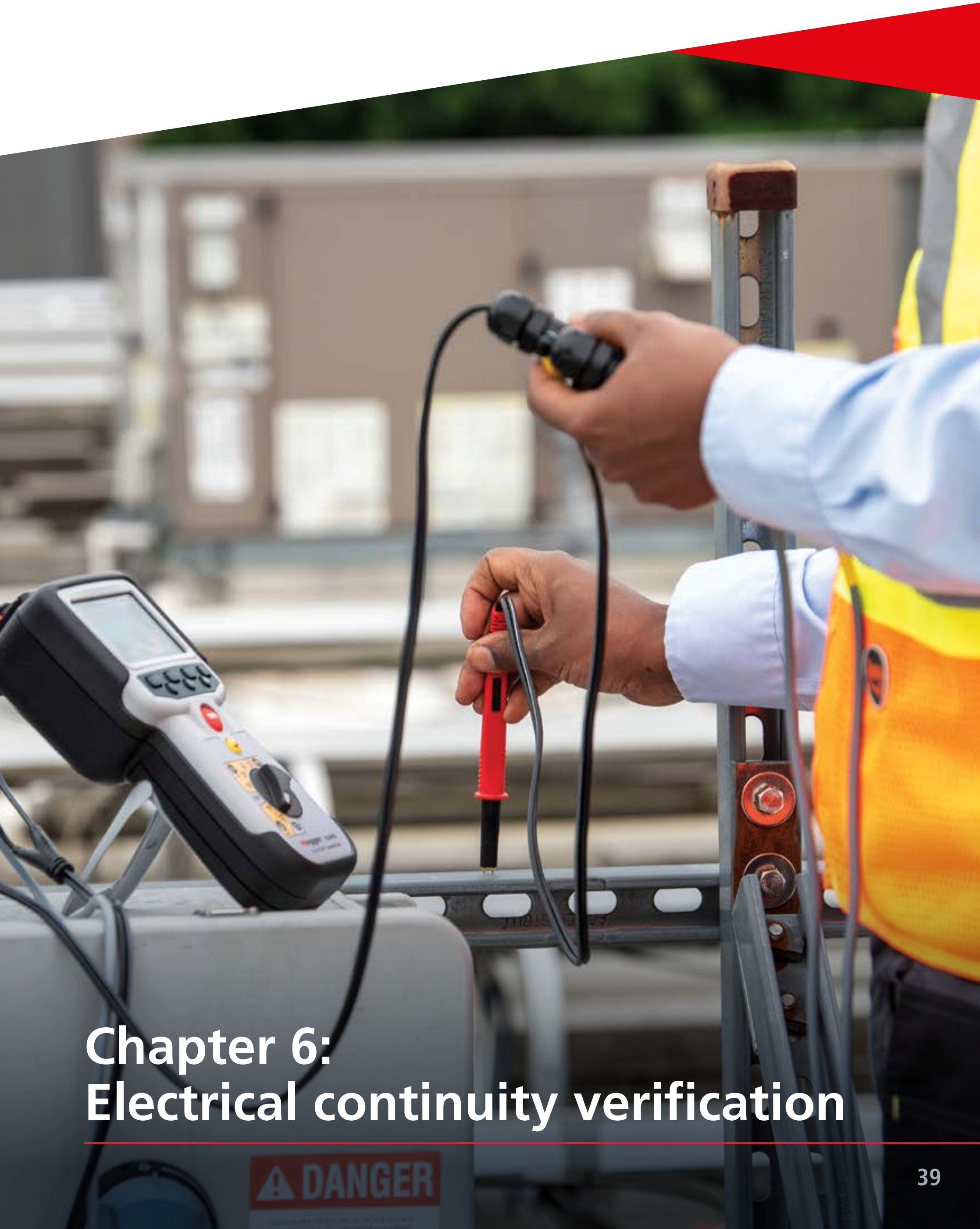



# Chapter 6:
# Electrical continuity verification

# Introduction

## Overview

Electrical continuity refers to a complete path for current flow within a circuit. Continuity tests for PV systems verify that electrical current has a continuous low-resistance path to return to the source and to enable ground-fault protection devices to detect and to interrupt fault currents.

