Not All Ground Rods Are Created Equal

Knowing what types of ground rods are available as well as understanding how they work and interact with different soil conditions help you prevent grounding problems.

By John Paschal, P.E., Editorial Consultant

Do you know how to select the best type of ground rod when working in sandy clay soil, how many ground rods it takes to achieve 25 ohms-meter or less, or how to select the best location for your ground rods? There are no simple answers to any of these questions. However, if you understand the types of ground rods available and how they interact with different soil conditions, you can overcome any grounding obstacle.

The grounding electrode system keeps your entire grounding system at earth potential during lightning and other transient events. Its function is not principally for conducting ground-fault current, even though some zero-sequence current could flow through the grounding electrode during a ground fault. However, when served from overhead lines (where the fault current return path(s) could break and become an open-circuit), grounding system designs should reduce the potential gradients in the vicinity of the ground rods. This helps you achieve safe step and touch potentials under ground fault conditions.

Earth electrode resistance is the number of ohms of resistance measured between the ground rod and a distant point on the earth called remote earth. At this point, the earth electrode resistance no longer increases appreciably when the distance measured from the grounding electrode increases. This distance is typically about 25 ft for a 10-ft ground rod.

Earth electrode resistance equals the sum of the resistance of the metal ground rod, the contact resistance between the electrode and the soil, and the resistance of the soil itself. Since the resistance values of the ground rod and soil contact resistance are very low, for all practical purposes, earth electrode resistance equals the *resistance of the soil surrounding the rod*. Note: This is not obvious, given the wide variety of ground rod metals available.

Although the internal abilities of these different rod materials to conduct current vary from 100% for copper to 2.4% for stainless steel (Fig. 1), corrosion and other physical considerations typically govern which type of metal rod you should install. Except for corrosion considerations discussed below, the type of metal has almost no effect on the ground rod's earth electrode resistance. Soil almost entirely determines the resistance value (Fig. 2).

Regardless of the rod material, you can use the quick formulas in Fig. 3 to estimate ground rod resistance. For example, if the soil resistivity averages 10,000 ohm-cm, then the resistance of one ¾-in. 10-ft electrode is 32.1 ohms. Notice that rod diameter and soil resistivity are the determining factors. Fig. 4, on page 42, shows the relative values of resistance to remote earth of various lengths of ground rods as well as various sizes of ground rods. This graphic shows the diameter of the rod has very little effect on the ultimate resistance to remote earth. Installing ground rods that are longer than 10 ft often provides only insignificant additional reductions in resistance to remote earth, assuming uniformity of soil resistivity.

Material	% Conductivity
Copper	100
Stainless steel	2.4
Zinc-coated steel	8.5
Copper-clad steel	40

Fig. 1. *Common metal ground rods and their conductivity values.*

Soil Resistivities (ohm-meters)	
Soil description	**Resistivity value**
Loam	25
Clay	33
Sandy clay	43
Slate or shale	55
Silty sand	300
Gravel-sand mixture	800
Granite	1000
Gravel with stones	2585
Limestone	5000

Fig. 2. *Average soil resistivity values.*

Rod Diameter (D)	Resistance (R)
1/2 in.	ρ/292 ohms
5/8 in.	ρ/302 ohms
3/4 in.	ρ/311 ohms
Source: IEEE Green Book	

Fig. 3. *Formula for calculating the resistance of a ground rod.*

For example, Fig. 4, on page 42, shows the resistance of a ¾-in. rod in a loam soil decreases from 8.2 ohms for a 10-ft rod to 3.2 ohms for a 30-ft rod. This is a relatively small improvement when compared to the reduction of 52 ohms for a 1-ft rod to 8.2 ohms for a 10-ft rod.

Fig. 5, on page 42, shows improving the soil resistivity characteristics immediately surrounding the rod can do this same job easier and more cost-efficiently. However, two exceptions apply to this rule:

1) In very dry soil, extending the ground rod down into the permanent ground water improves the resistance value. (see Fig. 6, on page 44).

2) During the winter, having the ground rod extended to the deep non-frozen soil greatly improves its resistance value over what it would have been in frozen soil or ice. (see Fig. 7, on page 44).

Soil resistance is nonlinear. You'll find most of the earth electrode resistance within a few feet of the ground rod—concentrated within a horizontal distance that is 1.1 times the length of the ground rod (Fig. 8, on page 44). Therefore, if you install ground rods too close together, you essentially design the current to flow into the same earth volume. This causes the rod's parallel resistance values to remote earth to be less than

NEC Ground Rod Rules

Sec. 250-56 of the 1999 NEC requires a minimum resistance to remote earth of 25 ohms for a grounding electrode made of a rod buried at least 8 ft. When its measured resistance exceeds the 25 ohms, the Code requires the installation of *one* additional ground rod to be located at least 6 ft away from the first. Sec. 250-52(c) requires that the rod(s) be a minimum O.D. of ¾ in. if made of galvanized pipe, a minimum of 5/8 in. O.D. if solid iron or steel, and a minimum of ½ in. if made of nonferrous material such as copper or stainless steel. Sec. 250-52(e) prohibits the ground rods from being made of aluminum.

