Section 10
Electrical Grounding Systems & Testing*

Action Items

1. If your electrical system has not been inspected by a competent licensed-commercial electrician, have it done and make the corrections needed to meet the requirements of the National Electric Code.

2. Keep fuses available for replacement which have the correct “ampere” and “current interrupting” ratings. The electrical inspection should provide you with the correct numbers for these two parameters. Search for the cause of fuses which continually open and avoid the temptation to arbitrarily replace them with higher-rated fuses. This dangerous practice will overheat wires destroying the insulation and greatly increasing the likelihood of fire. It also increases the chance of electrocution in the event of a ground fault condition.

3. Install ground fault circuit interrupters on all outlets used for hand tools.

4. Purchase battery-powered hand tools whenever this is feasible. Use a combination of double insulated hand tools and GFCI protection when battery-powered tools are not available. Cords with GFCI protection and multiple outlets are also available.

5. Use ground-fault detector lights on ungrounded delta systems.

* Note that this section was reviewed and edited by Todd Wilen, Energy Consultant, 6664 59th Avenue SE, Fredonia, ND 58440-9776 (Telephone (701) 485-3456 or email consulting@gigawatt.biz)
6. Test electrical cords frequently using a simple continuity tester to make sure the ground wire is continuous.

7. Test resistance/impedance between equipment frames and the service entrance annually or whenever changes are made and maintain below 1 ohm.

8. Test or have the grounding electrode system resistance tested annually using the fall-of-potential method as discussed here, and have the measured value available for the MSHA inspector. Ideally, for the safety of you and your employees, this resistance should be below 5 ohms. The law does not require this ideal resistance, but follows the requirements of the National Electrical Code (25 ohms maximum or drive in an additional ground rod, which may or may not even get you 25).

Proper Grounding and Grounding Electrode System Testing

**What is a ground fault?** – Under normal conditions in a single-phase system used for small motors, lights, handtools, etc. the current flow on the two current-carrying conductors (the “hot” and the neutral) is balanced. In a three-phase system, two or more “hot” wires feed the load, and the current flow will be balanced among them. If something causes one conductor to contact a metal equipment frame, a ground fault condition occurs, and the operator of the equipment is in danger of electrocution. However, if the person is grounded and touches the energized frame, current will pass through the person’s body to ground and the person will receive a shock, which may or may not cause electrocution. The magnitude of this shock depends upon how much current flows through the person, which in turn depends upon factors such as the voltage, how well grounded the person is, the resistance of the person’s body to current flow, the direction of current flow through the person’s body etc.

**How can this potential hazard be prevented?** If a Ground Fault Circuit Interrupter (GFCI) is in use, it will stop current flow as soon as current begins to flow through the person’s body to ground. GFCI protection is the preferred safe way to prevent electrocution due to ground faults. However, many circuits, for one reason or another,
cannot be GFCI protected. In these, if the energized frame of the equipment is properly grounded, current will flow from the frame through the **equipment grounding conductor** and back to the grounding bus, which is bonded to the neutral bus in the building’s service entrance. The **equipment grounding conductor** simply offers an alternate path for the **fault current** to flow in the event of a ground fault. Ground fault detector lights are used to detect ground faults in ungrounded three-phase systems (see Figures 10-1 and 10-2)


**What is the advantage of having this alternate path for current to flow?** If the **equipment grounding conductor** has sufficiently low resistance to current flow (less than 1 ohm), it will allow enough current to flow to cause **overcurrent protective devices** (fuses or circuit breakers) to open, stopping the flow of current to the faulty equipment as soon as the fuse opens the circuit, which is dependent upon it’s clearing time (time it takes for the element to melt and interrupt the arc that occurs as the element opens).
How can one be sure the equipment grounding system is functioning correctly? There are many requirements for equipment grounding systems to function correctly including:

1. The system must be wired correctly, meeting all requirements of the National Electric Code. An inspection by a competent licensed commercial electrician followed by correction of faulty equipment should ensure that the system is wired correctly.

2. Always replace fuses and circuit breakers with the correct size and type, as originally installed by the competent electrician. The ampere rating must be correct for the circuit wiring and components. Since a fault current is many times the ampere rating of an overcurrent device, there is danger of the device becoming damaged before it is able to stop this large current flow. For this reason, each overcurrent device must also
have a current interrupting rating (IR or Underwriters Current Limiting (CL) rating). The IR or CL must be sufficient to carry the calculated maximum fault current. The person designing the electrical system will perform this calculation and determine that downstream electrical components have sufficient “withstand” capabilities to carry the calculated fault current (Note that short-circuit-current studies and protective-device coordination in industrial applications are typically beyond the capability of most electricians. Because of the number of factors involved, to perform this work correctly is a significant undertaking).

