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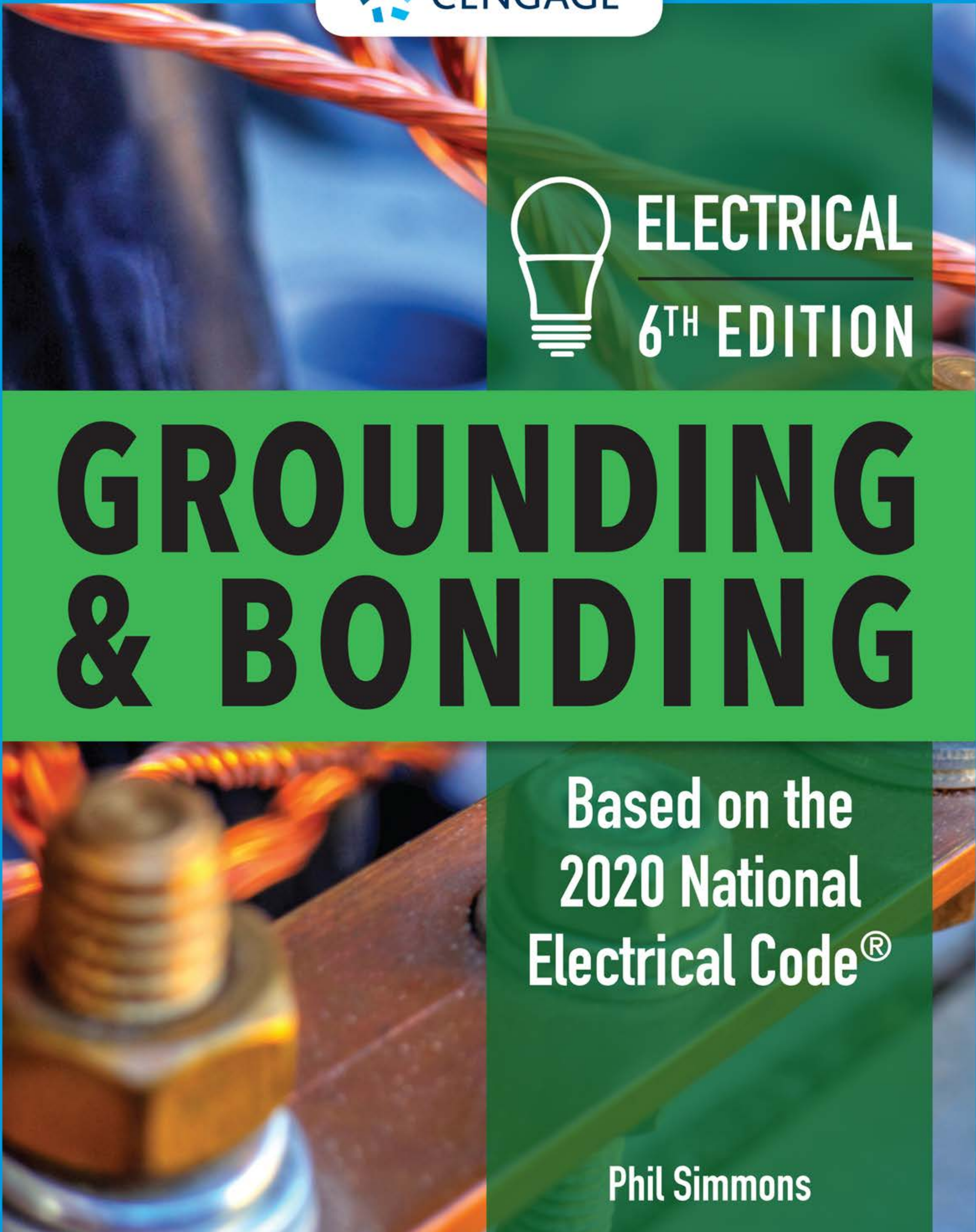
6TH EDITION

GROUNDING & BONDING

Based on the 2020 National Electrical Code®



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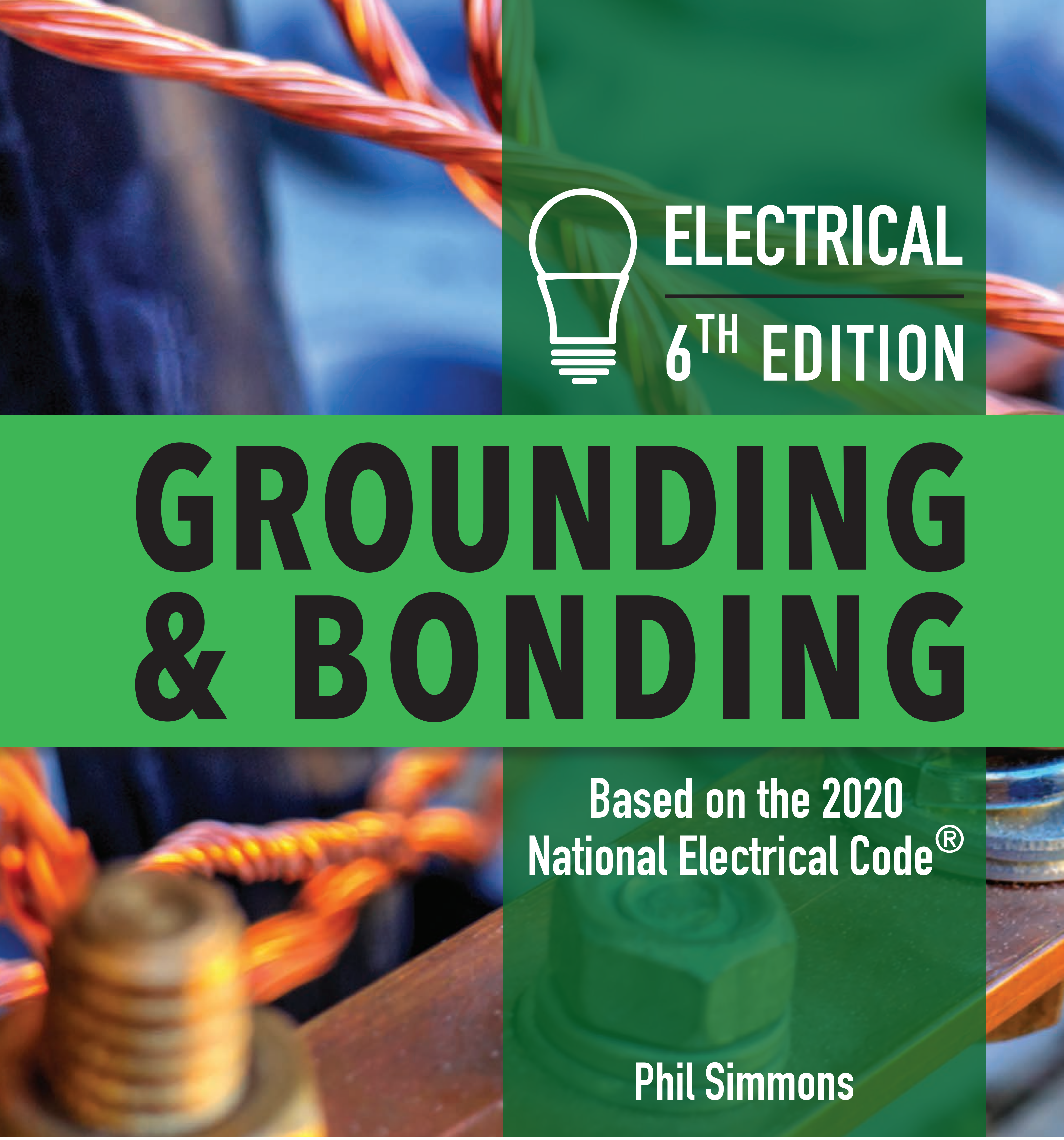

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Phil Simmons

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Australia • Brazil • Mexico • Singapore • United Kingdom • United States

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Electrical Grounding and Bonding, 6th Edition
Phil Simmons

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Foreword

Just who is Phil Simmons, the author of this book, *Electrical Grounding and Bonding*? I have known Phil for a long time. He has been involved in the electrical industry for many years. Phil is one of the most knowledgeable individuals I know when it comes to the electrical industry and the *National Electrical Code*® (*NEC*®).*

Phil's credentials are endless. He has held many high-level positions. He was the Executive Director of the International Association of Electrical Inspectors (IAEI), where he orchestrated the writing, producing, editing, revising, and reviewing of many of the technical manuals available from the IAEI. As editor-in-chief of the *IAEI News*, he saw to it that this bimonthly magazine became one of the finest technical publications available today. He was Chief Electrical Inspector for the State of Washington. He has worked with many state and national code officials.