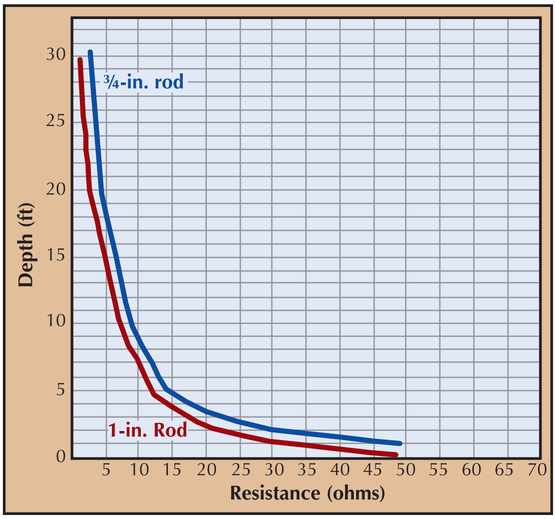

Fig. 4. *Ground rod resistance varies with depth and rod diameter.*

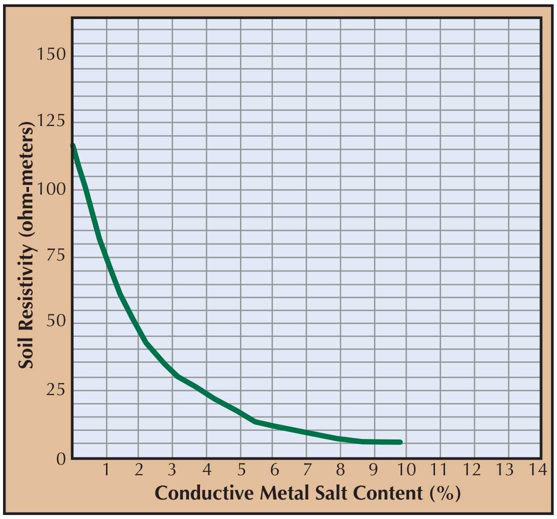

Fig. 5. *Soil resistivity decreases as conductive metal salt content increases.*

expected for parallel resistances in a normal electrical circuit. For maximum effectiveness, you must provide each rod with its own volume of earth, having a diameter about 2.2 times the rod length. In fact, tests show two 10-ft ground rods driven only 1 ft apart provide almost exactly the same conductivity as a single 10-ft rod. This is why the National Electrical Code (NEC) requires you to install a second rod at least 6 ft away from the first rod, if the resistance of the first rod is greater than 25 ohms (see sidebar).

You can think of the soil surrounding a ground rod as a series of conductive onion-like layers of equal thickness. The current flowing from the ground rod must flow through these layers. The earth layer closest to the ground rod has the smallest surface area and consequently, offers the greatest resistance. As the distance from the ground rod increases, the cross-sectional area of each layer increases. Therefore, if you improve the conductive characteristics of the soil immediately adjacent to the ground rod, you can greatly reduce the overall earth electrode resistance of the ground rod.

During an event, current flows only through the electrolyte portion of the soil, not through the soil itself. Without the moisture to form the electrolyte, almost all soils exhibit poor conductive characteristics. However, you can cut the resistance in half by excavating a 12-in. O.D. hole, installing the 10-ft ground rod in the hole, and then filling it with a chemical that has high electrical conductivity, holds water, and exhibits stable resistivity (Fig. 9, on page 44). If you excavate

Installation Guidelines

You can reduce the earth resistance values of a ground rod system by using these installation techniques:

- Use electrolytic electrode augmentation (filling hole around the rod with bentonite clay, concrete, or other low-resistivity material);
- Install hollow copper "rods" with holes drilled in the sides, through which the self-contained conductive chemicals can flow into the surrounding earth over time;
- Increase ground rod lengths; making certain that the rods extend below the frost line in cold climates and below the moisture line in dry climates;
- Extend ground rod installation down to the permanent water level;
- Use multiple electrodes in parallel and spaced apart a minimum of 2.2 times the rod length;
- Install copper-coated $^5/_8$ in. O.D. steel rods about 10 ft in length. If one rod does not provide sufficiently low resistance to remote earth, excavate around the rod and backfill with concrete, add a conductive moisture-holding chemical to the surrounding soil, or install additional rods not closer than 22 ft apart. If the water table is below 10 ft deep, then install one copper-coated, continuously-joined rod (with either thermowelded or threaded couplings) long enough to extend below the water table. If the soil contains chemicals such as H_2S, then use ½ in. O.D. or larger stainless-steel rods instead of copper-coated steel rods; and
- For temporary installations only, install ¾ in. trade size galvanized rigid conduit 10 ft in length. If one such electrode does not provide a resistance of 25 ohms or less to remote earth, then install one additional rod no closer than 22 ft from the first rod (even though the Code requires only 6 ft).