Figure 9-3. 225-Amp Circuit Breaker with 100,000 Amp Interrupting Rating (from “Electrical Grounding” – See Fig. 9-1). (IR)
3. Electrical equipment fastened in place must be grounded if it is within 8 feet vertical distance or 5 feet horizontal distance of a grounded surface. Noncurrent carrying metal parts in contact with electrical equipment, likely to become energized, or when subject to contact by persons must be grounded. The equipment grounding conductor connecting equipment frames to the neutral bus at the service entrance must be adequately sized, continuous, and wired correctly, so that it offers only minimal resistance to current flow (less than 1 ohm).

4. The resistance between equipment frames and the neutral bus at the service entrance must be tested and maintained below 1 ohm. In an AC system, the impedance would need to be maintained at less than 1 ohm. The distinction between resistance in DC and impedance in AC is important, because, while resistance alone has the greatest effect on current flow in a DC system, resistance, inductive reactance and capacitive reactance all affect current flow in an AC system. For example, a seemingly harmless condition such as passing the equipment grounding conductor through a steel raceway without proper bonding and other precautions, can greatly impede the flow of AC current.
through this conductor and render it unsuitable to provide ground fault protection.

**What happens to the fault current once it reaches the grounding bus in the service entrance?** The fault current follows both the *grounding electrode conductor* to the *grounding electrode* and the *grounded (neutral) conductor* back to the transformer or generator. The portion of the overall fault current following a particular path is dependent upon the resistance to current flow of that path. Unless the grounding electrode system resistance is very low, nearly all of the fault current will flow through the grounded neutral conductor.

**If fault current flows through the neutral conductor back to the transformer or generator, what is the purpose of the grounding electrode system?** The purposes of the grounding electrode system, which is connected to the neutral conductor at the service entrance, are said to include conducting current to ground from:

- Lightening Surges
- Line Surges
- Unintentional Contact with Higher Voltage Lines
- Help Stabilize voltage to ground during normal operations
- Possible facilitation of overcurrent device operation in case of ground fault on a solidly grounded system
- Provide an additional path for the flow of fault current

*In grounding electrode systems with excessively-high ground resistance, or even in those systems just meeting the minimum required standards, the grounding electrode system resistance is much too high to allow sufficient current to flow to trip correctly-sized circuit breakers or to blow fuses. Current which goes to the “grounding electrode system” must flow into the earth, then through the earth back to the transformer or generator grounding electrode system, then to the transformer or generator ground. Because of this high resistance (NEC wants you to use an additional ground*
rod if above 25 ohms – Figure 10-5), simply connecting equipment frames to a ground rod or other grounding electrode system will not protect a worker from electrocution in the event of a ground fault.

Does the grounding electrode system protect personnel during lightening or high voltages from other sources? No:

1. If a lightening bolt or other high-voltage surge from an external electrical source energizes any frame in the plant, every frame in the plant becomes energized because they are all connected to the ground bus at the service entrance.

2. When the transient occurs, if a difference in potential exists between the energized components and anything else that you happen to be touching exists, your body may become part of the path between these different
potentials, and you may be electrocuted. Take immediate steps to avoid this situation during a lightening storm such as going inside a building or into a vehicle with a metal roof for protection.

What are some possible grounding electrode system types?

- Driven rod
- Pipe electrode
- Plate electrode
- Ground grid

**Testing Grounding System Resistance**

**How often are mines required to test grounding systems?**

30 CFR Parts 56/57.12028 -- testing grounding systems.

- Continuity and resistance of grounding systems shall be tested immediately after installation, repair, and modification; And annually thereafter.

- A record of the resistance measured during the most recent tests shall be made available upon request by the secretary or his duly authorized representative.

**Testing Continuity of the Equipment Grounding Conductor**

- “Continuity” between equipment frames and the ground bus at the service entrance is tested by measuring the resistance between the two points.
• Conductors in fixed installations that are not subject to vibration damage and where you can see by eye that the system is continuous, can be visually inspected instead of making actual measurements.

• Electric cords that supply power tools and portable or mobile equipment must be tested. (not applicable to double insulated tools or where protected by a GFCI that trips at 5 ma or less).

• Testing is not required if a fail-safe ground wire monitor is used to continuously monitor the grounding circuit and which will cause the circuit protective devices to operate when the ground conductor continuity is broken.

• The **grounding electrode conductor** and grounding electrode system must also be tested.

• A record of the most recent tests must be kept and made available to the MSHA inspector. MSHA wants the test results to be recorded in resistance value in ohms.

**Testing Grounding Electrode System Resistance**

• “Grounding electrode system resistance” is tested using a tester that has been specifically designed for this purpose.

