CONSTRUCTION ELECTRICIAN APPRENTICESHIP PROGRAM

Level 1 Line G: Install Low-Voltage Distribution Systems



LEARNING GUIDE G-3

INSTALL GROUNDING AND BONDING

ita
industry training authority

THE RIGHT SKILLS ▶ A PROVEN ADVANTAGE

BRITISH COLUMBIA

Foreword

The Industry Training Authority (ITA) is pleased to release this major update of learning resources to support the delivery of the BC Electrician Apprenticeship Program. It was made possible by the dedicated efforts of the Electrical Articulation Committee of BC (EAC).

The EAC is a working group of electrical instructors from institutions across the province and is one of the key stakeholder groups that supports and strengthens industry training in BC. It was the driving force behind the update of the Electrician Apprenticeship Program Learning Guides, supplying the specialized expertise required to incorporate technological, procedural and industry-driven changes. The EAC plays an important role in the province's post-secondary public institutions. As discipline specialists the committee's members share information and engage in discussions of curriculum matters, particularly those affecting student mobility.

ITA would also like to acknowledge the Construction Industry Training Organization (CITO), which provides direction for improving industry training in the construction sector. CITO is responsible for organizing industry and instructor representatives within BC to consult and provide changes related to the BC Construction Electrician Training Program.

We are grateful to EAC for their contributions to the ongoing development of BC Construction Electrician Training Program Learning Guides (materials whose ownership and copyright are maintained by the Province of British Columbia through ITA).

Industry Training Authority
January 2011

Disclaimer

The materials in these Learning Guides are for use by students and instructional staff and have been compiled from sources believed to be reliable and to represent best current opinions on these subjects. These manuals are intended to serve as a starting point for good practices and may not specify all minimum legal standards. No warranty, guarantee or representation is made by the British Columbia Electrical Articulation Committee, the British Columbia Industry Training Authority or the Queen's Printer of British Columbia as to the accuracy or sufficiency of the information contained in these publications. These manuals are intended to provide basic guidelines for electrical trade practices. Do not assume, therefore, that all necessary warnings and safety precautionary measures are contained in this module and that other or additional measures may not be required.

Acknowledgements and Copyright

Copyright © 2016 Industry Training Authority

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or digital, without written permission from Industry Training Authority (ITA). Reproducing passages from this publication by photographic, electrostatic, mechanical, or digital means without permission is an infringement of copyright law.

The issuing/publishing body is: Crown Publications, Queen's Printer, Ministry of Citizens' Services

The Industry Training Authority of British Columbia would like to acknowledge the Electrical Articulation Committee and Open School BC, the Ministry of Education, as well as the following individuals and organizations for their contributions in updating the Electrician Apprenticeship Program Learning Guides:

Electrical Articulation Committee (EAC) Curriculum Subcommittee

Myles Andrew (University of the Fraser Valley)
Carmen Bradley (Camosun College)
Nathan Chapin (British Columbia Institute of Technology)
Paul Eisenhauer (Northwest Community College)
Joel Feenstra (University of the Fraser Valley)
Jim Gamble (Okanagan College)
John MacMillan (College of New Caledonia)
Ron Murray (Kwantlen Polytechnic University)
Peter Poeschek (Thompson Rivers University)
Jim Reaugh (British Columbia Institute of Technology)
Daniel Smythe (University of the Fraser Valley)
Ted Simmons (British Columbia Institute of Technology)
Jeremiah Williamson (Okanagan College)

Members of the Curriculum Subcommittee have assumed roles as writers, reviewers and subject matter experts throughout the development and revision of materials for the Electrician Apprenticeship Program.

Open School BC

Open School BC provided project management and design expertise in updating the Electrician Apprenticeship Program print materials:

Adrian Hill, Project Manager
Monique Brewer, Director
Sharon Barker, Production Technician (print layout)
Christine Ramkeesoon, Graphics Media Coordinator
Keith Learmonth, Editor
Joel Feenstra, Writer

Publishing Services, Queen's Printer

Spencer Tickner, Director of QP Publishing Services

Intellectual Property Program

Ilona Ugro, Copyright Officer, Ministry of Citizens' Services, Province of British Columbia

To order copies of any of the Electrician Apprenticeship Program Learning Guide, please contact us:

Crown Publications, Queen's Printer
PO Box 9452 Stn Prov Govt
563 Superior Street 3rd Flr
Victoria, BC V8W 9V7
Phone: 250-387-6409
Toll Free: 1-800-663-6105
Fax: 250-387-1120
Email: crownpub@gov.bc.ca
Website: www.crownpub.bc.ca

Version 1
Corrected, January 2017
New, December 2016

LEVEL 1, LEARNING GUIDE G-3:

INSTALL GROUNDING AND BONDING

Learning Objectives 9

Learning Task 1: Describe the objectives of grounding 11
Self-Test 1. 24

Learning Task 2: Describe the objectives of bonding 26
Self-Test 2. 34

Learning Task 3: Select appropriate materials for grounding and bonding 35
Self-Test 3. 44

Learning Task 4: Determine grounding and bonding requirements 46
Self-Test 4. 49

Answer Key 55

Learning Objectives

The learner will be able to:

- Describe the objectives of grounding and bonding as applied to DC and residential single-phase AC systems.
- Discriminate between grounding and bonding.
- Apply grounding and bonding techniques to DC and single-phase AC systems.

Activities

- Read and study the topics of Learning Guide G-3.
- Complete Self-Tests 1 through 4. Check your answers with the Answer Key provided at the end of this Learning Guide.

Resources

You are encouraged to obtain the following text to provide supplemental learning information:

- *Canadian Electrical Code, Part 1* (latest edition)*, published by the Canadian Standards Association.

Note: emphasis has been added (italics) to all excerpts from the *Canadian Electrical Code, Part 1, Safety Standard for Electrical Installations*, 2015. The purpose behind adding emphasis is to draw attention to those quotations that come directly from the CEC.

* In the Province of British Columbia, it is also required to amend the CEC with the BC Amendments, which you can obtain from the BC Safety Authority website. The Electrical Information Bulletin titled *2015 BC Electrical Code Adoption IB-EL 2015-06* can be referenced at the following link:

http://safetyauthority.ca/regulations/electrical/information-bulletins

Additional resources cited throughout this Learning Guide may be referenced online.

BC Trades Modules
https://www.bctradesmodules.gov.bc.ca

We want your feedback! Please go the BC Trades Modules website to enter comments about specific section(s) that require correction or modification. All submissions will be reviewed and considered for inclusion in the next revision.

SAFETY ADVISORY

Be advised that references to the Workers' Compensation Board of British Columbia safety regulations contained within these materials do not/may not reflect the most recent Occupational Health and Safety Regulation.

The current Standards and Regulation in BC can be obtained at the following website: http://www.worksafebc.com.

Please note that it is always the responsibility of any person using these materials to inform him/herself about the Occupational Health and Safety Regulation pertaining to his/her area of work.

Industry Training Authority
January 2011

Note: emphasis has been added (italics) to all excerpts from the *Canadian Electrical Code, Part 1, Safety Standard for Electrical Installations*, 2015. The purpose behind adding emphasis is to draw attention to those quotations that come directly from the CEC.

Learning Task 1:

Describe the objectives of grounding

The primary purpose of the *Canadian Electrical Code, Part 1, Safety Standard for Electrical Installations* is to protect human life. It does this by preventing shock hazards as well as fire hazards.

Even though safe installation and work practices should be adhered to, it is recognized that there may be times where people may be inadvertently exposed to electrical shock hazards. But if the electrical system is properly grounded and bonded, the maximum potential shock that any person may be exposed to will be limited. Also, by limiting the voltage-to-ground of an electrical system, it will be harder to create and maintain an electrical arc between any live conductor and any grounded equipment enclosures. This lowered voltage-to-ground means the current carried in the arc will also be much lower. And together this means the duration, intensity, and resultant heat of that arc will be at a much lower value, thereby reducing fire risk. Lastly, circuit protective devices like fuses and breakers will also respond sooner on a properly grounded and bonded system.

Because safety, fire prevention, and overcurrent operation are all improved through proper grounding and bonding methods, the Canadian Electrical Code (CEC) has established rigorous standards to ensure this happens. Section 10 of the CEC is where most of those rules are found.

Grounding to limit DC voltage-to-ground

The main purpose of the grounding conductor is to limit the system voltage-to-ground.

CEC Rule 10-002(2) states: "*The object of grounding the electrical system and non-current-carrying metal parts is to connect the earth to the equipotential plane, thereby minimizing any potential difference to earth.*"

The phrase "minimizing any potential difference to earth" means that the system voltage should be neither excessively high nor excessively low in relation to the voltage potential of ground. Maintaining it in this range means it will be at the safest comparative level possible.

To visualize this, imagine working on a (unsafe!) job site next to a 7-m-tall (24 ft.) structure (Figure 1). If something falls off the top and hits a worker, it will do so with a lot of force. This is due to the potential difference in relative elevations of the worker and the top of the structure.

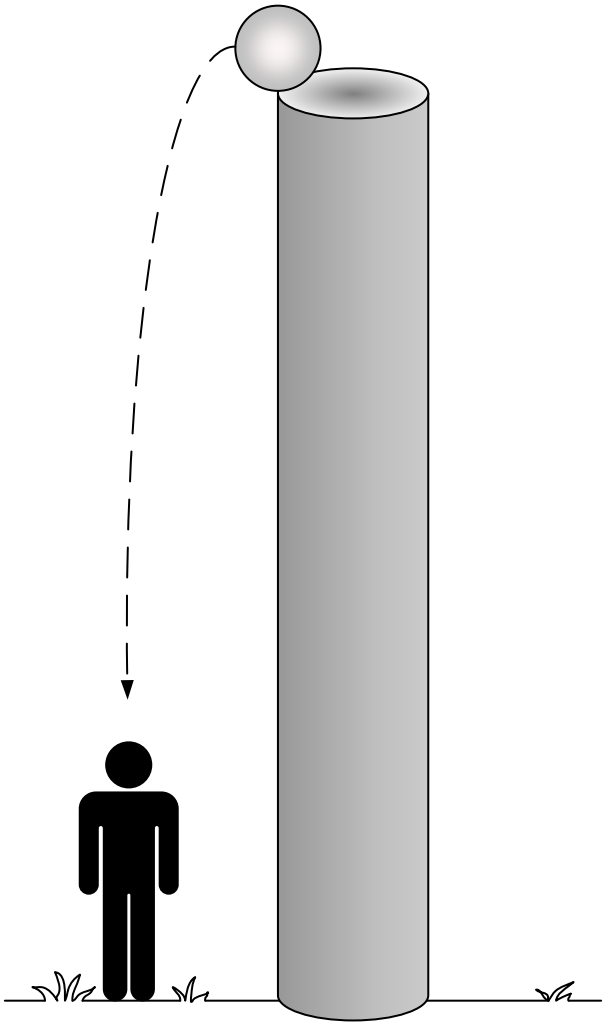


Figure 1—Potential caused by height

In the same way that a height can pose a danger, a depth can as well. If a worker were to walk over the edge of an unguarded 7-m-deep pit (Figure 2), they would most likely suffer serious injury as well. This is once again due to the potential difference in relative elevations of the worker and the bottom of the pit.

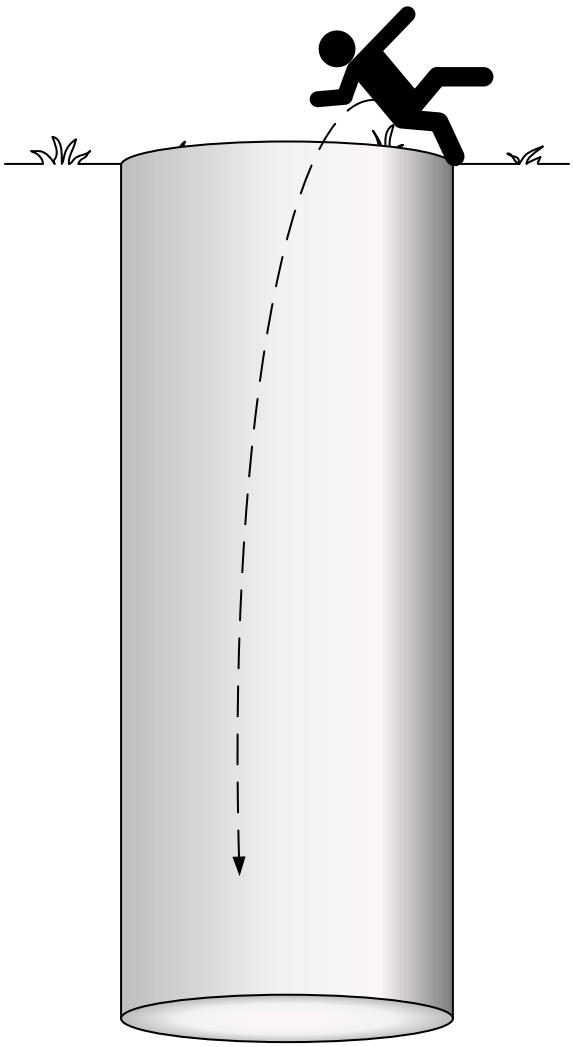


Figure 2—Potential caused by depth

Both of these hazards could be limited. If the structure was lowered (which means there would be less energy given to a falling object), anything that might fall onto a worker will do so with less force (Figure 3). And if the pit was shallower, then anyone who falls into it will land with less force.