Phil served as Acting Chairman of Code Making Panel 5 a few *Code* cycles back and was responsible for the major reorganization of *Article 250* in the *NEC*. *Article 250* is all about grounding and bonding.

Phil served on the Underwriters Laboratories Electrical Council and their Board of Directors.

Phil has conducted numerous seminars for many large organizations, such as General Motors, Ford Motor Company, Daimler/Chrysler, the University of Wisconsin, the University of Missouri, the U.S. Navy, and the U.S. Marines. He has conducted continuing education seminars for electrical inspectors, electrical contractors, electricians, and electrical apprentices.

Phil also is a master electrician and was an electrical contractor. When electrical installations and the *NEC* are discussed, he can say: "Been there . . . done that." This tremendous experience in the real world is the basis for his outstanding knowledge of the *NEC*.

In addition, Phil has made major contributions to efforts at standardization within the electrical industry. Many of you may not be aware that Phil brought the IAEI Soares grounding book up to date and contributed to the IAEI *Analysis of the NEC*, the *Neon Sign Manual*, *Ferm's Fast Finder*, and videos on the *NEC*. Over the years, he has served on the *Code* panels at IAEI Section and Chapter meetings. He has conducted innumerable seminars under the auspices of the National Fire Protection Association and the IAEI.

As most of you know, the *NEC* is not the most "user-friendly" document. Some individuals know the *Code* but find it difficult to teach others. Phil has the innate ability to explain the *NEC* in words and diagrams that can be understood by everyone.

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Phil has written textbooks and examinations and has developed diagrams, PowerPoint presentations, slides, and transparencies. All of this knowledge is apparent in this excellent textbook on the difficult subject of electrical grounding and bonding.

Like the three legs of a stool that provide its stability, Phil's expertise has three essential components, each of which ensures the effectiveness of the others. "Leg one" is the experience he has had in the electrical field. "Leg two" is his incredible knowledge of electrical codes and standards. "Leg three" is his ability to share this wealth of experience and knowledge with the reader of this book.

I congratulate Phil for a job well done in writing this book. It will be an important addition to your collection of electrical books.

Ray C. Mullin *(1929–2018)*

Preface

Electricity follows the basic laws of physics, regardless of whether it is current flow over ungrounded ("hot") conductors, over grounded conductors (sometimes neutral conductors), or in the grounding system. So, if we can understand basic circuit flow, we can understand the requirements and performance rules for grounding and bonding of electrical systems and equipment. You will find several of the illustrations in this book to be fairly basic and uncomplicated. This complements the overall effort to make the rules for grounding and bonding as easy to understand as possible and to take the concepts of grounding and bonding back to the basics.

I want to mention here and applaud the efforts of Ronald P. O'Riley, who wrote a book titled *Electrical Grounding: Bringing Grounding Back to Earth,* through the sixth edition. Mr. O'Riley is now deceased. Although this book is not based on or intended to be a continuation of Mr. O'Riley's efforts, our goals in presenting a book on grounding and bonding of electrical systems are very similar. Quoting from the preface to Mr. O'Riley's sixth edition:

> "The author's wish is for this book to be a learning experience for members, and those in training for a career in the electrical industry. It is the author's hope that simplifying, illustrating, reasoning through, and coordinating the grounding requirements, as contained in *Article 250* of the *National Electrical Code*®, will promote better understanding and use of the *Code.* This can result in safer, cleaner electrical installations and maintenance. The first rule is to make it safe: the second is to make it work. Both can be done. With this thought in mind, this book is directed at vocational instructors of electricity, electrical engineers, design engineers, construction electricians making installations in the field, maintenance electricians at factories or buildings, electrical inspectors, and many other members of the electrical industry. It is also the author's hope that the apprentice or person preparing for a career in the electrical industry and studying the *National Electrical Code*® will find the detailed explanations and accompanying diagrams in this book to be an interesting learning experience."

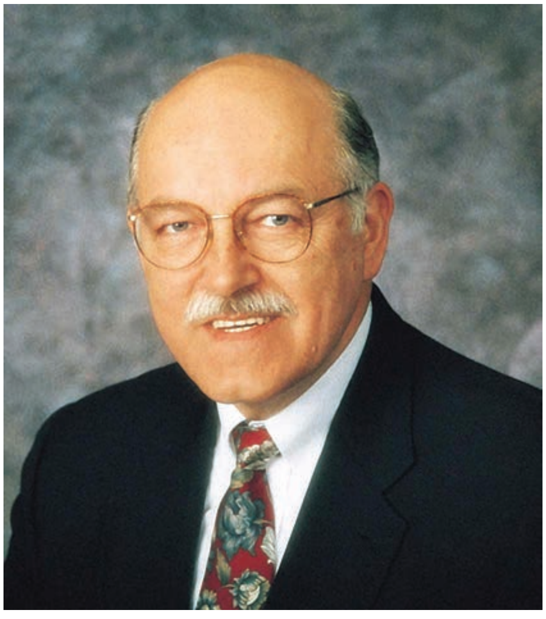
Electrical Grounding and Bonding is based on my many years of experience in teaching subjects related to the *NEC,* field experience in the electrical construction industry, and association with the International Association of Electrical Inspectors (IAEI).

Other than the Introduction, which includes an explanation of many definitions applicable to electrical grounding and bonding along with a brief review of electrical theory, this book is organized by section number of the *NEC.* For example, if you're interested in learning about requirements for a grounding electrode system, you can follow the rule from the *NEC Section 250.50* to an identical code reference in this book.

Other features of the organization of this book are as follows:

1. The requirement from the *NEC* is included. Note that in most cases, the requirement is paraphrased rather than being a direct quote.
2. The requirement is discussed and explained.
3. An illustration of the requirement is provided.
4. Where appropriate, there is an explanation of how to comply with the rules, such as determining the appropriate size system bonding conductor.

ABOUT THE AUTHOR



Phil Simmons is owner of Simmons Electrical Services. The firm specializes in training, writing and illustrating of technical publications related to the electrical industry, inspecting complex electrical installations, and consulting on electrical systems and safety.

Phil has served the International Association of Electrical Inspectors (IAEI) in the following capacities:

- Secretary-treasurer of the Puget Sound Chapter
- Secretary-treasurer of the Northwestern Section
- International President in 1987
- Executive Director (1990–1995)
- Codes and Standards Coordinator (1995–1999)
- Editor of *IAEI News*

Phil is a licensed master electrician and former electrical contractor in the State of Washington. He also was a licensed journeyman electrician in the states of Alaska and Montana. He was chief electrical inspector for the State of Washington from 1984 to 1990, after serving as an electrical plans examiner and field electrical inspector.

Phil has had extensive experience for several years in preparing and presenting training at many locations on the following and additional subjects:

- Update to the *National Electrical Code*
- Electrical Systems in One- and Two-Family Dwellings
- Grounding and Bonding of Electrical Systems
- Wiring for Hazardous Locations
- Motors and Transformers
- Electrical Safety in Employee Workplaces

Phil is author of several technical articles that have been published in the *IAEI News.* He is also the author and illustrator of several technical books on electrical codes and safety, including these:

- IAEI *Analysis of the National Electrical Code*
- *Ferm's Fast Finder Index*
- *Electrical Systems in One- and Two-Family Dwellings*
- *IAEI Soares Book on Grounding of Electrical Systems*
- *NJATC Significant Changes in the National Electrical Code*

Beginning with the 2011 *NEC*, Phil was co-author, with Ray Mullin, of *Electrical Wiring Commercial* and *Electrical Wiring Residential*. Both are published by Cengage Learning. After Mr. Mullin's passing in 2018, Phil continues as author of these titles.

