



How to Measure Ground Resistance and Optimize Grounding Grid

An Online Continuing Education Course for Engineers

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How to Measure Ground Resistance and Optimize Grounding Grid

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Understanding Ground Resistance

The term ground is specified as a conducting link by which a circuit or device is connected to the earth. The link is used for establishing and keeping as closely as possible the potential of the ground on the circuit or device linked to it. A ground consists of a grounding conductor, a bonding connector, its grounding electrode(s), and the soil which is in contact with the electrode. Grounds have few basic protection applications. For natural phenomena, such as lightning, grounds are used to secure a discharge path for the current to decrease shock hazard to staff and to avoid damage to equipment and property.

For induced potentials due to failures in electric power systems with earth returns, grounds help in ensuring quick operation of the protection relays by giving low resistance fault current paths. This allows clearing the induced potential as fast as possible. The earth must drain the induced potential before staff is injured and the power or communications equipment is damaged. In ideal conditions, to keep a reference potential for instrument safety, to protect against static electricity, and limit the equipment earth voltage for operator safety, an earth resistance needs to be 0Ω . However, this value cannot be reached. Also, low earth resistance is demanded by NEC, OSHA, and other electrical safety codes and regulations.

Grounding Electrode Resistance

Grounding rod (electrode) is presented in Figure 1. Grounding resistance is comprised of the following elements:

1. Electrode resistance and resistance of its connection.
2. Ground resistance immediately surrounding the grounding electrode or resistivity of ground. Typically, this is the major factor.
3. Contact resistance of the surrounding ground to the electrode.

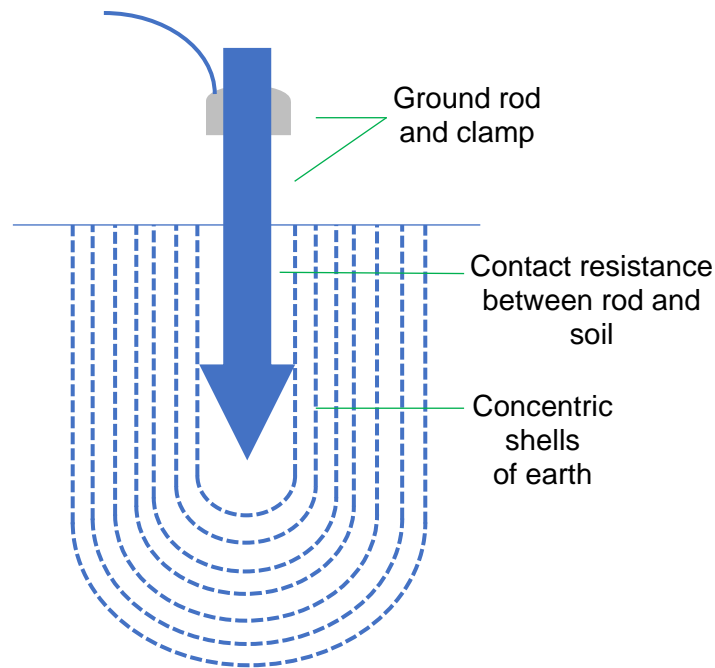


Figure 1. Schematic drawing of grounding electrode

Typically, grounding electrodes are made of a very conductive metal (usually copper or copper clad) with sufficient cross sections so that the overall resistance can be neglected. The resistance between the grounding electrode and the surrounding ground can be neglected if the electrode does not contain paint, grease, or other coating, and if the soil is compactly packed. The only element that remains is the resistance of the surrounding ground. The electrode can be looked at as being surrounded by concentric shells of ground, all the same thickness. The closer the shell to the grounding electrode, its surface area is smaller. Therefore, its resistance is higher. The farther away the shells are from the grounding electrode, the surface of the shell is bigger. Therefore, the resistance is lower. Finally, adding shells at a distance from the grounding electrode will no longer noticeably impact the total ground resistance surrounding the electrode. The distance at which this effect happens is known as the effective resistance area and it directly depends on the depth of the grounding electrode.