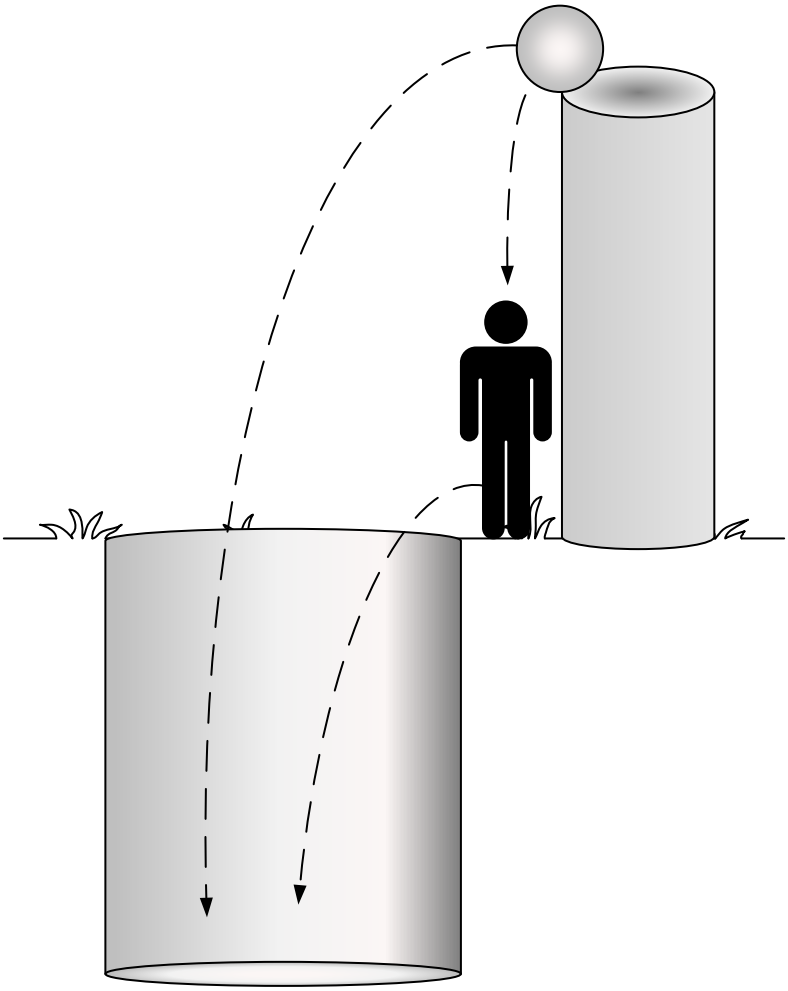


Figure 3—Limited potential by reducing both height and depth

By allowing a structure of no higher than 3.5 m (12 ft.) and an excavation of no more than 3.5 m, the maximum forces from a fall or falling object are limited for the workers. Note that there is still a 3.5-m difference between the top of the structure and the bottom of the pit. So if an object falls from the top of the structure to the bottom of the pit, it will still have the ability to achieve the same force and acceleration as if it were falling off the top of a 3.5-m structure.

This analogy shows what limiting potential difference by grounding a system achieves. But when dealing with electricity, instead of a height differential, there is a voltage differential. The system can have either an extremely high positive voltage or an extremely high negative voltage. Both would cause large amounts of current to flow back to the source. But if the system is grounded in the middle, there will be a moderate voltage (in relation to ground) seen at each line, resulting in a lower value of current flow back to the source.

Any ungrounded power supply can be safely grounded at only one electrical point. Applying a single system ground does not cause a fault; it just acts as an electrical anchor point, and all the rest of the points in a circuit will then have their voltage levels read in reference to the ground. It is the electrician's responsibility to identify the proper electrical point to be grounded

in the system, and then ground it according to Code. Refer to Figure 4. For a 3-wire DC system, that means the most negative lead could be grounded (Situation A), the most positive lead could be grounded (Situation B), or the middle junction between sources could be grounded (Situation C).

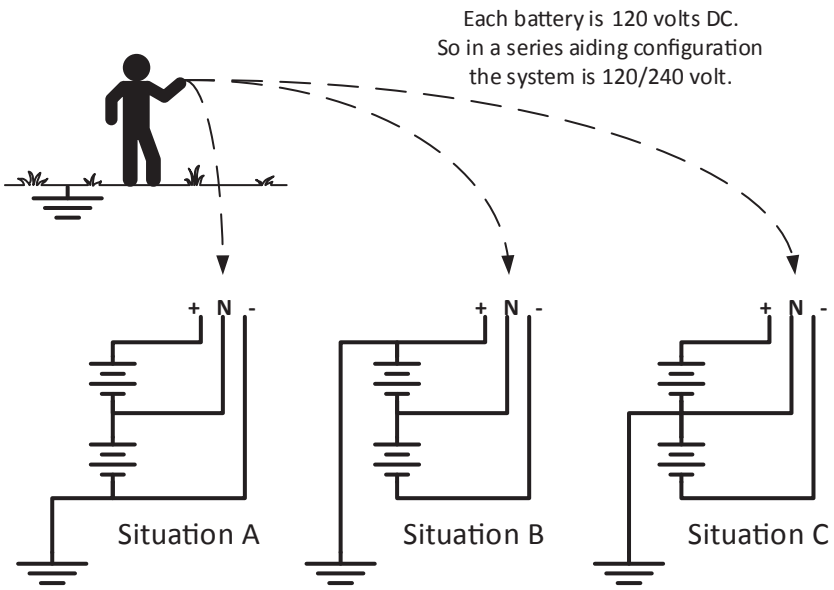


Figure 4—Three grounding options for a DC 3-wire supply

In Situation A, if a person in contact with ground touches the positive supply lead, they will receive a +240 volt DC shock. If they touch the negative supply lead, they will not receive a shock, as they are at the same potential as that lead. If they touch the middle neutral junction between sources, they will receive a +120 volt DC shock.

In Situation B, if a person in contact with ground touches the negative supply lead, they will receive a –240 volt DC shock. If they touch the positive supply lead, they will not receive a shock, as they are at the same potential as that lead. If they touch the middle neutral junction between sources, they will receive a –120 volt DC shock.

In Situation C, if a person in contact with ground touches either the positive or negative supply lead, they will receive a respectively positive or negative 120 volt DC shock. If they touch the middle neutral junction between sources, they will not receive a shock, as there is no potential difference between their body and that point.

From looking at the potential shock voltages a user could be exposed to, it is quite obvious that grounding the system at the central point (referred to as the *neutral*) will keep all voltages at their lowest levels in relation to the earth itself. This is directly mandated in Rule 10-104: "*The neutral conductor of all 3-wire DC systems supplying interior wiring shall be grounded.*"

Grounding to limit AC voltage-to-ground

The exact same concept of picking the midpoint of a voltage source as the optimal place to ground the system is applied to AC single-phase systems as well. But in an AC system, there is no fixed positive or negative voltage like in a DC system. Instead, the voltage is constantly switching back and forth between being positive and negative. Still, despite the constantly changing polarities, a single-phase AC circuit can have a neutral point that is established halfway between the line-to-line voltages. So, just like in a 3-wire DC system, the CEC mandates the grounding of the neutral conductor when present: Rule 10-106(1)(b) states: *"Except as otherwise provided for in this Code, AC systems shall be grounded if the system incorporates a neutral conductor."* See Figure 5.

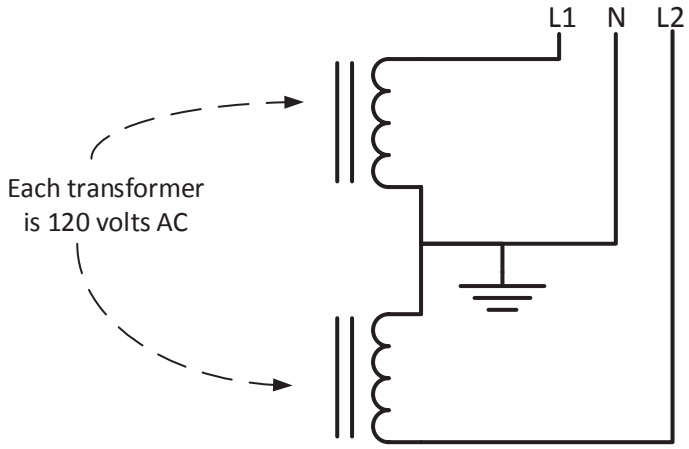


Figure 5—Properly grounded AC 3-wire supply

Grounding the central point of a 120/240 volt AC single-phase system also limits the maximum voltage (seen to ground) on either of the line conductors to a value less than 150 volts, as required by Rule 10-106(1)(a): "*Except as otherwise provided for in this Code, AC systems shall be grounded if by so doing, their maximum voltage-to-ground does not exceed 150 V.*"

Limiting of the voltage-to-ground is necessary in order for an AC system to be allowable for use in a single-family residential dwelling unit. An AC 120/240 volt 3-wire system would not be allowed until the circuit voltage had been properly limited to 150 V or less: Rule 2-110 states: *"Branch circuits in dwelling units shall not have a voltage exceeding 150 volts-to-ground …"*

Grounding to aid overcurrent operation

Overcurrent devices (circuit breakers and fuses) are designed to open up a circuit whenever an excessive amount of current passes through them. Anytime any line conductors in a circuit come into contact with the earth (or other conductive objects that are in electrical contact with the earth), it is said to be in a *ground fault* situation. The earth provides innumerable parallel paths for current to flow between points of potential electrical difference. Therefore it can be used to create a very low impedance (resistance) path for current to travel through. If that path is continuous between the ground faulted line on a system and the grounded neutral, a very large current (called a *fault current*) will flow due to the low-impedance path. That resultant fault current can then be used to trip the overcurrent device.

If an ungrounded 3-wire AC electrical supply has a ground fault on one of its line conductors, the overcurrent protection will not respond, since a single ground alone will not cause a high fault current. Instead, all other points in the circuit will see their voltages rise in relation to ground (Figure 6).

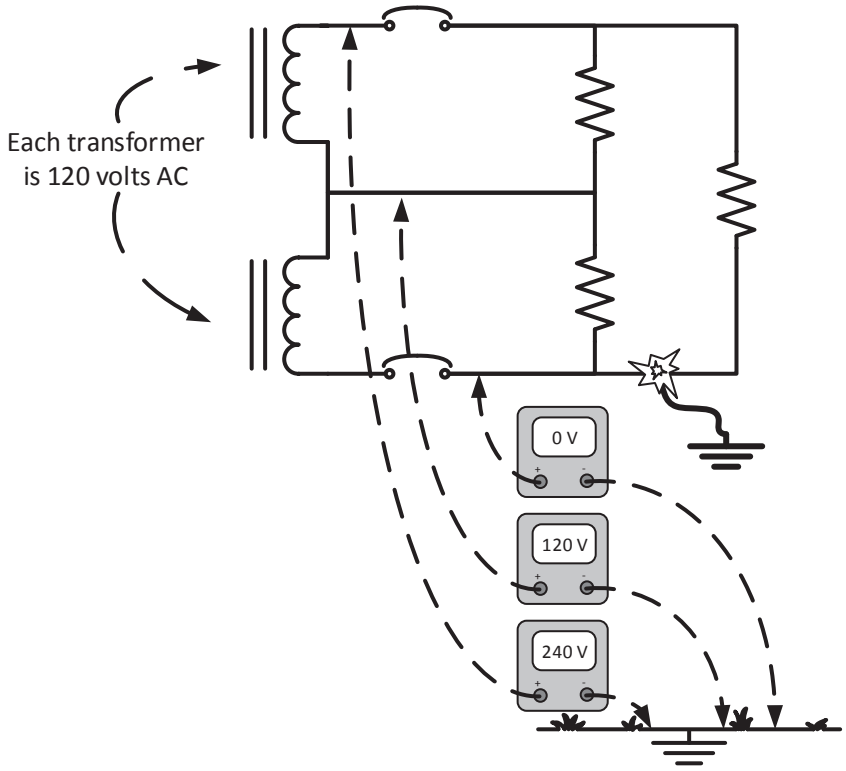


Figure 6—Ground fault on ungrounded system

If a second ground fault happens on the system, it will then finally have a low-impedance path, causing a high fault current to flow and be able to trip the overcurrent protection (Figure 7).

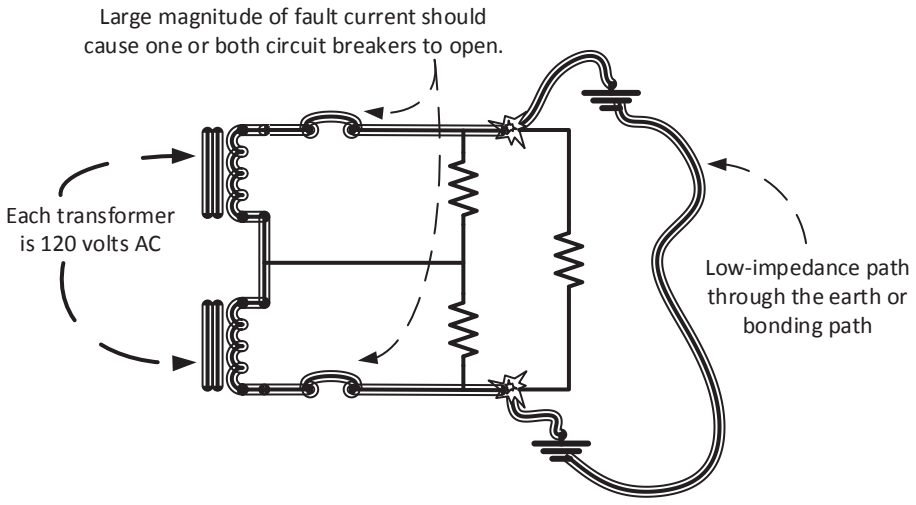


Figure 7—Second ground fault on an ungrounded system causing fault current

Rather than waiting for two ground faults before overcurrent devices operate, it would be much safer to start with the system already solidly grounded at the neutral (Figure 8). This way, if any of the lines develop a ground fault, there will immediately be a sufficiently large fault current to operate the overcurrent protection on the ground faulted line.

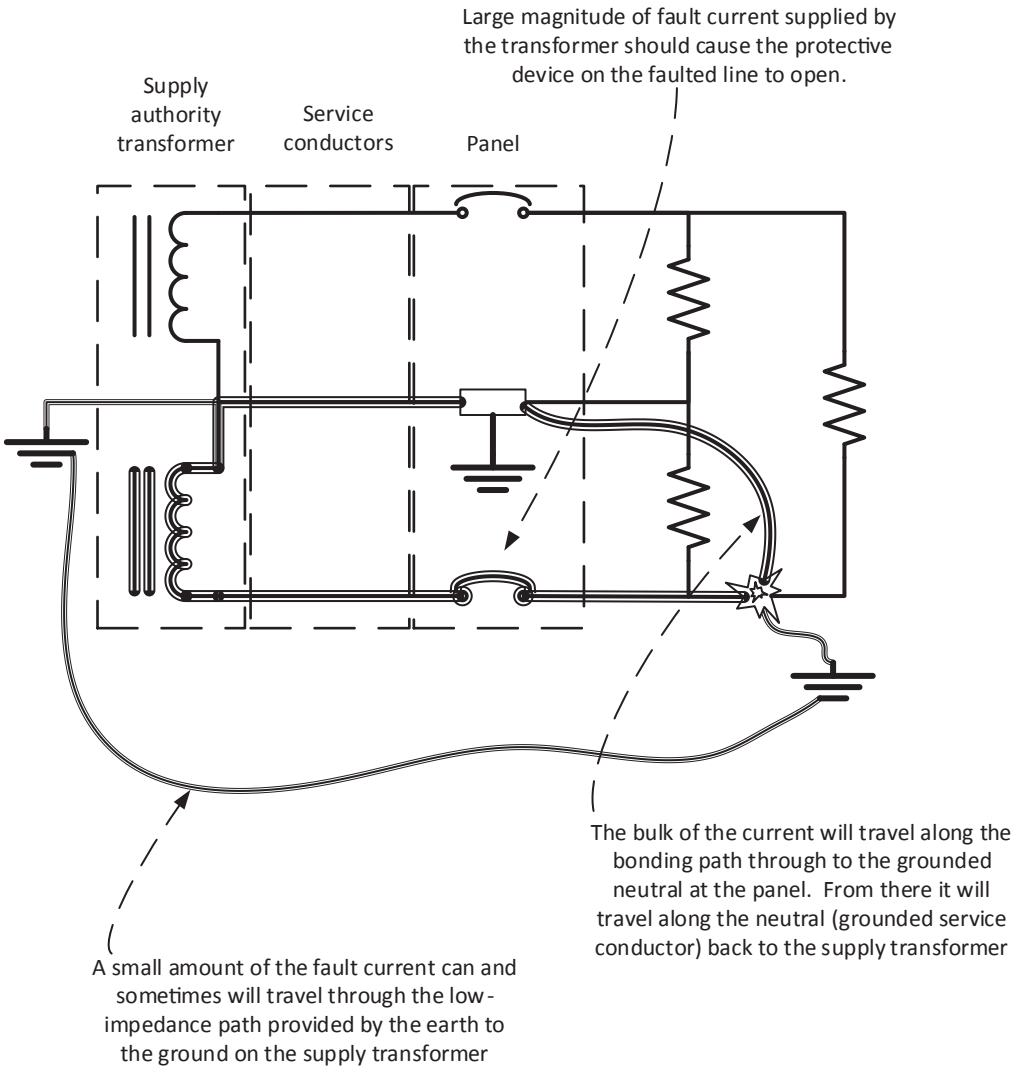


Figure 8—Enhanced operation of overcurrent devices on a grounded system

Types of grounds

In order to be considered a ground conductor, that conductor must eventually terminate on a grounding electrode. (A *grounding electrode* is a bare metallic object buried in direct contact with the earth that provides a much greater surface area than that of a buried wire alone. Their construction will be covered in much greater detail later on in Learning Task 3.) There are two types of ground conductors: system ground and equipment ground.