• The accepted technique is called the “fall-of-potential”, 3-Point, or 62% method.

• Grounding electrode system resistance cannot be tested using an ordinary ohm meter, or an insulation tester (Also called a Meggar), or a Welder. Most suitable instruments cost more than about $600.

• The instrument supplies the current to be measured at a frequency different than 60 Hz to avoid interference from stray currents. Too great a difference from 60 Hz will also cause errors because ground resistance (impedance) varies with frequency.
• An instrument that uses dc should be avoided due to problems with polarization and electro-osmosis.

• The leads from the instrument to the electrodes should be spaced as far apart as possible to minimize effects of mutual inductive reactance and capacitance.

• There are several instruments on the market with prices ranging from about $600 to $3000 depending on features.

• An inferior instrument will give readings that vary widely depending upon probe resistance.

**Measuring Ground Bed Resistance – How is it Done Safely?**

• By Following The Safe Procedures Recommended By The Instrument Manufacturers. **Before starting:**
  
  o Check for voltage or current in the system

  o Disconnect power

  o Tag out

  o Lock out
This “Megger” is one of a number of commercially available ground bed resistance testers.

Figure 10-6. Meggar Brand 3-Terminal Ground Resistance Testers from Biddle Instruments.

Follow the instrument manufacturers’ procedures.
The following description is to aid understanding and help you get started.
The current electrode is driven into the soil at a distance greater than 5 times the largest bed dimension. For a single ground rod it would be at least 5 times the length of the rod. The illustration shows a distance of 10 times the largest bed dimension.

Figure 10-7. Distance From Ground Bed to Current Probe.
The special meter causes current to flow from the ground bed to the current electrode. The voltage electrode is driven in at various distances on a line connecting the ground bed and current electrode.

Figure 10-8

Figure 10-9
This illustrates a number of positions for the voltage electrode. The voltage $P_2$ is measured at each position.

Figure 10-10. Illustration of Connections on Ground Bed Resistance Meter and Current and Potential Electrode Positions Measured.

**How Are the Resistance Values Calculated?**

- The resistances are calculated from the measured voltages and the measured or known current -- $R=P_2/I$, where $R$ is the resistance and $I$ is the current in amps.
The single meter and its leads includes the voltage source, ammeter and a voltmeter:

![Diagram](image)

**Figure 10-11. Functions Included in the Ground Bed Resistance Meter.**

**What to Expect in Performing the Test**

- At positions close to either the grounding electrode system or the instrument’s current electrode, resistances change rapidly with distance from the electrode.

- The readings become constant at about 62% of the distance from the grounding electrode system to the current electrode. At this distance, the current passes through a much larger cross-sectional area of earth than it does at distances closer to either the grounding electrode system or current electrode. For example, right next to a ground rod the cross-sectional area of earth only equals the surface area of the rod.
The resistance values are plotted on the vertical axis against distance from the ground bed on the horizontal axis. The plot flattens in the area where the resistance remains constant with increasing distance. The resistance in this flat area is the measured ground bed resistance.

Figure 10-12. Graph of Resistance Vs. Distance from the Ground Bed.

In the Plots below, line “a” represents a correctly-done test, while line “b” is for a test where the current electrode was positioned too close to the ground bed (less than 5-10 times the largest dimension of the ground bed).

Figure 10-13. Graph of Resistance Vs. Distance from Ground Bed for Correctly- and Incorrectly-Made Measurements.
Table 10-1. Some of The Intruments Available For Grounding Electrode System Resistance Testing by the Fall-Of-Potential Method – All have different features.

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What are some factors, which determine grounding electrode system resistance?

1. Number of rods or mesh.
2. Length of rods or mesh.
3. Depth of rods or mesh.
4. Ground moisture content should be above about 15%.
5. The soil should contain some dissolved minerals—clean water is not as good a conductor as water containing high dissolved minerals.
6. The resistance of water to current flow increases with decreasing temperature. Ice at –15 deg. C has a resistance about 46,000 times higher than water at 20 deg. C.
7. Loams and clays are low while shales, sandstones, and crystalline rocks are high.
8. Particle size range and packing.
9. Location, in particular the distance between ground conductors or electrodes, known as the “sphere of influence”.

What are some controls that are available to decrease ground resistance?

- Positive changes in any of the above factors
- There are various special ground rods available that automatically trickle small amounts of minerals into the soil to increase conductivity. These may be oriented horizontally, if necessary. The horizontal systems, which may have holes all along the length of the pipe, work well when properly applied.
Fig. 10-14 Cutaway view of the installation of an electrolytic ground rod. Courtesy Lyncole XIT Grounding (from “Electrical Grounding” – See Fig. 10-1).