

ARTICLE 250

GROUNDING AND BONDING

Introduction to Article 250—Grounding and Bonding

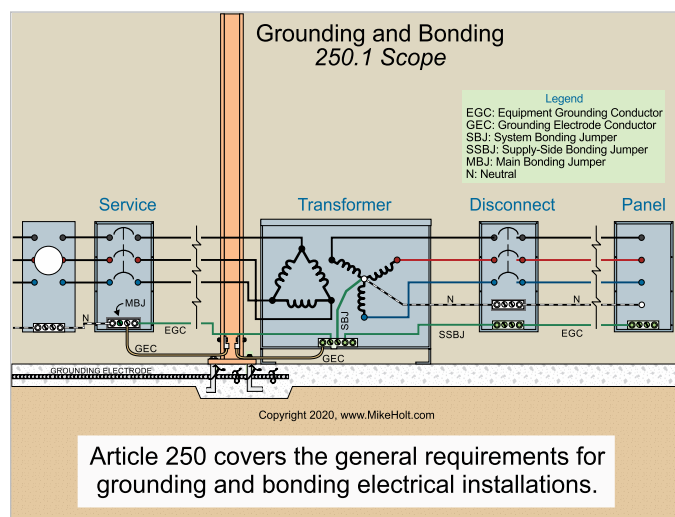
No other article can match this one for misapplication, violation, and misinterpretation. The terminology used in Article 250 has been a source of much confusion but has been improved during the last few *NEC* revisions. It is very important for you to understand the difference between grounding and bonding in order to correctly apply the provisions of this article. Pay careful attention to the definitions of important terms located in Article 100 that apply to grounding and bonding. Article 250 covers the grounding requirements for providing a path to the Earth to reduce overvoltage from lightning strikes, and the bonding requirements that establish a low-impedance fault current path back to the source of the electrical supply to facilitate the operation of overcurrent protective devices in the event of a ground fault.

This article is arranged in a logical manner as illustrated in Figure 250.1 in the *NEC*. It may be a good idea for you to just read through the entire article first to get a big picture overview. Then, study Article 250 closely so you understand the details and remember to check Article 100 for the definitions of terms that may be new to you. The illustrations that accompany the text in this textbook will help you better understand the key points.

Part I. General

250.1 Scope

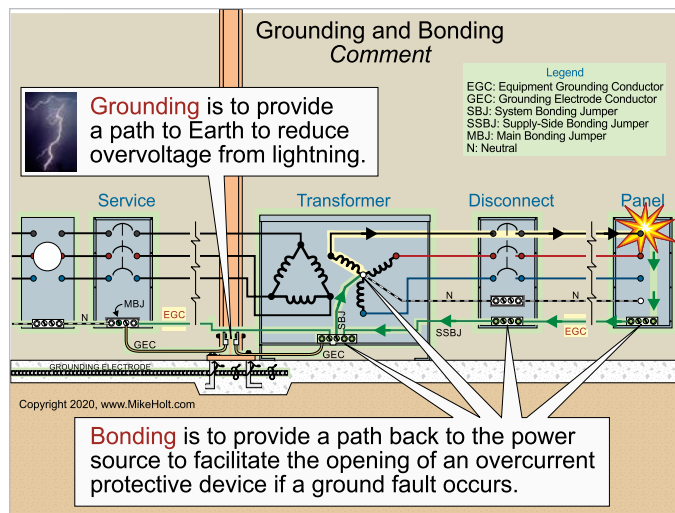
Article 250 covers the general requirements for the grounding and bonding of electrical installations. ▶Figure 250-1



▶Figure 250-1

Author's Comment:

- ▶ There are two completely different concepts being covered in this article; “Grounding” which is the connection to the Earth, and “Bonding” which is mechanically connecting electrically conductive components together to ensure electrical conductivity between metal parts [Article 100]. While these two systems overlap each other, that portion of the electrical system that needs to be able to carry fault current to the source must be heartier and capable of handling excessive amounts of current. This is called the “Effective Ground-Fault Current Path.” The effective ground-fault current path needs a low-impedance fault current path to the source so fault current can rise as quickly as possible to operate the overcurrent protective device as soon as possible. Since fault current can be thousands of amperes, the effective ground-fault current path must be designed to safely handle those high current levels. ▶Figure 250-2



▶Figure 250-2

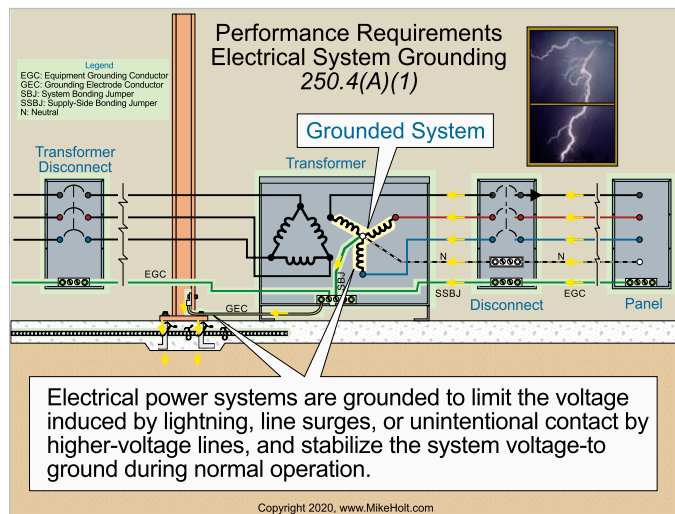
250.4 Performance Requirements for Grounding and Bonding



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(A) Solidly Grounded Systems.

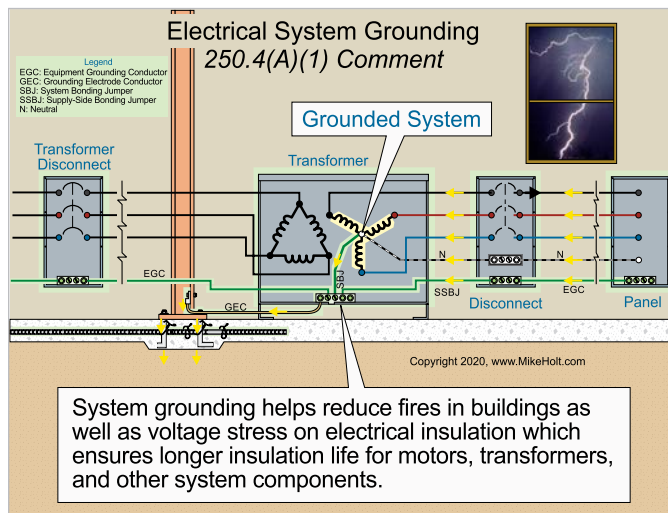
(1) Electrical System Grounding. Electrical power systems, such as the secondary winding of a transformer, are required to be connected to the Earth (grounded) in order to limit the voltage induced on the conductors by lightning strikes, line surges, or unintentional contact by higher-voltage lines, and to stabilize the secondary conductor's voltage to ground during normal operation. ▶Figure 250-3



▶Figure 250-3

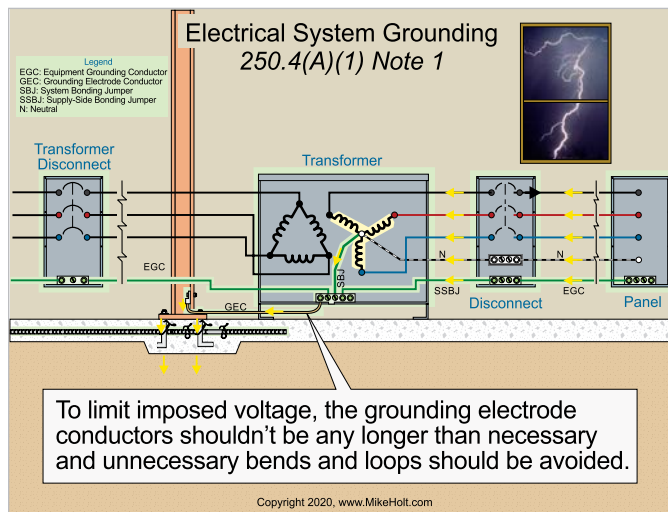
Author's Comment:

- ▶ System grounding helps reduce fires in buildings as well as voltage stress on electrical insulation, thereby ensuring longer insulation life for motors, transformers, and other system components. ▶Figure 250-4



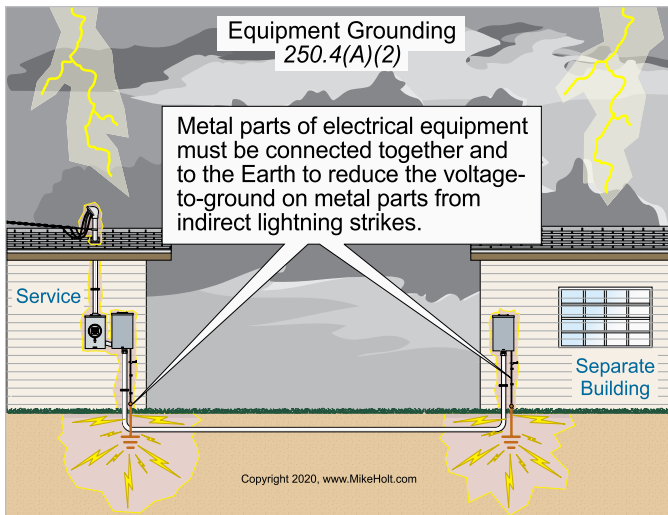
▶Figure 250-4

Note 1: To limit imposed voltage, the grounding electrode conductors should not be any longer than necessary and unnecessary bends and loops should be avoided. ▶Figure 250-5

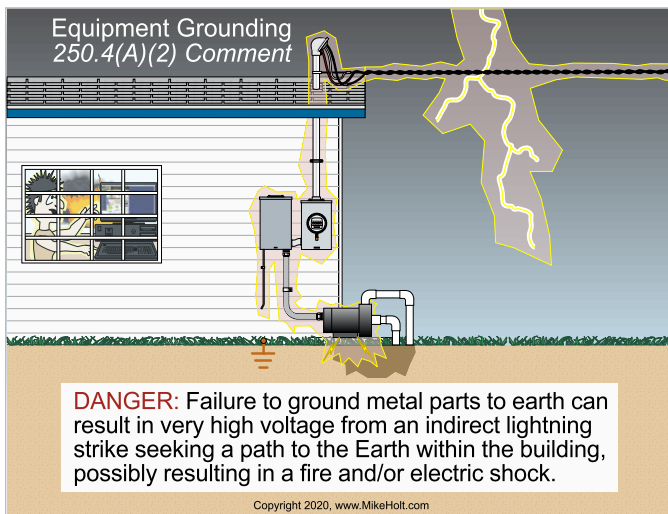
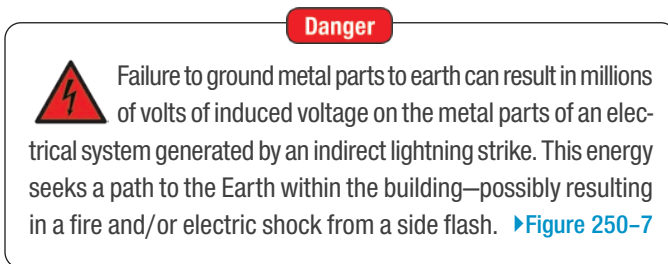


▶Figure 250-5

(2) Equipment Grounding. Metal parts of electrical equipment must be connected to other and to the Earth to reduce the voltage to ground on the metal parts from indirect lightning strikes. ▶Figure 250-6

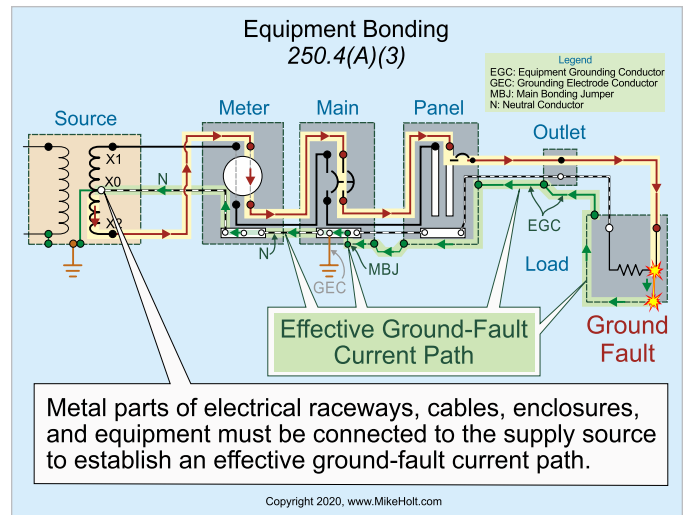


►Figure 250-6



►Figure 250-7

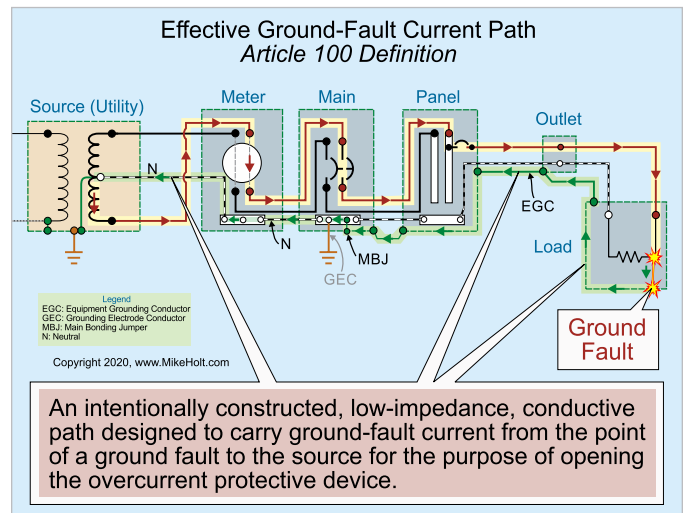
(3) Equipment Bonding. Metal parts of electrical raceways, cables, enclosures, and equipment must be connected together and to the supply system in a manner that establishes an effective ground-fault current path. See 250.4(A)(5). ►Figure 250-8



►Figure 250-8

Author's Comment:

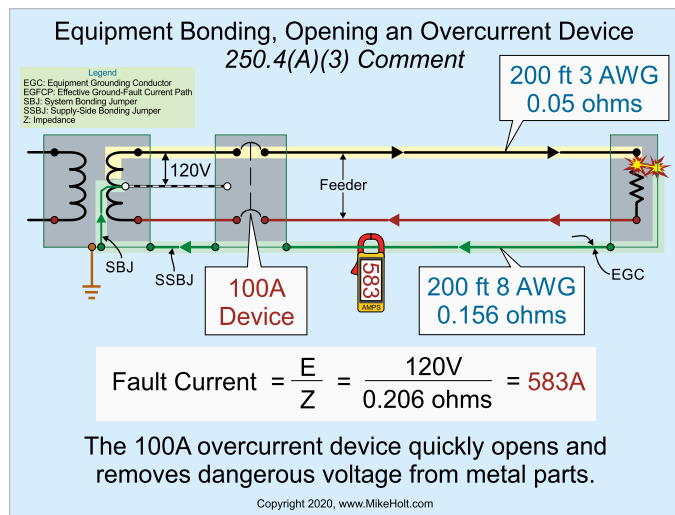
- According to Article 100, an “Effective Ground-Fault Current Path” is an intentionally constructed low-impedance conductive path designed to carry fault current from the point of a ground fault to the source for the purpose of opening the circuit overcurrent protective device. ►Figure 250-9