Technicians regularly perform continuity tests during PV project commissioning and troubleshooting. This chapter describes the relevant tools, techniques, and safety considerations for continuity tests.

## Electrical continuity concepts explained

Electrical circuits form closed loops that follow the law of conservation of energy, meaning that no energy is created or destroyed as current flows through the circuit. Some energy dissipates as heat, but the total energy input equals the total energy output. As long as a continuous, current-carrying path is present, electricity flows in a loop from the source to the loads and back to the source again. Breaking the loop—for example, by opening a switch or by accidentally slicing through a conductor—results in an open-circuit condition under which no current can flow.

Continuity tests verify that a circuit forms a complete loop such that electrical current can return to the source during normal operation and ground faults have an unimpeded path to ground under fault conditions.

### Continuity versus open circuit

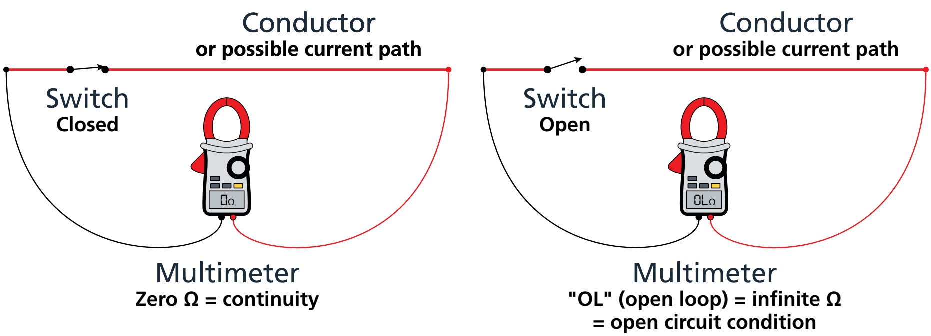



Figure 6-1: Electrical current wants to flow in a loop, and will follow the lowest-resistance path available to complete the loop. Continuity tests verify the presence of a low-resistance path for current to flow. Under open-circuit conditions such as a switch in the open position or a broken equipment grounding conductor, the current-carrying path is severed and resistance along the path rises to near-infinity. A multimeter will display this "infinite" resistance as "OL" or "open loop."

Technicians who perform continuity tests should already have a thorough understanding of core electrical concepts such as **voltage**, **current**, and resistance, which are described in detail in previous chapters. Bonding and grounding must also be well understood, as discussed in this chapter.

Electrical bonding is the connection of conductive components that are not intended to carry current. For PV systems, it includes metallic parts that are potentially exposed to electrical faults or induced voltage to the grounding electrode conductor. Bonding provides a low-resistance path for fault currents to follow so they can trip overcurrent protection devices quickly.

The quality of component bonding affects the severity of a ground fault. If PV components are improperly bonded, ground faults do not have a complete path to ground and may go undetected. An undetected ground fault poses a major fire and shock hazard, creating a dangerous situation.

Grounding conductors connect the electrical circuit to the earth. The grounding system consists of equipment grounding conductors (EGCs), grounding electrode conductors (GECs), and grounding electrodes, all electrically bonded together.

## How are PV modules grounded?

Most racking systems today are listed to bond PV module frames to the racking. The racking and modules are effectively bonded by connecting the equipment grounding conductor to one rail in each row of modules. The bond is continued throughout the array and is connected to all other metallic components.

