal conduit.

Figure 21 details the requirements for using the conduit as the grounding conductor. After determining the requirements and the ampacity of this application, a No. 8 copper EGC would be required.

7.2.0 Grounding Enclosures

As previously mentioned, equipment grounding covers the metallic noncurrent-carrying parts of an electrical system. Such parts include metallic conduit, outlet boxes, enclosures, and frames on motors, and other electrically operated equipment. These items are bonded together to ensure operation of overcurrent devices in case of ground faults.

A bare or green-insulated grounding wire is usually attached to the metal frame or cabinet of the equipment. When connected to the circuit, this grounding wire is attached to the equipment grounding system that, in turn, was originally bonded to the system neutral busbar at the service-entrance equipment. When properly connected, if a live ungrounded wire should make contact with the frame or cabinet of a motor, appliance, or other metallic object in the system, a

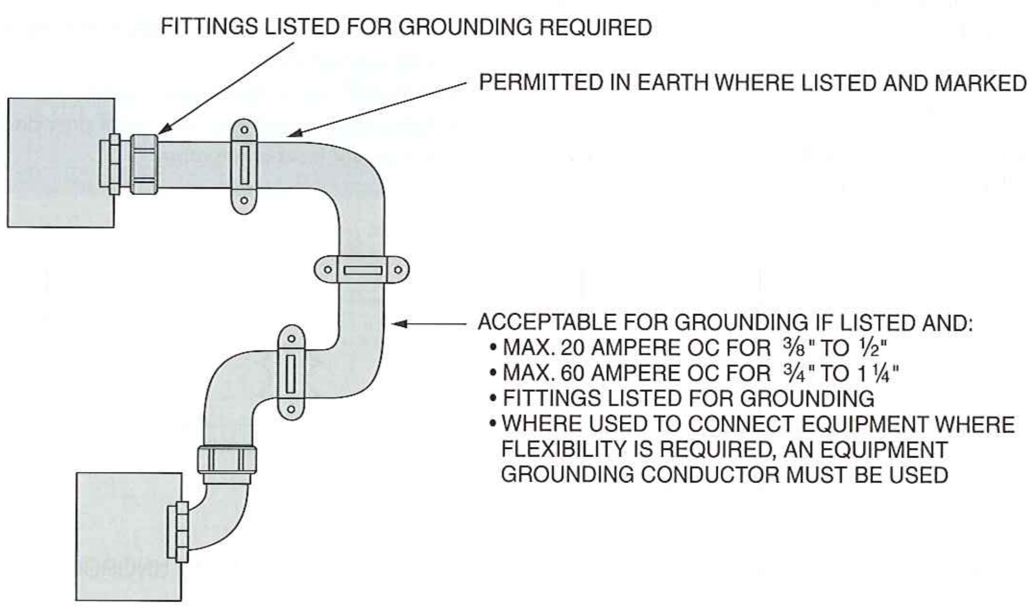


Figure 21 ◆ Installation requirements for liquidtight flexible metal conduit.

ground fault will occur and open the overcurrent protective device that is protecting the circuit. Consequently, equipment grounding is one of the best methods of protecting life and property should a ground fault occur.

7.2.1 Grounding Outlet Boxes and Devices

All receptacles used in residential, commercial, or industrial applications must be of the grounding type, which means that one of the receptacle openings connects the equipment ground to the appliance, tool, or other apparatus that is connected to the receptacles.

Ensuring continuity of the equipment grounding system to each receptacle can be handled in different ways, depending upon the wiring method used. For example, in most residential wiring systems, Type NM cable will be used. If metallic device boxes are used, the bare or green-insulated grounding wire must be attached to the box. This is accomplished by using either a **grounding clip**, as shown in *Figure 22*, or a screw designed for this purpose that is secured to the outlet box. *NEC Section 250.8* prohibits the use of sheet metal screws to connect grounding conductors to enclosures.

Figure 23 shows methods of providing a grounding conductor to duplex receptacles using several wiring methods. For example, if nonmetallic boxes are used with Type NM cable, no connection to the box itself is required. However, the equipment grounding conductor must be connected to the grounding terminal on the receptacle. If two or more cables enter the nonmetallic box, each of the equipment grounding wires must be connected with an approved connector, and one wire must then be attached to the grounding terminal on the receptacle. The terminal itself may not contain more than one grounding wire. Therefore, if more than one grounding wire enters the box, they must be spliced independently from the device, and then only one conductor may be attached to the device.

When metallic boxes are used, these equipment grounding wires must be attached to the box, along with the wiring device (receptacle). As mentioned previously, this may be accomplished with either a grounding clip or a grounding screw.

Any of the following are recognized by *NEC Section 250.118* as being adequate for use as an equipment grounding conductor:

- A copper or other corrosion-resistant conductor (solid or stranded; insulated, covered, or bare; and in the form of a wire or a busbar of any shape)
- Rigid metal conduit
- Intermediate metal conduit
- Liquidtight flexible metal conduit
- Electrical metallic tubing
- Flexible tubing
- Flexible metal conduit as permitted by *NEC Sections 250.118(5), 250.118(6), and 250.118(7)*
- Armor of Type AC cable
- The copper sheath of mineral-insulated, metal-sheathed cable
- The metallic sheath or the combined metallic sheath and grounding conductors of Type MC cable
- Cable trays as permitted in *NEC Sections 392.3(C) and 392.7*
- Cable bus framework as permitted in *NEC Section 370.3*
- Other electrically continuous metal raceways listed for grounding

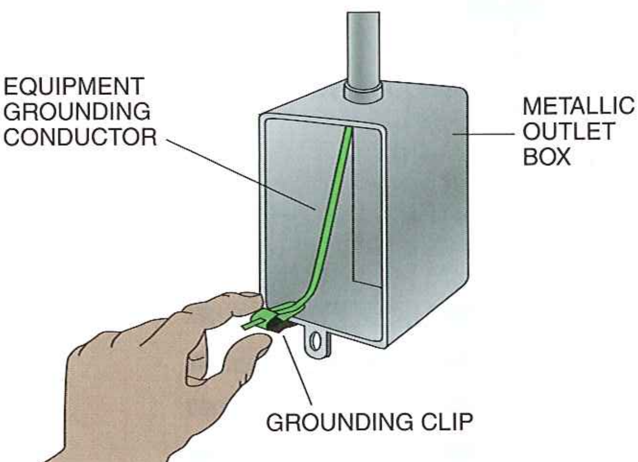


Figure 22 ◆ Grounding clip.

Sheet Metal Screws

Why does the *NEC*® prohibit the use of sheet metal screws to connect grounding conductors to enclosures?

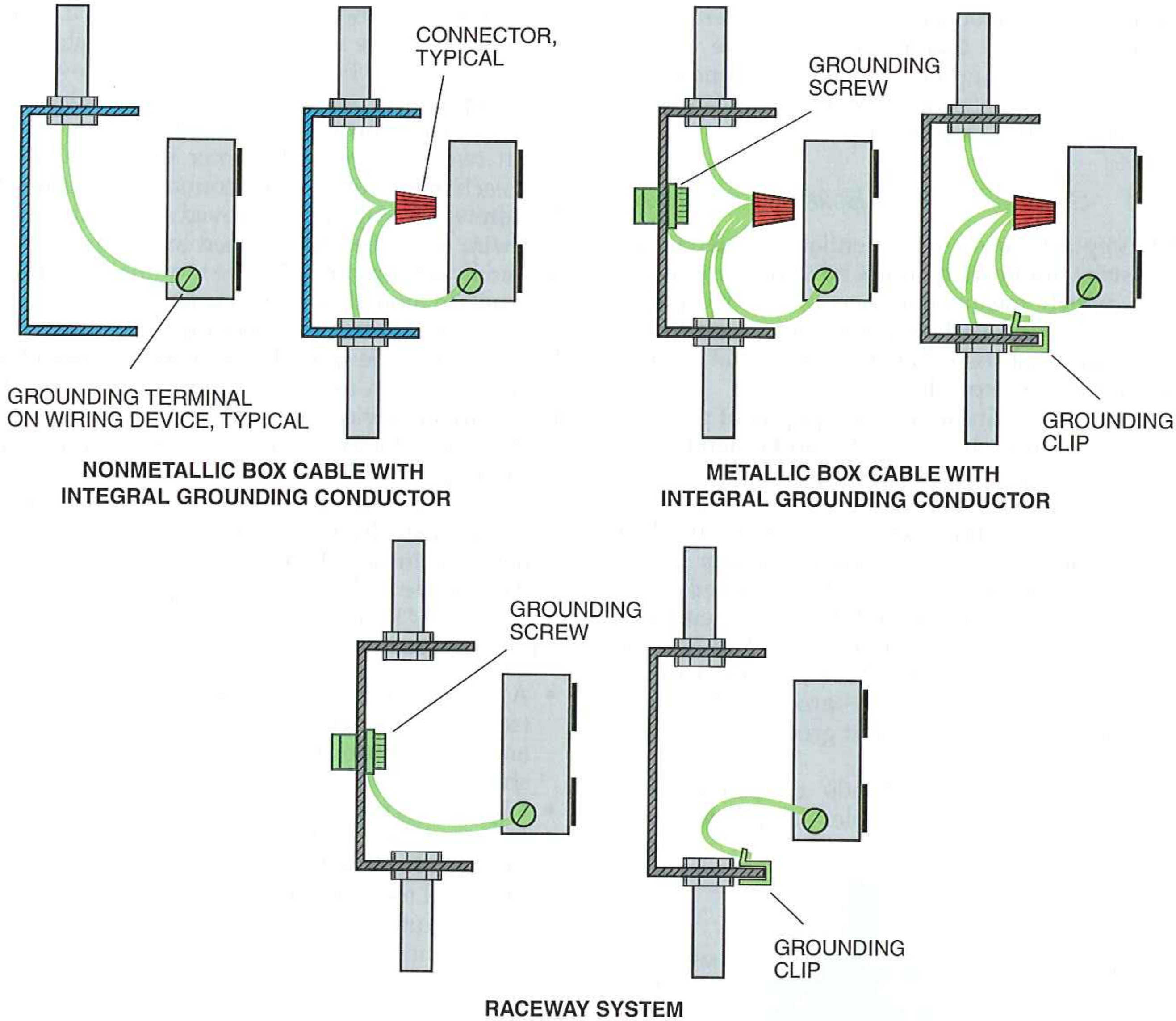


Figure 23 ◆ Grounding receptacles with different wiring methods.

7.3.0 Main Bonding Jumper

When a listed switchboard or panelboard is installed, the **main bonding jumper** that is provided with the equipment is rated for the size of conductors used for the service. The proper size of the main bonding jumper is verified by the listing agency and can be used without calculating the size.

Since the main bonding jumper must carry the full ground fault current of the system back to the grounded service conductor, its size must relate to the rating of the service conductors that supply the service. *NEC Table 250.66* is used to determine the size of the main bonding jumper. *Figure 24* shows how to calculate the size of the main bonding jumper when parallel runs are used.

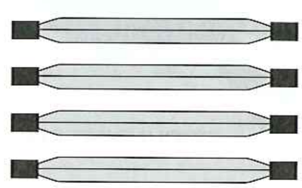


Figure 24 ◆ Main bonding jumper for parallel runs.

Grounding and Bonding

THINK ABOUT IT

When measuring voltage at a grounded duplex receptacle installed in a metal outlet box, you measure 120VAC between the hot and neutral terminals, 120VAC between the hot and ground terminals, and 120VAC between the hot terminal and the outlet box enclosure. You also measure 0VAC between the neutral and ground terminals. Does this represent a short circuit or ground fault?

Where the multiple conductors are larger than the maximum given in *NEC Table 250.66,* the jumper cannot be less than 12.5% of the area at the largest phase conductor [*NEC Section 250.28(D)*].

An example of three 500 kcmil copper conductors gives a total area of 1,500 kcmil. Because this is larger than that of *NEC Table 250.66,* we must take 12.5% of the total area. This is 187.5 kcmil. Since this is not a standard size conductor, we must refer to *NEC Chapter 9, Table 8.*

The table shows that the next larger conductor size in circular mils is 211,600. This gives a conductor of 4/0 AWG.