►Figure 250-9

Author's Comment:

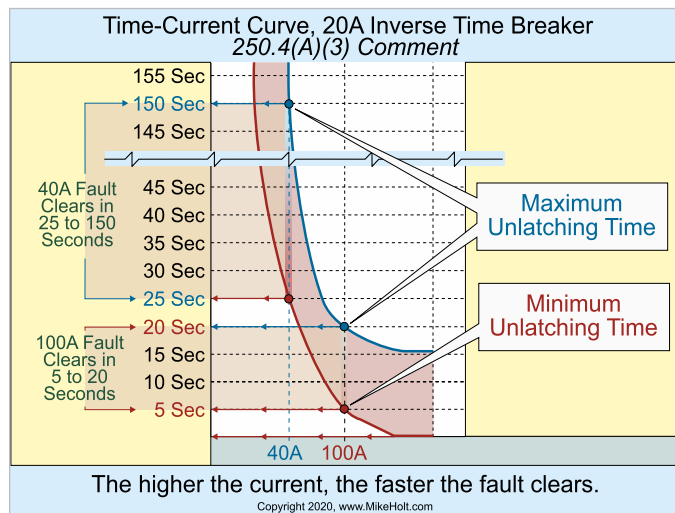
- To quickly remove dangerous voltage on metal parts from a ground fault, the effective ground-fault current path must have sufficiently low impedance to the source so fault current will quickly rise to a level that will open the circuit overcurrent device. ►Figure 250-10



►Figure 250-10

Author's Comment:

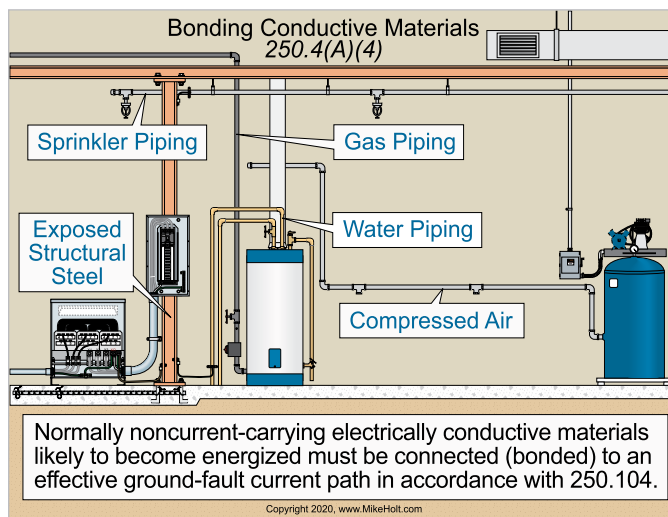
- The time it takes for an overcurrent device to open is dependent on the magnitude of the fault current. A higher fault current value will result in a shorter clearing time for the overcurrent protective device. For example, a 20A overcurrent device with an overload of 40A (two times the 20A rating) takes 25 to 150 seconds to open. The same device at 100A (five times the 20A rating) trips in 5 to 20 seconds. ►Figure 250-11



►Figure 250-11

(4) Bonding Conductive Materials. Electrically conductive materials that are likely to become energized, such as metal water piping systems, metal sprinkler piping, metal gas piping, and other metal-piping systems, and exposed structural steel members must be connected

(bonded) to the supply source via an effective ground-fault current path. ►Figure 250-12

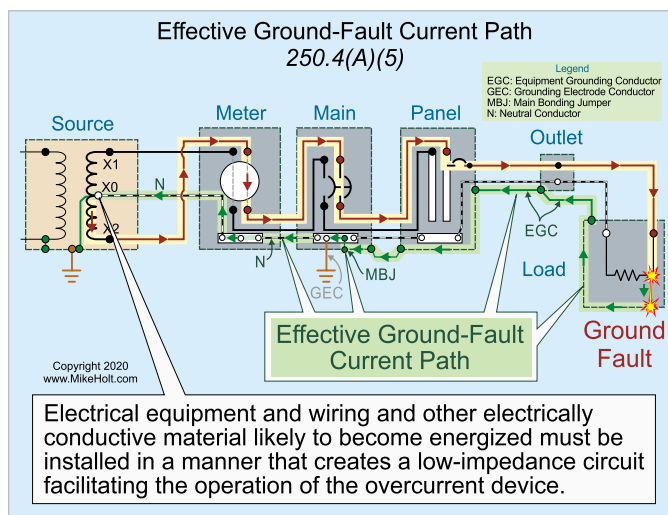


►Figure 250-12

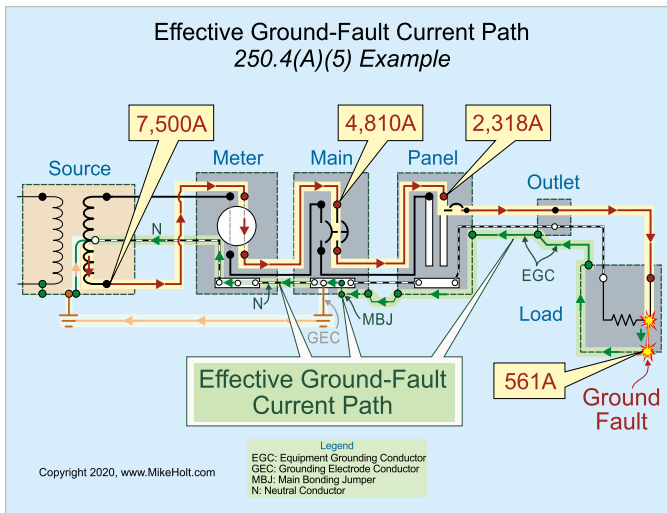
Author's Comment:

- According to the NFPA style manual, "Likely to Become Energized" means that an electrical conductor is present in some capacity.

(5) Effective Ground-Fault Current Path. Metal parts of electrical raceways, cables, enclosures, or equipment must be bonded together and to the supply source in a manner that creates a low-impedance path for ground-fault current facilitating the opening of the circuit overcurrent protective device. ►Figure 250-13 and ►Figure 250-14



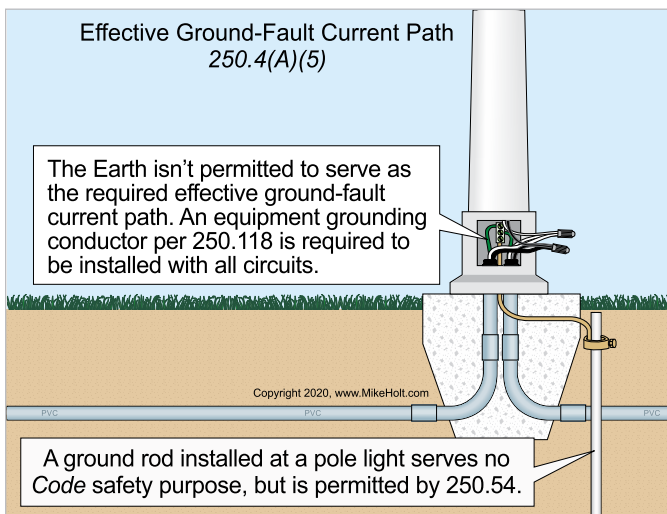
►Figure 250-13



►Figure 250-14

The effective ground-fault current path must be capable of safely carrying the maximum ground-fault current likely to be imposed on it from any point on the wiring system where a ground fault may occur to the electrical supply source.