System ground

A *system ground* ties the neutral point of an electrical system to the earth, thereby "minimizing any potential difference to earth" for that system. There are two different places that a system ground must be created.

The first system ground must be created at the neutral of the power authority main transformer supplying the service (Figure 9). This is directly stated in Rule 10-204(1)(a): *"When a consumer's service is supplied by an AC system that is required to be grounded in accordance with Rule 10-106(1), the system shall be connected to a grounding conductor at the transformer or other source of supply."*

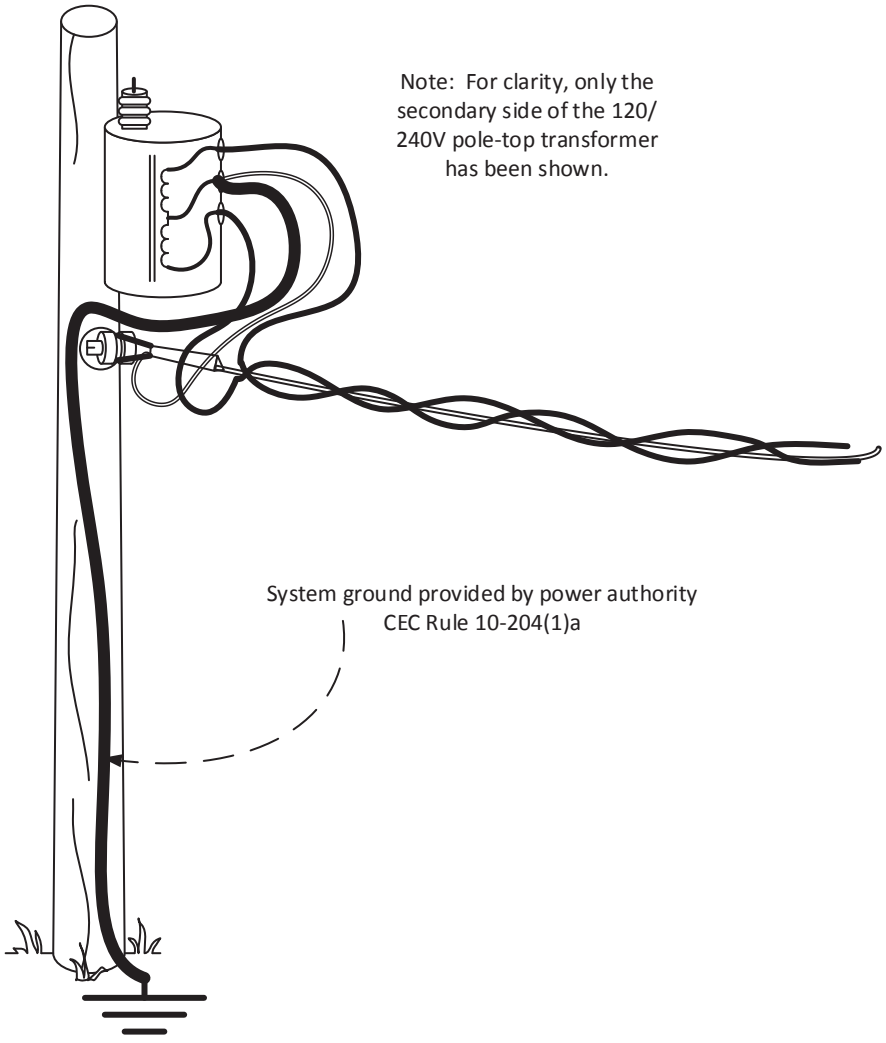


Figure 9—Power authority system ground

This particular system ground is not usually the responsibility of the electrician. BC Hydro or the local power authority will supply and connect it between their equipment (often a pole-mounted transformer) and the earth. As illustrated in Figure 9, this system ground can usually be seen running from the earth to the equipment on the side of any pole that carries a transformer.

In the case of a grade-mounted transformer (often called a *pad-mount transformer* or *low-profile transformer*), the system ground (often called the *counter-poise*) will be completely buried and brought up underground into the transformer.

The second system ground is the responsibility of the site electrician to create. It must run directly between the first user-accessible neutral point in the main service (the neutral bar or pad located in the main panel or switch) and the grounding electrode (Figures 10 and 11):

> Rule 10-204(1)(b): *When a consumer's service is supplied by an AC system that is required to be grounded in accordance with Rule 10-106(1), the system shall be connected to a grounding conductor at each individual service, with the connection made on the supply side of the service disconnecting means either in the service box or in other service equipment.*

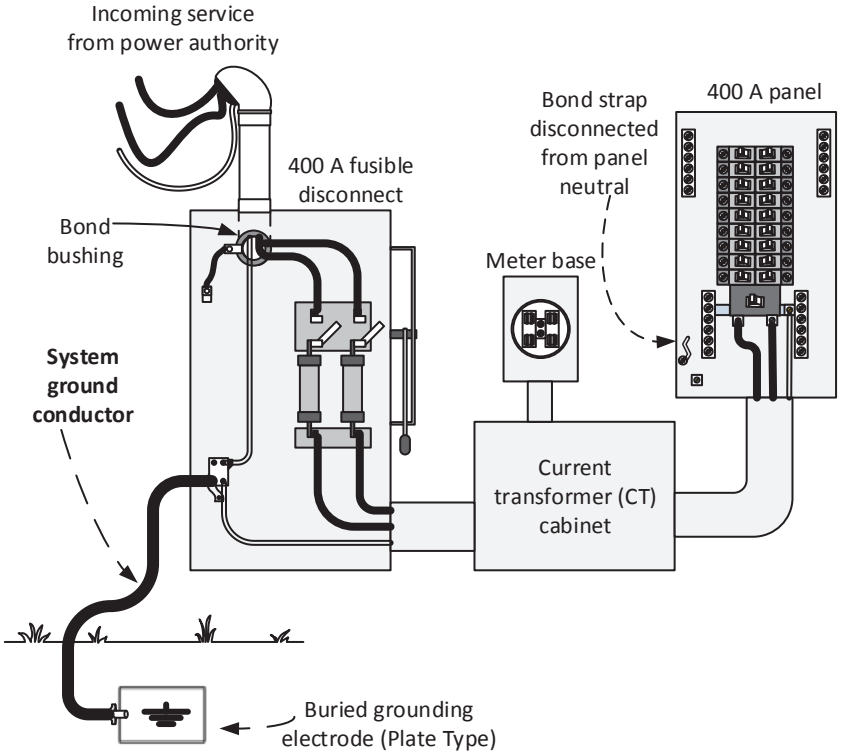


Figure 10—System ground on 400 A switch service

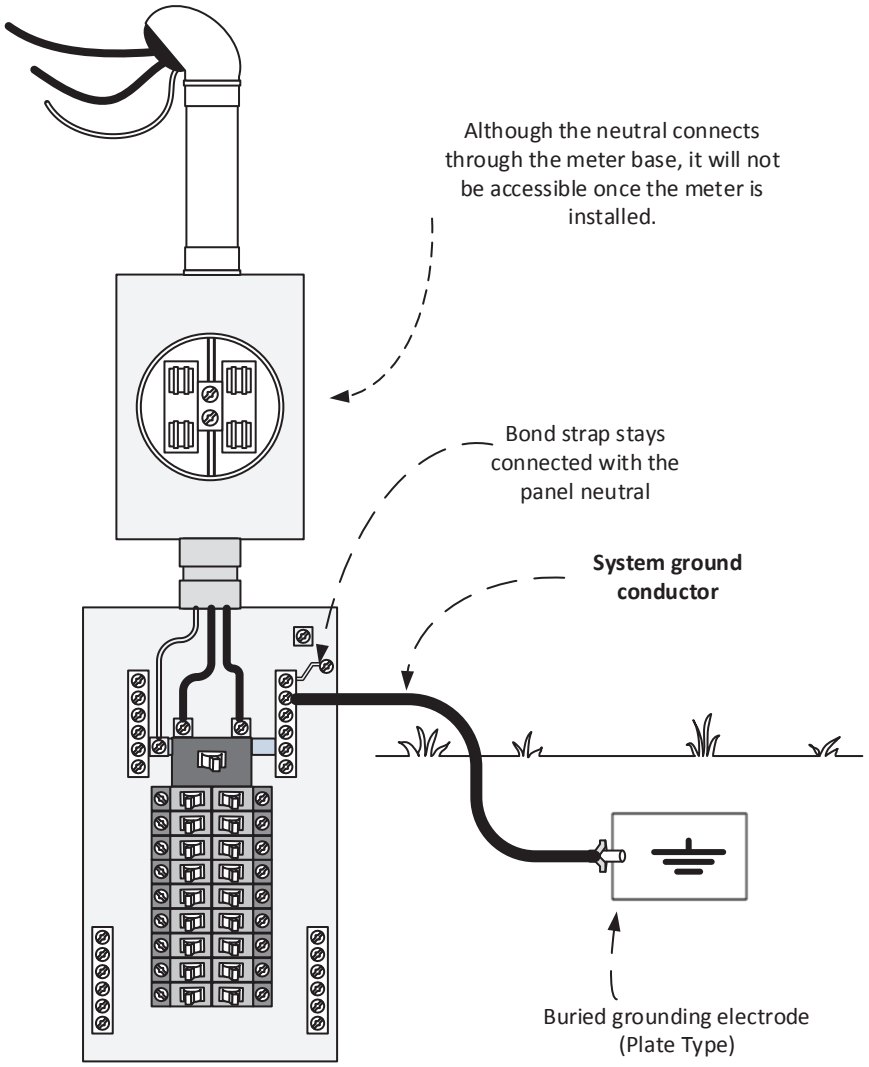
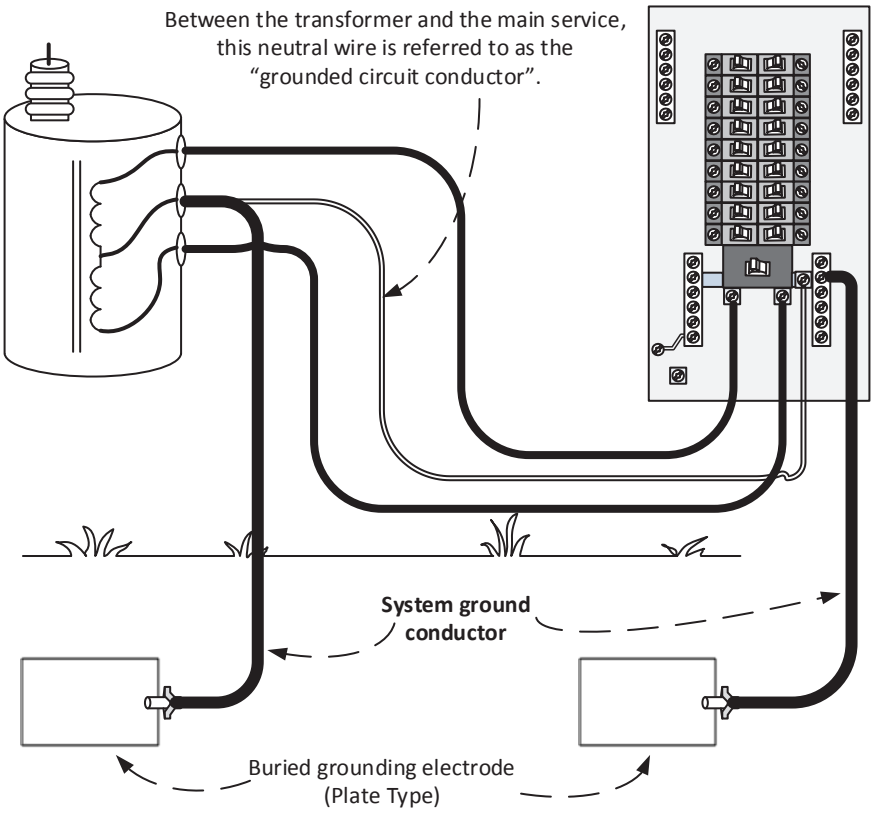


Figure 11—System ground on residential panel service

Although there are two separate system grounding conductors, electrically they are at the same point of potential in the system. If the service was only grounded at the power authority transformer (whether pole-mounted or pad-mounted) or at the service equipment, the entire system could become ungrounded if that solitary system ground was removed. Having two system grounds provides redundant safety in case of damage to one of the system grounds (Figure 12).



Note: For clarity, some physical components such as the mast and meter base are not shown. Just the wiring path between the power authority transformer and service panel are shown.