Phil has served the National Fire Protection Association (NFPA) in several capacities, including the following:

- Standards Council (six years)
- *National Electrical Code* Technical Correlating Committee
- Code Making Panel (CMP)-17, Chairman of CMP-19, CMP-1, Acting Chair of CMP-5, and CMP-5 member
- Chair of the NFPA Electrical Section
- Electrical Codes Coalition Committee
- Instructor at NFPA's *NEC*, Electrical Safety in the Workplace (NFPA 70E), and related seminars

Phil is a past member of the Underwriters Laboratories Electrical Council and is a past UL Trustee. He is a member of the Standards Technical Panel for Grounding and Bonding Equipment. He is also a retired member of the International Brotherhood of Electrical Workers.

Phil has passed the electrical inspector certification examinations for One- and Two-Family, General, and Plan Review. He served for several years on the Educational Testing Service Electrical Advisory Committee for national electrical inspector certification examinations. He also served on the joint IAEI/NFPA Electrical Inspector Certification Examination development committee.

NEW TO THIS EDITION

- *New and Updated Artwork*. Revisions of many diagrams and figures have been made to improve clarity and ease of understanding. Several new illustrations have also been added.
- *National Electric Code 2020*. All *Code* requirements have been updated to the 2020 edition of the *NEC*.
- *Revised Learning Objectives*. The Objectives have been fine-tuned for easier readability.
- *New MindTap Features*. The accompanying MindTap product has been enhanced with newly created videos and flashcards.

SUPPLEMENT PACKAGE

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The *Instructor Companion Website*, found on cengage.com, offers the following components to help minimize instructor preparation time and engage students:

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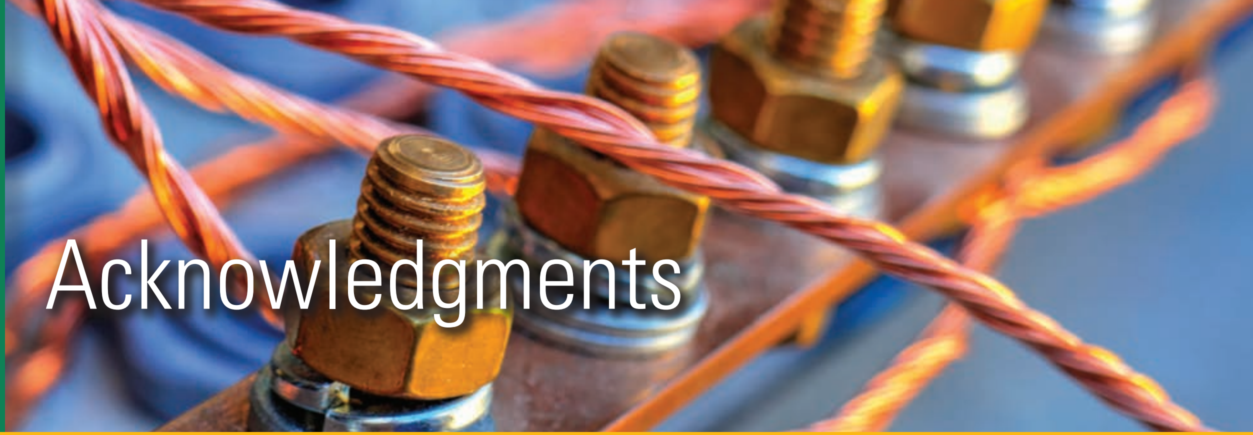


I first want to thank the Lord Jesus Christ for giving me the abilities I have as well as the tremendous opportunities I have enjoyed over my career. I feel blessed in so many ways. “In Him we live and move and have our being.”

I have been blessed with several friends who deserve special mention for their assistance, encouragement, contributions, wisdom, and support over the years: Ray Mullin, Mike Holt, Richard Loyd, and Mike Johnston.

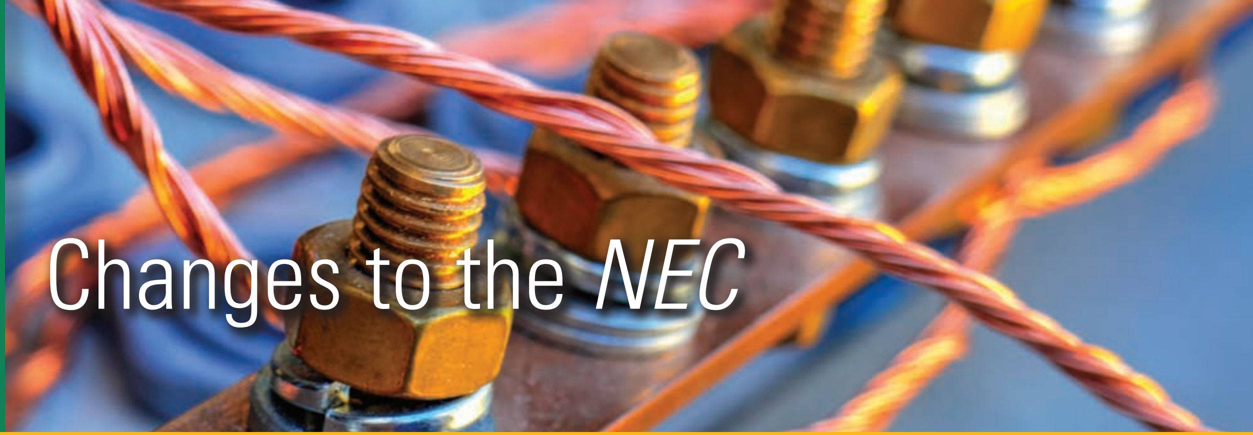
I want to thank my wife **Della** for her support while I had to spend so much time devoted to this project, as well as keep the consulting business going. I promise I will really get after the “Honey-Do” list as soon as this project is completed!

I want to express my appreciation to **Paul W Abernathy**. Paul served as lead reviewer and editor for two of the chapters of this edition. He currently serves on the National Fire Protection Association’s (NFPA) *NEC*® Code Making Panel 5 and 17. He has held ICC Certifications as an electrical inspector, electrical plans examiner, commercial electrical inspector, building inspector, plumbing inspector, and mechanical inspector.

Paul served as electrical engineer II for the City of Richmond, Virginia and as code supervisor for the City of Alexandria, Virginia. He also served as the southern region Field Representative for the National Electrical Manufacturers Association (NEMA). He holds a BS and MS in Engineering as well being a licensed Master Electrician in Texas and Virginia.

Paul also serves as the CEO & President of Electrical Code Academy, Inc. a corporation dedicated to providing electrical seminars and educational training for electricians and electrical engineers on the National Electrical Code. In addition, he is the head of the Codes and Standards Division for Encore Wire Corporation in McKinney, TX.

Phil Simmons



Changes to the *NEC*

CHANGES TO *ARTICLES 100* AND *250* AND *CHAPTER 5* FOR THE 2020 EDITION

Once again, many changes were made to the portions of the *NEC* Code for which Code Panel 5 is responsible as well as those articles in Chapter 5 that we cover in this book.

The most significant changes are shown in the following table.