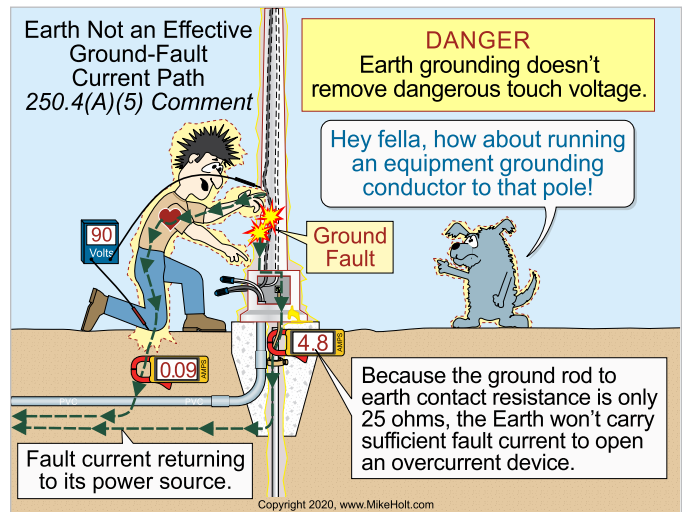
The Earth is not permitted to serve as the required effective ground-fault current path, therefore an equipment grounding conductor of a type recognized in 250.118 is required to be installed with all circuits. ►Figure 250-15



►Figure 250-15

Danger

Earth grounding does not remove dangerous touch voltage. Because the contact resistance of a grounding electrode (like a ground rod) to the Earth is so high, very little fault current returns to the power supply. As a result, the circuit overcurrent protective device will not open, and all metal parts associated with the electrical installation, metal piping, and structural building steel will become and remain energized. ►Figure 250-16



►Figure 250-16

► Example

Question: What will the maximum fault current be when there is a 120V ground fault to the metal parts of a light pole that is grounded to a 25-ohm ground rod, but not bonded to an effective ground-fault current path? ►Figure 250-17

- (a) 3.70A (b) 4.80A (c) 5.20A (d) 6.40A

Solution:

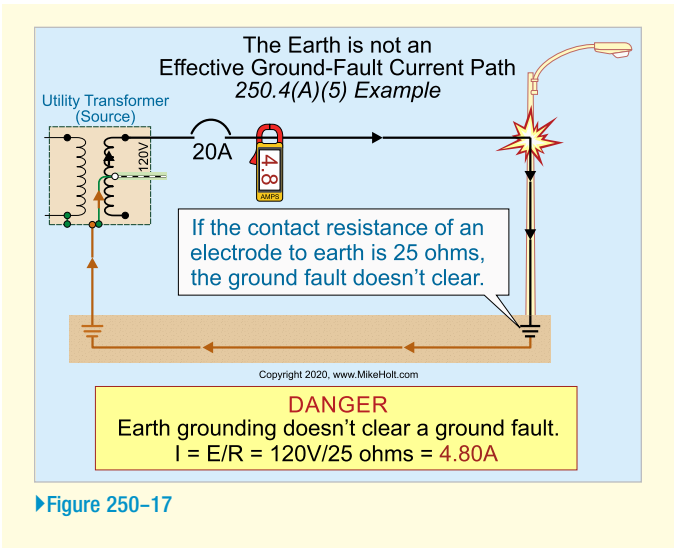
$$I = \text{Volts/Resistance}$$

$$I = 120\text{V}/25 \text{ ohms}$$

$$I = 4.80\text{A}$$

Answer: (b) 4.80A

...



►Figure 250-17

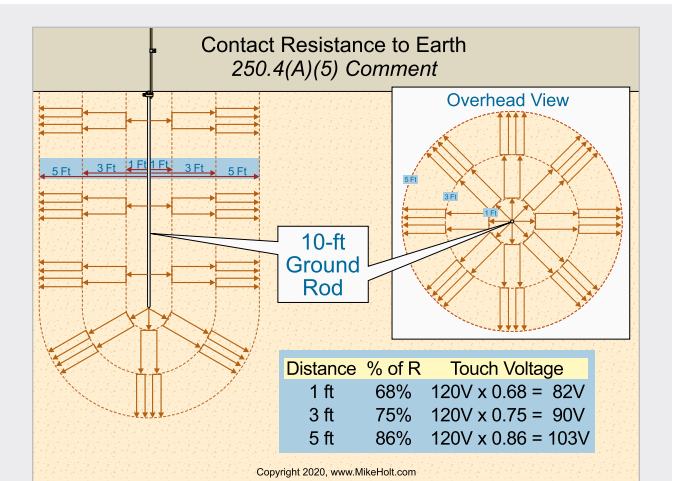
Earth Shells

According to ANSI/IEEE 142, *Recommended Practice for Grounding of Industrial and Commercial Power Systems* (Green Book) [4.1.1], the resistance of the soil outward from a 10-ft ground rod is equal to the sum of the series resistances of the Earth shells. The shell nearest the ground rod has the highest resistance and each successive shell has progressively larger areas and progressively lower resistances. Do not be concerned if you do not understand this statement; just review the table below.

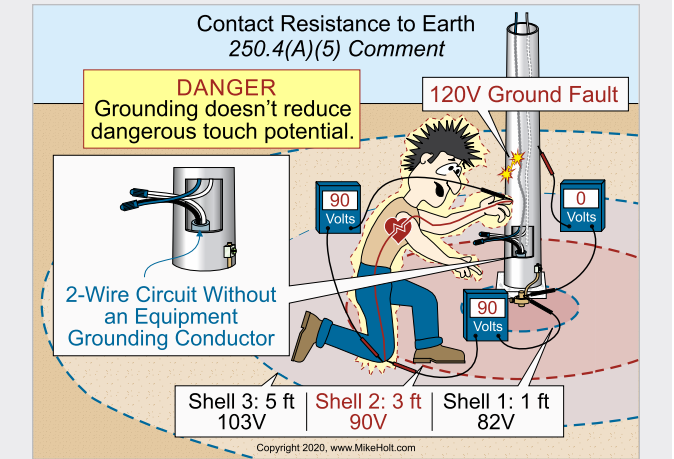
Distance from Rod	Soil Contact Resistance
1 ft (Shell 1)	68% of total contact resistance
3 ft (Shells 1 and 2)	75% of total contact resistance
5 ft (Shells 1, 2, and 3)	86% of total contact resistance

Contact Resistance. The Earth is an excellent conductor due to an almost limitless number of parallel paths over which electrons can flow. However, the problem lies in the contact resistance between the grounding electrode and the Earth. The surface area of the electrode contacting the Earth is minimal compared to the Earth itself.

Since voltage is directly proportional to resistance, the voltage gradient of the Earth around an energized rod (assuming a 120V ground fault) will be as follows: ►Figure 250-18 and ►Figure 250-19



►Figure 250-18



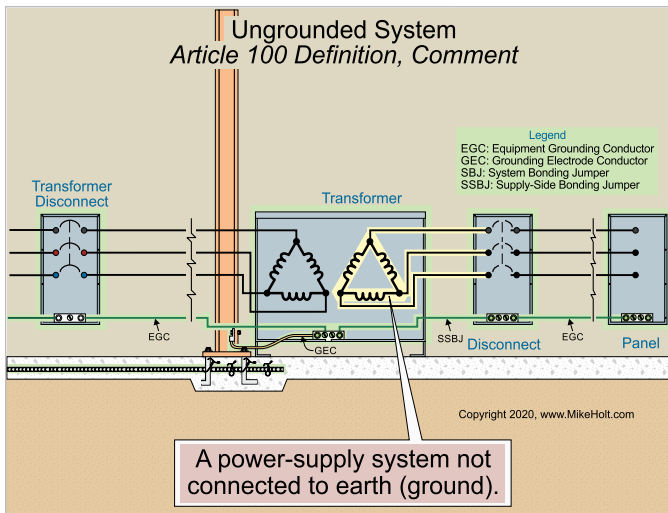
►Figure 250-19

Distance from Rod	Soil Contact Resistance	Voltage Gradient
1 ft (Shell 1)	68%	82V
3 ft (Shells 1 and 2)	75%	90V
5 ft (Shells 1, 2, and 3)	86%	103V

(B) Ungrounded Systems. Ungrounded Systems must be grounded in accordance with 250.4(B)(1) through 250.4(B)(4).