Figure 12—Both system grounds on an AC system

Equipment ground

Later in the Electrician Apprenticeship Program, you will learn that not every type of electrical service contains a neutral. Yet when using these ungrounded and neutral-free electrical systems, a ground will still be required for safety. This *equipment ground* is connected between a grounding electrode and the grounding terminal inside the main service equipment (Figure 13). This is directly stated in Rule 10-212(2): "*The grounding conductor shall connect the grounding electrode to the grounding terminal at the service box, or the equivalent where a service box is not installed.*"

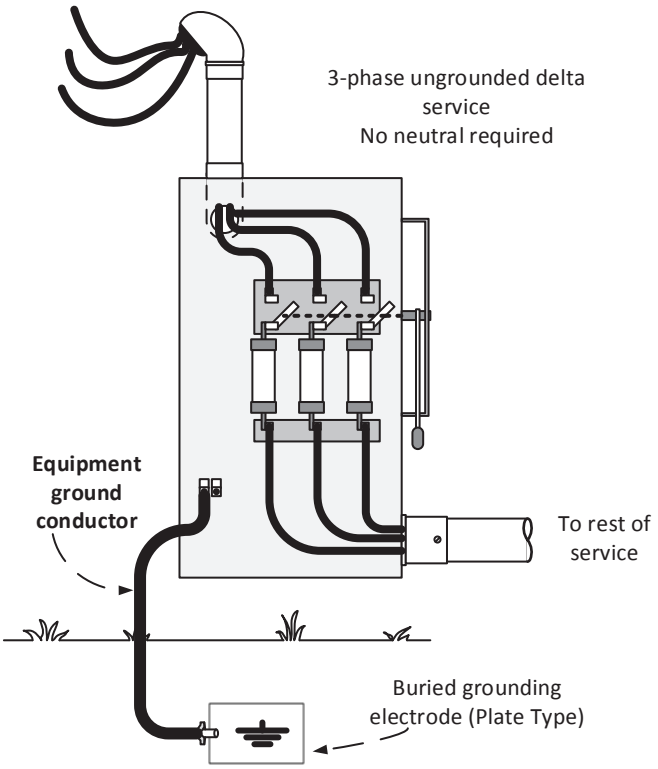


Figure 13—Equipment ground on an ungrounded electrical system

Now do Self-Test 1 and check your answers.

Self-Test 1

1. List three reasons to properly ground a system.

   _____

   _____

   _____

2. Which of the following electrical points should be grounded on a DC 3-wire system?

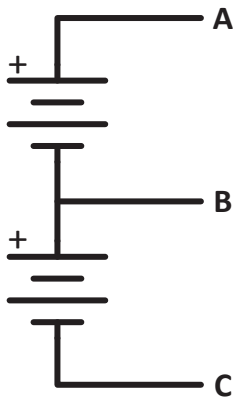
   a. Positive voltage terminal

   b. Negative voltage terminal

   c. Neutral voltage terminal _____

3. Fill in the chart below.

   If a ground is placed at the following locations on an ungrounded DC 3-wire supply, what voltages will be measured across the following points?

	If the service was grounded at point A …	If the service was grounded at point B …	If the service was grounded at point C …
… What magnitude and polarity of shock could be felt between point A and ground?			
… What magnitude and polarity of shock could be felt between point B and ground?			
… What magnitude and polarity of shock could be felt between point C and ground?			

4. Which of the following electrical points should be grounded on an AC 3-wire system?
   a. Line 1
   b. Neutral
   c. Line 2 _____

5. What is the maximum voltage-to-ground allowed for a single-phase residential application?

   _____

6. An electrical system may be grounded at how many electrical points?

   _____

   _____

7. May a single electrical point of a system be grounded at more than one physical location?

   _____

   _____

8. A system ground goes from the grounding electrode to the _____ inside the main service equipment.

9. An equipment ground goes from the grounding electrode to the _____ inside the main service equipment.

10. What is the minimum number of grounded points that are necessary on a circuit before the overcurrent devices will operate?

    _____

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 2:

Describe the objectives of bonding

Grounding is something that can be done to current-carrying system components (like a neutral), but bonding is something that is **only** done to non-current-carrying parts. Non-current-carrying parts are necessary metallic components used in wiring systems and equipment that are never supposed to be energized, but could become energized when a fault occurs. Examples can include metallic junction boxes, service equipment enclosures, equipment frames, metal conduits, and metallic cable armour.

Section 0 Definitions of the CEC defines bonding as follows:

> *Bonding — A low-impedance path obtained by permanently joining all non-current-carrying metal parts to ensure electrical continuity and having the capacity to conduct safely any current likely to be imposed on it.*

From this definition it can be seen that there are three conditions that need to be met in order for the bonding of non-current-carrying parts to be satisfied. Bonding between parts must be:

- Low impedance (resistance)
- Permanent
- Capable of carrying a system fault current

The object of this bonding is then defined in Rule 10-002(1):

> *The object of bonding metal parts and metal systems together and to the grounded system conductor is to reduce the danger of electric shock or property damage by providing a low-impedance path for fault current back to the source and to establish an equipotential plane such that the possibility of a potential difference between metal parts is minimized.*

This rule states that the bonded metal parts shall be connected to the system ground conductor. Since the ground conductor is already connected to the main neutral, there is usually then a connection from the neutral back to the metallic enclosure (switch or panel casing, which in turn is bonded to all other non-current-carrying parts of the installation). This connection between the bonded metal parts and the neutral is done to provide a path for any fault current back to the source of current at its supply transformer. By ensuring continuity of all bonded parts back to the main ground, the potential severity of any shocks or the intensity of any arc are both reduced.

Dangers of bonding without grounding

Because the insulation surrounding conductors is often fairly soft and flexible, those wires need protection, especially when being used in many commercial or industrial premises where damage from machines or processes could easily occur. As a result, the conductors are often given *mechanical protection*. This means they are enclosed in a rigid or flexible metal armour or conduit. Because the armour or conduit is often bare metal (and therefore conductive), there can be danger to personnel if that mechanical protection is not adequately bonded and then

tied back to the system ground. If a live conductor comes into contact with the conductive enclosure or wiring system, the entire metallic system could become energized.

A live electrical line and an identified conductor can both be enclosed inside a metallic conduit system to feed a load. But if a fault were to occur on that live conductor to the enclosing system (boxes and conduit, perhaps where it was skinned entering a box), it could potentially energize all electrically continuous boxes and conduits (Figure 1).

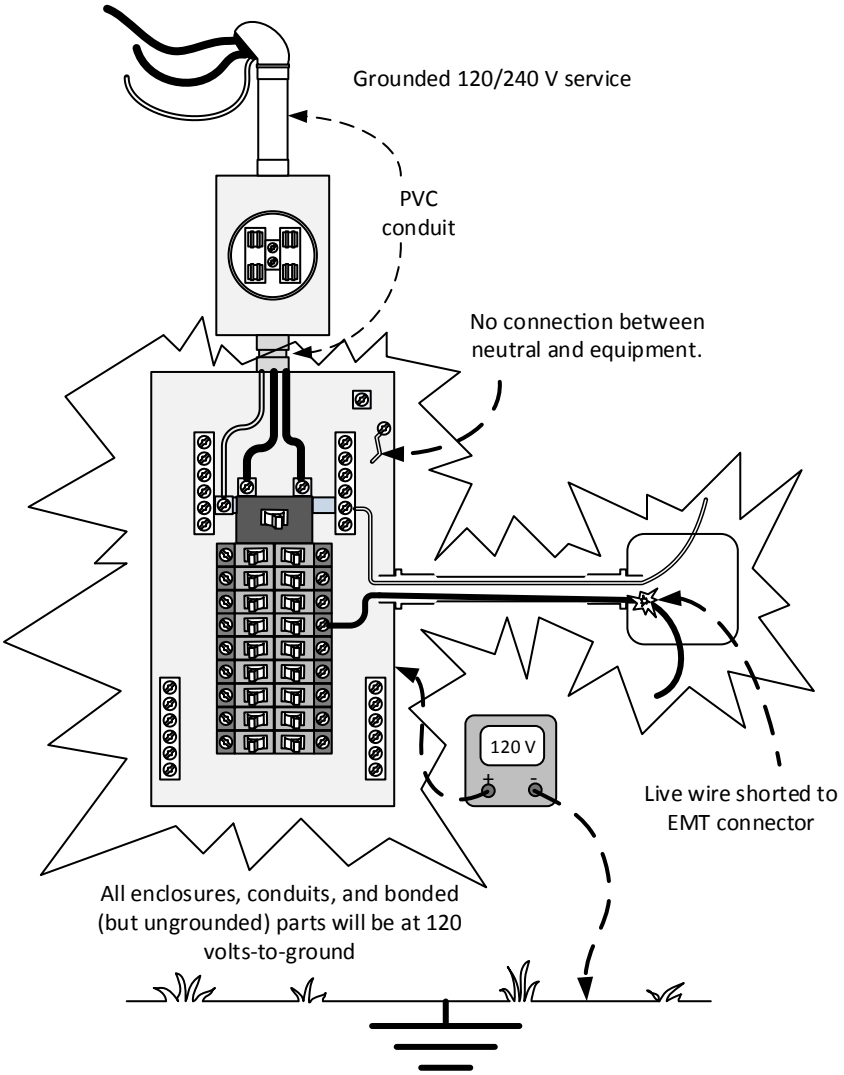


Figure 1—Short to ungrounded conduit and potential danger

If there is no connection between the bonded metal parts and the grounded neutral, there will be no complete path all the way back to the source. Consequently there would be no fault current to trip the overcurrent protection. The conduit system would stay energized at full line potential. This would result in danger for any personnel that might come in contact with the conduit or enclosures. If the individual is in contact with ground, they would receive a 120-volt shock, as their body would become the return path for current to return to its source at the transformer.

Bonding in conjunction with grounding

If that same ungrounded conduit not only had all boxes and sections bonded together, but also was bonded back to the system ground conductor at the neutral, there would be a complete path for fault current to flow back to the source (transformer supplying the system). And if the conduit path was properly installed, with good metallic contact all the way along so that it was a low-impedance path (for example, 2 Ω), a sufficient value of fault current (60 A = 120 V / 2 Ω) would be allowed to flow to trip the overcurrent (15 A branch circuit breaker) (Figure 2). This fault current would flow from the source transformer, through the overcurrent protection, through the conductor, through the fault, and then back to the neutral point (and transformer neutral) along the grounded and bonded conduit and enclosure path.

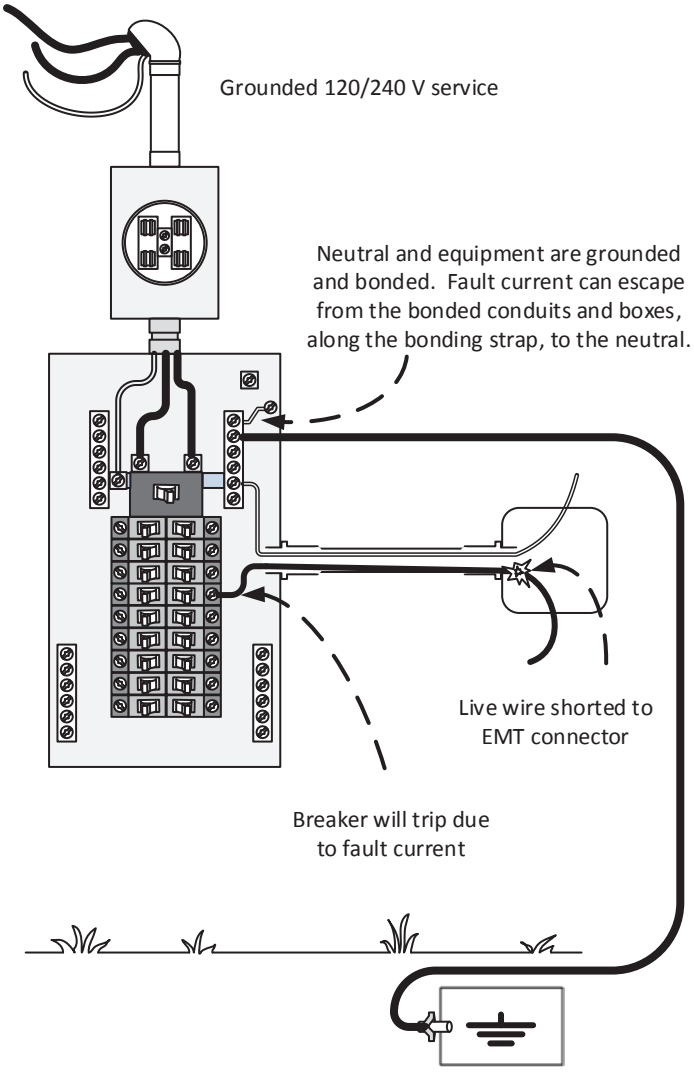


Figure 2—Fault current path along bonded conduit

A properly bonded and grounded system will cause overcurrent devices to operate upon a fault, and thereby reduce any shock hazard potentially caused by that fault.

Elimination of potential differences

Any time that a metallic object is cut by a changing magnetic field, a voltage differential will be created on that object through a process called *induction*. Since the magnetic field is constantly changing for an AC system, any metal close to an AC conductor could potentially be energized through this effect. If two pieces of metallic equipment were placed in proximity with each other and a current-carrying AC line, each will potentially have differing levels of voltage induced into them (Figure 3). Anyone making contact between one piece of equipment and the next could receive an electric shock.

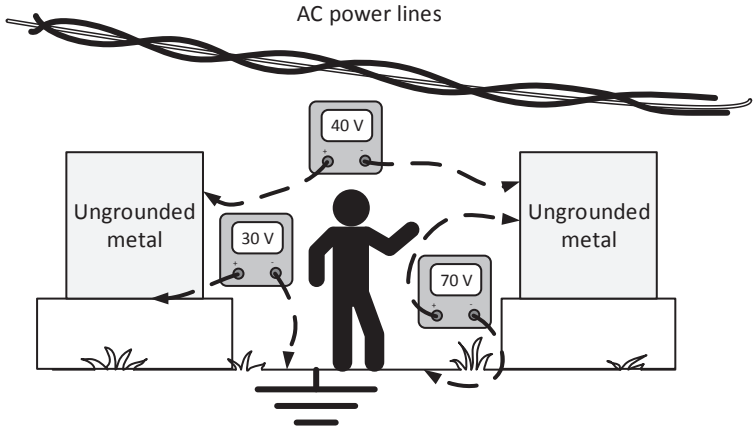


Figure 3—Unbonded and ungrounded inductively charged bodies

But if these pieces of equipment were to be bonded together, the low-impedance path from unit-to-unit and back to ground would ensure that they would both be at the same potential as each other and the earth (Figure 4). A person could touch both and receive no shock. This is what is meant in Rule 10-002, where it says *"...establish an equipotential plane such that the possibility of a potential difference between metal parts is minimized."*

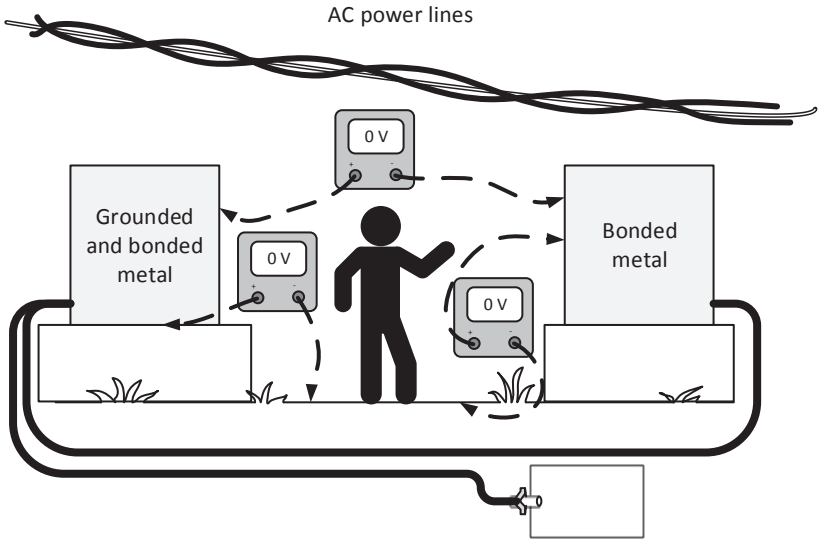


Figure 4—Bonded equipment with no potential differences

Non-electrical equipment

It is possible for metallic non-electrical equipment to become accidentally energized. Whether from induction caused by an AC conductor or by direct contact with an energized conductor, the results could be catastrophic. If these metallic pieces of non-electrical equipment are not bonded together and then back to the main ground, they could be at a potentially high voltage, creating electrical shock and fire hazards.