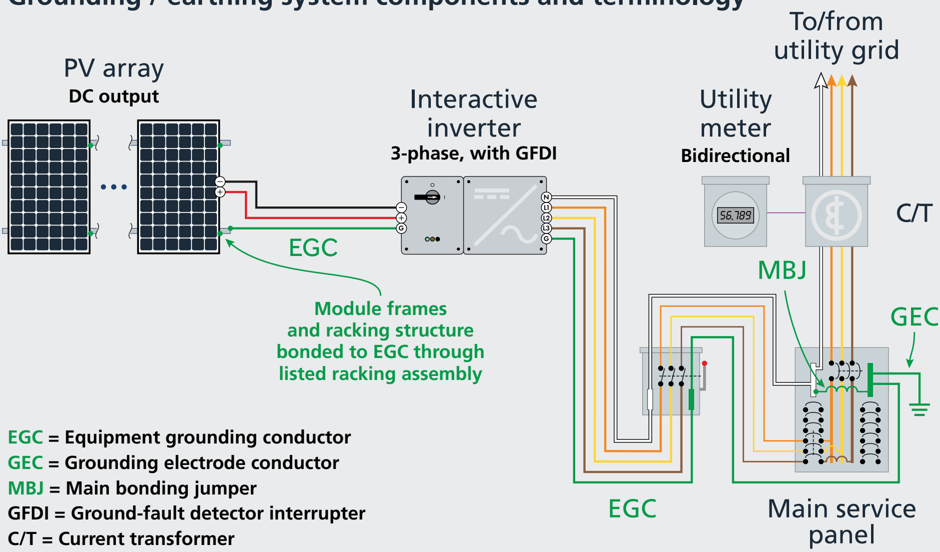
Before listed racking systems were available, PV systems were grounded by connecting a lay-in lug to a dedicated grounding point on the module frame and by connecting the lugs with a bare copper conductor. Many installations used improper materials and techniques, compromising the module-lug connection with an electrically resistive layer of aluminum oxide that builds up with exposure to the elements. Therefore, the low-resistance connection to ground may be absent in older installations. Technicians can use lugs and copper wire to bond PV modules today, but the lugs and installation methods must be listed.

Figures 6-2 and 6-3: Left—Dubious bonding. Right—A lay-in lug bonds listed PV racking to the equipment grounding conductor.

Figure 6-4: Listed PV racking is designed to create an electrical bond between mounting and racking components, and through the anodized layers.

Bonding and grounding work together to keep all exposed metallic components on a continuous ground-fault path. During installation, all metallic components must be bonded, regardless of the system grounding type. Older PV systems use isolation transformers, and modern inverters are nonisolated, which is commonly called “transformerless.” The specific grounding configurations may differ in these systems, but in both cases, all the metallic components are bonded together and to ground.

## Grounding / earthing system components and terminology




EGC = Equipment grounding conductor
GEC = Grounding electrode conductor
MBJ = Main bonding jumper
GFDI = Ground-fault detector interrupter
C/T = Current transformer

Figure 6-5: PV systems use equipment grounding (bonding) to maintain continuity of all exposed metallic components and provide a continuous, low-resistance path for ground-fault currents. Note that the EGC connects all components to the GEC, which is bonded to the grounding electrode. In addition, PV systems use grounding systems on the utility side according to local codes and regulations.

# Environmental impacts on continuity tests

Environmental wear and tear can damage the bonding connections on solar PV systems. Acute weather events such as strong wind gusts or lightning strikes may rapidly degrade bonding connections. More likely causes of damage, however, are improper installation, interaction with wildlife, and long-term environmental exposure.

## Improper installation

PV modules use anodized aluminum for their frames. The clear anodization protects the frame from long-term environmental effects. However, this anodization layer must be broken to properly bond the frames to the metallic structures that support the modules. Racking systems that use attachment points for mechanical and electrical bonding help reduce the risk of improper installation.

As was typical for PV installations before 2015, PV systems that use ground lugs are susceptible to improper installation and a poor connection to the EGC. During operations and maintenance (O&M) activities, technicians must carefully evaluate bonding systems that use ground lugs.

## Acute weather events

PV systems are deliberately installed in open areas that have plenty of sun exposure, with an expectation to produce power for 20 years or more. These locations also expose systems to lightning strikes, wind gusts, and violent storms that may directly damage equipment. Lightning arresters, surge protection devices, twisted-pair wiring, and properly installed grounding systems can all mitigate the safety risks from lightning. Equipment bonding methods must be durable enough to withstand weather events like high winds and ice exposure.

## Long-term environmental effects

Exposure to cycles of hot and cold weather and dry and wet periods can slowly wear down PV equipment. Repeated expansion and contraction can degrade bonding connections. Such degraded or improper connections can result in a high-resistance connection between the metallic frame and the equipment bonding conductor.