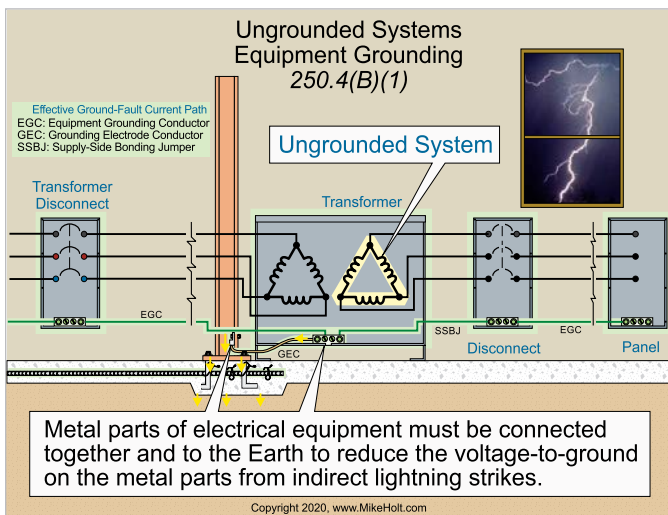
Author's Comment:

- According to Article 100, an ungrounded system is “a power-supply system not connected to earth (ground),” as demonstrated in the secondary winding of a transformer where there is no connection between the system winding and earth (ground) or to a conductive body that extends the Earth (ground) connection. ►Figure 250-20



►Figure 250-20

(1) Equipment Grounding. Metal parts of electrical equipment must be connected to each other and connected to the Earth to reduce the voltage to ground on the metal parts from indirect lightning strikes. ►Figure 250-21



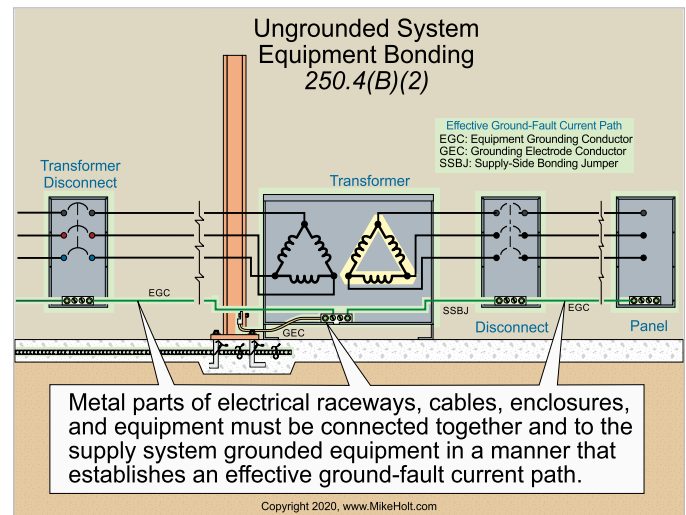
►Figure 250-21

Danger

Failure to ground metal parts to earth can result in millions of volts of induced voltage on the metal parts of an electrical system from an indirect lightning strike. This energy seeks a path to the Earth within the building—possibly resulting in a fire and/or electric shock from a side flash.

(2) Equipment Bonding. Metal parts of electrical raceways, cables, enclosures, and equipment must be connected together and to the

supply source in a manner that establishes an effective ground-fault current path. ►Figure 250-22

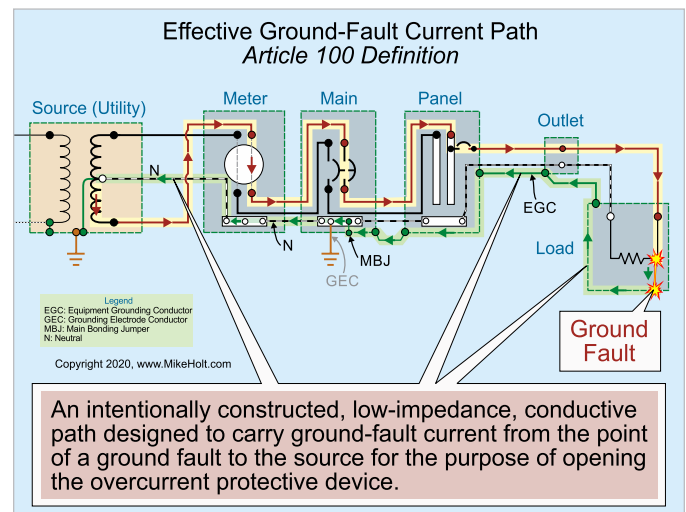


►Figure 250-22

The effective ground-fault current path must be capable of safely carrying the maximum fault current likely to be imposed on it from any point on the wiring system should a ground fault occur at the electrical supply source.

Author's Comment:

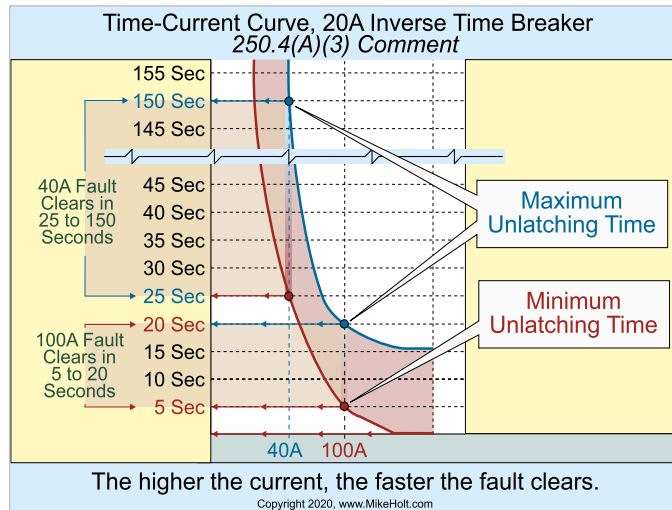
- According to Article 100, an “Effective Ground-Fault Current Path” is an intentionally constructed low-impedance conductive path designed to carry fault current from the point of a ground fault to the source for the purpose of opening the circuit overcurrent protective device. ►Figure 250-23



►Figure 250-23

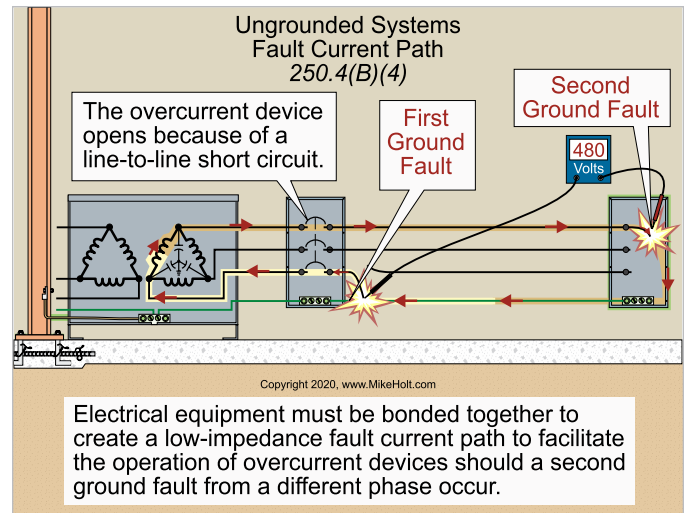
Author's Comment:

- ▶ To quickly remove dangerous voltage on metal parts from a ground fault, the effective ground-fault current path must have sufficiently low impedance to the source so fault current will quickly rise to a level that will open the circuit overcurrent protective device [250.4(A)(3)].
- ▶ The time it takes for an overcurrent protective device to open is dependent on the magnitude of the fault current. A higher fault current value will result in a shorter clearing time for the overcurrent device. For example, a 20A overcurrent protective device with an overload of 40A (two times the 20A rating) takes 25 to 150 seconds to open. The same device at 100A (five times the 20A rating) trips in 5 to 20 seconds. ▶ **Figure 250-24**

▶ **Figure 250-24**

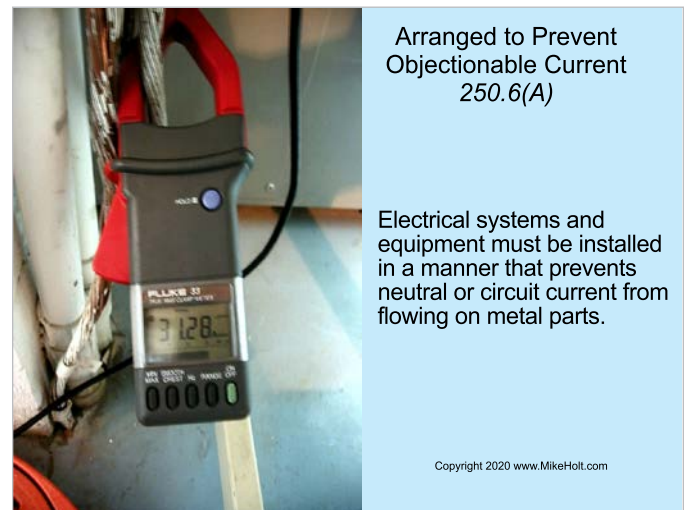
(3) Bonding Conductive Materials. Conductive materials such as metal water piping systems, metal sprinkler piping, metal gas piping, and other metal-piping systems, as well as exposed structural steel members likely to become energized must be bonded together in a manner that creates a low-impedance fault current path capable of carrying the maximum fault current likely to be imposed on it.

(4) Fault Current Path. Electrical equipment, wiring, and other electrically conductive material likely to become energized must be installed in a manner that creates a low-impedance fault current path to facilitate the operation of overcurrent devices should a second ground fault from a different phase occur. ▶ **Figure 250-25**

▶ **Figure 250-25****250.6 Objectionable Current**

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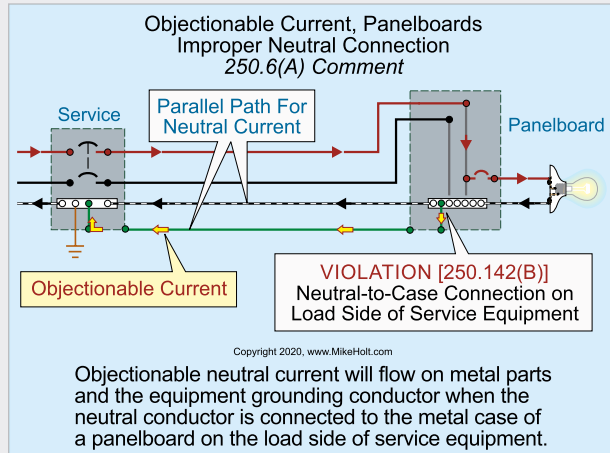
(A) Arranged to Prevent Objectionable Current. Electrical systems and equipment must be installed in a manner that prevents neutral or circuit current from flowing on metal parts (objectionable current). ▶ **Figure 250-26**

▶ **Figure 250-26**

Objectionable Current

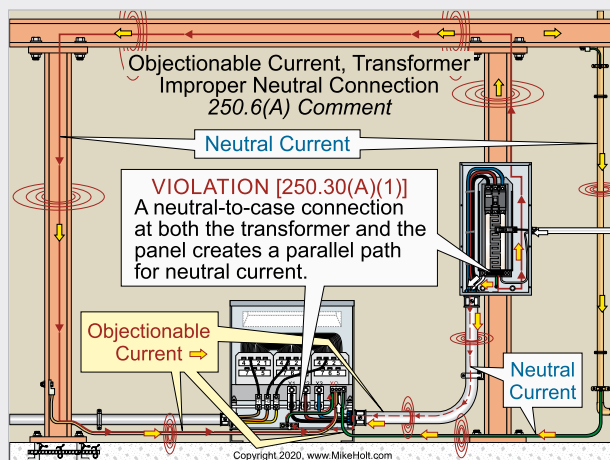
Objectionable neutral current occurs because of improper neutral-to-case connections or wiring errors that violate 250.142(B).

Panelboards. Objectionable neutral current will flow on metal parts and the equipment grounding conductor when the neutral conductor is connected to the metal case of a panelboard on the load side of the service disconnect. ▶Figure 250–27



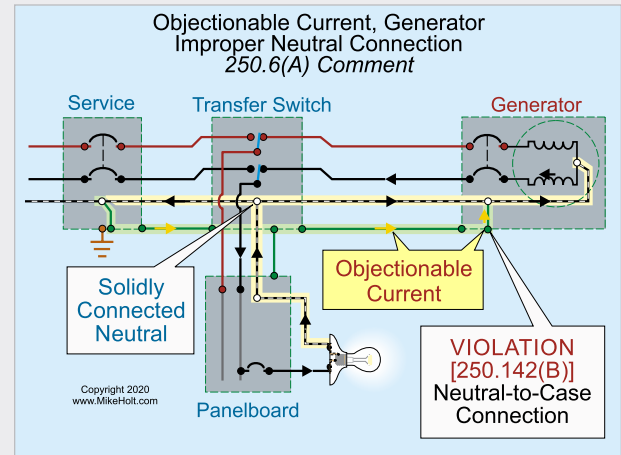
▶Figure 250–27

Transformers. Objectionable neutral current will flow on metal parts if the neutral conductor is connected to the circuit equipment grounding conductor at both the transformer and any other location on the load side of the system bonding jumper. ▶Figure 250–28



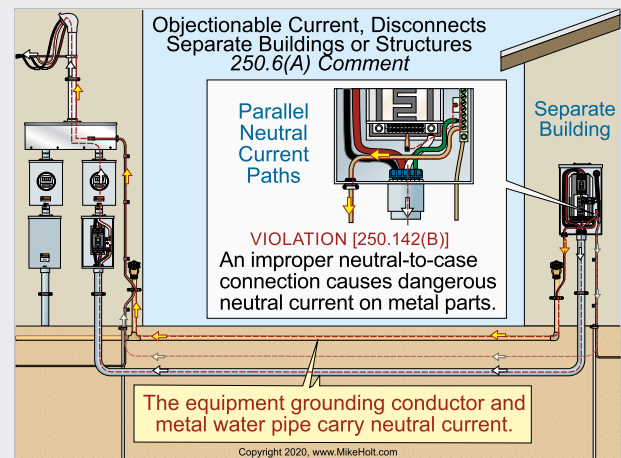
▶Figure 250–28

Generator. Objectionable neutral current will flow on metal parts and the equipment grounding conductor if a generator is connected to a transfer switch with a solidly connected neutral, and a neutral-to-case connection is made at the generator. ▶Figure 250–29