Changes to the 2020 *NEC*

Significant Changes for *Articles 100, 250*, and *Chapter 5* of the 2020 *NEC*

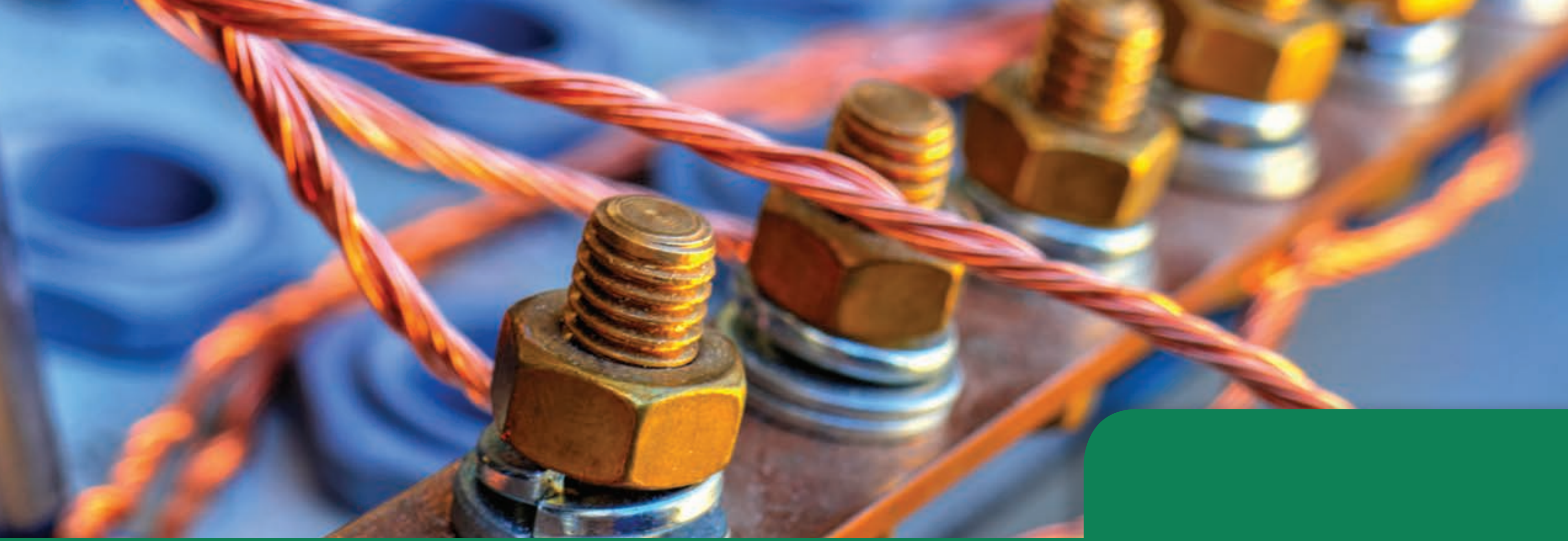
Section	**Change**
100: Grounding Conductor, Equipment (EGC)	The equipment grounding conductor serves as part of an effective ground-fault return path.
250.30	Multiple power sources of the same type that are connected in parallel to form one system that supplies premises wiring are considered as a single separately derived system.
250.30(A)(1)(b) Exception	The system bonding jumper is permitted to be installed at paralleling switchgear, switchboards, or other paralleling connection point for separately derived systems consisting of multiple sources that are connected in parallel.
250.30(A)(6)(b) Exception	If the only grounding electrodes that are present are of the types covered in 250.66(A), (B), or (C), the common grounding electrode conductor is not required to be larger than the largest grounding electrode conductor required by those sections for the type of grounding electrode that is used.
250.34	Vehicle-mounted and trailer-mounted generators are added to this section.
250.53(A)(4) and (5)	Section 250.53(G) in the 2017 *NEC* was removed to become 250.53(A)(4) in the 2020 *NEC* and 250.53(H) in the 2017 *NEC* was moved to become 250.53(A)(5) in the 2020 *NEC*.
250.53(C)	Rebar (concrete-encased grounding electrode) is not permitted to be used as a conductor to interconnect grounding electrodes of the grounding electrode system.
250.64(A)	The restrictions on the installation and connection of aluminum or copper-clad aluminum grounding electrode conductors have been organized in a list format and significantly revised.
250.68(C)(3)	The requirements for the use of reinforcing steel to serve as an extension or grounding electrode conductor to the rebar-type concrete-encased grounding electrode have been extensively revised. Rebar (concrete-encased grounding electrode) is not permitted to be used as a conductor to interconnect grounding electrodes of the grounding electrode system.
250.104(A)(1)	The bonding conductor to metal water pipe is not required to be larger than 3/0 copper or 250 kcmil aluminum or copper-clad aluminum. Identical changes were made to 250.104(C), (D)(1), and (D)(2).

(*Continues*)

Changes to the 2020 *NEC*

(*Continued*)

Section	Change
250.109	Metal enclosures are permitted to be used to connect bonding jumpers or equipment grounding conductors together and to become part of an effective ground-fault current path.
250.120(B)	The restrictions on the installation and connection of aluminum or copper-clad aluminum equipment grounding conductors have been organized in a list format and significantly revised.
250.121	The requirement that a metal frame of a building or structure not be used as an equipment grounding conductor has been moved here from 250.136(A).
250.122(B)	When increasing the size of equipment grounding conductors to correspond to the increase in size of ungrounded conductors of the circuit, the previous requirements to comply with 310.15(B) (more than 3 current-carrying conductors) and 310.15(C) (elevated ambient temperatures) have been deleted.
250.122(F)	Requirements for equipment grounding conductors that are installed or connected in parallel have been revised. Revisions include for conductors that are installed in raceways, auxiliary gutters, or cable trays, as well as for multiconductor cables.
250.134	This section that requires grounding of equipment that is fastened in place or connected by permanent wiring methods has been extensively revised editorially.
250.146	This section covers connecting receptacle grounding terminals to an equipment grounding conductor and has been extensively revised editorially.
250.148	This section covers continuity of equipment grounding conductors and has been revised editorially.
517.13(B)	Grounding requirements for metal faceplates are revised from an exception to a rule.
517.16	Requirements for isolated ground receptacles have been clarified for both inside and outside the patient care vicinity.
517.17(D)	Requirements for testing the ground-fault protection of equipment system are revised to require that the testing be performed by a qualified person(s).
517.21	Requirements for ground-fault protection for personnel are significantly revised.
547.5(G)	Ground-fault circuit-interrupter protection is required to comply with 210.8(B) but is limited in specific locations to 125-volt, 15- and 20-ampere receptacles.
550.32(E)	Receptacles located outside a mobile or manufactured home are required to be provided with GFCI protection in accordance with 210.8(A). Receptacles that provide power to a mobile or manufactured home in accordance with 550.10 are not required to have GFCI protection.
555.1	Floating buildings are now covered in Article 555 because previous Article 553 has been combined with Article 555.
555.35(A)(1)	Receptacles providing shore power to vessels are required to have ground-fault protection of equipment (GFPE) not exceeding 30 milliamperes.
555.35(A)(2)	GFCI protection for personnel is required for 125-volt, single-phase, 15- and 20-ampere receptacles for other than shore power.
555.35(A)(3)	Feeders and branch circuit conductors that are installed on docking facilities are required to have ground-fault protection of equipment set to open at currents not exceeding 100 milliamperes.



Introduction to Grounding and Bonding

OBJECTIVES

After studying this Introduction, the reader will be able to

- recall the importance of using accepted definitions of terms applicable to grounding and bonding.
- explain the importance of providing a low-impedance path of proper capacity to ensure the operation of overcurrent protective devices.
- explain the various components of the grounding and bonding system.
- summarize Ohm's law and basic electrical theory.
- explain electric shock hazards and the effect of electricity on the human body.

THE MYSTERY

Over the years, the subject of grounding electrical systems, circuits, and equipment has been among the most misunderstood of topics related to electricity. Great debates were held around the turn of the twentieth century over whether electrical systems were safer if they were grounded or if they were left ungrounded. (This was also the era of debate between Thomas Edison and George Westinghouse over whether direct current [dc] was more economical and safer than alternating current [ac]. We all recognize ac distribution systems were adopted as the de facto standard primarily because of the ease of increasing or reducing voltages by means of a transformer.)

Article 250 of the *National Electrical Code®* *(NEC®)* contains the general requirements for when systems are required to be grounded, those systems that are permitted but not required to be grounded, and systems that are required to be ungrounded. These requirements apply generally throughout the *NEC*. *Section 90.3* of the *NEC* tells how the *NEC* is organized. We will have additional discussion about the organization of the *NEC* later in this chapter. *NEC Chapters 1* through *4* apply generally. *Article 250* is part of *Chapter 2*. Other requirements in *NEC Chapters 5*, *6*, and *7* can and do amend or modify the general requirements in *NEC Chapter 2*. A list of those electrical systems or circuits that are not permitted to be grounded is contained in *NEC 250.22*.