Bonding Jumpers

INSIDE TRACK

Use a bonding jumper to provide continuity at cable tray joints.

203P0302.EPS

8.0.0 ◆ BONDING SERVICE EQUIPMENT

Electrical continuity is the key to successful ground fault circuits. This continuity between service equipment and enclosures must be maintained by bonding. The items that are required to be bonded together are listed in *NEC Section 250.92(A)*. They include:

- The service raceways, cable trays, cable bus framework, or service cable armor or sheath
- All service equipment enclosures containing service conductors, including meter fittings, boxes, etc., interposed in the service raceway or armor
- Any metallic raceway or armor that encloses the grounding electrode conductor

NEC Section 250.92(B) defines the methods permitted to be used to ensure continuity at service equipment. These methods are:

- Bonding equipment to the grounded service conductor in a manner provided by *NEC Section 250.8*
- Connections utilizing threaded couplings or threaded bosses on enclosures when made up wrenchtight
- Threadless couplings and connectors when made up wrenchtight
- Other approved devices, such as bonding-type locknuts

The exception to this requirement is found in *NEC Section 250.84(A)*. This refers to an underground service cable that is metallically connected to the underground service conduit. The code states that if a service cable contains a metal armor, and if the service cable also contains an uninsulated grounded service conductor that is in continuous electrical contact with its metallic armor, then the metal covering of the cable is considered to be adequately grounded.

8.1.0 Bonding Multiple Service Disconnecting Means

Multiple disconnecting means can take several forms. *NEC Article 230* discusses the various forms.

Because this bonding jumper is located on the supply side of the service disconnect, the basic rule for sizing the **equipment bonding jumper** for bonding these various configurations is found in *NEC Section 250.102(C)*. This section requires the use of *NEC Table 250.66* for selecting the size. However, if the size of the service conductor is larger than 1,100 kcmil copper or 1,750 kcmil aluminum, the bonding jumper must have a cross-sectional area not less than 12.5% of the largest phase conductor. Where the service conductors are paralleled in two or more raceways, the equipment bonding jumper shall be run in parallel. The size of each bonding jumper shall be based on the largest phase conductor in each raceway or cable.

Table 1 shows various sizes of bonding jumpers based on the size of the service-entrance conductor.

Table 1 Bonding of Multiple Service Disconnecting Means

Service-Entrance Conductor	Bonding Jumper (Copper)
500 kcmil in service mast	1/0
1,000 kcmil in wireway	2/0
300 kcmil to 300A service	No. 2
3/0 to 200A service	No. 4
No. 2 to 125A service	No. 8

INSIDE TRACK

Multiple Load Centers

For installations in which the main service panel is located at a distance from areas that have many circuits and/or a heavy load concentration, subpanels may be installed near these loads. Doing so allows the branch circuit wiring runs to be shorter, resulting in lower line voltage losses than would occur if the branch circuits had been run all the way back to the main panel.

8.2.0 Bonding of Enclosures and Equipment

8.2.1 Bonding of Services Over 250 Volts

NEC Section 250.97 defines the methods permitted to be used on circuits over 250V. The methods permitted for these circuits are the same as for services, with the exception of using the service grounded conductors beyond the service.

Figure 25 shows examples of these bonding methods.

8.2.2 Bonding Multiple Raceway Systems

NEC Section 250.102(D) allows the use of a single conductor to bond two or more raceways or cables where the bonding jumper is sized in accordance with *NEC Table 250.122* for the largest overcurrent device supplying circuits therein. *Figure 26* shows bonding of multiple raceways.

It is acceptable to install one equipment bonding jumper individually from each raceway to the equipment grounding terminals of the equipment. This is shown in *Figure 27*. Each bonding conductor is sized per *NEC Table 250.122.*

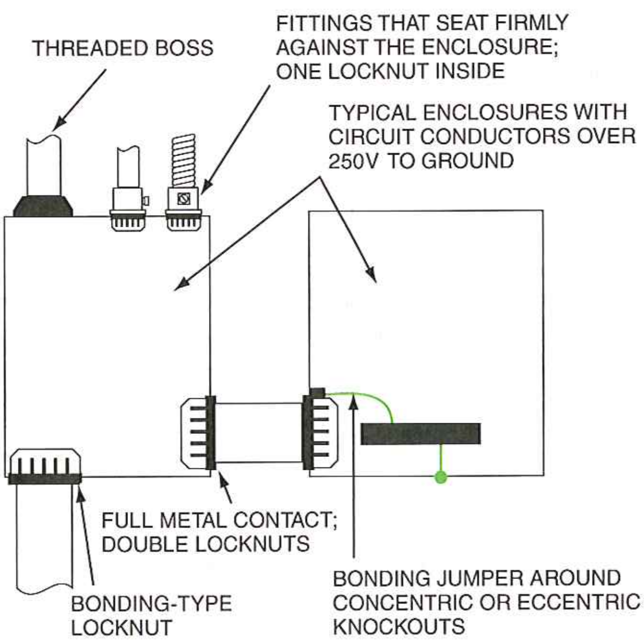


Figure 25 ◆ Bonding for circuits over 250 volts.

8.2.3 Installation of Equipment Bonding Jumper

The equipment bonding jumper is permitted to be installed either inside or outside of a raceway or enclosure. When the jumper is installed outside, the length is limited to not more than 6'. The bonding jumper must also follow the raceway routing. This is vital to keep the impedance of the equipment bonding jumper as low as possible.

Figure 28 shows a bonding jumper installed inside an enclosure.

> **NOTE**
> The equipment bonding jumper must be sized for the overcurrent device.

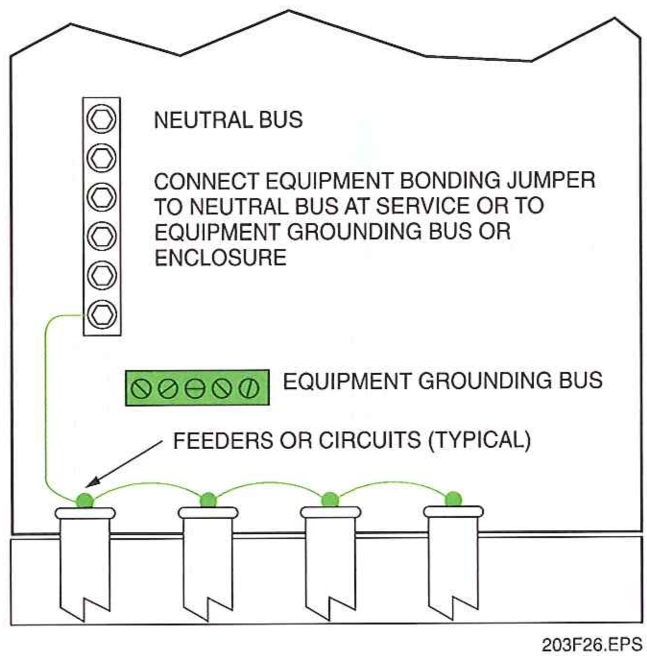
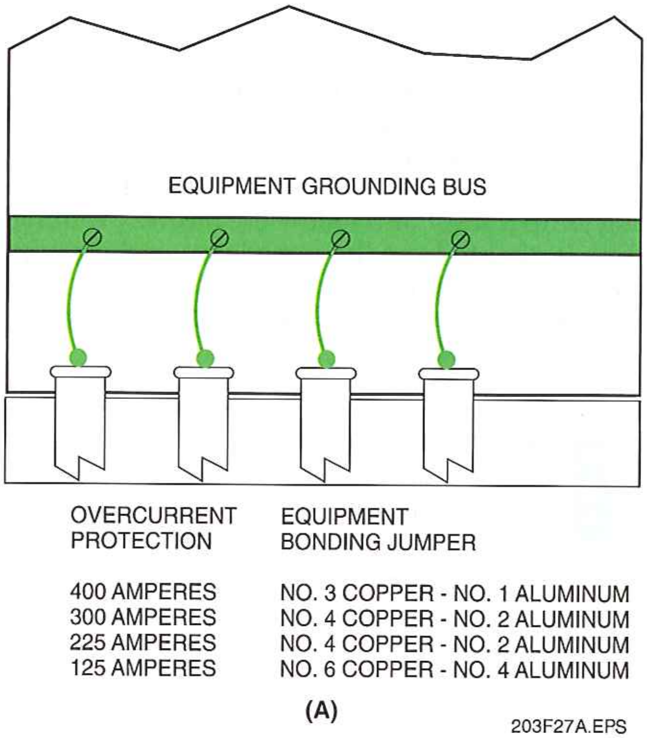


Figure 26 ◆ Bonding multiple raceways.



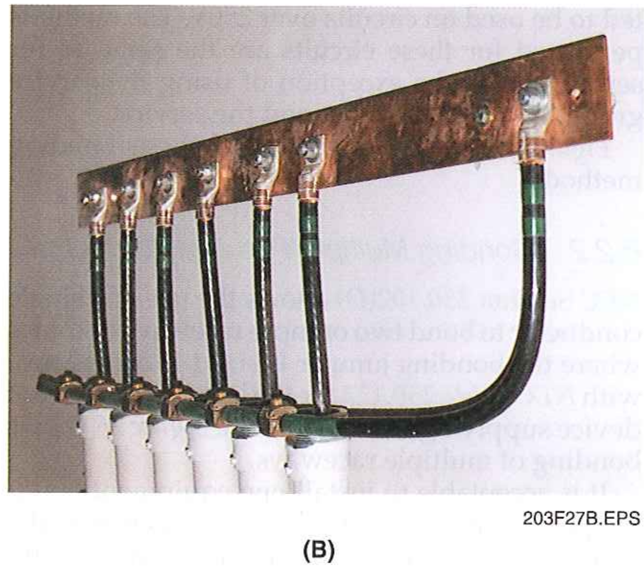


Figure 27 ◆ Individual bonding jumpers.

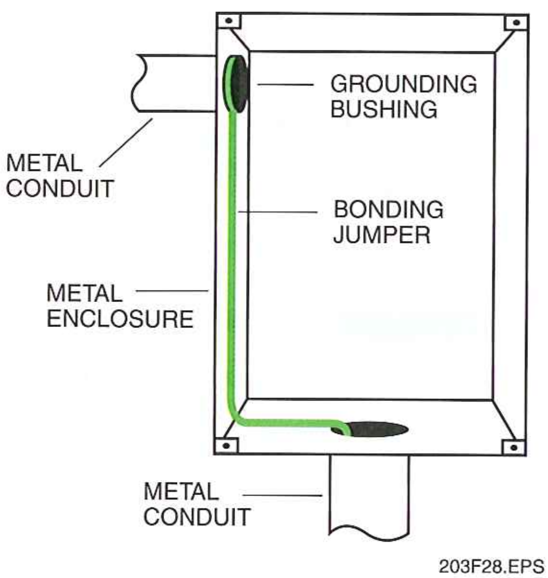


Figure 28 ◆ Bonding jumper.

9.0.0 ◆ EFFECTIVE GROUNDING PATH

As previously stated, to have effective grounding for both a grounded and an ungrounded system, the grounding system shall have an **effective grounding path** to provide a permanent and continuous path, sized to safely conduct any fault current that is likely to occur, and it shall have impedance that is low enough to limit the voltage to ground and to facilitate the operation of the circuit protective devices in the circuit.

Low impedance means that the grounding path and the circuit conductors must always be within the same raceway, or the raceway may provide the grounding path.

9.1.0 Clearing Ground Faults

A ground fault is a different circuit that becomes dependent on the impedance of the ground circuit. The current flow depends on the impedance. The higher the current, the harder it becomes to maintain voltage in the system. It is at this voltage that the short circuit capacity plays its role by attempting to maintain voltage. As the system tries to maintain voltage, its current will increase, and when the current reaches the overcurrent setting of the device, the system will be protected.

10.0.0 ◆ GROUNDED CONDUCTOR

The neutral in a grounded system serves two main purposes:

- It permits utilization of power at line-to-neutral voltage. This will allow the current-carrying conductor to carry any unbalanced current.
- It provides a low-impedance return path for the flow of fault current to the source to facilitate the operation of the overcurrent devices in the circuit.