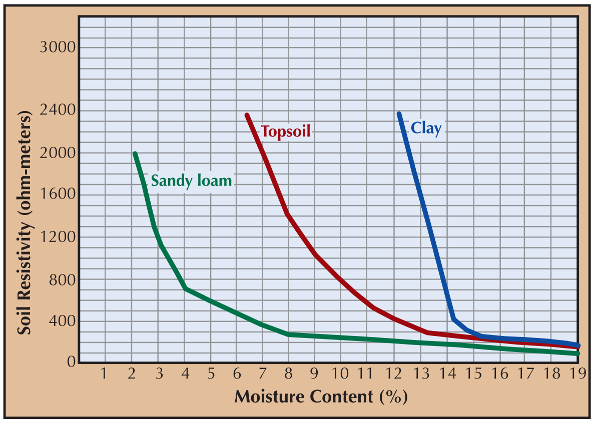

Fig. 6. *Soil resistivity decreases as moisture content increases.*

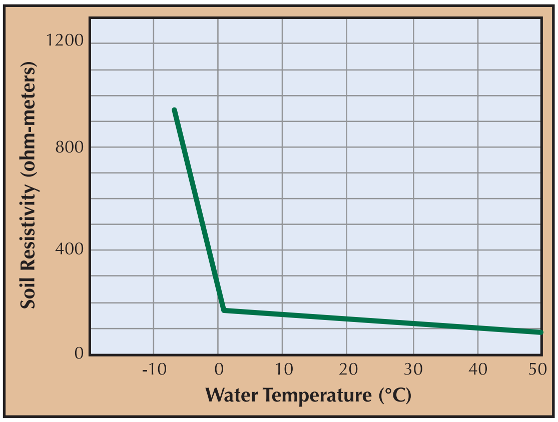

Fig. 7. *As the water in soil freezes, the soil resistivity increases greatly.*

a 24-in. hole, you can reduce the resistance of the rod to one- third of its untreated value.

As another alternative, you can encase ground rods in concrete to reduce ground rod resistance, particularly in highly resistive soils. The concrete, being hygroscopic, attracts moisture and acts as a semiconducting medium with a very low resistivity (in the range of 40 ohm-cm to 100 ohm-cm). The concrete encasement reduces the overall resistivity in much the same manner as a chemical treatment of the soil.

Selecting the best ground rod. The installation process influences the integrity of driven rods. You can damage ground rods during installation. While copper components are highly conductive and resist underground corrosion, copper cladding doesn't primarily provide better conductivity.

If you scratch or chip the copper coating during installation, the steel underneath galvanically reacts with the surrounding soil and quickly corrodes. During excavation, you'll typically find ground rods of this type totally disintegrated.

In an electrolyte, conventional current flows from the anode (+) to the cathode (−). Measurable voltages (with respect to a copper sulfate reference cell) of different metals in a water electrolyte differ significantly, by −1.1V for zinc, −0.5 for steel, and −0.2 for copper. Therefore, when installation damage causes a break in the copper covering on a steel-core ground rod, conventional current flows from the anode (steel) to the cathode (copper) in the groundwater electrolyte.

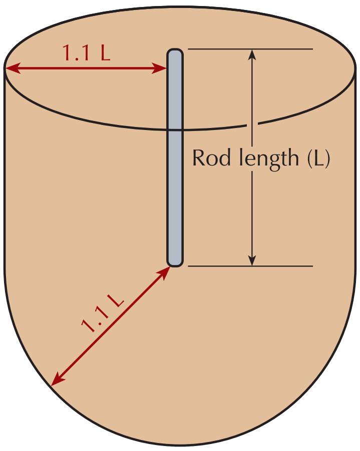

Fig. 8. *The ground rod injects current into the surrounding volume of soil.*

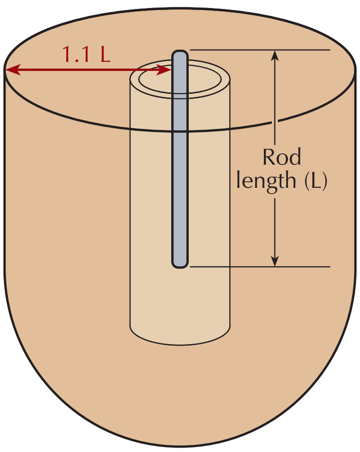

Fig. 9. *The cylinder of soil closest to the ground rod should be of low resistivity material.*

Thus, you sacrifice the steel ground rod to the copper in an aggravated corrosion process.

Similarly, you sacrifice the zinc galvanized coating on pipe or conduit while protecting the steel pipe. When the galvanizing is gone, the unprotected steel pipe simply oxidizes (rusts) and disappears after time. Either of these conditions causes the resistance of the ground rod to increase over time.

At the wire connection end of the ground rod, mechanical clamps may be effective when first installed, but they tend to loosen over time. You must tighten them periodically to maintain a low resistance grounding path.

Even after periodic tightening, mechanical clamps provide a physically non-homogeneous bond that is often not continuous at RF frequencies. This means a DC resistance check doesn't tell the whole story. Use either exothermic welds or high-compression fittings to eliminate potential problems.

Ground rods are available in various lengths, diameters, shapes, and metals. By carefully analyzing each work site and understanding the variety of installation options available, you can rest assured your installation will function as designed. **EC&M**

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