Section 250.3 includes a reference to *Table 250.3* where you will find a list of many locations in the *NEC* that have specific requirements related to grounding and bonding of circuits or electrical systems. Locations, occupancies, or systems included in this Table vary from Agricultural Buildings to Floating Buildings, and Health Care Facilities to Swimming Pools and X-ray Equipment.

Generally, lower voltage systems such as those that operate at 50 volts to ground or less, are not required to be grounded. Several safety standards including those of the Occupational Safety and Health Administration (OSHA) use 50 volts as the minimum voltage beyond which systems are considered to be an electric shock hazard.

Grounded and ungrounded systems behave differently. Generally, the first ground fault on the grounded system will cause an overcurrent device to operate and remove the faulted circuit from operation. This will remove any shock hazard that might have been present. Ungrounded systems will typically tolerate the first ground fault which will simply ground the system. But if the equipment containing the ungrounded circuit conductors is properly grounded and bonded, the equipment will not present a shock hazard. A second ground fault on an ungrounded system, if it occurs on a different phase from the first ground fault, becomes a phase-to-phase fault. If an adequate and Code-compliant effective ground-fault current path is present and the overcurrent protection is functioning correctly, the overcurrent device will operate to remove the phase-to-phase or phase-to-ground fault.

With regard to these grounding issues, the requirements in the *NEC* has ended the debate over whether grounded or ungrounded systems are safer.

Speaking the Same Language

There are several reasons for the confusion about grounding and bonding of electrical systems and equipment. Inconsistent use of terms related to grounding and bonding no doubt plays a major role. Heated debates are often held about grounding when the parties may not clearly understand the definition of the term being used to describe a component of the grounding system. Use of terms that are closely related may add to the confusion. What does *grounded* mean? Does *bonded* mean the same thing as *grounded*? If a piece of equipment is *grounded*, is it also *bonded*? Can something be *grounded* and not be *bonded*? Conversely, can something be *bonded* and not be *grounded*?

Consider a grounding-type receptacle located on the twenty-seventh floor of an office building: Is the receptacle still grounded even though the grounding electrode connection to the service equipment from which it is supplied is located many stories below? The *NEC* definition of *grounded* is Connected (connecting) to ground or to a conductive body that extends the ground connection.* Is the grounding terminal of the receptacle in fact connected to earth? If so, how? What "extends the connection to ground or earth" to other parts of the electrical system?

Answers to these and other questions about grounding and bonding are explored and explained throughout this book.

*Source: NFPA 70-2020

DEFINITIONS

Let's look at some definitions next. An excellent grasp of the terms that are used in the *NEC*, as well as in this book, is essential for understanding the subject of grounding and bonding of electrical systems for safety. Unless noted otherwise, all definitions are from the *NEC* and are reprinted with permission from NFPA 70-2020.

As we look at these definitions, we find several have been changed in recent editions of the *NEC*. The *NEC* Correlating Committee created a Task Group that was directed to review the use of terms related to grounding and bonding. The Task Group met several times between the 2005 and 2008 *NEC* revision cycles and reviewed the use of terms throughout the *NEC*. Many improper uses of existing terms were found. In addition, it was determined that several terms related to grounding and bonding were not clear or required revision for clarity. This review resulted in proposals and comments from the Task Group for many sections in the *NEC*, including for *Article 250.* In these proposals and comments, the Task Group made an effort to be more prescriptive (state what is required) in a *Code* rule and to rely less on defined terms. These changes make the requirements on grounding and bonding easier to understand and the *NEC* more user-friendly.

For the 2011 edition of the *NEC*, this work continued with a focus on getting the requirements related to grounding and bonding in *Chapter 8* of the *NEC* harmonized with the definitions in *Article 100* as well as with *Article 250*.

Ground (*NEC Article 100*). The earth.*

Discussion: The definition of this term was changed to its simplest form during the processing of the 2008 *NEC*. Coordinating changes were made throughout the *NEC*. Although electrical codes in other countries may use the terms *earthed* or *connected to earth*, as equivalent to *ground* or *grounded*, the Code-Making Panel responsible for *NEC* rules on grounding and bonding has not accepted proposals to include those terms.

It is recognized that the earth consists of many different types of soil, from sandy loam to rock. The photo in Figure I-1 shows several types of soil, from what appears to be soil that is clear of rocks, to solid rock. Obviously, the ability to make an electrical connection to organic matter like "dirt" can vary from being fairly easily accomplished to almost impossible.

FIGURE I-1 The earth is made up of many different types of soil.

Soil resistivity is determined largely by its content of electrolytes, which consist of moisture, minerals, and dissolved salts. Soil resistivity also is determined by its ability to retain moisture. Soil with high organic content, such as black dirt, is usually a good conductor because it retains a higher moisture level and thus electrolyte level. Sandy soils, which drain faster, tend to have a much lower moisture content and electrolyte level. As a result, they tend to have a higher resistance. Solid rock and volcanic ash contain or retain virtually no moisture and have high resistivity.

The resistance of soil varies from an average of 2370 ohm-centimeters for ashes, cinders, brine, or waste, to 94,000 ohm-centimeters for gravel, sand, and stones with little clay or loam. As a result, the earth's ability to carry current varies widely. See an additional explanation of the resistance of several types of soil in Appendix C in this book, as well as a guide for determining soil electrical resistance.

As discussed in several locations in this text, electrical connections to earth are not made for the purpose of carrying neutral or fault current. Primarily, earth connections are made for dissipating overvoltages from lightning or mishaps caused by contact between electric utility system higher-voltage lines and lower-voltage lines.

*Source: NFPA 70-2020

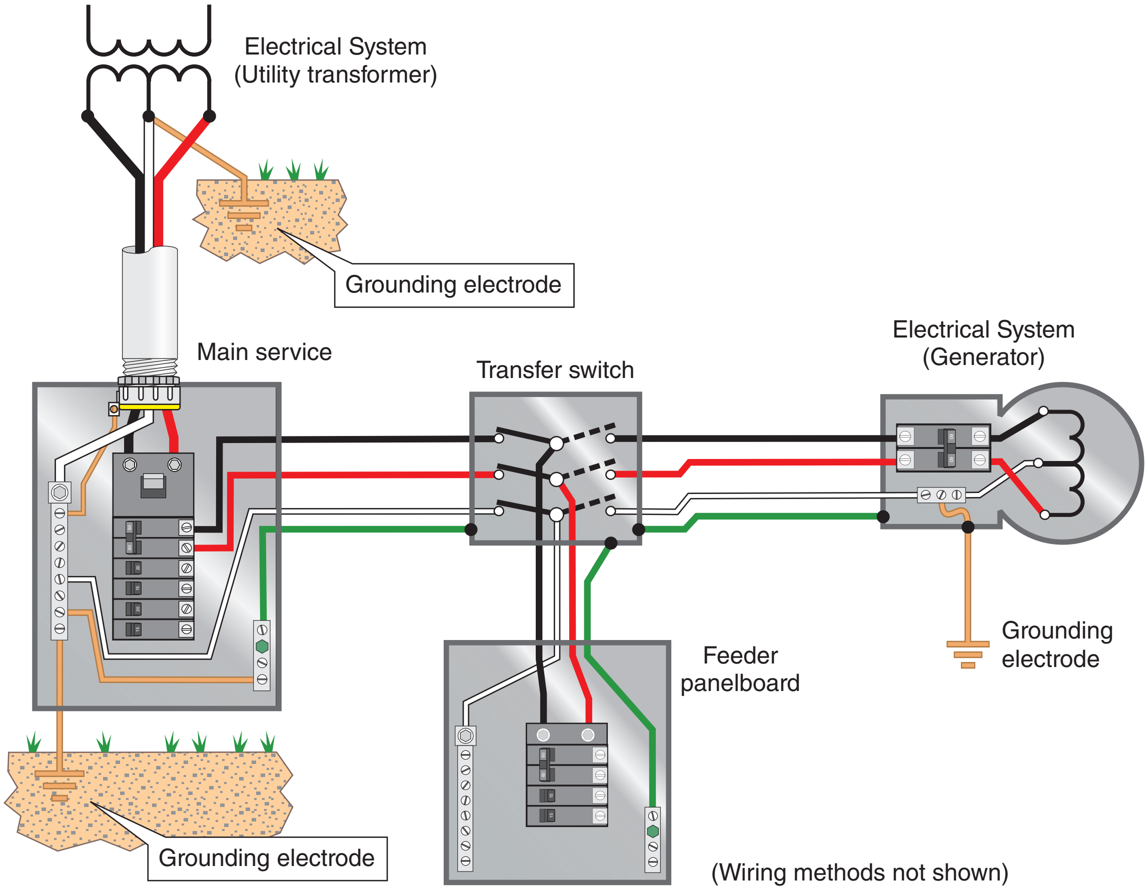


FIGURE I-2 Electrical systems are *grounded* at their transformer by the electric utility, at the service, and at or near the source of a separately derived system.