Separately Derived Systems

INSIDE TRACK

The requirements of *NEC Section 250.30* pertaining to the grounding of separately derived AC systems are most commonly applied to 480Y/277V transformers that transform a 480V supply to a 208Y/120V system for lighting and appliance loads. The requirements provide for a low-impedance path to ground, so that line-to-ground faults on circuits supplied by the transformer will result in sufficient current flow to operate the overcurrent devices.

Figure 29 shows the path to ground for this neutral. If the neutral is not needed for voltage requirements, it still must be run to the service and connected to the grounded electrode conductor and equipment grounding conductor at the service.

11.0.0 ◆ SEPARATELY DERIVED SYSTEMS

Figure 30 shows a transformer-type separately derived system. This system has no direct electrical connection with the premises' source of electrical power. *NEC Section 250.20(D)* discusses whether or not a separately derived system is required to be grounded. Each voltage level that is required to be grounded must meet the requirements of *NEC Section 250.30(A)(1).* The grounding electrode conductor is connected to the grounded conductor within the enclosure. That connection will become a common point for the grounded conductor and the equipment grounding conductor where the common conductor shall be attached and run to the grounding electrode.

In *Figure 30*, the supply to the transformer will be at one voltage level while the secondary is at either a higher or a lower voltage level.

11.1.0 Grounding of Separately Derived Systems

For separately derived systems that are required to be grounded, an equipment grounding conductor must be supplied with the primary circuit. This will provide a low-impedance fault-current path from the transformer case to the

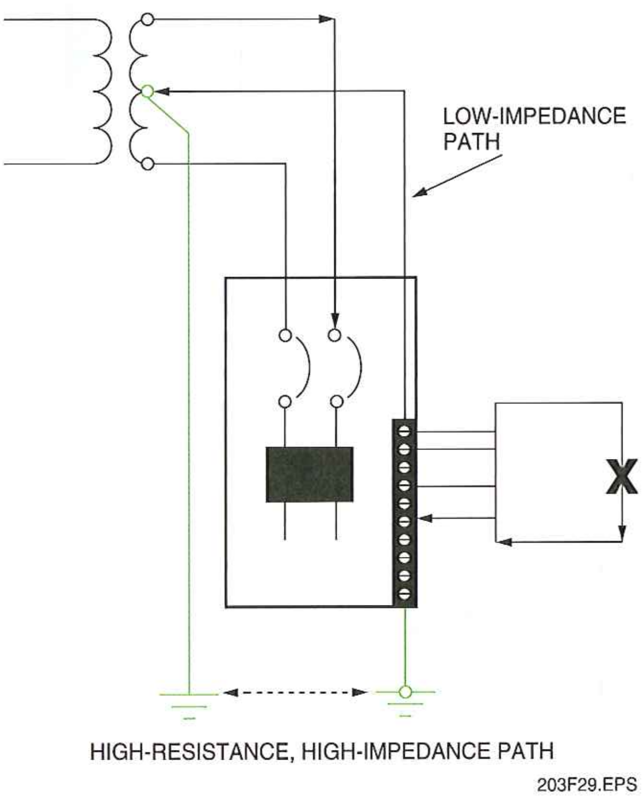


Figure 29 ◆ Grounded service conductor run to service.

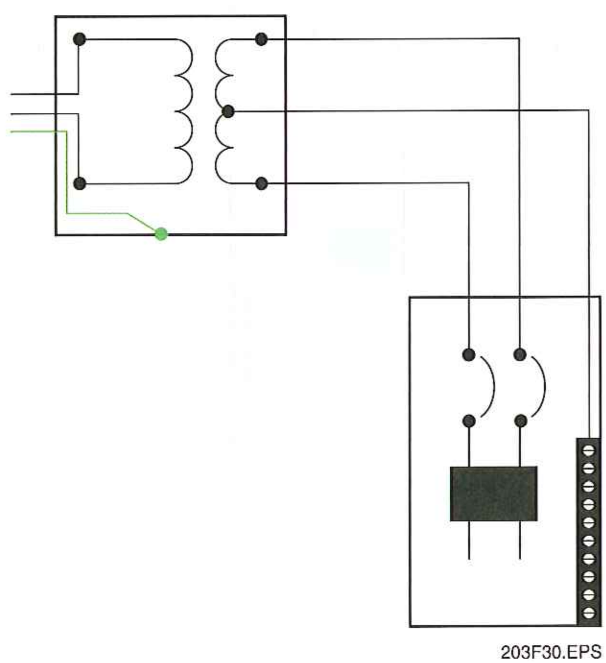


Figure 30 ◆ Transformer-type separately derived system.

main service. Along with the equipment grounding conductor, *NEC Section 250.30(A)(1)* requires a bonding jumper be installed for the derived system required to be grounded. This bonding jumper may be placed in either the transformer or the panel, but not in both. Installing it in both locations would create a parallel path with the grounded conductor, resulting in an unwanted current flow on the grounding conductor. Next, a grounding electrode conductor must be installed. This is illustrated in *Figure 31*.

The grounding electrode for separately derived systems must be:

- As near as practicable to the system
- The nearest available effectively grounded structural metal member or the nearest available effectively grounded water pipe
- Other electrodes where the above are not available (*NEC Sections 250.50 and 250.52*)

11.2.0 Generator-Type Separately Derived System

A simple generator-type separately derived system is shown in *Figure 32*.

The way to determine that a generator is a separately derived system is to examine the transfer switch. If the neutral and all phase conductors are switched, then the system is separately derived. If the neutral is not switched, but solidly connected, then the system is not a separately derived system.

The neutral bonding jumper must be installed either at the generator or any point in between. A grounding electrode conductor must be installed between the neutral and a grounding electrode.

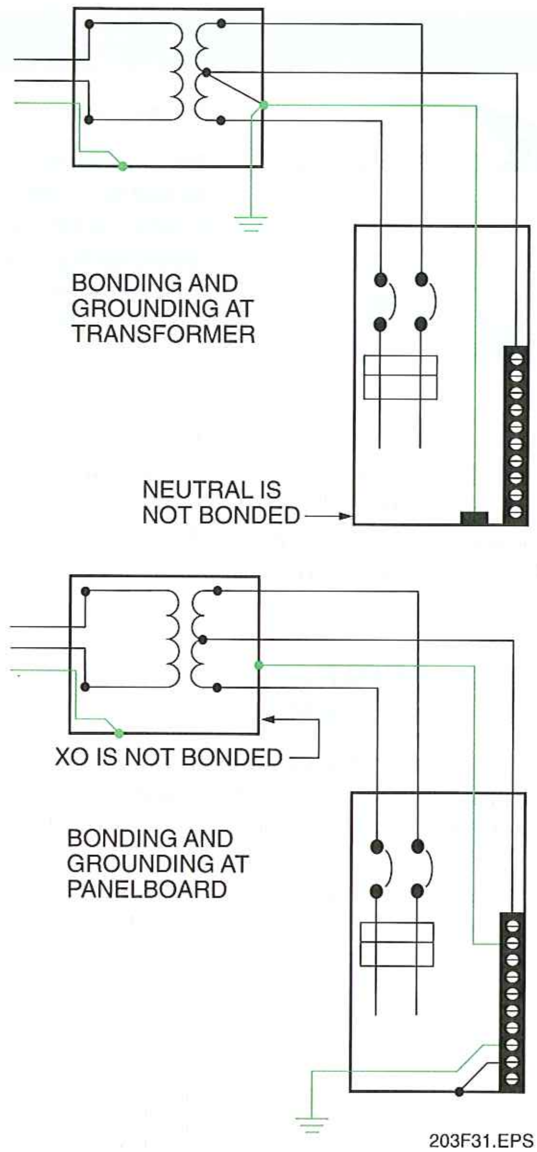


Figure 31 ◆ Separately derived system grounding and bonding locations.

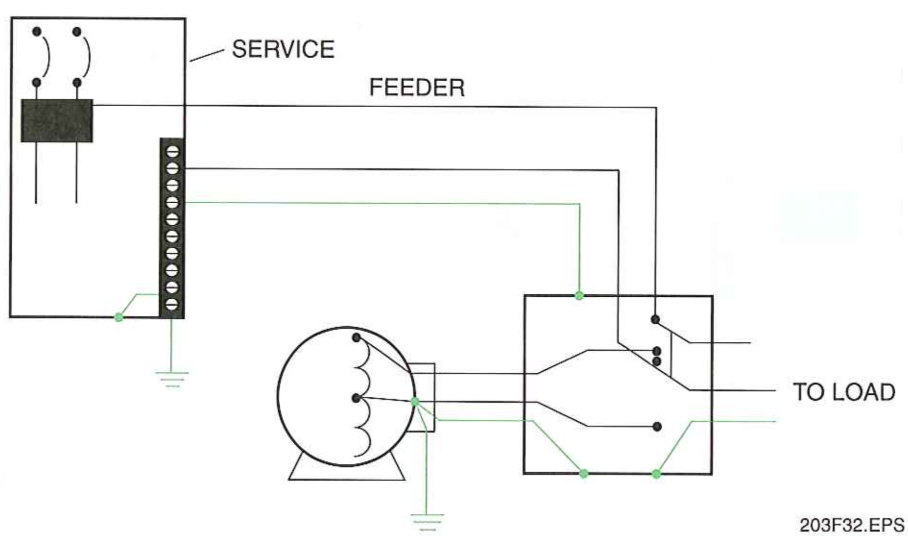


Figure 32 ◆ Generator-type separately derived system.

When the generator is not a separately derived system, the neutral bonding jumper must be removed from the generator and the neutral must not be grounded. Grounding is accomplished through direct connection to the neutral of the premises wiring.

12.0.0 ◆ GROUNDING AT MORE THAN ONE BUILDING

NEC Section 250.32 provides two general methods for grounding electrical systems at additional buildings on the premises.

In the first method, the grounded circuit conductor and the equipment grounding conductor are extended to the second building. The grounded conductor is terminated on an insulated bus isolated from the metal cabinet, while the grounding conductor from the main building is terminated on an equipment grounding terminal bus, directly connected to the cabinet. The equipment grounding conductor would be sized using *NEC Table 250.122* based on the overcurrent device supplying the second structure. All grounding electrodes present at the second building would connect to the grounding bus. The GEC in the second structure is sized using *NEC Table 250.66* based on the size of the feeder conductors. *Table 2* shows the number and type of conductors that must be taken from the first structure to where service is located in the second structure.

When no grounding electrodes are at the additional structures, a grounding electrode must be installed. These electrodes include underground metal pipes, the effectively grounded metal frame of the structure, or concrete-encased electrodes. Rod, pipe, or plate electrodes may also be permitted, in accordance with *NEC Section 250.52.*

In the second method, shown in *Figure 33*, no equipment ground is extended to the second building. The grounded conductor is extended to and terminated on a terminal bus that is bonded to the equipment, similar to the connection made at the grounded conductor at the service equipment. The grounded system will be connected to all grounding electrodes at the second building. In this case, the grounded conductor is sized using *NEC Sections 220.22 and 250.122.* This second method may only be used when an equipment grounding conductor is not run with the supply to the second building, there are no continuous metallic paths bonded to the grounding system in both buildings, and ground fault protection has not been installed on the common electrical service in the first building. These additional provisions prevent the possibility of parallel current paths between grounded and grounding conductors, as well as nuisance tripping of a ground fault protective device.

Table 2 Equipment Grounding Conductor Not Installed

System	Ungrounded	Grounded	Equipment Ground
120V	1	1	1
120/240V	2	1	1
208/120V	3	1	1
480/277V	3	1	1

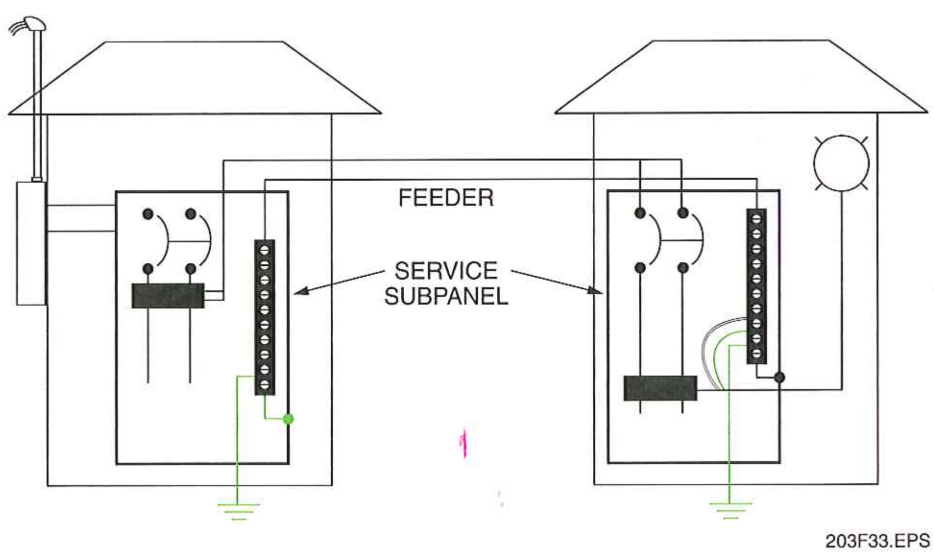


Figure 33 ◆ Grounding neutral at second building.