## Damage from local wildlife

Technicians should be aware of wildlife in and around the PV system. Frequently, an array attracts rodents that are looking for shelter or warmth. Hungry rodents, squirrels, deer, and other animals can gnaw through the insulation on PV and bonding conductors, which can degrade system performance and lead to ground faults or arc-flash hazards.

Figure 6-6: Animals nesting on and around PV system conductors can create damage. potentially causing ground faults.

# Types of electrical continuity tests

Technicians commonly perform continuity tests with a handheld digital multimeter (DMM). Digital low-resistance ohmmeters (DLROs) enable more accurate measurements over greater distances, however.

## Two-point tests with a DMM

**Tool:** A DMM with black and red leads inserted acts as a voltage source.

**Test procedure:** With the DMM set to measure continuity, the red and black leads are applied across a conductor, component, or conductive pathway. The meter displays the resistance by using the known voltage. The DMM beeps when the resistance between the leads is low enough to be considered a continuous path.

**Benefits:** The two-point DMM test is simple and can be performed quickly by a technician in the field.

**Limitations:** The distance between the DMM leads is limited to the technician's arm span and the meter lead length, meaning that the two points under testing must be physically close. Testing electrical continuity between components that are far apart is impossible with a handheld DMM. The two-point measurement cannot induce a current; therefore, the resistance measurement is not as accurate as with the four-point method that is described next.


Figure 6-7: A two-point test can be performed by a single technician with a handheld DMM, but the components being tested must be within arm's reach.


Figure 6-8: PV arrays often span large distances, with exposed metal components distributed throughout the array. Continuity tests may need to be performed between components that are far apart.

## Four-point tests with a DLRO

**Tool:** A DLRO has two pairs of black and red leads to insert. One pair injects current; the other pair connects to the inside of the current leads to measure voltage.

**Test procedure:** With the DLRO set to measure continuity, the first lead clamps to one piece of conductive equipment (such as a PV rack), and the second lead connects to a separate metallic component. A small amount of direct current (DC) passes between the leads, and the DLRO measures the voltage drop to calculate the resistance value. A spool extension enables technicians to test components up to 100 meters away.

**Benefits:** A DLRO takes highly accurate resistance measurements and can measure continuity between remote components.

**Limitations:** Four-point tests are slower and more complicated than two-point tests with a DMM are.

Although two-point tests with handheld DMMs are more common, four-point tests with DLROs provide a best practice because of their higher accuracy and extended reach. The four-point test procedure is described in greater  detail in the **How to perform electrical continuity tests** section later in this chapter.

Figure 6-9: A DLRO is a simple but powerful handheld tool capable of taking highly accurate continuity measurements.

Figure 6-10: In tandem with an extension spool, the DLRO can measure electrical continuity between components up to 100 meters apart.

# Where to measure electrical continuity

Technicians perform continuity tests throughout the entire PV system—at any point with exposed metallic parts. Tests can even cross over from the DC to the alternating current (AC) side of the system as long as the two sides share a ground reference.

Common testing locations include modules to racking, row-to-row racking (for ground- and roof-mount systems), PV module racking to the racking supporting equipment such as inverters and disconnects, and between inverters and disconnects. All components must have a low-resistance bond, so it is essential to verify this bond during the commissioning and O&M processes.