In particular, some non-electrical systems commonly used in residential applications are more dangerous than others under this condition. In order to prevent electrical shock or fire, they need to be bonded to ground. Specifically, these systems are:

- Water piping made of metal. If a line conductor faults to it, all taps and the hot water tank could potentially energize.
- Septic piping made of metal. If a line conductor faults to it, all metallic drains, sinks or bathing facilities could potentially energize.
- Gas piping made of metal. If a line conductor faults to it, all gas-fired appliances could potentially energize, or even worse, cause an arc that could ignite the gas system and cause an explosion.

Due to these dangers, the CEC has mandated rules that govern what must be done anytime that these systems are encountered in the field. Rule 10-406(2–4) lays out the non-electrical equipment that must be bonded (Figure 5):

> *(2) Where a metal water piping system is installed in a building supplied with electric power … the metal water piping system shall be bonded to the system grounding conductor.*
>
> *(3) Each continuous metal waste water piping system installed in a building supplied with electric power shall be bonded to the system grounding conductor or to the grounded metal water supply piping.*
>
> *(4) All interior metal gas piping that may become energized shall be made electrically continuous and shall be bonded.*

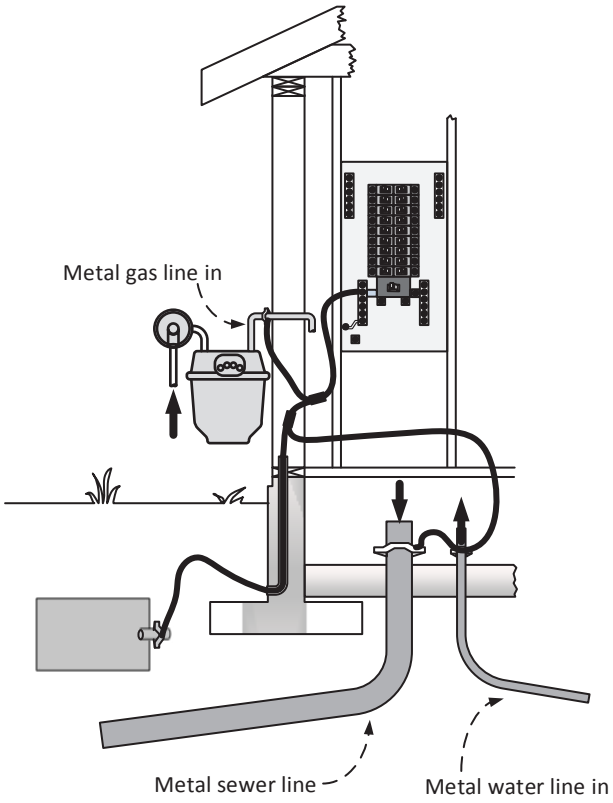


Figure 5—Bonded non-electrical equipment

Both the potable water system and the waste water system only need to be bonded when the system is continuous and made of metal. In other word, short pieces of metal composing parts of either system do not need to be bonded (e.g., sink stems, metal water faucets, backflow preventers, etc.). However, for a gas system, **ALL** metal parts must be bonded together and to the grounding electrode. So if the gas system is metal piping that transitions to a non-metallic flexible section and then back to metal again, it would need a bond jumper to make the system continuous (Figure 6).

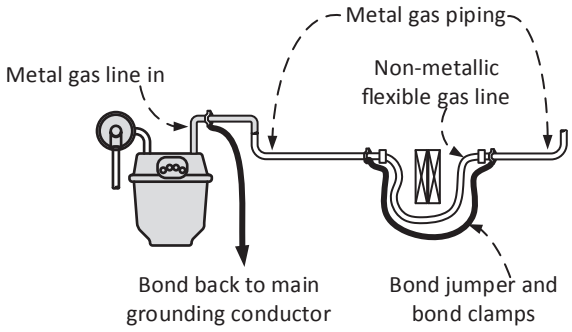


Figure 6—Bonding of metallic gas piping

There are other systems not mentioned in CEC Section 10 that must also be bonded to ground: the communications and television systems. Because these systems are connected to a much greater network of telephone and television wires both inside and outside a dwelling unit, there is a fairly significant chance that a fault could occur. To prevent faults on the exterior network (e.g., lightning) from crossing to the internal dwelling unit, or internal faults (e.g., contact with energized lines) from crossing to the external network, they have special devices, called *power blocking devices* (for cablevision) or *primary protectors* (for telephone) where the wiring transitions out of the dwelling unit (Figure 7). These devices provide a path for any unwanted faults to discharge to ground. Therefore these devices must be bonded back to the main system grounding point.

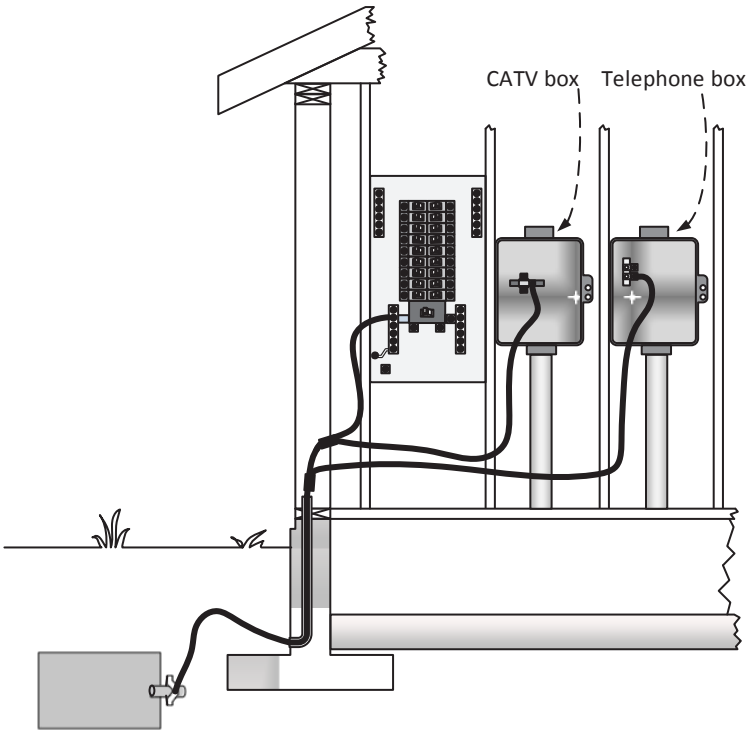


Figure 7—Bonding of television and CATV systems

Now do Self-Test 2 and check your answers.

Self-Test 2

1. Bonding between non-current-carrying metallic parts must be:

The following situation applies in questions 2 to 5:

An energized wire faults to the metallic box at a receptacle in a building piped in *electrical metallic tubing (EMT)*. Explain what happens to the receptacle's breaker for each of the following situations. Indicate what, if any, parts of the system will be energized after the fault. Determine whether each situation would be dangerous.

2. The box is not bonded to the EMT, and the electrical system is ungrounded.

3. The box and EMT are all bonded together and the electrical system is ungrounded.

4. The box is not bonded to the EMT, and the electrical system is grounded.

5. The box and EMT are all bonded together, and the electrical system is grounded.

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 3:

Select proper materials for grounding and bonding

In order for grounding and bonding to be effective, the materials used should be low impedance and not easily destroyed. That destruction could arise from mechanical damage or from degradation due to the environment they are used in. Because the integrity of a grounding and bonding system is so important to reduce hazards of electrical shock and fire, the CEC is very specific as to the construction of all parts to do with grounding and bonding.

Connections

Because the system grounding conductor is so critical for the entire system, it shall not be spliced between the grounding electrode and the first point of contact with the neutral, unless absolutely necessary. If it must be spliced, it shall be done with a method that it is substantial and non-reversible. Rule 10-806(1) states this:

> *(1) The grounding conductor for a system shall be without joint or splice throughout its length, except in the case of busbars, thermit-welded joints, compression connectors applied with a compression tool compatible with the particular connector.*

The bonding conductor is less critical to the system as a whole. A failure in it will only affect system components downstream from it. When entering and splicing cables in boxes, their bonds must be connected together and then to the box. Therefore Rule 10-808(1–2) allows the bonding conductor to be spliced and tapped ("pigtailed"):

> *(1) The bonding conductor for equipment shall be permitted to be spliced or tapped, but such splices or taps shall be made only within boxes, except in the case of open wiring where they shall be permitted to be made externally from boxes and shall be covered with insulation.*
>
> *(2) Where more than one bonding conductor enters a box, all such conductors shall be in good electrical contact with each other by securing all bonding conductors under bonding screws, or by connecting them together with a solderless connector and connecting one conductor only to the box by a bonding screw or a bonding device, and the arrangement shall be such that the disconnection or removal of electrical equipment fed from the box will not interfere with, or interrupt, the bonding continuity.*

This splicing together of bonds should never be done **on or under the screw of a device** because removal of that device would interrupt the bonding path (Figure 1). This is not permitted by Rule 10-808(2), and it is reinforced in Rule 10-904(6), which states:

> *(6) A bonding jumper shall be installed to connect the bonding conductor to the grounding terminal of a receptacle and in such a manner that disconnection or removal of the receptacle will not interfere with, or interrupt, grounding continuity.*

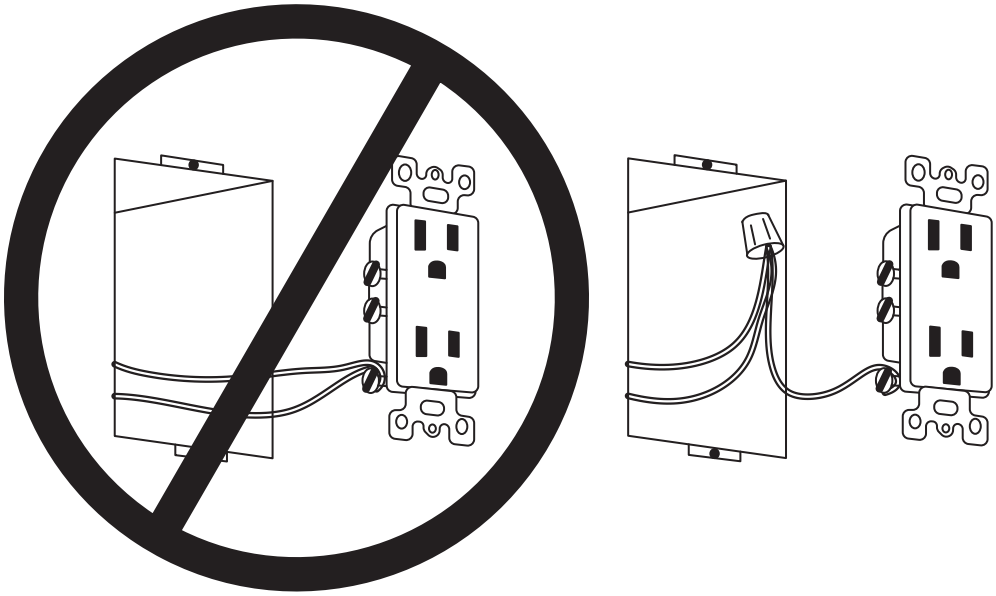


Figure 1—Proper tapping of a bond wire to a receptacle

The connection from the box to the bonding conductor must be done at every box that has a bond screw. Non-metallic boxes often have a metal bond strap that ensures a good bond to all device straps (the "ears" on every receptacle and switch). The bond strap in the box must not be relied upon as the only bond for that receptacle. Read Rule 10-904(6) again, and note that a bond wire is required.

In order to ensure a low-impedance connection when bonding, there must be good metal-to-metal contact between surfaces. If necessary, any potentially non-conductive surface coating must be scraped or sanded away as per Rule 10-600. Anytime that a lug is to be installed on a painted box, the paint beneath it should be removed prior to installation. This will ensure a solid, low-impedance connection between the box and lug.

> Rule 10-600: *Where a non-conductive protective coating such as paint or enamel is used on the equipment, conduit, couplings, or fittings, such coating shall be removed from threads and other contact surfaces in order to ensure a good electrical connection.*

Electrodes

The electrode is the part of a grounding system that is in direct contact with the earth. It is a bare, corrosion-resistant metallic object buried in direct contact with the earth that will provide a much greater surface area than that of a buried wire alone. Rule 10-700 defines three different types of grounding electrodes and gives further instructions as to burial depths, assemblies, etc.:

> Rule 10-700(1): *(1) Grounding electrodes shall consist of*
> *(a) manufactured grounding electrodes;*
> *(b) field-assembled grounding electrodes installed in accordance with this Rule; or*
> *(c) in-situ grounding electrodes forming part of existing infrastructure as defined in this Rule.*

Manufactured grounding electrodes are sold by wholesalers and then used on site. They are either a set of ground rods or a ground plate. These are in direct contact with either earth or the building concrete footing and are connected to the system grounding conductor with a ground clamp (Figure 2).

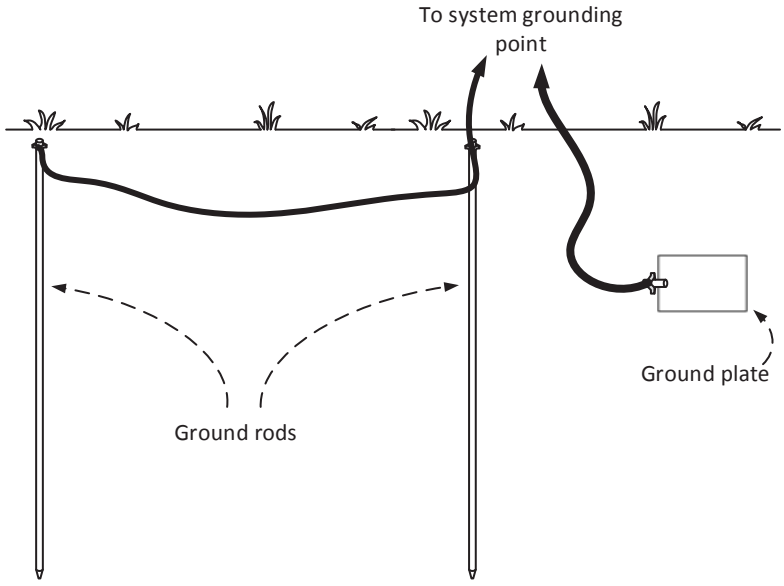


Figure 2—Manufactured grounding electrodes

Field-assembled grounding electrodes are made in the field by using bare copper wire sized off Table 43. A suitable length of wire (6 m or more, which gives the same surface area as a manufactured grounding electrode) is buried in either earth or the building concrete footing (Figure 3). This is commonly called a *Ufer* ground.