13.0.0 ◆ SYSTEMS OVER 1,000 VOLTS

NEC Article 250, Part X discusses the grounding requirements for high-voltage systems. It also lists a few additional requirements for derived neutral systems, solidly grounded neutral systems, and impedance-grounded neutral systems.

14.0.0 ◆ TESTING FOR EFFECTIVE GROUNDS

An earth ground resistance tester (*Figure 34*) may be used to make soil **resistivity** measurements or to measure the resistance to earth of the installed grounding electrode system.

NOTE

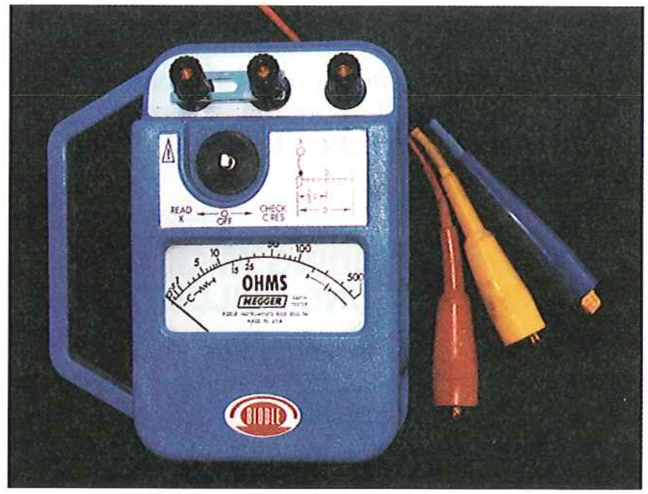
An ordinary ohmmeter is not used to measure the resistance of a grounding electrode to earth because it does not provide for adequate levels of current and voltage.

WARNING!

Ground testers can be hazardous to both equipment and personnel if improperly used. Always check with your supervisor before using a ground tester.

One use of the ground tester is for testing electrical systems after they are installed and before normal voltage is applied. This test is made after all the conductors, fuses or circuit breakers, panelboards, outlets, etc., are in place and connected. The current used for testing is produced by a small generator within the ground tester that generates DC power, either by turning a crank handle (also a part of the ground tester), or by using a small electric DC motor within the ground tester.

The test is made by connecting the terminals to the two points between which the test is to be made and then rapidly turning the handle on the ground tester. The resistance in ohms can then be read from the meter dial. Satisfactory insulation resistance values will vary under different conditions, and the charts supplied with the ground tester should be consulted for the proper value for a particular installation.



203F34.EPS

Figure 34 ◆ Earth ground resistance tester.

15.0.0 ◆ MEASURING EARTH RESISTANCE

An earth ground is commonly used as an electrical conductor for system returns. Although the resistivity of the earth is high compared to a metal conductor, its overall resistance can be quite low because of the large cross-sectional area of the electrical path.

Connections to the earth are made with grounding electrodes, **ground grids,** and **ground mats.** The resistance of these devices varies proportionately with the earth's resistivity, which in turn depends on the composition, compactness, temperature, and moisture content of the soil.

A good grounding system limits system-to-ground resistance to an acceptably low value. This protects personnel from a dangerously high voltage during a fault in the equipment. Furthermore, equipment damage can be limited by using this **ground current** to operate protective devices.

Ground testers measure the **ground resistance** of a grounding electrode or ground grid system. Some of the major purposes of ground testing are to verify the adequacy of a new grounding system, detect changes in an existing system, and determine the presence of hazardous **step voltage** and **touch voltage.**

In addition to personnel safety considerations, ground testing also provides information for equipment insulation ratings. Equipment can be damaged by an overvoltage that exceeds the rating of the insulation system. *Figure 35* depicts a poorly grounded system where the ground resistance (R_1) is 10Ω.

Assuming a power source resistance (R_2) of 40Ω, a short circuit between the 5,000V power line

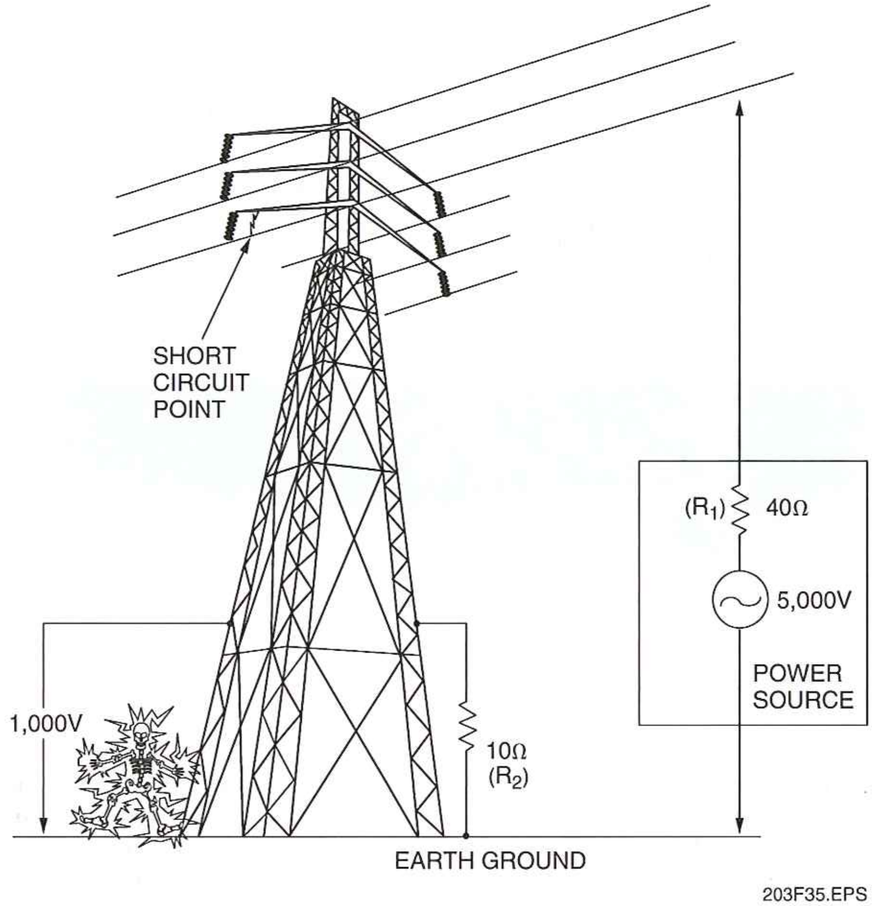


Figure 35 ◆ Poorly grounded system.

and the steel tower would produce 100A of short circuit current (I).

$$I = \frac{E}{R_1 + R_2} = \frac{5,000}{40 + 10} = 100\text{A of short circuit current}$$

A person touching the tower would be subjected to the voltage (E') developed across the ground resistance:

$$E' = IR = 100 \times 10 = 1,000 \text{ volts}$$
between power and ground

Statistics vary widely concerning what may be considered a dangerous voltage. This depends largely on body resistance and other conditions. However, to limit the touch voltage for this situation to 100V, the ground resistance for the tower would have to be less than 1Ω.

15.1.0 How the Ground Tester Works

Several methods are used for measuring the resistance to earth of a grounding electrode; one of the most common is the fall-of-potential method. See *Figure 36*.

In this method, **auxiliary electrodes** 1 and 2 are placed at sufficient distances from grounding electrode X. A current (I) is passed through the earth between the grounding electrode X and auxiliary current electrode 2 and is measured by the ammeter. The voltage drop (E) between the grounding electrode X and the auxiliary potential electrode 1 is indicated on the voltmeter. Resistance (R) can therefore be calculated as follows:

$$R = \frac{E}{I}$$

Certain problems may arise in measuring with the simple system shown in *Figure 36*:

- Natural currents in the soil caused by electrolytic action can cause the voltmeter to read either high or low, depending on polarity.
- Induced currents in the soil, instrument, or electrical leads can cause vibration of the meter pointer, interfering with readability.
- Resistance in the auxiliary electrode and electrical leads can introduce error into the voltmeter reading.

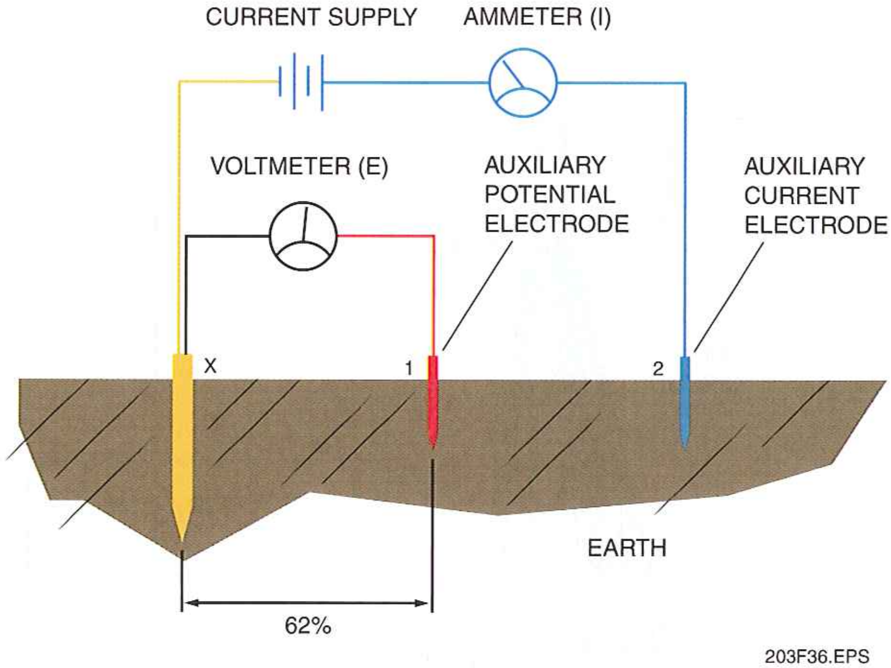


Figure 36 ◆ Fall-of-potential method of testing.

Most ground testers use a null balance metering system. Unlike the separate voltmeter and ammeter method, this instrument provides a readout directly in ohms, thus eliminating calculation. Although the integrated systems of the ground testers are sophisticated, they still perform the basic functions for fall-of-potential testing.

15.2.0 Current Supply

As in the simple circuit, the ground tester also has a current supply circuit (see *Figure 37*). This may be traced from grounding electrode X through terminal X, potentiometer R1, the secondary of power transformer T1, terminal 2, and auxiliary current electrode 2. This produces a current in the earth between electrodes X and 2.

When switch S1 is closed, battery B energizes the coil of vibrator V. Vibrator reed V1 begins oscillating, thereby producing an alternating current in the primary and secondary windings of T1. The negative battery terminal is connected alternately across first one and then the other half of the primary winding.

15.3.0 Voltmeter Circuit

The voltmeter circuit can be traced from grounding electrode X through terminal X, the T2 secondary, switch S2, resistors R2 and R3 (paralleled by the meter and V2 contacts), capacitor C, terminal 1, and auxiliary potential electrode 1. The current in the earth between grounding electrode X and auxiliary current electrode 2 creates a voltage drop due to the earth's resistance. With auxiliary potential electrode 1 placed at any distance between grounding electrode X and auxiliary current electrode 2, the voltage drop causes a current in the voltmeter circuit through balanced resistors R2 and R3. The voltage drop across these resistors causes galvanometer M to deflect from zero center scale.