As shown in Figure I-2, to ground the electrical system, it is connected to earth by one or more grounding electrodes. Very often, electrical equipment is also connected to ground or is grounded in the same manner. Often a metallic object like a ground rod is used to attempt to make an electrical connection to organic matter—to dirt!

What Is the Electrical System? Although the term *electrical system* is not defined in the *NEC*, this is the source voltage and current usually present at the electrical service as supplied by the electric utility. Perhaps more scientifically, the electrical system is often the source of electromotive force, the strength or intensity of which is measured in volts. Even though the actual production of electrical energy by the electric utility usually takes place some distance from the premises served, we consider the connection to the electric utility transformer(s) as connecting to or the transformer providing the electrical system. (See the definitions of *service* and *premises wiring system* in *Article 100* of the *NEC*.)

Another example of an electrical system is the supply voltage and current from a separately derived system. Some of these systems are power production sources or equipment that usually are located on the premises. These systems include but are not limited to a battery (or bank of batteries), transformers, generators, solar photovoltaic systems, wind-driven generators, and fuel cells. Granted, electrical energy is not "produced" by the transformer as it is by a generator, solar photovoltaic system, or fuel cell. The transformer simply increases or decreases voltage, depending on the ratio of the primary to the secondary windings. A transformer (depending on how it is connected) is either a separately derived or a non-separately derived system. For discussion of grounding and bonding, we also consider a separately derived system to be an "electrical system."

Additional discussion on the subject and purposes of connecting the electrical system to ground can be found in this book at *250.4(A)*. A discussion on the purposes of grounding electrical equipment can be found in this book at *250.4(A)(2)* for grounded systems and at *250.4(B)(1)* for ungrounded systems.

Grounded (Grounding) ***(NEC Article 100).*** Connected (connecting) to ground or to a conductive body that extends the ground connection.*

Discussion: Figure I-2 illustrates the concept of grounding electrical systems and equipment. The phrase "connected to ground" is not defined. It is generally accepted that equipment or systems are connected to *ground* (earth) through one or more grounding electrodes that make a satisfactory earth connection. The requirements for connecting a service and separately derived system to a grounding electrode (system) are found in *Part II* of *Article 250*. The requirements for installing or creating a grounding electrode system are found in *Part III* of *Article 250*. The reasons for grounding electrical systems are found in *250.4(A)(1)*, where the performance goals of grounding electrical systems are stated. The purpose of connecting equipment to earth is found in *250.4(A)(2)* for grounded systems and in *250.4(B)(1)* for ungrounded systems.

Likewise, the phrase "a conductive body that extends the earth connection" is not defined. Although this phrase can perhaps have more than one meaning, for our purposes it means the following: a metallic conductive element, such as a raceway, cable, wire, or enclosure, that extends from the point where an earth connection is made at one or more grounding electrodes to another point on the electrical system where equipment such as a switchboard, panelboard, junction or pull box, or grounding-type receptacle is properly connected to it.

As shown in Figure I-3, this equipment, even if located on an upper floor of a multistory building, is considered to be *grounded* or *connected to earth*. It should be fairly easy to follow this grounding path through one or many points or connections to the

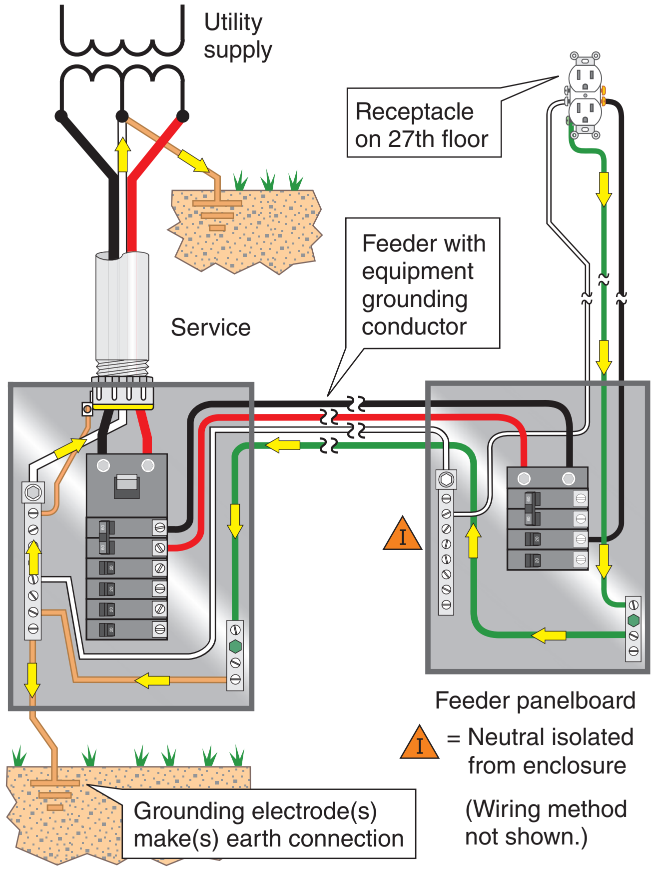


FIGURE I-3 Grounded by conductive body that extends the earth connection.

grounding electrode (system). The extension of the connection to the earth is provided by:

- the grounding electrode conductor from the grounding electrode to the service equipment
- the main bonding jumper from the neutral bar to the equipment grounding conductor terminal bar
- the equipment grounding conductor to the panelboard (may be any of those recognized or permitted by *250.118*)
- the equipment grounding conductor in the branch circuit to the receptacle

Requirements for providing an "effective ground-fault current path" are contained in *250.4* as well.

What does the word *equipment* mean here? This term as defined in *Article 100* of the *NEC* includes essentially anything and everything that is used in an electrical installation: fittings, devices, appliances, luminaires, apparatus (switchboards, panelboards, and motor control centers), and so forth.

*Source: NFPA 70-2020

As defined in *Article 100*, grounding electrodes are used to make the electrical connection to earth. Consider the metal support structure of a building. If a metal structural column such as a piling is driven into the earth for 10 ft (3.0 m) or more, it qualifies as a grounding electrode as described in *250.52(A)(2)*. The portion of the metal column that extends above the earth is permitted to serve as a grounding electrode conductor. See *250.68(C)(2)*. A structural metal grounding electrode often extends many stories above the point where it is either bonded to a concrete-encased grounding electrode or itself makes an earth connection. Separately derived systems can then use the structural metal as a grounding electrode conductor even though located many stories above grade level. Metal water pipe grounding electrodes are also recognized as "extending the earth connection" for certain occupancies where continuity of the water pipe can be verified. Extensive discussion of the rules for grounding separately derived systems is found in *250.30* in this book.

A system or equipment can be grounded (connected to ground or earth) and not be in compliance with *Code* rules. Figure I-4 shows a branch circuit that is extended to a metal pole that supports a parking lot luminaire. An equipment grounding conductor is not run with the circuit. A ground rod is installed at the pole to ground the metal pole and the luminaire. According to the definition of *grounded,* the metal pole and luminaire are in fact grounded because the installation is literally "connected to earth" as specified in the definition. However, the pole and the luminaire are not grounded properly and cannot be considered to be in compliance with *Code* rules because an effective ground-fault current path as required by *250.4(A)(5)* and *250.4(B)(4)* has not been provided. As seen in *250.4(A)(5),* the earth is not permitted to be used as the sole (only) equipment grounding conductor, and as a result is not considered to be an effective ground-fault current path.