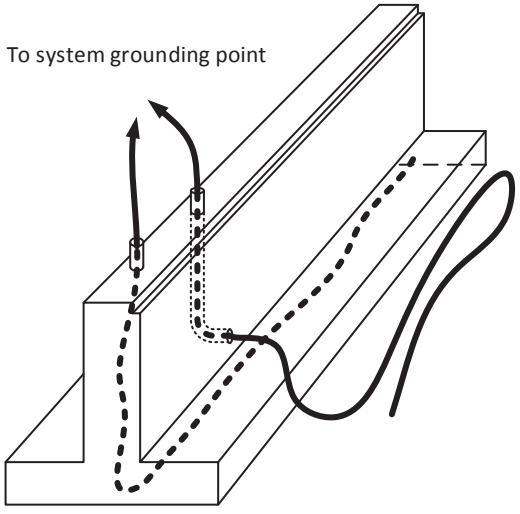


Figure 3—Field-assembled grounding electrodes

In-situ (Latin for *on site*) grounding electrodes are bare metallic objects that are in direct contact with earth and already exist on site. These must have a surface area equivalent to a manufactured grounding electrode. Most commonly they are things like metal water pipes, steel pilings, or well casings (Figure 4). These metal objects must not be treated with a non-conductive anti-corrosion compound (like the exterior epoxy coating commonly seen on metal water pipes), as that would prevent the object from electrically contacting the earth and providing a suitable ground. If choosing to use an in-situ grounding electrode, it is advisable to first contact the authority having jurisdiction to ensure that it is acceptable.

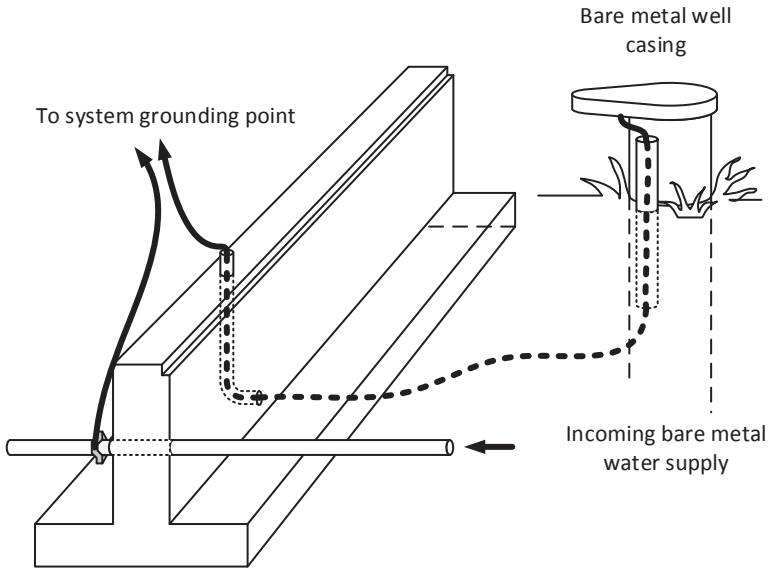


Figure 4—In-situ grounding electrodes

The connection from a grounding electrode to a conductor must not be easy to undo. Therefore the CEC requires the use of a substantial means of fastening, whether bolted clamp, thermite welding ("Cad welding"), or other equivalent means. Because the connection to the ground rods, ground plate, or in-situ electrode typically happens underground, the ground clamps for that purpose must be able to withstand the corrosion that could result. Soldering is not allowed as a connection means, unless it is silver solder. All of this is covered in Rule 10-906, where it states:

(1) The grounding conductor shall be attached to the grounding electrode by means of
(a) a bolted clamp;
(b) a pipe fitting plug or other device, screwed into the pipe or into the fitting;
(c) copper welding by the thermit process, brazing, or silver solder; or
(d) other equally substantial means.

(2) Where a bolted clamp is used for a wet location or for direct earth burial, the clamp shall be of copper, bronze, or brass, and the bolts shall be of similar material or of stainless steel.

(4) Connections that depend on solder shall not be used, except for connections utilizing silver solder.

Conductors

The conductors used for grounding and bonding vary widely depending upon the installation. Due to the frequency of copper theft, the power authority often uses a steel grounding conductor, whereas many electricians use bare copper for their conductor. For the grounding conductor, Rule 10-802 states:

> *(1) The grounding conductor shall be permitted to be insulated or bare and shall be of copper, aluminum, or other acceptable material.*
>
> *(2) The material for grounding conductors shall be resistant to any corrosive condition existing at the installation or shall be protected against corrosion.*

Although the CEC is a national code, provinces have the authority to amend it if deemed necessary.

In BC, the CEC has been amended to allow only copper as the grounding conductor going outside to the electrode. This is due to concerns over possible corrosion that could happen if aluminum was in direct contact with earth and moisture.

The construction of the bonding conductor is much more varied. Both copper and aluminum conductors may be used for bonding. Rule 10-804 gives many options for a bonding conductor:

> *The bonding conductor for equipment and metal raceways and enclosures for conductors shall be one of the following:*
> *(a) a conductor of copper or other corrosion-resistant material, insulated or bare;*
> *(b) a busbar or steel pipe;*
> *(c) rigid metal conduit …*
> *(d) electrical metallic tubing …*
> *(e) the copper or aluminum sheath of mineral-insulated cable or any conductor of a mineral-insulated cable if it is permanently marked at the time of installation …*
> *(f) the sheath of aluminum-sheathed cable or copper-sheathed cable …*
> *(g) other metal raceways or cable armour as provided for in Rule 10-618.*

Note that while the Code does allow an aluminum sheath to be used as a bonding method, this does not mean that aluminum armour can be used. Aluminum-sheathed cable is defined in CEC Section 0 as *"a cable consisting of one or more conductors of approved type assembled into a core and covered with a liquid- and gas-tight sheath of aluminum or aluminum alloy."* Regular spirally wrapped aluminum armour (like that seen on BX, TECK, or ACWU) is neither liquid-tight nor gas-tight, and is therefore not considered a sheath.

Raceways vs. armour

When using certain metallic raceways, instead of needing to draw a bond conductor into the system itself, the raceway can be used to bond boxes and equipment together. But this means that all connections between raceway sections and from the raceways to enclosures must be clean and tight. When using threaded conduit, the threads must be done up tight, and if using EMT, all couplings and connectors must have their set screws and locknuts tightened to ensure a low-impedance pathway.

Rule 10-804 specifically allows rigid metal conduit and EMT to be used in place of a conductor as the bonding method, provided that they are not in any place that will readily encourage corrosion or damage. If the conduit or EMT is in danger of damage or corrosion, then a separate bond conductor must be drawn into the conduit or EMT with the circuit conductors.

While conduit and EMT are allowed to be used as a bonding method, flexible metal conduits and the flexible armour used in many cables (BX, ACWU, TECK) are not allowed to be used as a bonding conductor. Specifically, this is laid out in Rule 10-618. Note as well that the term *armour* is used in this Rule, in contrast to Rule 10-804(f), which refers to those cables having an aluminum or copper sheath:

> Rule 10-618(2–3): *(2) The armour of those constructions of armoured cables incorporating a bonding conductor shall not be considered as fulfilling the requirements of a bonding conductor for the purpose of this Rule …*
>
> *(3) The armour of flexible metal conduit and liquid-tight flexible metal conduit shall not be considered as fulfilling the requirements of a bonding conductor for the purposes of this Rule, and a separate bonding conductor shall be run within the conduit.*

While flexible conduit and cable armour are not allowed to be used as a bond conductor, they are still required to be bonded by Rule 10-300, which states: *"Service raceways, service cable sheaths, or armouring, if of metal, shall be bonded to ground."*

Equipment and enclosures

Electrical equipment is all required to be bonded together back to the main service. Consequently, eventually there needs to be a connection between the equipment and the main system grounding conductor. This will happen at the point where the system grounding conductor connects to the neutral. Rule 10-624 states that this can be done with a "bonding screw" or "bonding strap." Note that the neutral bus is called the "grounded conductor bus" in this rule:

> *(1) Where the system is grounded at any point, the metal enclosure of the service box, or equivalent where a service box is not provided, shall be bonded to the grounded conductor bus with a bonding screw or bonding strap supplied with the equipment.*

The bonding screw is usually identifiable as a large brass machine screw going through the neutral pad and into the service box enclosure. Note that this connection between the neutral bus and the bonding system is only allowed to happen at the service box (Figure 5). The service box is the first enclosure housing a disconnecting means (panel or fusible disconnect) that the service conductors enter. **So any panels or switches downstream from the service box must have their bonding screw or bond strap removed.** (Refer as well to Figure 10 and Figure 11 of Learning Task 1 or Figure 7 of Learning Task 3 in this Learning Guide for more examples.)

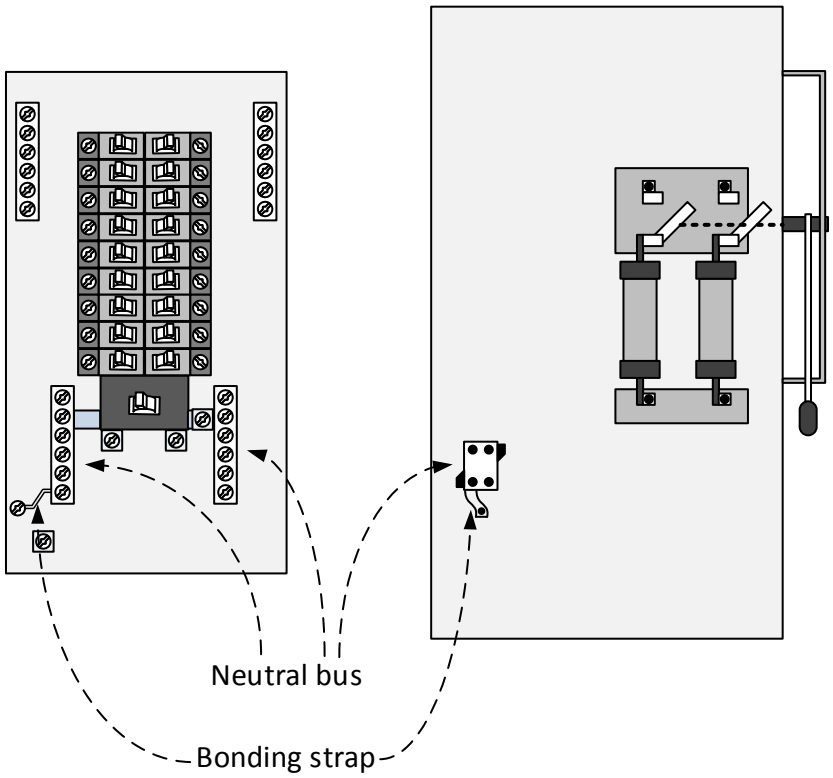


Figure 5—Bonding at main service neutral

For many services, there are components that are mounted ahead of the main overcurrent device (ahead of the main breaker or the main fusible disconnect). These may be things like meter bases or pullboxes (Figure 6). Any pieces of equipment that are ahead of the main overcurrent device at the service must have greater precautions taken to bond them, as any faults they are exposed to will never pass through the main overcurrent to trip that protection. Instead, those faults could only be cleared by the protection at the power authority transformer feeding that service. And since that transformer and protective device might be sized to feed several installations, that overcurrent device could take a while to operate. These strict rules are dealt with in Rule 10-606. Ahead of the main service overcurrent, regular locknuts are not considered sufficient unless they are only used for bonding the connector and armour of a cable (like a TECK or ACWU).

> Rule 10-606(1–2): *(1) Electrical continuity at service equipment shall be assured by*
> *(a) the use of bonding conductors, or threaded couplings and threaded bosses on enclosures with joints made up tight where rigid metal conduit is used;*
> *(b) the use of bonding conductors or threadless couplings made up tight where electrical metallic tubing is used;*
> *(c) the use of bonding conductors or bonding jumpers meeting the requirements of Rules 10-614 and 10-904; or*
> *(d) other devices (not standard locknuts and bushings), such as grounding bushings equipped with bonding jumpers meeting the requirements of Rule 10-614.*

(2) Notwithstanding Subrule (1)(d), box connectors with standard locknuts shall be permitted for bonding the armour of those types of cable assemblies incorporating an internal bonding conductor where the armour is not permitted to be used for bonding purposes.