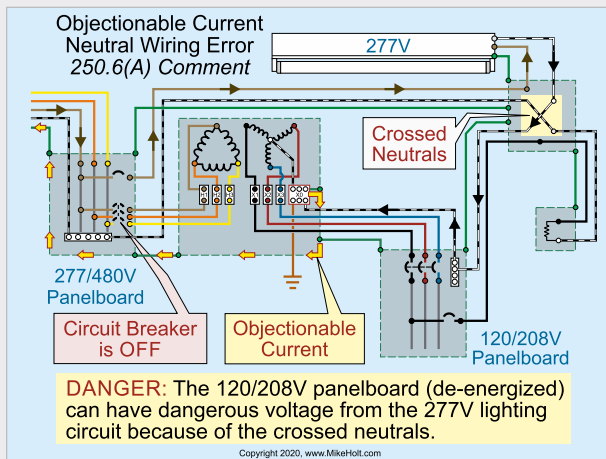
▶Figure 250–29

Disconnects. Objectionable neutral current will flow on metal parts and the equipment grounding conductor if the neutral conductor is connected to the metal case of a disconnect that is not part of the service disconnect. ▶Figure 250–30



▶Figure 250–30

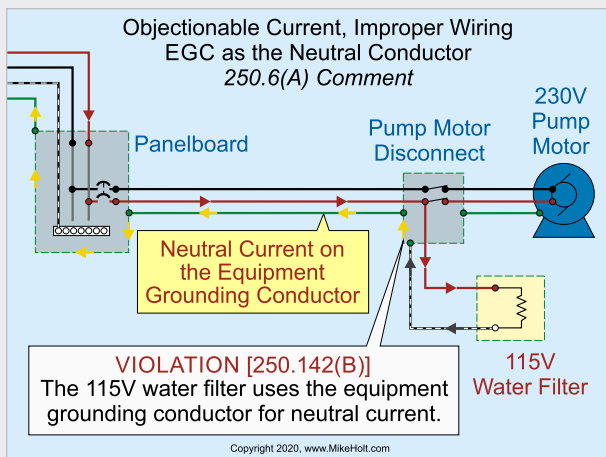
Wiring Errors. Objectionable neutral current will flow on metal parts and equipment grounding conductors if the neutral conductor from one system is used as the neutral conductor for a different system. ▶Figure 250–31



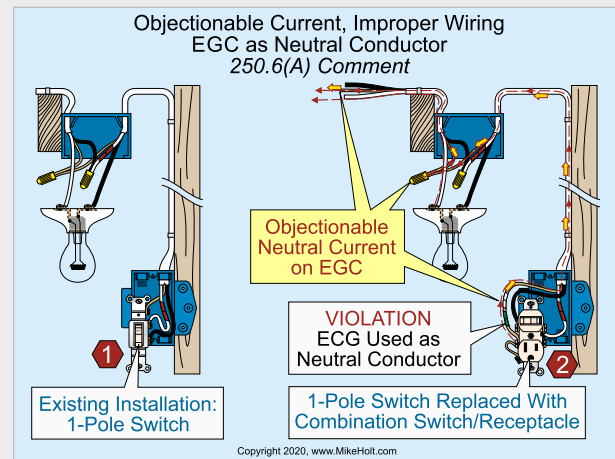
►Figure 250-31

Improper Wiring. Objectionable neutral current will flow on the equipment grounding conductor if the circuit equipment grounding conductor is used as a neutral conductor, such as where:

- ▶ A 230V time-clock motor is replaced with a 115V time-clock motor, and the circuit equipment grounding conductor is used for neutral return current.
- ▶ A 115V water filter is wired to a 240V well-pump motor circuit, and the circuit equipment grounding conductor is used for neutral return current. ►Figure 250-32
- ▶ The circuit equipment grounding conductor is used for neutral return current. ►Figure 250-33



►Figure 250-32

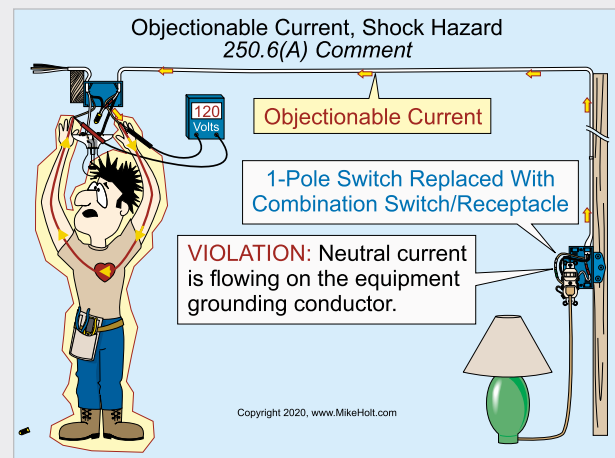


►Figure 250-33

Dangers of Objectionable Current

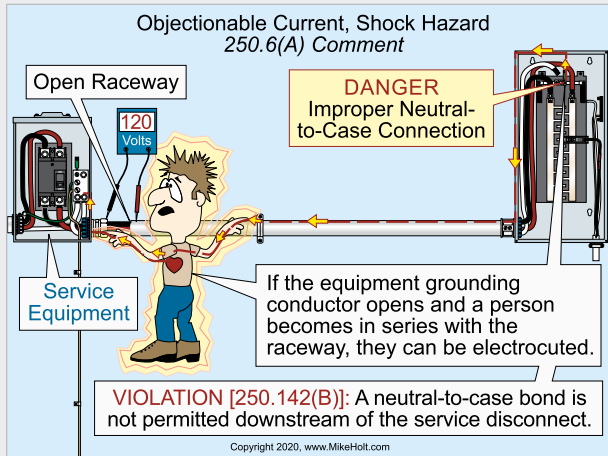
Objectionable neutral current on metal parts can cause electric shock, fires, and the improper operation of electronic equipment and overcurrent protective devices such as GFPEs, GFCIs, and AFCIs.

Shock Hazard. When objectionable neutral current flows on metal parts or the equipment grounding conductor, electric shock and even death can occur from the elevated voltage. ►Figure 250-34 and ►Figure 250-35

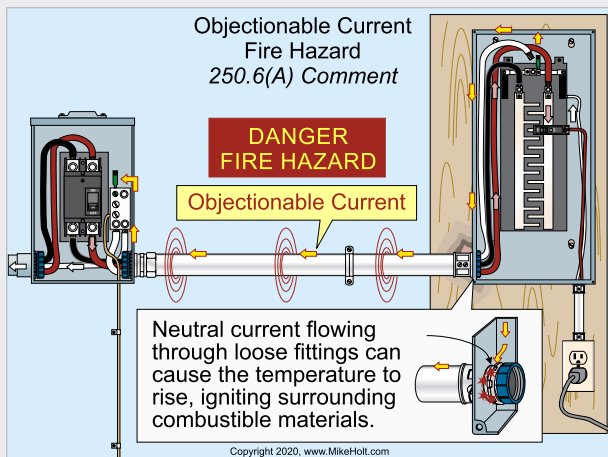


►Figure 250-34

Fire Hazard. When objectionable neutral current flows on metal parts, a fire can ignite adjacent combustible material. Heat is generated whenever current flows, particularly over high-resistance parts. In addition, arcing at loose connections is especially dangerous in areas containing easily ignitable and explosive gases, vapors, or dust. ►Figure 250-36