Vibrator reed V2 operates at the same frequency as V1, thereby functioning as a mechanical rectifier for galvanometer M. The vibrator is tuned to operate at 97.5 hertz (Hz), a frequency unrelated to commercial power line frequencies and their harmonics. Thus, currents induced in the earth by power lines are rejected by most ground testers and have virtually no effect on their accuracy. Stray direct current in the earth is blocked out of the voltmeter circuit by capacitor C.

The current in the primary of T2 can be adjusted with potentiometer R1. Primary current in T2 induces a voltage in the secondary of T2, which is opposite in polarity to the voltage drop caused by current in the voltmeter circuit.

With R1 adjusted so the primary and opposing secondary voltages of T2 are equal, current in the voltmeter circuit is zero, and the galvanometer reads zero. The resistance of grounding electrode X can then be read on the calibrated dial of the potentiometer.

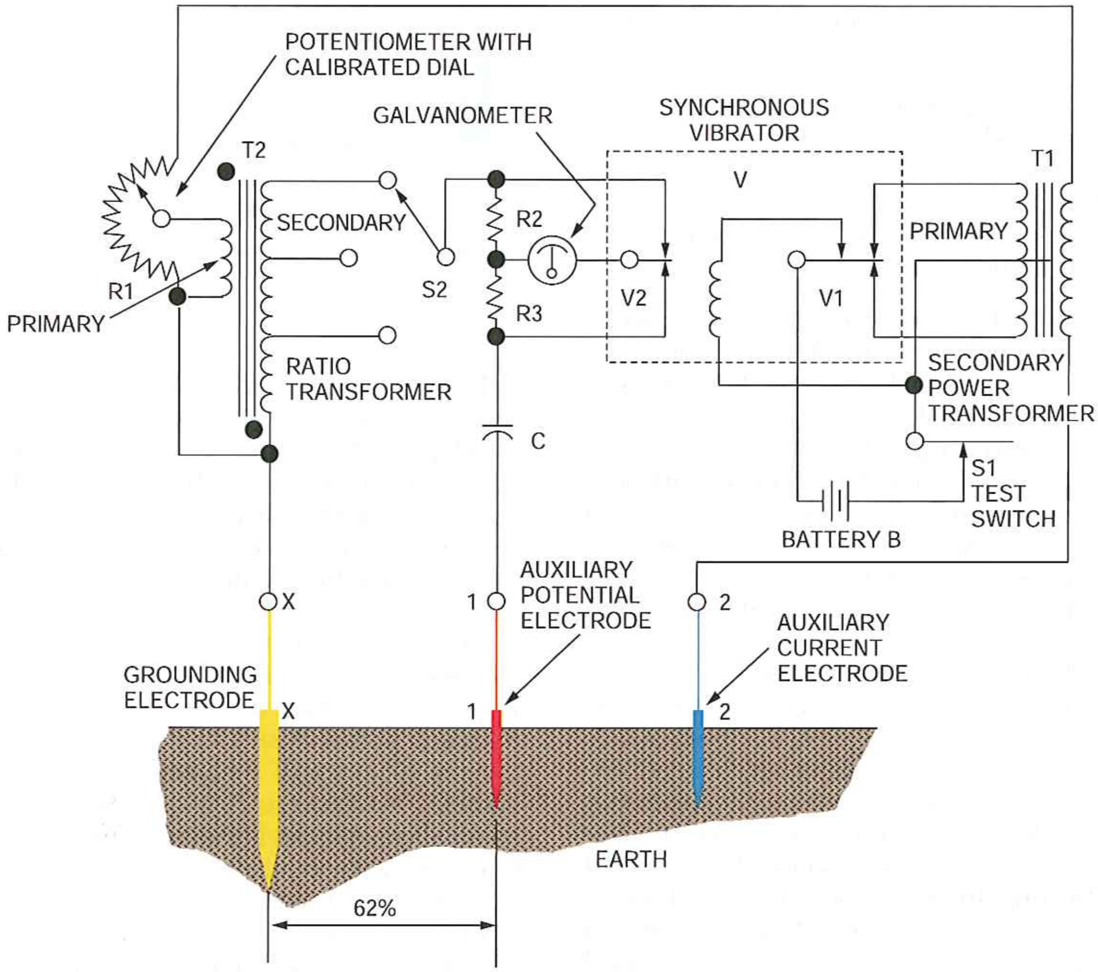


Figure 37 ◆ Three-point testing using a ground tester.

With no current in the voltmeter circuit, the lead resistance of the auxiliary potential electrode 1 has no bearing on accuracy. (With no current, there is no voltage drop in the leads.) Resistance to earth of the current electrode results only in a reduction of current, and consequently, a loss of sensitivity. Therefore, the auxiliary electrodes need only be inserted into the earth 6" to 8" to make sufficient contact. In some locations, where the soil is very dry, it may be necessary to pour water around the current electrode to lower the resistance to a practical value.

15.4.0 Nature of Earth Electrode Resistance

Current in a grounding system is primarily determined by the voltage and impedance of the electrical equipment. However, the resistance of the grounding system is very important in determining the voltage rise between the ground electrode and the earth as well as the voltage gradients that will occur in the vicinity when current is present.

THINK ABOUT IT

Size and Depth of Ground Electrode

What effect do the diameter and driven depth of a ground electrode have on its resistance?

Three components constitute the resistance of a grounding system:

- Resistance of the conductor connecting the ground electrode
- Contact resistance between the ground electrode and the soil
- Resistance of the body of earth immediately surrounding the electrode

Resistance of the connecting conductor can be dealt with separately since this is a function of the conductor cross-sectional area and length. Contact resistance is usually negligibly small if the electrode is free from paint or grease. Therefore, the main resistance is that of the body of earth immediately surrounding the electrode. Current from a grounding electrode flows in all directions via the surrounding earth. It is as though the current flows through a series of concentric spherical shells, all of equal thickness.

The shell immediately surrounding the electrode has the smallest cross-sectional area, and therefore its resistance is highest. As the distance from the electrode is increased, each shell becomes correspondingly larger; thus, the resistance becomes smaller. Finally, a distance from the electrode is reached where additional shells do not add significantly to the total resistance. From a theoretical viewpoint, total resistance is included only when the distance is infinite. For practical purposes, only the volume that contributes the major part of the resistance need be considered. This is known as the effective resistance area and depends on electrode diameter and driven depth.

16.0.0 ◆ THREE-POINT TESTING PROCEDURE

To measure resistance of a grounding electrode with most ground testers, an auxiliary current electrode and an auxiliary potential electrode are required (see *Figures 38* and *39*). The current electrode is placed a suitable distance from the grounding electrode under test, and the potential electrode is then placed at 62% of the current electrode distance.

NOTE

The 62% figure has been arrived at by empirical data gathered by many authorities on ground resistance measurement, and in some cases, has been computed based on analysis of an equivalent hemisphere.

If the current electrode is too near the grounding electrode, their effective resistance areas will overlap, as shown in *Figure 38*. If a series of measurements are made with the potential electrode driven at various distances in a straight line between the current electrode and grounding electrode, the readings will yield a curve as illustrated in *Figure 38*.

In *Figure 39*, a curve is plotted with the current electrode at a sufficient distance from the grounding electrode. Note that the curve is relatively flat between points B and C, which are usually considered to be at ±10' with respect to the 62% point. Usually, a tolerance is established for the maximum allowable deviation for the second and third readings with relation to the initial reading at 62%. This tolerance is a certain ±% of the initial reading, such as ±1%, ±2%, etc.

No definite distance from the current electrode can be forecast since the optimum distance is based on the homogeneity of the earth, depth of the grounding electrode, diameter, etc. However, for a starting point for a single driven grounding electrode, the effective radius of the equivalent hemisphere can be computed. The curve of *Figure 40* can then be used for initial placement of the auxiliary electrodes. Using the practical method of moving the auxiliary potential electrode 10' to either side of the 62% point, a curve can be plotted to determine if the current electrode spacing is adequate, as depicted by the curve flattening out between points B and C in *Figure 39*.

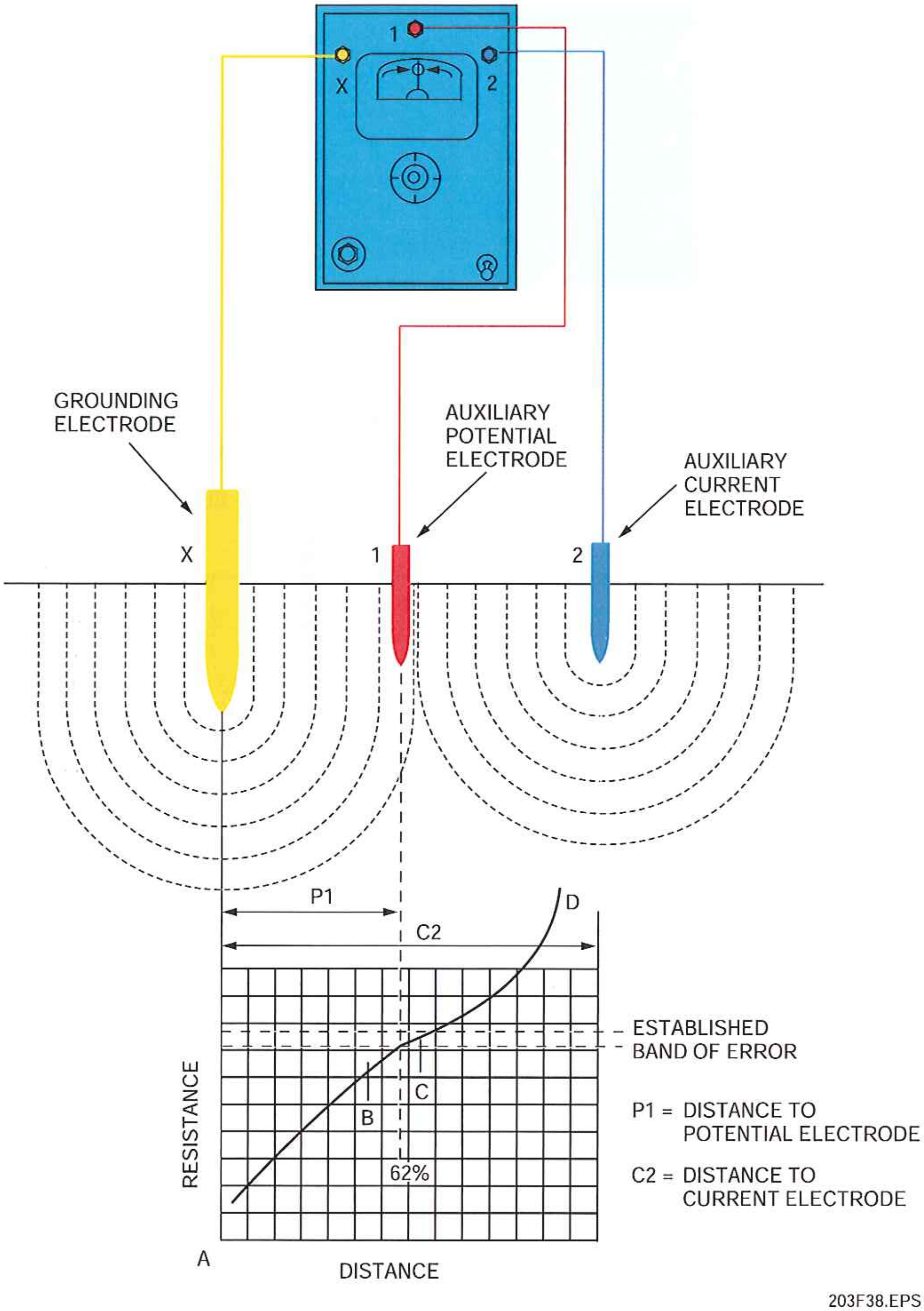


Figure 38 ◆ Plotted curve showing insufficient electrode spacing.