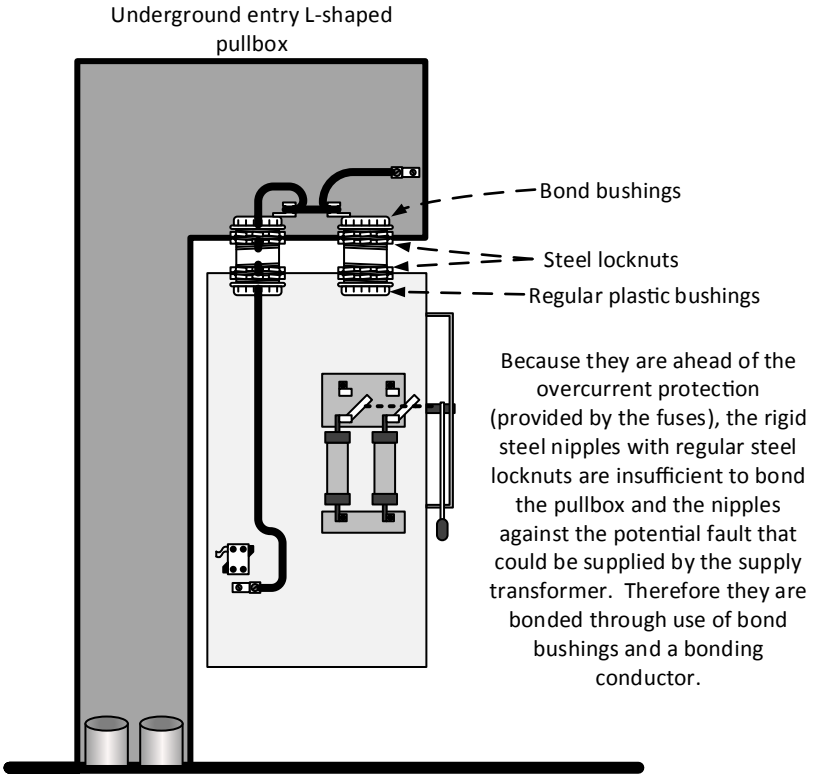


Figure 6—Bonding at pullbox

If the service equipment is destroyed in a cataclysmic event like a house fire, the bonding connection could be lost at the main panel. But if the meter base ahead of the panel was still intact, there could be a shock hazard if one of the burnt-off live lines were to be in contact with the ungrounded conduit. In order to prevent this, Rule 10-624(4) requires the neutral (grounded service conductor) to be bonded to the enclosure of the meter base:

Rule 10-624(4): *The grounded service conductor on the supply side of the service disconnecting means shall be permitted to be connected to the metal meter mounting devices and service equipment, and where the grounded service conductor passes through the meter mounting device it shall be bonded to the meter mounting device.*

For electrical equipment that is downstream of the main overcurrent, the rules on bonding are more relaxed, as any faults are smaller and should be more easily cleared by the service overcurrent device. Any equipment can be connected together by rigid conduit nipples or EMT. Rule 10-610 allows this equipment and wiring pathway to be bonded by the connector and locknut (EMT), or the use of locknuts (rigid conduit nipples) (Figure 7):

> Rule 10-610(a–c): *The electrical continuity of metal raceway, metal-sheathed, or armoured cable shall be assured by one of the methods specified in Rules 10-606(1)(a), (b), (c), and (d), or by the use of*
> *(a) threadless fittings, made up tight with conduit or armoured cable;*
> *(b) two locknuts, one inside and one outside of boxes and cabinets; or*
> *(c) one locknut and a metal conduit bushing, provided that the bushing can be installed so that it is mechanically secure and makes positive contact with the inside surface of the box or cabinet.*

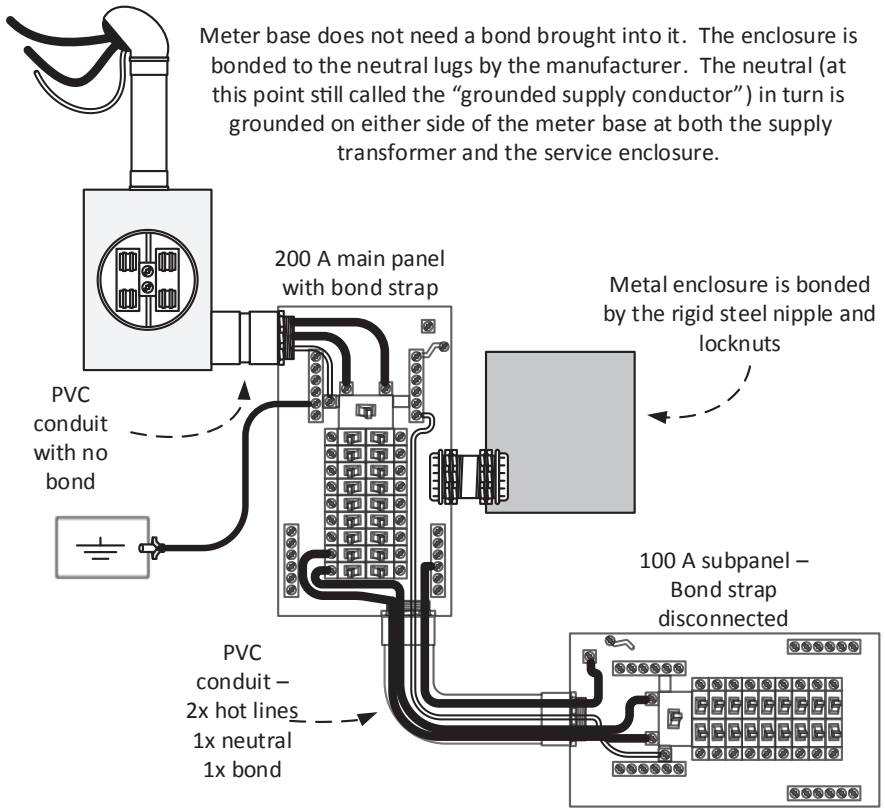


Figure 7—Bonding downstream of the service box

Now do Self-Test 3 and check your answers.

Self-Test 3

1. May a system grounding conductor be spliced?

2. Is the connection from a box bonding strap to the mounting strap ("ears") of a receptacle allowed to be used to bond a receptacle?

3. A well casing is a form of which of the following?

   a. Manufactured grounding electrode
   b. Field-assembled grounding electrode
   c. In-situ grounding electrode _____

4. Ground rods are a form of which of the following?

   a. Manufactured grounding electrode
   b. Field-assembled grounding electrode
   c. In-situ grounding electrode _____

5. A "Ufer" ground is a form of which of the following?

   a. Manufactured grounding electrode
   b. Field-assembled grounding electrode
   c. In-situ grounding electrode _____

6. Which of the following are allowed to be used to bond equipment downstream of the service equipment?

   a. EMT
   b. Rigid steel conduit
   c. Rigid PVC conduit
   d. Aluminum armour
   e. Aluminum sheath
   f. Copper conductors
   g. Aluminum conductors _____

7. Does a 120/240 V meter base need a grounding or bonding conductor brought to the neutral in it?

_____

_____

_____

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 4:

Determine grounding and bonding requirements

When there is a fault on a system, the current always tries to make its way back to its source, and it will use any available paths to do so. Inside of a building electrical system, this means that most fault currents will use the bonding pathways and conductors to try to get back to the grounded main neutral of that system. And since these fault currents are generally quite large (in the thousands of amps), the bond conductor will have to carry significant load, albeit for a short time until the overcurrent device on the circuit operates. Therefore the bond conductor is sized in relation to the ampacity of the circuit it is bonding, while the grounding conductor does not need to be.

Sizing

Since the grounding conductor is only being used to keep the neutral at the same potential as the electrode buried in earth, it carries no current. Practically, it could accomplish the same purpose even if it was #14 AWG. But because it is such a critical part of the system, the CEC mandates a larger size (minimum of #6 AWG), as this will be more durable and not as easily mechanically damaged. All rules on the sizing of grounding conductors, whether for AC or DC systems (including photovoltaic systems) are found in Rules 10-810 and 10-812.

Because the bonding system is used to carry fault current back to the neutral (Figure 1), it must be large enough to do so safely. So the CEC ensures this by making all sizing for bonding conductors dependent on the size of the circuit conductors supplying the equipment that must be bonded. This is found in Rule 10-814, which then refers to Table 16A (when using conductors) and Table 16B (when using busbars).

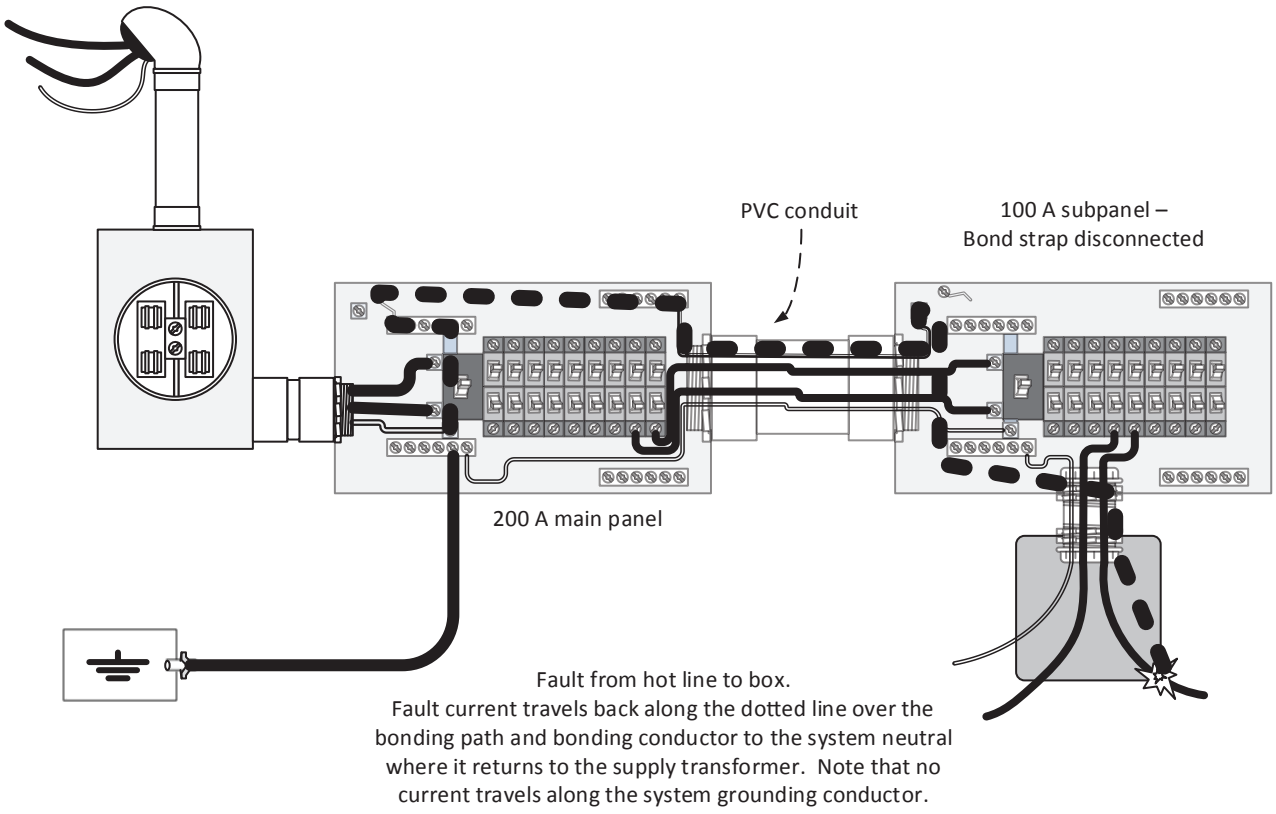


Figure 1—Fault current path to neutral along the bond

The non-electrical equipment (all metallic piping from the water piping, septic piping, and gas piping systems) that requires bonding will have their respective sizes listed in Rule 10-406.

The cablevision power blocking device is bonded to ground in accordance with Rule 54-300. It does not have to be brought all the way back to the main electrode, but can be attached to the grounding conductor by a crimped connection as per Rule 54-304(b).

> Rule 54-300(1–3): *(1) The grounding conductor for the outer conductive shield of a coaxial cable or the protector shall be insulated.*
> *(2) The grounding conductor shall be made of copper.*
> *(3) The grounding conductor shall be not smaller than No. 14 AWG.*

And Rule 60-704 tells us that the bonding conductor for the primary protector for telephone system shall be insulated, and it refers us to CEC Table 59 to size it. Like the CATV system, it does not have to be brought all the way back to the main electrode, but can be attached to the grounding conductor by a crimped connection as per Rule 60-708(b).

> Rule 60-704(a–b): *The grounding conductor used to ground primary protectors specified in Rule 60-202 shall be copper and shall*
> *(a) have rubber or thermoplastic insulation;*
> *(b) be not smaller than the required grounding conductor specified in Table 59.*

(Since most telephone systems for houses are wired in Cat5E or Cat6, they have four communication circuits, and since most primary protectors are fuseless, the most common minimum size picked out of Table 59 will be No. 10 AWG.)

The sizes required by the CEC for the bonding conductor for the cable and telephone systems are minimums. The service provider of each of those systems (telephone and cable TV) might require larger conductors. Be sure to check with the service provider before pulling these bond wires, and ensure they are insulated as per the rule requirements. Most communications service providers ask for #6 AWG copper.

Terminating

Most bonding conductors for cables or conduits will be bonded inside the panel or switch they are served from. They are brought to the bond lugs, or bond strip, which is a bare terminal strip mounted directly to the panel or switch enclosure.

The bonding conductors that are run from the telephone box, CATV box, gas piping, water piping, and septic piping are commonly crimped onto the main grounding conductor where it leaves the panel before it goes outside. The septic bond does not have to go all the way back to the main grounding conductor, but by Rule 10-406 it may be bonded back to the water piping if the water piping is already bonded.

Testing

Because the neutral is grounded, and the bonding system is also tied to that grounding conductor, it logically follows that there should be continuity between the identified (neutral) and bond conductor at any device. During the commissioning stage of the project, any receptacle should show continuity between the identified conductor (neutral) and bond conductor. The reading should be very low, in the single digits of ohms. If a higher reading than this is taken, there is a problem with the system, usually with the bonding system. Check that all bonding connections are tight, and if conduit or EMT is the system used, ensure that all couplings, locknuts, and set screws are tight.

If you are installing devices to finish an installation, and it is unclear if a set of conductors in a box are for a receptacle or a dead-end switch, a quick check for continuity (after verifying the system is not energized) between the identified conductor (white) and the bond can determine what it is. If it has been spliced correctly, a dead-end switch configuration will be using the white to bring power down to the switch, and the black to bring it back out as the switch-leg to the light. So there will be no continuity between the identified (white) conductor and bond in this case. If it was for a receptacle, there would be continuity between the identified and bond conductors. (See Rule 4-036(2), which mandates that the switched conductor must not be identified. Or in other words, the power to the load must come out of the switch on a conductor that is not white.)

 Now do Self-Test 4 and check your answers.

Self-Test 4

Refer to the figures below to answer the following questions, and identify the applicable CEC rules for each.

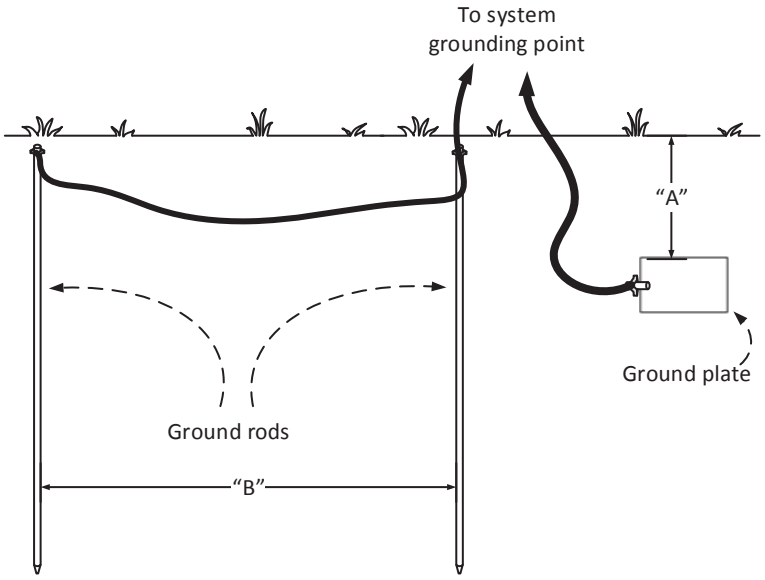


Figure 1

Questions 1 to 6 refer to Figure 1.