►Figure 250-35

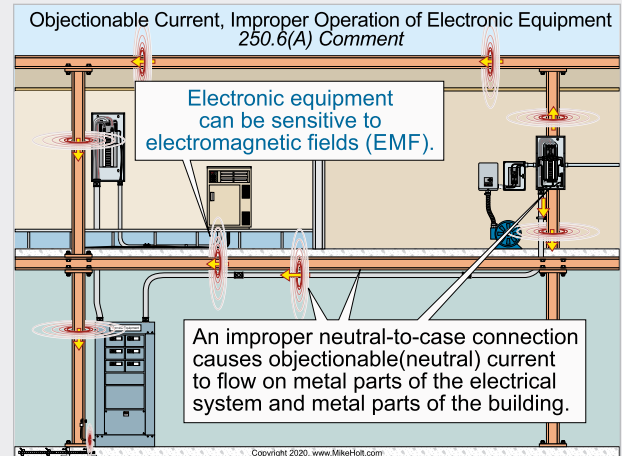


►Figure 250-36

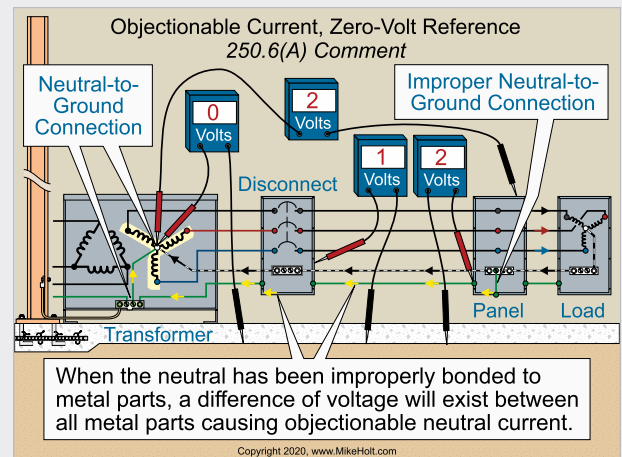
Improper Operation of Electronic Equipment. Objectionable neutral current flowing on metal parts of electrical equipment and building parts can create electromagnetic fields which negatively affect the performance of electronic devices; particularly medical equipment. ►Figure 250-37

When objectionable neutral current travels on metal parts and equipment grounding conductors because the neutral has been improperly bonded to metal parts, a difference of voltage will exist between all metal parts. This situation can cause some electronic equipment to operate improperly. ►Figure 250-38 and Figure 250-39

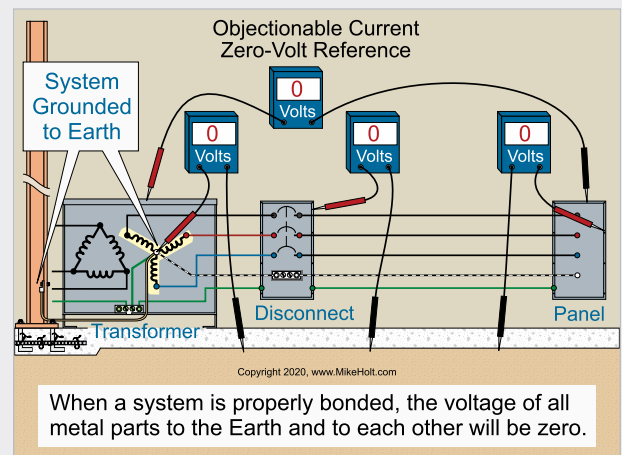
Operation of Overcurrent Protective Devices. When objectionable neutral current travels on metal parts, electronic overcurrent protective devices equipped with ground-fault protection can trip because some neutral current flows on the circuit equipment grounding conductor instead of on the neutral conductor.



►Figure 250-37



►Figure 250-38

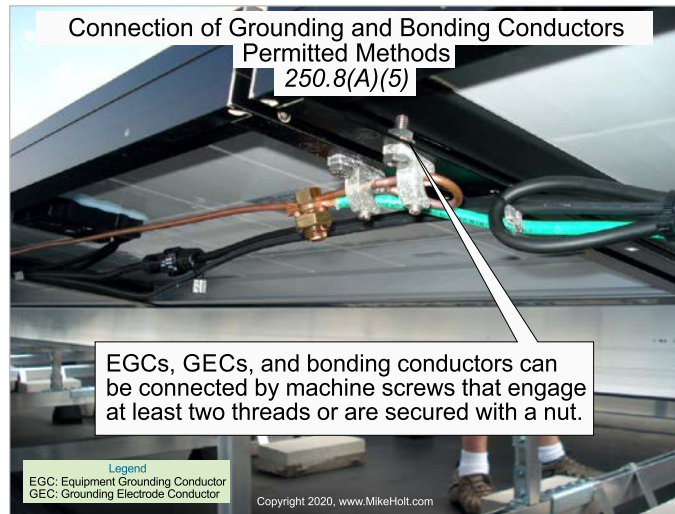


►Figure 250-39

250.8 Connection of Grounding and Bonding Connectors

(A) Permitted Methods. Equipment grounding conductors, grounding electrode conductors, and bonding jumpers must be connected by one or more of the following methods:

- (1) Listed pressure connectors
- (2) Terminal bars
- (3) Pressure connectors listed for grounding and bonding
- (4) Exothermic welding
- (5) Machine screws that engage at least two threads or are secured with a nut ▶ **Figure 250-40**

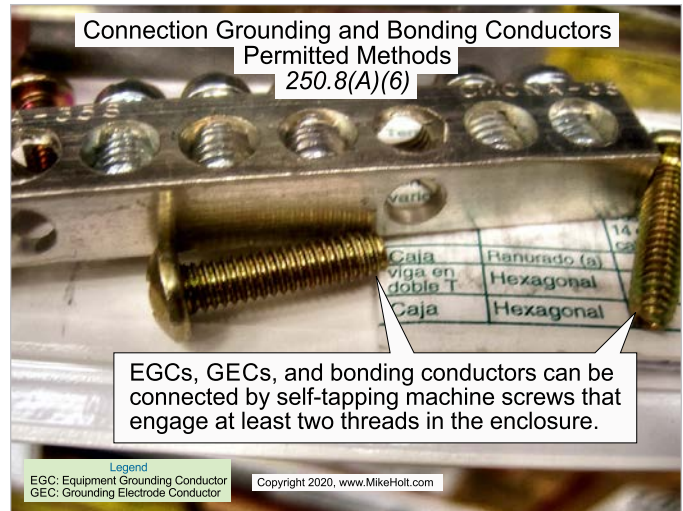


▶ **Figure 250-40**

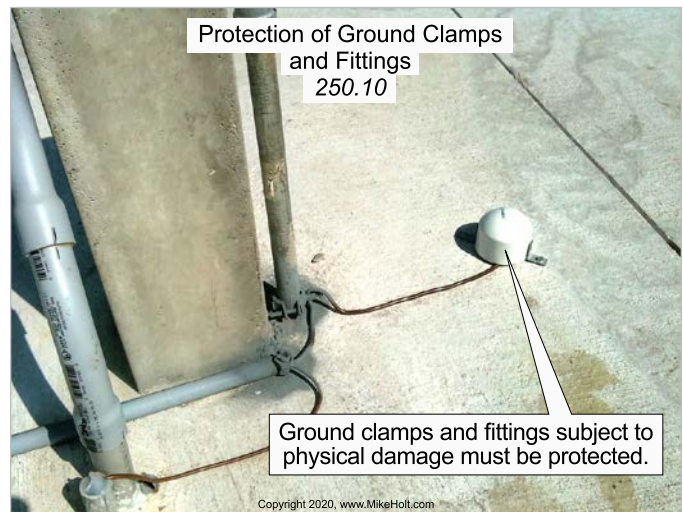
- (6) Self-tapping machine screws that engage at least two threads in the enclosure ▶ **Figure 250-41**
- (7) Connections that are part of a listed assembly
- (8) Other listed means

250.10 Protection of Ground Clamps and Fittings

Ground clamps and fittings subject to physical damage must be protected. ▶ **Figure 250-42**



▶ **Figure 250-41**



▶ **Figure 250-42**

250.12 Clean Surfaces

Nonconductive coatings (such as paint) on equipment to be grounded or bonded must be removed to ensure good electrical continuity, or the termination fittings must be designed so to make such removal unnecessary [250.53(A) and 250.96(A)].

Author's Comment:

- ▶ Fittings such as locknuts are designed to cut through the nonconductive coating and establish the intended electrical continuity when they are properly tightened.
- ▶ Tarnish on copper water pipe need not be removed before making a termination.