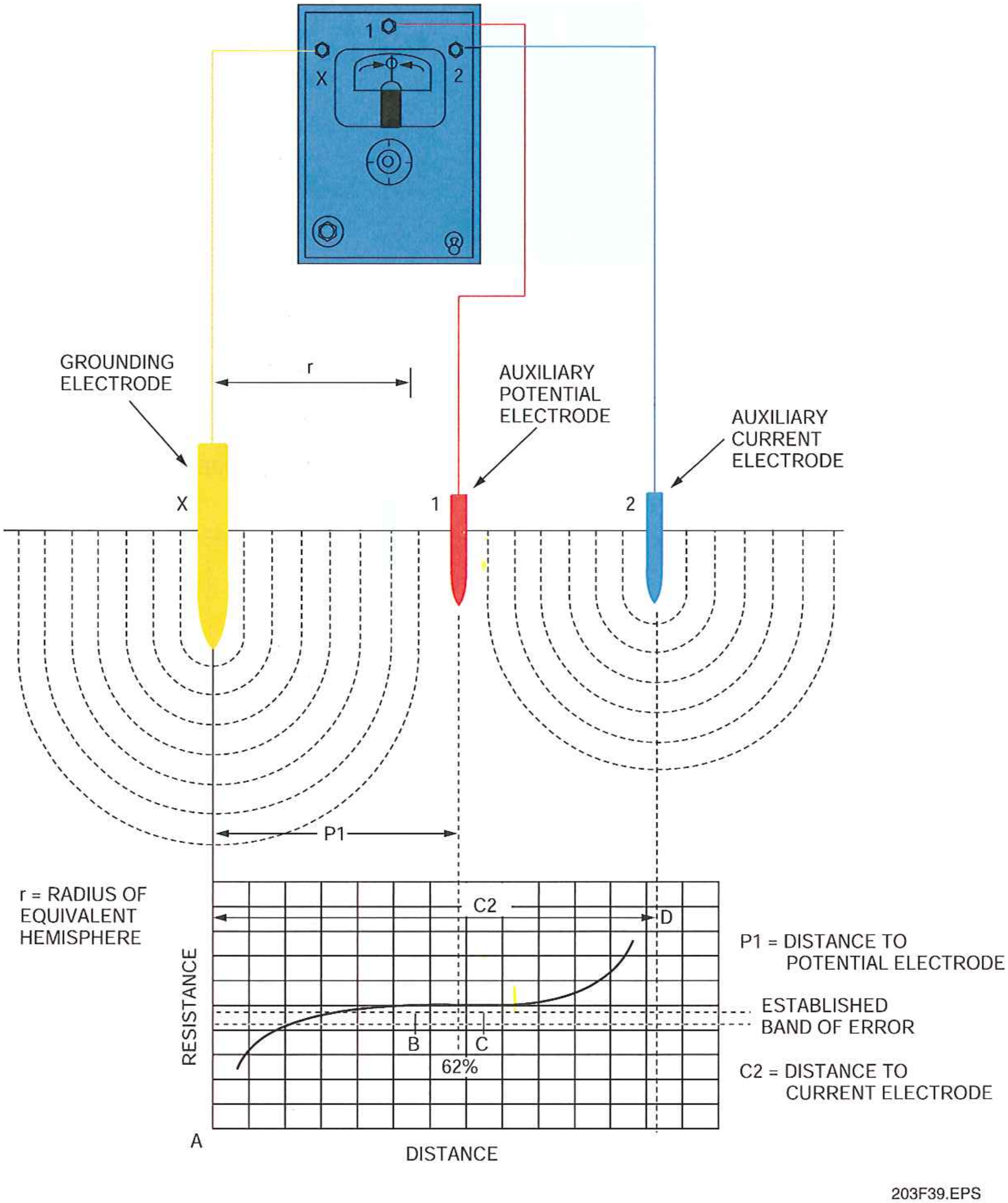


Figure 39 ◆ Plotted curve showing adequate electrode spacing.

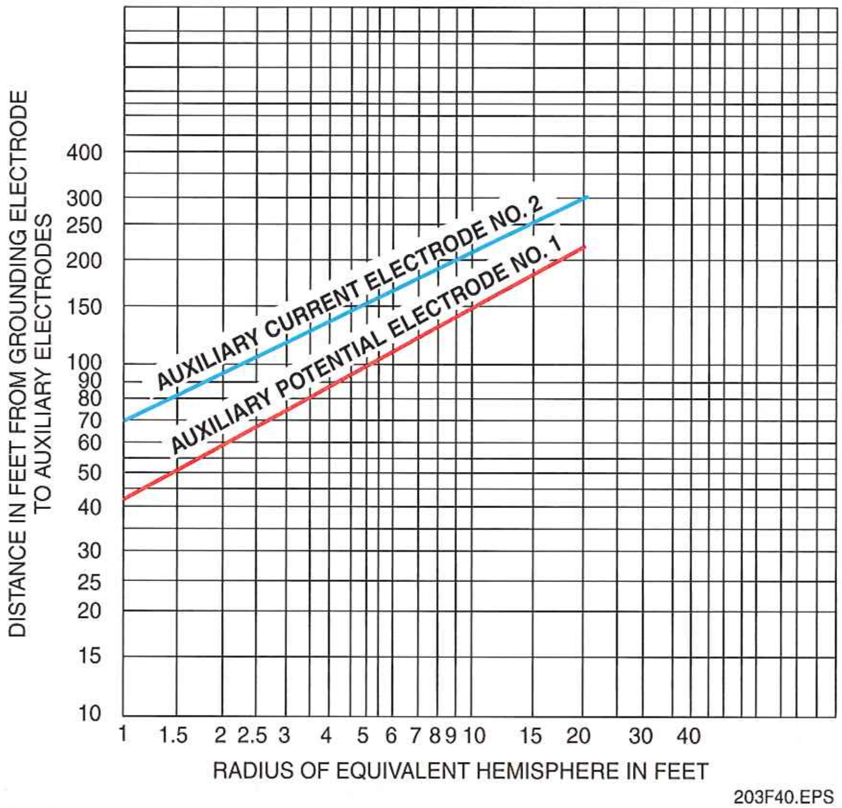


Figure 40 ◆ Auxiliary electrode distance/radii chart.

INSIDE TRACK

Testing Station Grounds

A lethal potential can exist between the station ground and a remote ground if a system fault involving the station ground occurs while earth resistance tests are being made. Since one of the objectives of tests on a station ground is to establish the location of an effectively remote point for both current and potential electrodes, the leads to the electrodes must be treated as though a possible potential could exist between these test leads and any point on the station ground grid.

For example, assume that a 1" (2.54 cm) diameter grounding electrode is buried 10' (3.0 m) deep. The equivalent hemisphere radius is 1.7' (51.8 cm). Using *Figure 40*, the current electrode would be established at approximately 90' (27 m), and the potential electrode at approximately 55' (17 m) for the initial reading. The results obtained when the potential electrode is moved (to 45' [14 m] and then to 65' [20 m]) will determine if the current electrode, and consequently the potential electrode, must be spaced at a greater distance.

It is usually advisable to plot a complete curve for each season of the year. See *Figure 41*. These curves should be retained for comparison purposes. Measurements at established intervals in the future need only be made at the 62% point and, if desired, 10' on each side, providing there is no erratic deviation from the original curve. Serious deviation, other than seasonal, could mean corrosion has eaten away some of the electrode.

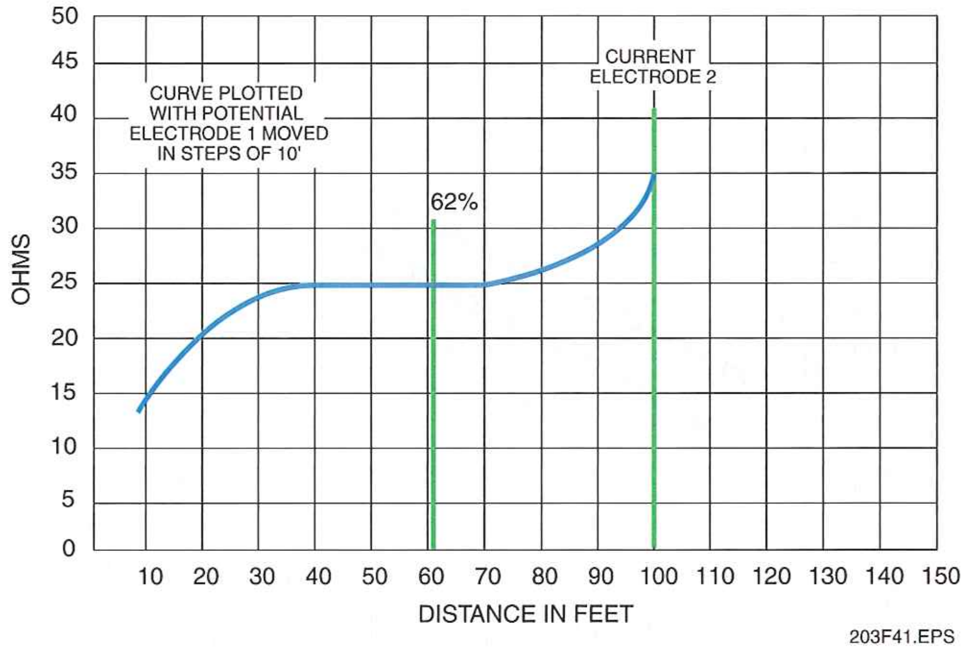


Figure 41 ◆ Typical grounding resistance curve to be recorded and retained.

16.1.0 Operating Procedure

Establish the proper location for the auxiliary current electrode and auxiliary potential electrode as follows:

Step 1 Determine the effective radius of the equivalent hemisphere in feet for the grounding electrode depth in feet, as well as the grounding electrode diameter in inches, using the curves in *Figure 42*.

Step 2 Using this effective radius and the data in Figure 40, determine the distances for the auxiliary current electrode No. 2 and auxiliary potential electrode No. 1 from the ground electrode.

Step 3 Position the ground tester in a suitable location near the grounding system to be tested.

Step 4 Using a test lead of less than 0.05Ω resistance, connect the tester terminal X to the grounding electrode or grounding grid to be measured, terminal 1 to the auxiliary potential electrode, and terminal 2 to the auxiliary current electrode (less than 1Ω).

Step 5 If the general range of resistance to be measured is anticipated, then set the MULTIPLY BY switch to a multiplying factor within this range. If unknown, select the highest multiplier range first.

Step 6 Move the TEST switch to the ADJ position. Rotate the OHMS control knob until the galvanometer indicates balance at center scale.

NOTE

Meter instructions will vary depending on the instrument used. Consult the manufacturer's operating manual.

Step 7 Should the galvanometer indication remain to the right of center scale with the OHMS control at zero, set the MULTIPLY BY switch to the adjacent lower range.

Step 8 Should the galvanometer indication remain to the left of center scale with the OHMS control fully clockwise, set the MULTIPLY BY switch to the adjacent higher range.

Step 9 After balance is achieved with the TEST switch in the ADJ position, move this switch to the READ position and rebalance the galvanometer using the OHMS control.

Step 10 Read the resistance on the calibrated OHMS scale. If this indication is less than $\frac{1}{10}$ of full range, set the MULTIPLY BY switch to the adjacent lower range and rebalance the galvanometer. (This provides better readability and resolution.)