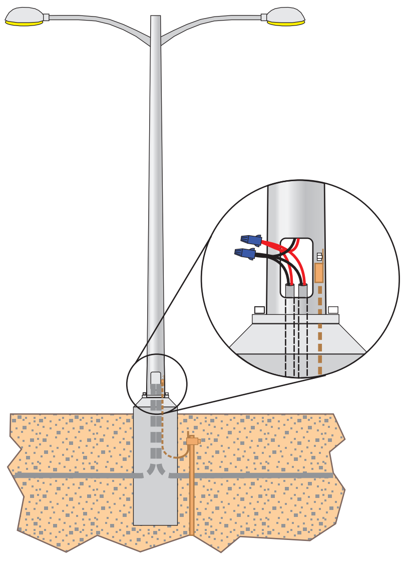


FIGURE I-4 Grounded improperly.

Therefore, when we use the word *grounded*, we imply that a connection is being made to the earth or to a conductive body that extends the earth connection in compliance with the applicable rules.

Effectively Grounded. This term was deleted during the processing of the 2008 *NEC*. The Code Panel concluded the term was vague and unenforceable. The term was thought to be an effort to add emphasis on the quality of grounding connections, not unlike being "very grounded." *Section 250.4* contains performance goals for grounding and bonding. The sections of *Article 250* following *250.4* contain "prescriptive" rules that provide the how-to requirements for installing grounding and bonding conductors, systems, and equipment.

Bonding (Bonded) *(NEC Article 100)*. Connected to establish electrical continuity and conductivity.*

Discussion: The term *bonded* is used as the past tense of *bonding*. *Bonding* is a verb meaning the ongoing action of connecting objects. *Bonded* means two or more objects have been connected. This is another term related to grounding and bonding that was revised during processing of the 2008 *NEC*. *Bonding* implies a present action and *bonded* represents equipment that has been connected together. The phrase about having adequate capacity was removed, because several sections of *Article 250* provide the minimum size of conductor required to provide adequate capacity to carry fault current.

Although there is more than one type of bonding, *bonding* in its simplest form means connecting metallic parts together. The conductor and connections provide the path or complete the path for fault current to flow (see Figure I-5).

*Source: NFPA 70-2020

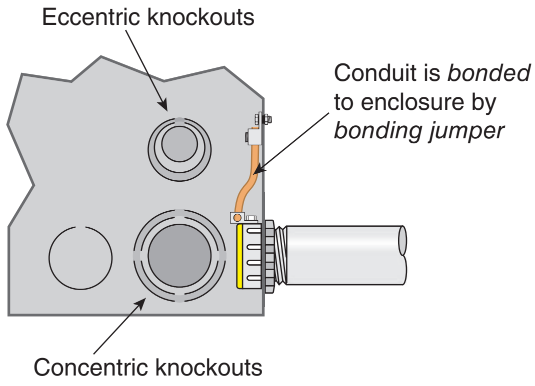


FIGURE I-5 Bonded, *NEC Article 100.*

Imagine a conduit connection to a panelboard or metal wireway for which a low-impedance connection cannot be ensured because of a painted surface or concentric or eccentric knockouts. A bonding jumper can be placed around the connection to ensure the continuity of the grounding path from the conduit to the enclosure.

Another essential element of bonding is the size of the bonding jumper. Though the concept of sizing has been removed from the definition, the bonding conductor must be large enough to "conduct safely any current likely to be imposed." Obviously, a bonding jumper is of little value if it is so small that it melts while carrying fault current. Specific requirements are found in the *NEC* for bonding of service equipment, for bonding other equipment to provide the ground-fault path, for bonding in hazardous locations as well as in other applications. The proper sizing and connections of the bonding jumper are discussed in this book at the applicable *NEC* section.

As can be observed in Figure I-6, a conduit or equipment grounding conductor in a metal-clad (Type MC) cable bonds metallic enclosures together. It can also be observed that once bonded to an enclosure that is connected to earth (grounded), the bonding conductors extend the earth connection to the connected enclosures. Because the bonding conductor serves dual purposes—that of connecting equipment together as well as extending the grounding connection—we can conclude that the functions of grounding and bonding become inseparable. The bonding conductor extends the ground connection, and the equipment grounding conductor connects metallic components together. Note as well that the definition of *equipment grounding conductor* has been revised to recognize the dual action of grounding and bonding.

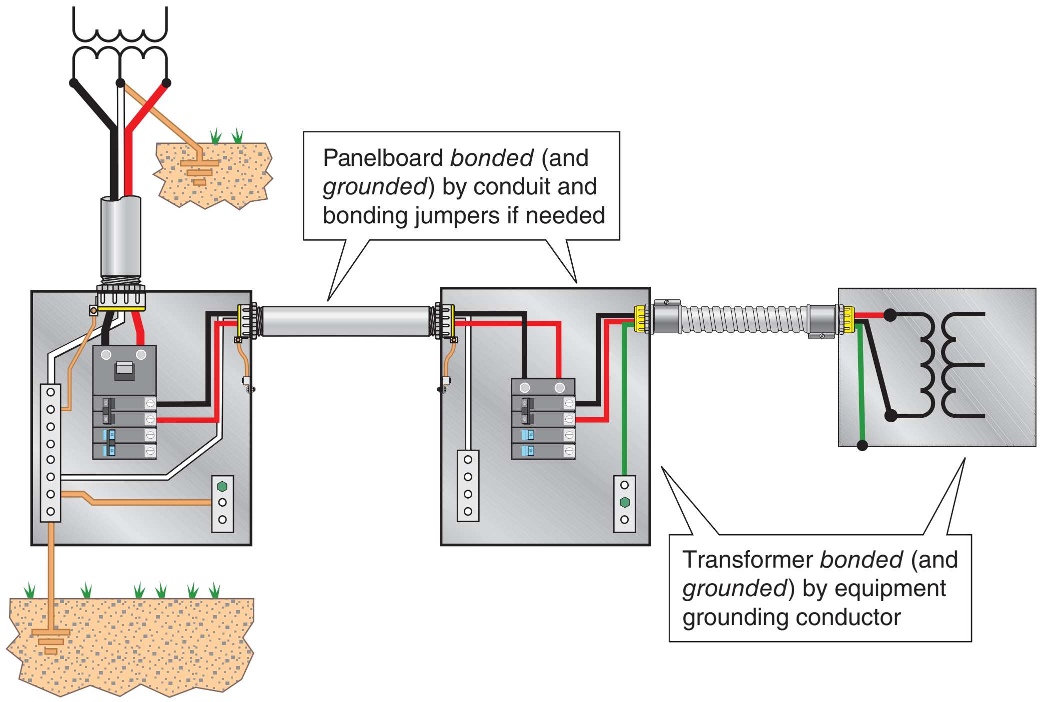


FIGURE I-6 Bonding with wiring methods and equipment grounding conductor.

Another type of bonding is equipotential bonding. The term *equipotential bonding* is not defined in the *NEC*, but the concept is that a bonding conductor is installed and connected between equipment so there is no shock hazard if a person or animal contacts both equipment at the same time. This equipotential bonding attempts to keep the equipment at the same voltage level even if a line-to-ground fault has occurred in one of the pieces of equipment. A voltage will be impressed on the equipment due to voltage drop of the circuit until the overcurrent device opens.

Equipotential bonding requirements appear in at least four locations in the *NEC*. Equipotential bonding is used in patient care areas of health care facilities, though the term is not used in *Article 517;* in *Article 680* for swimming pools and related equipment; in *Article 682* for certain metal equipment near natural and artificially made bodies of water; and in *Article 547* for agricultural buildings. Equipotential bonding is done to keep the potential (voltage) equalized so far as practicable, so there is no shock hazard to people or animals that have contact with more than one conducting surface or are immersed in water. In this book, the words *bonded* and *bonding* are not used to mean equipotential bonding unless stated otherwise.