1. How deep must the ground plate be buried? (Dimension "A")

   Answer:_____ Rule: _____

2. How far apart must the ground rods be? (Dimension "B")

   Answer:_____ Rule: _____

3. What material and gauge must the grounding conductors be?

   Answer:_____ Rule: _____

4. What material and gauge must the interconnecting conductor between the ground rods be?

   Answer:_____ Rule: _____

5. How far must the ground rods be driven into the earth?

   Answer:_____ Rule: _____

6. If the plate electrode were to be encased in a concrete footing, what minimum depth below grade would the plate electrode need to be?

   Answer:_____ Rule: _____

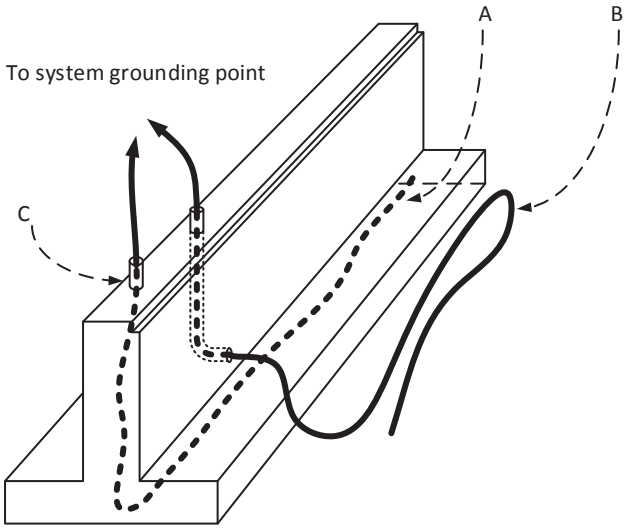


Figure 2

Questions 7 to 12 refer to Figure 2.

7. What minimum gauge, length, and material must Ufer ground "A" be if for a 100 A panel?

   Answer:_____ Rule: _____

8. What minimum gauge, length, and material must Ufer ground "B" be if for a 200 A panel?

   Answer:_____ Rule: _____

9. What minimum depth below grade must Ufer ground "A" be tied into the foundation?

   Answer:_____ Rule: _____

10. How deep below grade does Ufer ground "B" need to be?

    Answer:_____ Rule: _____

11. Does Ufer ground "B" need to be laid along the side of the footing or can it just be balled up and duped into a hole?

    Answer:_____ Rule: _____

12. What is the purpose of the PVC sleeve shown at point "C"?

    Answer:_____ Rule: _____

13. What are the minimum length and depth needed for a bare metal water line before it can be considered to be acceptable as an "in-situ grounding electrode"?

    Answer:_____ Rule: _____

14. Are any electrodes ever allowed to be buried less than the nominal depth of 600 mm used in most Code rules?

    Answer:_____ Rule: _____

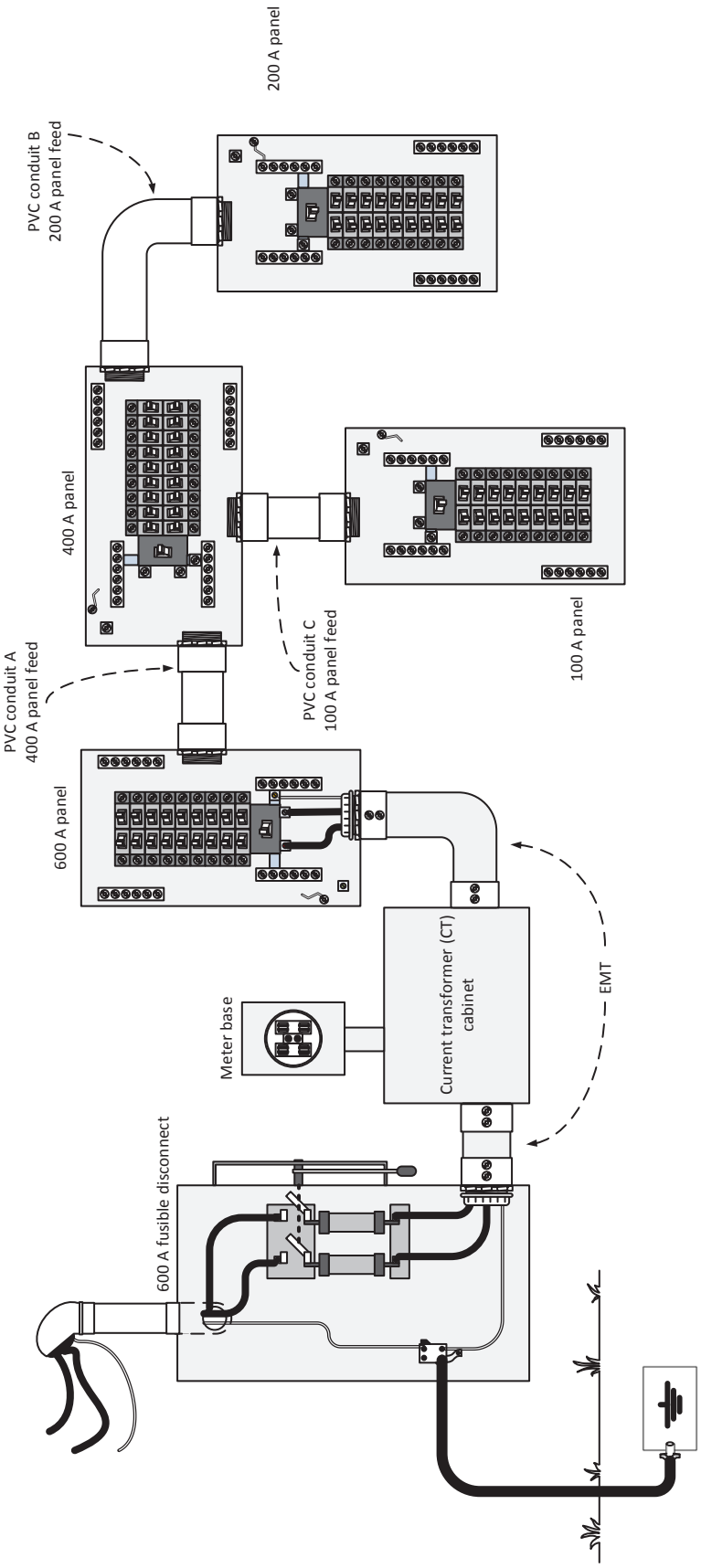

200 A panel
PVC conduit B
200 A panel feed
400 A panel
100 A panel
PVC conduit C
100 A panel feed
PVC conduit A
400 A panel feed
600 A panel
Current transformer (CT)
cabinet
EMT
Meter base
600 A fusible disconnect

Figure 3

Questions 15 to 19 refer to Figure 3.

15. If using single aluminum conductors terminating on 75° breakers, what size of aluminum bond wire will be required in PVC conduit A?

    Answer:_____ Rule: _____

16. If using aluminum conductors terminating on 75° breakers, what size of copper bond wire will be required in PVC conduit B?

    Answer:_____ Rule: _____

17. If using copper conductors terminating on 75° breakers, what size of copper bond wire will be required in PVC conduit C?

    Answer:_____ Rule: _____

18. What size of grounding conductor is needed?

    Answer:_____ Rule: _____

19. What grounding and bonding error is present?

    Answer:_____ Rule: _____

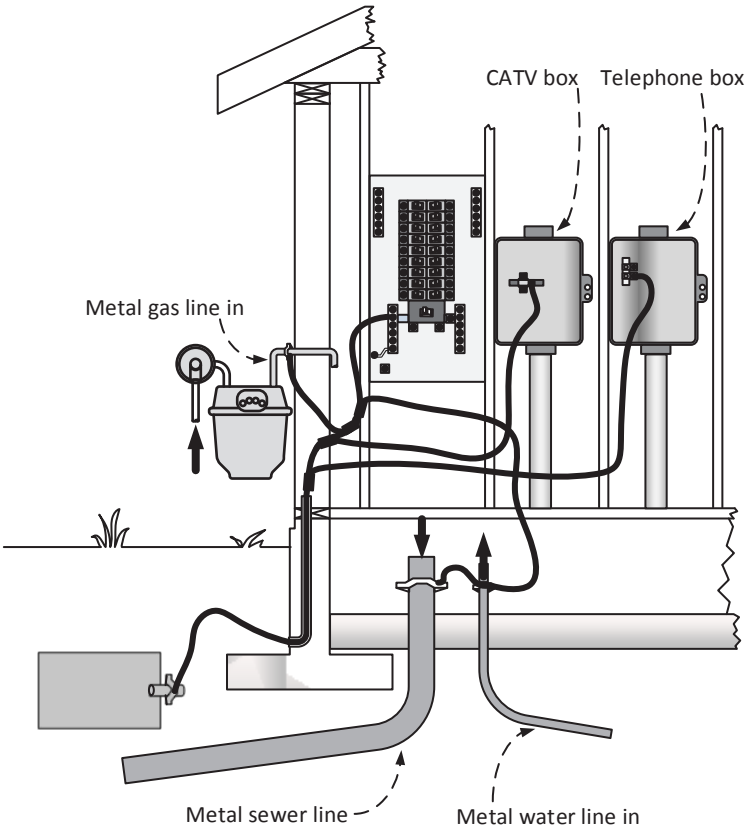


Figure 4

Questions 20 to 26 refer to Figure 4.

20. What is the minimum size bonding conductor needed for the gas meter?

    Answer:_____ Rule: _____

21. What is the minimum size bonding conductor needed for the water line?

    Answer:_____ Rule: _____

22. What is the minimum size bonding conductor needed for the sewer line?

    Answer:_____ Rule: _____

23. Where else other than the grounded water line is the sewer line allowed to be bonded to??

    Answer:_____ Rule: _____

24. What is the minimum size grounding conductor needed for the panel?

    Answer:_____ Rule: _____

25. What is the minimum size bonding conductor needed for the CATV box?

    Answer:_____ Rule: _____

26. What is the minimum size bonding conductor needed for the telephone "Network Interface Box" if it has a single Cat6 cable to feed it and has a fuseless primary protector?

    Answer:_____ Rule: _____

Go to the Answer Key at the end of the Learning Guide to check your answers.

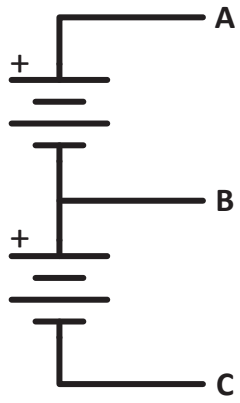
Answer Key

Self-Test 1

1. Improved human safety through lowered voltage-to-ground, improved overcurrent operation, reduced risk of fire

2. c. Neutral voltage terminal

3.

	If the service was grounded at point A …	If the service was grounded at point B …	If the service was grounded at point C …
… What magnitude and polarity of shock could be felt between point A and ground?	**0 volts**	**+ 120 volts**	**+ 240 volts**
… What magnitude and polarity of shock could be felt between point B and ground?	**– 120 volts**	**0 volts**	**+ 120 volts**
… What magnitude and polarity of shock could be felt between point C and ground?	**– 240 volts**	**– 120 volts**	**0 volts**

4. b. Neutral

5. 150 volts AC

6. Only one electrical point can be grounded.

7. Yes, if it is the same electrical point it may be grounded multiple times. (See System Ground.)

8. Neutral lugs or busbar

9. Main grounding terminals

10. Two

Self-Test 2

1. a. Low impedance (resistance)
   b. Permanent
   c. Capable of carrying a system fault current

2. The breaker will not trip, the box will be energized at line voltage, and there will be an undefined potential difference between the box and EMT due to the ungrounded system. This will be dangerous.

3. The breaker will not trip, the box and EMT will be energized at line voltage, which will be floating at an undefined voltage above ground due to the ungrounded system. This will be dangerous.

4. The breaker will not trip, the box will be energized at line voltage, and there will be 120 volts between the box and EMT. This will be dangerous.

5. The breaker will trip, and the box and EMT will not be energized. This will not be dangerous.

Self-Test 3

1. Only if absolutely necessary, and then if using a substantial method to rejoin it. Usually only in the case of damage done to an existing installation.

2. No. There must be a bond pigtail. See Rule 10-904(6).

3. c. In-situ grounding conductor

4. a. Manufactured grounding electrode

5. b. Field-assembled grounding electrode

6. a. EMT
   b. Rigid steel conduit
   e. Aluminum sheath
   f. Copper conductors
   g. Aluminum conductors

7. No. It has the enclosure bonded to the grounded circuit conductor (neutral), which is directly grounded by system grounding conductors on either side of the meter base at the supply transformer and service neutral bus.

Self-Test 4

1.	600 mm	Rule 10-700(2)(b)(i)
2.	3 m	Rule 10-700(2)(a)
3.	#6 AWG copper	Rule 10-812(a)
4.	#6 AWG copper	Rules 10-700(2)(a)(i) and 10-812(a)
5.	“driven to the full length of the rod”	Rule 10-700(2)(a)(ii)
6.	550–600 mm	Rule 10-700(2)(b)(ii) (Encased within the bottom 50 mm of a footing that extends 600 mm below grade.)
7.	6 m of #4 AWG copper	Rule 10-700(3)(b) and Table 43
8.	6 m of #3 AWG copper	Rule 10-700(3)(a) and Table 43
9.	550–600 mm	Rule 10-700(3)(a)
10.	600 mm	Rule 10-700(3)(b)

11. There are no rules as to the configuration of the cable, as long as it is all 600 mm below grade. So balling it all up would be acceptable.

12.	To guard the conductor’s point of emergence out of the concrete from mechanical damage.	Rule 10-806(6)
13.	3 m of length, all buried at least 600 mm below grade.	Rule 10-700(4) and Appendix B
14.	Only if conditions like rock or permafrost prevent deeper burial.	Rule 10-700(5)
15.	1/0 AWG aluminum	Rules 4-006, 10-814(1)(a), Table 4, and Table 16A
16.	#4 AWG copper	Rules 4-006, 10-814(1)(a), Table 4, and Table 16A
17.	#6 AWG copper	Rules 4-006, 10-814(1)(a), Table 2, and Table 16A

18. #6 AWG copper	Rule 10-812(a)
19. The bond strap has not been disconnected from the neutral of the 200 A panel.	Rule 10-624(6)
20. #6 AWG copper	Rules 10-406(4) and 10-406(2)(a)(i)
21. #6 AWG copper	Rule 10-406(2)(a)(i)
22. #6 AWG copper	Rule 10-406(3)(a)
23. The system grounding conductor	Rule 10-406(3)
24. #6 AWG copper	Rule 10-812(a)
25. #14 AWG insulated copper	Rule 54-300(3)
26. #10 AWG insulated copper	Rule 60-704(b)



ISBN 978-0-7726-7015-1