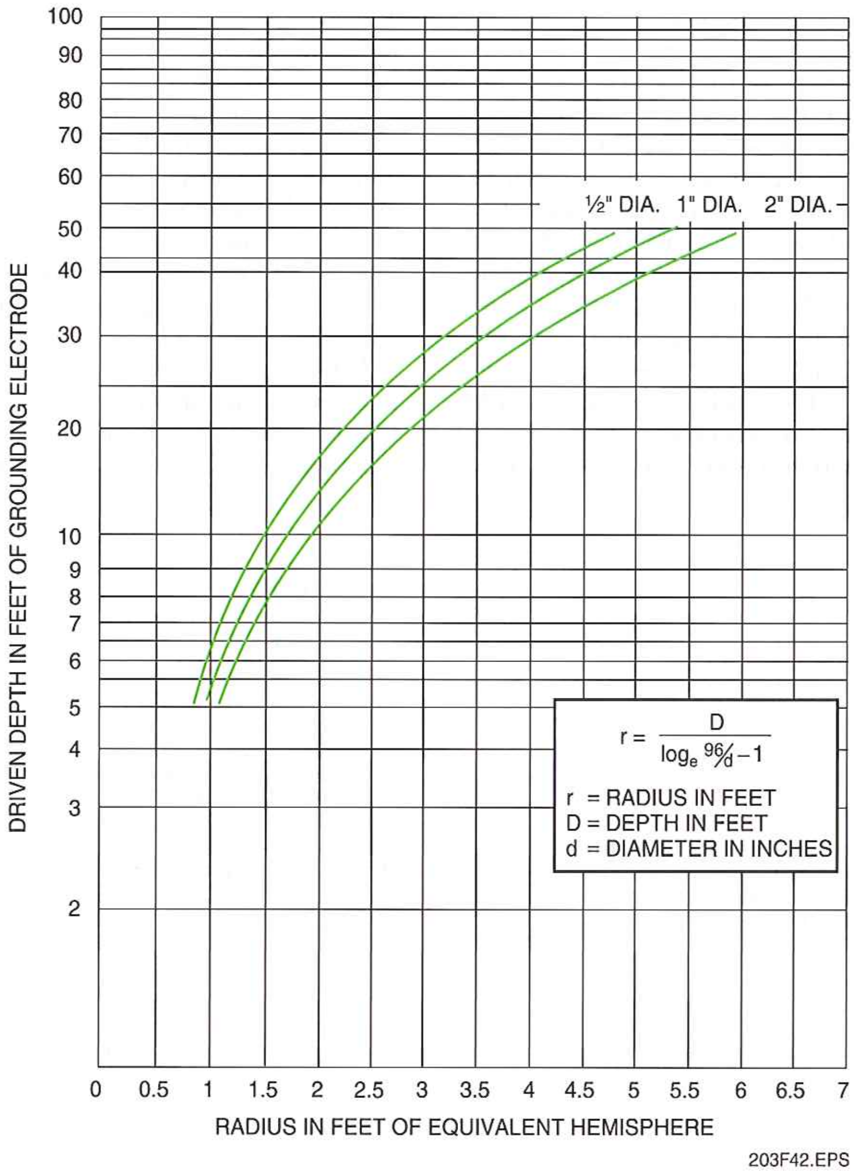


Figure 42 ◆ Ground rod depth versus equivalent hemisphere radii.

Step 11 Multiply the OHMS scale indication by the factor indicated by the MULTIPLY BY switch. This product is the resistance of the grounding system connected to terminal X. Record this resistance value. (If balance cannot be achieved under any conditions, check the test leads. Ensure that the leads are properly connected, as described in Step 4. If the trouble persists, the grounding system may be inadequate due to a high resistance beyond the range of the tester.)

Step 12 Move the auxiliary potential electrode 10' on each side of the 62% point, as shown by points B and C in *Figure 39*, and repeat Steps 5 through 11 for each. Record this resistance value.

Step 13 Compare the resistance values obtained in Steps 11 and 12. They should be within the established tolerance band as explained previously. If they are not within the established tolerance, move the auxiliary current and potential electrodes to a point farther away from the ground under test and repeat Steps 4 through 12. Record the resistance values obtained.

A single driven rod is an economical and simple means of making a grounding electrode. In general, however, a single driven rod does not provide a sufficiently low resistance, and consequently, several rods must be driven and connected in parallel by a grounding conductor or cable. Although these rods are connected as they would be in parallel resistance, their total resistance does not follow the usual law for computing resistances in parallel. To attain the full effect of resistances in parallel, these rods would have to be spaced at such distances that the effective resistance areas immediately surrounding them would not overlap. The extent to which the areas overlap determines how much of their effectiveness is lost.

The curves of *Figure 43* show a change in resistance for two, four, and eight parallel rods with various spacing.

When two, three, or four rods are used in parallel, they are usually driven in a straight line and connected together. In cases where more than four are used, they are usually driven in a hollow-square formation and connected in parallel. Distances between the rods are usually made equal, as in the hollow-square formation of eight rods shown in *Figure 44*.

When measurements are to be made on large formations or on substations contained within a fence that is part of the grounding system, the required distances for the auxiliary electrodes should be

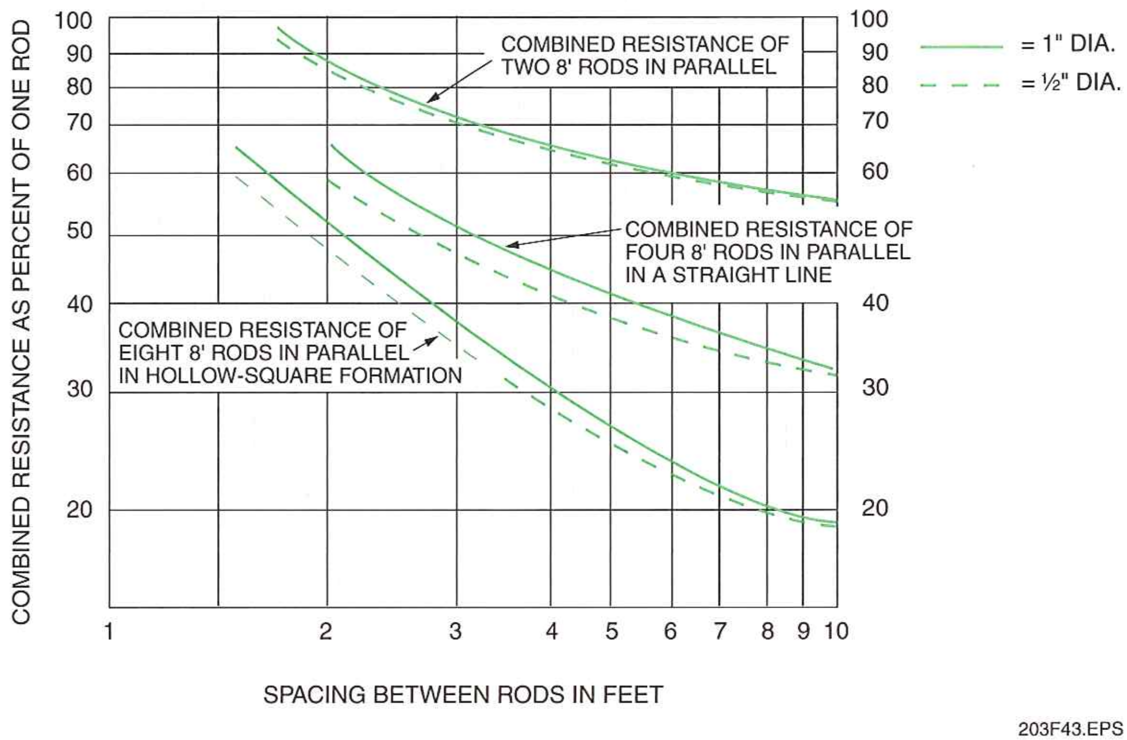


Figure 43 ◆ Combined resistances of rods in parallel.

INSIDE TRACK

Excessive Electrode Resistance During Testing

Excessive electrode resistance or transient noise during testing may indicate an incorrect measurement. If this problem occurs, try the following remedies:

- Check the integrity of all test connections between the leads and the electrodes.
- Make sure that the ground electrodes Y and Z are properly inserted in a quality ground and completely buried, if possible.
- Select a lower test current setting.
- If stray currents are suspected, try moving both electrodes Y and Z in an arc relative to the ground electrode (e.g., move them 90° and test again).

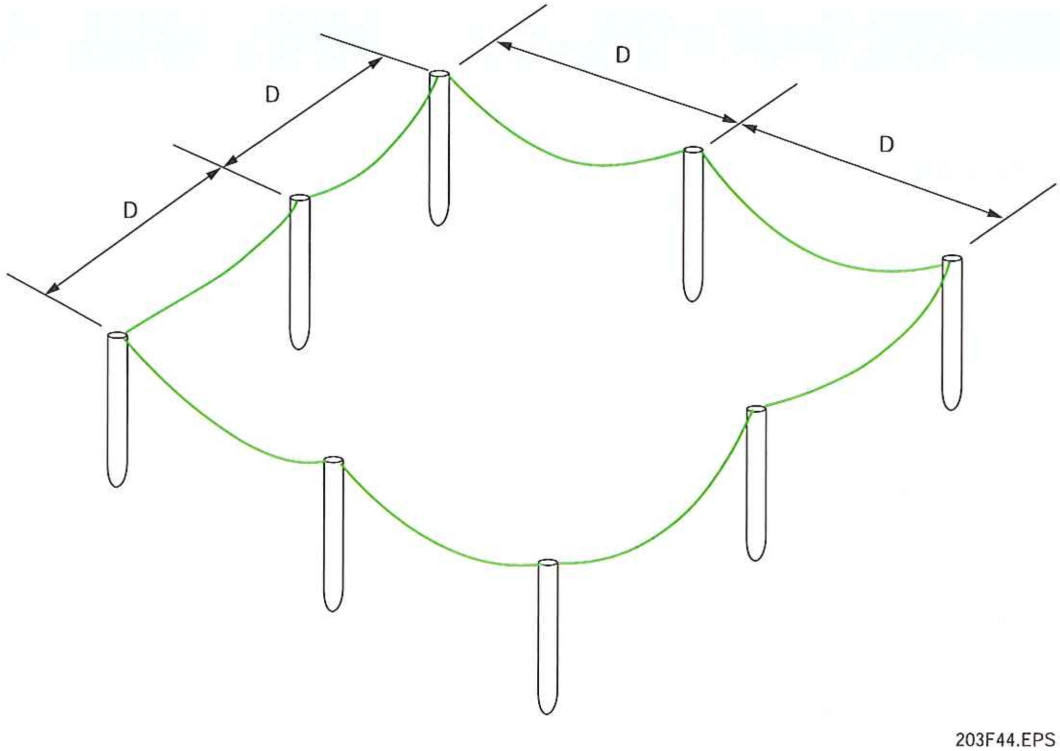


Figure 44 ◆ Hollow-square formation of grounding electrodes.

based on the diagonal (or longest dimension) of the entire grounding system. These distances can be determined from *Figure 45*, which is based on the computed hemisphere for various numbers of rods arranged in hollow-square formation.

For example, a hollow-square formation having 40' (12.2 m) sides would have a diagonal of about 57' (17.4 m). *Figure 45* shows that current and potential electrodes should be spaced at about 370' (113 m) and 230' (70 m), respectively.

Major difficulties are encountered when measuring large grid systems due to the fact that theory and computations are usually based on homogeneous soil. Differences in the soil will affect penetration depth and consequently distort the curve being plotted. In extremely large ground grid systems using several configurations of electrodes, the true center from which to properly space the current and potential electrodes is difficult to determine.

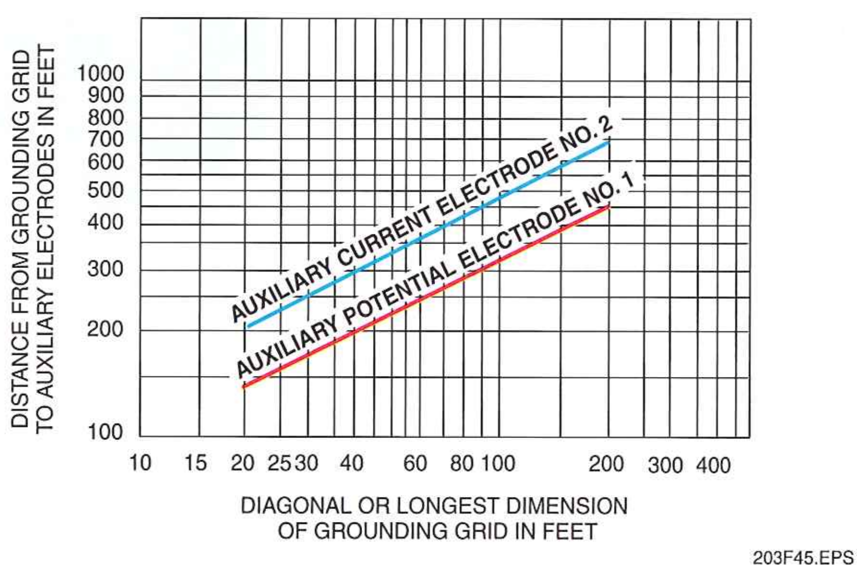


Figure 45 ◆ Auxiliary electrode distances versus longest grid dimension.