## Locations to test continuity in PV systems

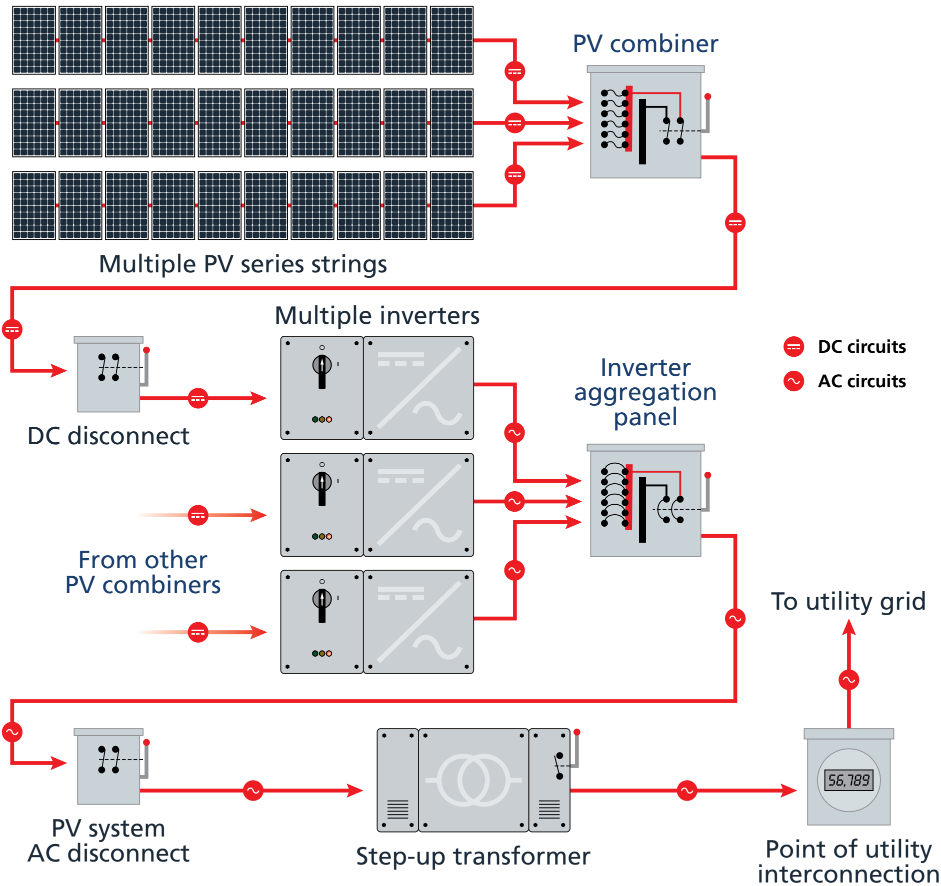



Figure 6-11: Tests to verify electrical continuity can be performed between any two metallic components in the PV system. All equipment must be kept at the same potential for proper operation of overcurrent and ground fault protection devices.

# Why test for electrical continuity?

## Codes and standards

Continuity verification during PV system commissioning is required by the International Electrotechnical Commission standard IEC 62446, Section 6.1, which details the information and documentation to complete before customer handoff. This standard includes electrical continuity testing as a protocol to meet general safety and commissioning standards. Although not required by all U.S. jurisdictions, many large-scale contractors are adopting IEC 62446 and supplemental guides such as SunSpec Alliance's *Commissioning for PV Performance* to promote safety and to mitigate costs and liabilities. IEC 60364 Section 6.4.3.2 also references continuity tests for conductors and connection to exposed conductive parts in low-voltage systems.

### Applicable standards for various agencies Figure 6-12

| International Electrotechnical Commission (IEC) |
|---|
| IEC 62446 Section 6.1 (2016) |
| IEC 60364 Section 6.4.3.2 (2016) |

## Confirmation of proper installation at project commissioning

By performing continuity tests during commissioning, technicians can establish a baseline continuity reading before they complete the project. A baseline measurement enables future analysis to help determine whether the resistance between any components has increased, indicating a potential issue within the equipment bonding.

## O&M plans

Electrical continuity tests should be part of routine maintenance testing to confirm proper equipment bonding. These connections can deteriorate over time, leaving the system at risk of forming ground faults without the ground-fault protection devices being able to detect the faults and to operate as designed. Incorporating these tests during routine O&M activities helps reduce the risk of undetected faults.

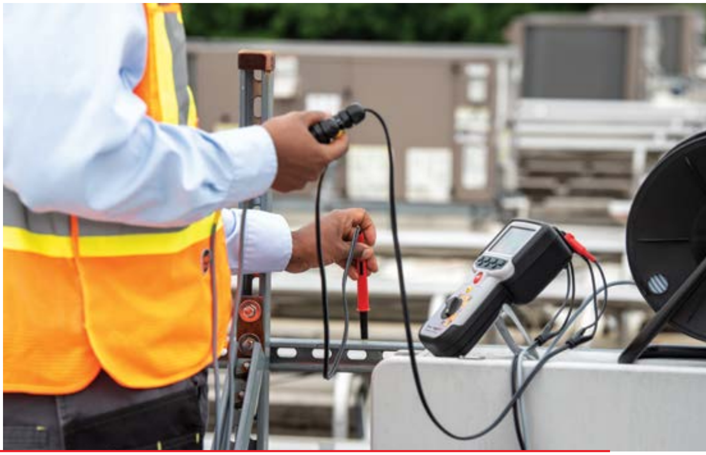


Figure 6-13: Technicians should measure electrical continuity throughout a system's lifetime—from commissioning to routine O&M—to ensure proper installation and verify a complete and safe path for fault currents to flow to ground.