Bonding Conductor or Jumper *(NEC Article 100).* A reliable conductor to ensure the required electrical conductivity between metal parts required to be electrically connected.*

Discussion: A bonding conductor or jumper is a conductor, made of copper or aluminum, used to ensure electrical conductivity between metal parts that must be electrically connected (see Figure I-7). Obviously, a bonding jumper is used to comply with the requirement for bonding equipment or completing the path for current to flow. For some installations, the *NEC* requires the bonding jumper to be copper; for others, an aluminum conductor is permitted to be used. The *NEC* specifies the minimum size of copper or aluminum conductor permitted for the particular application. In every case, the conductor must be large enough to safely carry the fault current imposed on it without becoming so hot the connectors or conductors are damaged.

It is also obvious that a piece of conduit or other metal raceway functions as a bonding conductor.

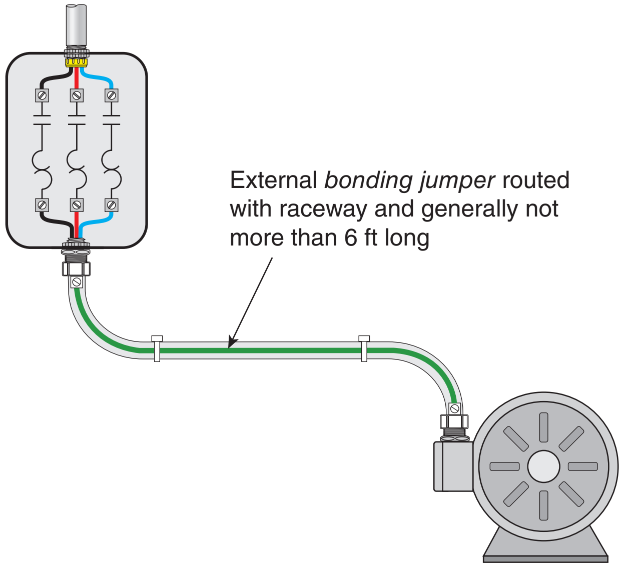


FIGURE I-7 Bonding conductor or jumper, *Article 100.*

When properly connected to each metallic enclosure, the metallic raceway connects or bonds the metal enclosures together. In reality, the connection of the conduit to the first enclosure bonds the conduit to the enclosure. The connection of the metal conduit to the second enclosure makes a bonding connection. Thus, the metal enclosures are connected together, or bonded, by the proper connection of the metal raceway between them.

As previously discussed, if the first or second metal enclosure is grounded, the bonding conductor also extends the earth connection to the other enclosure or equipment.

Equipment Bonding Jumper (Bonding Jumper, Equipment) *(NEC Article 100).* The connection between two or more portions of the equipment grounding conductor.*

Discussion: Equipment bonding jumpers are used to complete the path provided by the equipment grounding conductors should it be impaired in any way such as a suspect connection of conduit or EMT to an enclosure (see Figures I-5 and I-7). Equipment grounding conductors are permitted to consist of conduit or metallic tubing, in addition to the wire-type conductors. A list of acceptable equipment

*Source: NFPA 70-2020

grounding conductors is found in *NEC 250.118*. An equipment bonding jumper sometimes is needed to provide a reliable and low-impedance connection between conduit fittings, or between conduit and enclosure. An equipment bonding jumper should be installed if the integrity of connection of the equipment grounding conductor, be it conduit or otherwise, is not assured or is suspect in any way. Remember, we need to provide the effective ground-fault return path.

Equipment grounding conductors and bonding jumpers are permitted to be installed outside a raceway or cable assembly in certain situations. These equipment grounding or bonding jumpers generally are limited to not more than 6 ft (1.8 m) in length and must be routed with the raceway; an example is shown in Figure I-7. See *250.102(E), 250.130(C),* and *250.134(B).* Bonding jumpers are permitted to be longer than 6 ft (1.8 m) for outside installations on poles.

For conduit and metallic tubing installations, a single loose locknut, connector, or coupling connection will interrupt the ground-fault return path, creating a shock hazard if a ground fault occurs beyond the loose connection. (This cautionary note is not intended as a criticism of properly made conduit or metallic tubing installations.) As can be seen in Figure I-8, a ground fault on the downstream side of a loose conduit connection will create a shock hazard, as equipment on the load side of the fault will rise to the voltage of the system. This voltage will appear across the point of the loose connection. As an example, this is identical to measuring the voltage across a switch. You will find system voltage across a switch that is open.

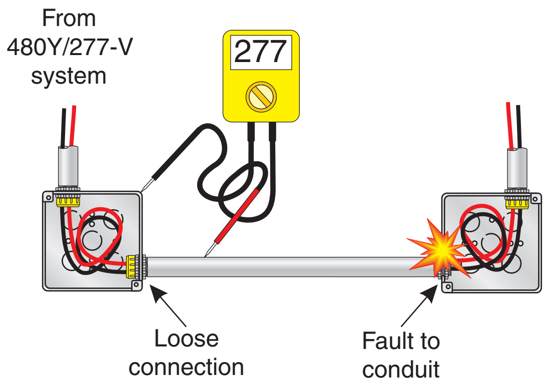


FIGURE I-8 Incomplete path.

Main Bonding Jumper (Bonding Jumper, Main) *(NEC Article 100).* The connection between the grounded-circuit conductor and the equipment grounding conductor, or the supply-side bonding conductor, or both, at the service.*

Discussion: *Article 250* has specific requirements for the size of the main bonding jumper. As with other bonding jumpers, the main bonding jumper must be large enough not to melt while carrying current. The main bonding jumper is located within the service equipment or the service disconnecting means and is permitted to be a wire, a bus, or a screw (see Figure I-9). It is identical in function to the system bonding jumper that is located in separately derived systems. The main bonding jumper and the system bonding jumper are

*Source: NFPA 70-2020

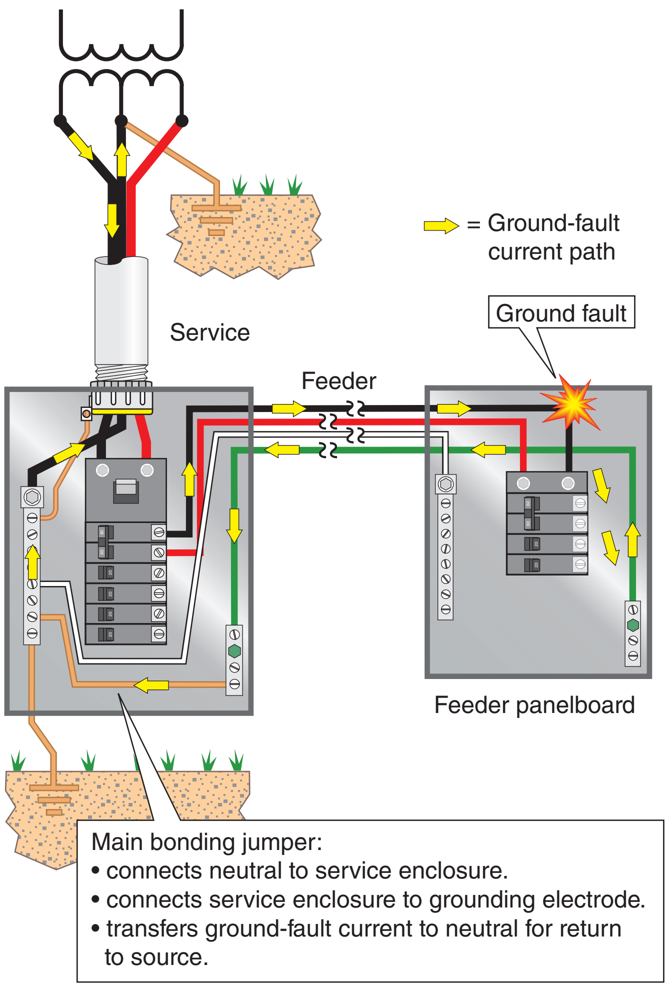


FIGURE I-9 Main bonding jumper, *NEC Article 100.*