THINK ABOUT IT

Poor Soil Conductivity

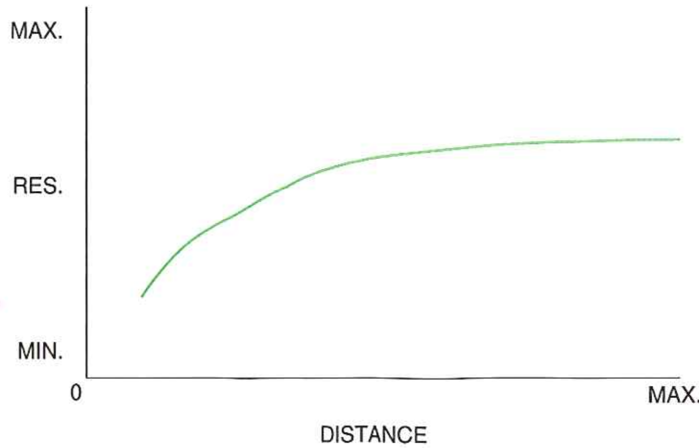
What can be done to lower the ground electrode (rod) resistance when it is driven into soil with poor conductivity?

When measuring the resistance of any grounding system, single-driven electrodes, or grid systems, it must be realized that other common grounding connections will influence the total measured resistance. For instance, if a ground grid system consisting of multiple-driven rods connected in parallel is in turn connected to a fence surrounding a substation, the fence can be considered connected in parallel with the grid system. The total resistance measured will be that of the entire grounding system. Whether these grounds can be isolated and measured separately is primarily a matter of regulations, the danger involved while they are isolated, and practicality.

16.2.0 Electrode Arrangements

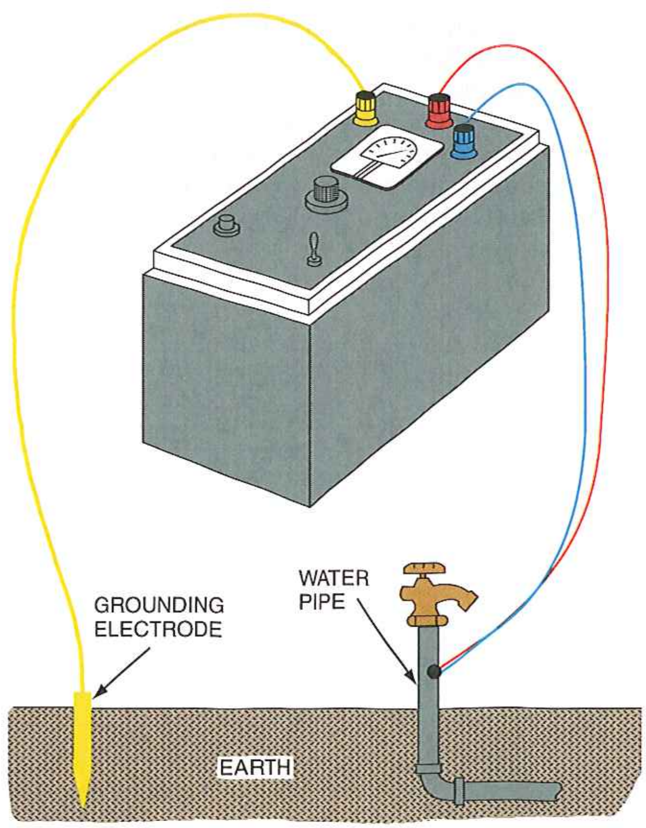
The angle at which the electrodes are placed with respect to a ground grid system is primarily a matter of choice or requirement due to surrounding obstructions. However, there are pros and cons as to whether the electrodes should be placed at 90° with respect to the sides of the grid or diagonally from a corner. Many times, one placement as opposed to the other has yielded different test results. This may very well be due to the homogeneity of the soil of one area versus the other. Curves have also been plotted with the current electrode on one side of the grounding electrode or ground grid system, and the potential electrode on the opposite side (180° apart). This arrangement yields a curve similar to that shown in *Figure 46*. This arrangement may give erroneous results, because there is no way of checking for the presence of errors during the test.

Another method of measuring ground resistance is the two-point method. With this method, a reference ground system of known or negligible resistance is used. Here, the resistance of the grounding electrode and reference ground system are measured in series. (See *Figure 47*.) The resistance of the known reference ground system is then subtracted from the total resistance indication to yield the resistance of the grounding electrode.



203F46.EPS

Figure 46 ◆ Plotted curve with current and potential electrodes spaced 180° apart.



203F47.EPS

Figure 47 ◆ Two-point method of measurement.

Clamp-On Resistance Testing

INSIDE TRACK

Clamp-on resistance testers offer the ability to measure the resistance without disconnecting the ground. This type of measurement also has the advantage of including the bonding to ground and the overall grounding connection resistance.

There are several objections to this method. One is that the resistance of reference ground systems such as water pipes or other structures is usually unknown. Another objection is that if the reference ground resistance is known, it may be excessively high in comparison, and thus the small fraction end results may be very doubtful. Still another objection is the fact that the reference ground may be extensive and the resistance areas of the reference ground and grounding electrode may overlap considerably.

16.3.0 Equipotential Grounding

Safety grounds should be applied in such a way that a zone of equal potential is formed in the work area. This equipotential zone is formed when fault current is bypassed around the work area by metallic conductors. In this situation, the worker is bypassed by the low-resistance metallic conductors of the safety ground.

Putting It All Together

THINK ABOUT IT

A low-impedance ground is essential to the performance of any electrical protection system. The ground must dissipate electrical transients and surges in order to minimize the chance of damage or injury. Proper grounding, which includes bonding and connections, protects personnel from the danger of shock and protects equipment and buildings from hazardous voltages. Proper grounding also contributes to the reduction of electrical noise and provides a reference for circuit conductors to stabilize their voltage to ground during normal operation. Examine the grounding system of the electrical service at your home or workplace. Is it adequate? If not, how can it be corrected to meet current *NEC®* requirements?

Review Questions

1. The use of _____ as a grounding electrode is in violation of the *NEC*®.
   a. copper cold-water pipe
   b. galvanized pipe
   c. an underground gas line
   d. a grounding ring

2. Which of the following copper AWG sizes should be used for the grounding conductor for a 200A service using 3/0 copper conductors?
   a. No. 2
   b. No. 4
   c. No. 6
   d. No. 8

3. The maximum distance allowed by the *NEC*® to connect a grounding conductor to a water pipe after the pipe enters the building is _____.
   a. 5'
   b. 10'
   c. 15'
   d. 20'

4. A _____ is used to connect a ground rod with a grounding conductor.
   a. grounding clip
   b. butt-and-slide connector
   c. wire nut
   d. grounding clamp

5. The _____ conductor(s) are grounded on a single-phase, three-wire, 120/240V system.
   a. hot
   b. current-carrying
   c. neutral
   d. black

6. Which of the following should you keep in mind when disconnecting a ground?
   a. Exercise extreme caution.
   b. A grounding conductor never carries current.
   c. All grounds are dead (have zero potential) and require no special precautions.
   d. Make sure your body completes a circuit between the two points.

7. The minimum length allowed for driven ground rods under normal conditions is _____.
   a. 4'
   b. 8'
   c. 0'
   d. 16'

8. All of the following are suitable materials for ground rods *except* _____.
   a. ½" solid stainless steel rod
   b. ¾" galvanized pipe
   c. ⅝" copperweld solid rod
   d. ½" solid aluminum rod

9. When a metal water pipe is used as a grounding electrode, _____ must be provided at the water meter.
   a. bonding jumpers
   b. a floor drain
   c. a grounding locknut
   d. a grounding bushing

10. Most residential systems are grounded at the _____.
    a. pole-mounted transformer
    b. service drop
    c. neutral bus in the main panelboard
    d. meter outdoors

Summary

There is no subject in the electrical industry more important than grounding. It is the chief means of protecting life and property from electrical hazards. It also ensures proper operation of the system and helps other protective devices to function properly.

The term grounded means connected to earth by a conductor or to some conducting body that serves in place of the earth. The earth as a whole is properly classed as a conductor. For convenience, its electric potential is assumed to be zero. When a metal object is grounded, it too is thereby forced to take the same zero potential as the earth. Therefore, the main purpose of grounding is to ensure that the grounded object cannot take on a potential differing sufficiently from earth potential to be hazardous.

Notes

Trade Terms Introduced in This Module

Auxiliary electrodes: Metallic electrodes pushed or driven into the earth to provide electrical contact for the purpose of performing measurements on grounding electrodes or ground grid systems.

Bonding: The permanent joining of metallic parts to form an electrically conductive path that will assure electrical continuity and the capacity to safely conduct any current likely to be imposed on it.

Effective grounding path: An intentionally constructed, permanent, low-impedance electrically conductive path designed and intended to carry current under ground-fault conditions from the point of a ground fault on a wiring system to the electrical supply source and that facilitates the operation of the overcurrent protective device or ground-fault detectors on a high-impedance grounded system.

Effectively grounded: Intentionally connected to the earth through a ground connection or connections of sufficiently low impedance and having sufficient current-carrying capacity to prevent the buildup of voltages that may result in undue hazards to personnel or connected equipment.

Equipment bonding jumper: The connection between two or more portions of the equipment grounding conductor.

Equipment grounding conductor: The conductor used to connect the noncurrent-carrying metal parts of equipment, raceways, and other enclosures to the system grounded conductor, the grounding electrode conductor, or both, at the service equipment or at the source of a separately derived system.

Ground: A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth, or to some conducting body that serves in place of the earth.

Ground current: Current in the earth or grounding connection.

Ground grids: System of grounding electrodes interconnected by bare cables buried in the earth to provide lower resistance than a single grounding electrode.

Ground mats: System of bare conductors, on or below the surface of the earth, connected to a ground or ground grid to provide protection from dangerous touch voltage.

Ground resistance: The ohmic resistance between a grounding electrode and a remote or reference grounding electrode that are spaced such that their mutual resistance is essentially zero.

Ground rod: A metal rod or pipe used as a grounding electrode.

Grounded: Connected to earth or to some conducting body that serves in place of the earth.

Grounded conductor: A system or circuit conductor that is intentionally grounded.

Grounding clip: A spring clip used to secure a bonding conductor to an outlet box.

Grounding conductor: A conductor used to connect equipment or the grounded circuit of a wiring system to a grounding electrode or electrodes.

Grounding connections: Connections used to establish a ground; they consist of a grounding conductor, a grounding electrode, and the earth surrounding the electrode.

Grounding electrode: A grounding electrode consists of (1) the nearest available effectively grounded structural metal member of the structure; or (2) the nearest available effectively grounded metal water pipe; or (3) other electrodes as specified in *NEC Sections 250.50 and 250.52.*

Grounding electrode conductor: The conductor used to connect the grounding electrode to the equipment grounding conductor, the grounded conductor, or both, of the circuit at the service equipment or at the source of a separately derived system.

Main bonding jumper: The connection between the grounded circuit conductor and the equipment grounding conductor at the service.

Neutral: A grounded conductor in an electrical system that does not carry current until the system is unbalanced.

Resistivity: Resistance between opposite faces of a unit cube. Expressed in ohm-centimeters or ohms per cubic centimeter.

Separately derived system: A premises wiring system whose power is derived from a source of electric energy or equipment other than a service. Such systems have no direct electrical connection, including a solidly connected ground circuit conductor, to supply conductors originating in another system.

Short circuit: An often unintended low-resistance path through which current flows around, rather than through, a component or circuit.

Step voltage: The potential difference between two points on the earth's surface separated by a distance of one pace, or about three feet.

System grounding: Intentional connection of one of the circuit conductors of an electrical system to ground potential.

Touch voltage: The potential difference between a grounded metallic structure and a point on the earth's surface equal to the normal maximum horizontal reach—approximately three feet.

Ungrounded conductors: Conductors in an electrical system that are not intentionally grounded.

Additional Resources

This module is intended to present thorough resources for task training. The following reference works are suggested for further study. These are optional materials for continued education rather than for task training.

American Electrician's Handbook, Latest Edition. New York: Croft and Summers, McGraw-Hill.

National Electrical Code® Handbook, Latest Edition. Quincy, MA: National Fire Protection Association.