# Safety considerations

Only technicians who are familiar with the potential hazards of the system that they are testing should operate the DLRO. Performing the tests injects a low voltage and a small amount of current into the equipment that is under testing. Therefore, all equipment needs to be isolated from other technicians.


Figure 6-14: DLROs typically have a CAT III safety rating to help protect technicians while they are using the tools.

## Relevant safety hazards

Technicians should proceed cautiously with any electrical system and should wear appropriate personal protective equipment (PPE) whenever they are on a site. Continuity tests do not expose technicians to hazardous voltages within combiner boxes or inverters. However, technicians must remain aware of the potential hazards of the electrical equipment and should work safely throughout the array.

Figure 6-15: Technicians should understand the electrical hazards before they visit a site and should wear appropriate PPE.

# How to perform electrical continuity tests

During project commissioning, standard O&M, and troubleshooting, technicians should perform tests to verify electrical continuity. Each site presents its own challenges, but following are the general steps to perform continuity tests.

## Step-by-step instructions for PV circuits

When preparing to commission a system, identify all circuits for testing before you arrive at the site. While testing, use a site map and sequential operation to maintain proper recordkeeping. Collecting data within the tools expedites the process, but you must be aware of the data that has been collected and verify that the measured circuits match the plans. To perform the tests, you need a DLRO, and you need high-voltage safety gloves and safety glasses as a minimum for PPE.

## 1. Document environmental conditions

This step is crucial to establish accurate trend lines. The environmental conditions affect the test results. Properly accounting for the environmental conditions better informs the data that is collected. For future reference, document the time, date, and ambient temperature.

## 2. Shut down and perform lockout/tagout (LOTO)

Place all solar equipment (inverters, DC disconnects, combiner boxes, etc.) in the open (off) position and use LOTO methods to maintain a safe working environment.

## 3. Measure the continuity of adjacent components

Use a DLRO to verify the continuity of adjacent metallic parts. This measurement establishes the proper functionality of the meter and the test leads that you are using. Insert the test leads into the meter. Connect one lead to the metallic component to test it. Turn the meter to a resistance measurement (verify the setting with the manufacturer's instructions). Connect the second lead to an adjacent metallic structure. Press the test button to complete the test. Document the reading for future reference.

## 4. Measure the continuity of nonadjacent components

You can use the DLRO to repeat the test for intentionally bonded nonadjacent metallic components. If the nonadjacent components are a significant distance apart, use an extended test lead spool and work in pairs. One technician connects the spool to one of the meter's test leads, then spools out the test lead to the other location. That technician connects the test clamp to the spool at the new test location. The second technician, at the meter, make connection to the metal structure and  then presses the test button to complete the test. Record the values and repeat for all other components.

## 5. Record data

Record all measurements and document the test location on a site plan. The results should be collected and stored for future reference.

Figure 6-16: Meters with data storage can be utilized to document site readings and establish long term trends.

## 6. Evaluate the results in the field

Take a moment to review the readings and to verify that they are within reason. Many installation issues are identified by a voltage reading, and you can identify and fix problems in real time. Problems that are commonly encountered include:

- **Infinite resistances are measured.** Verify that the test leads are correctly connected. Establish a valid resistance measurement by testing across a single piece of metal. A missing equipment bonding conductor between components can also return an infinite resistance measurement. To verify proper installation, investigate the equipment bonding conductors.

- **Excessive resistances are measured.** This situation occurs when the metal-to-metal connection is compromised. This measurement can be caused by several scenarios, most commonly from improperly installed ground lugs, that create a high-resistance connection.