When ground fault current goes from a ground rod to earth, it dissipates in all directions through a series of concentric spheres or shells. These are known as effective cylinders of ground surrounding the rod. The resistance of the closest sphere to the ground rod is the highest since it is the smallest sphere. As the distance from the ground rod increases, the resistance becomes lower since the sphere becomes larger. Finally, a distance from the electrode is reached where the sphere resistance becomes zero. Hence, in any ground resistance measurement only the part of ground resistance is considered that contributes a major part of the resistance. In theory, the ground resistance needs to be measured up to infinite distance from the ground rod. Nevertheless, for practical purposes, the effective cylinder of ground (shells) that contributes the major portion of the ground resistance is two times the length of the ground rod. Theoretically, the ground resistance can be calculated using the general equation:

$$R = \rho \frac{L}{A} \quad (1)$$

Where:

- R is the ground resistance
- ρ is the soil resistivity
- L is the grounding electrode length
- A is the surface area

This equation shows why resistance of concentric ground shells decreases the farther they are from the ground rod:

$$R = \text{Resistivity of soil} \times \frac{\text{thickness of shell}}{\text{area}} \quad (2)$$

In the case of ground resistance, uniform soil resistivity throughout the volume is assumed, even though this is rarely the case in nature. The mathematical formulas for systems of electrodes are very complex and typically expressed only as approximations. The most typically used equation for single-ground electrode arrangement is:

$$R = \frac{\rho}{2\pi L} \times \frac{[(\ln 4L) - 1]}{r} \quad (3)$$

Where:

- R is the ground rod resistance (Ω)
- L is the length of the grounding electrode
- r is the grounding electrode radius
- ρ is the average soil resistivity(Ω -cm)

Effects of Electrode Size and Depth on Grounding Resistance

Size: Increasing the rod diameter does not reduce its resistance. Doubling ground rod diameter decreases resistance by less than 10%, as shown in Figure 2.

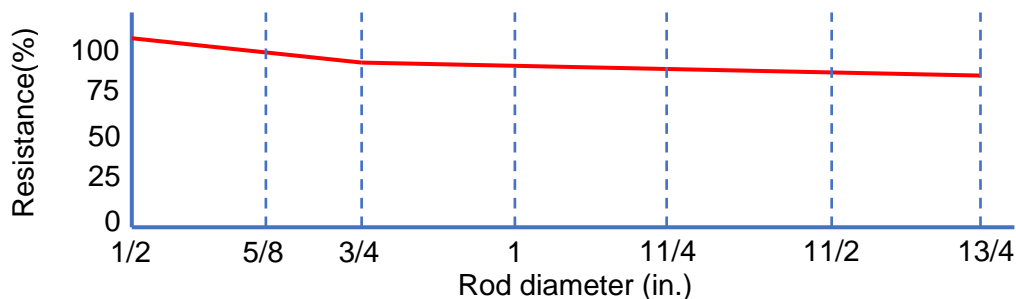


Figure 2. Ground resistance vs. rod diameter

Depth: Since a ground rod is driven deeper into the ground, its resistance is substantially decreased. Typically, doubling the rod length decreases the resistance by an extra 40%, as presented in Figure 3. The NEC demands a minimum of 8 ft. (2.4 m) to be in contact with the soil. The most typically used is a

10 ft. (3 m) cylindrical rod which meets the NEC code. A minimum diameter of 5/8 in. (1.59 cm) is needed for steel rods and 1/2 in. (1.27 cm) for copper rods.

Minimum practical diameter for driving limitations for 10 ft. (3 m) rods is 1/2 in. (1.27 cm) in average soil. Also, these values can be:

- 3/4 in. (1.91 cm) in hard soil or more than 10 ft. driving depths
- 5/8 in. (1.59 cm) in moist soil

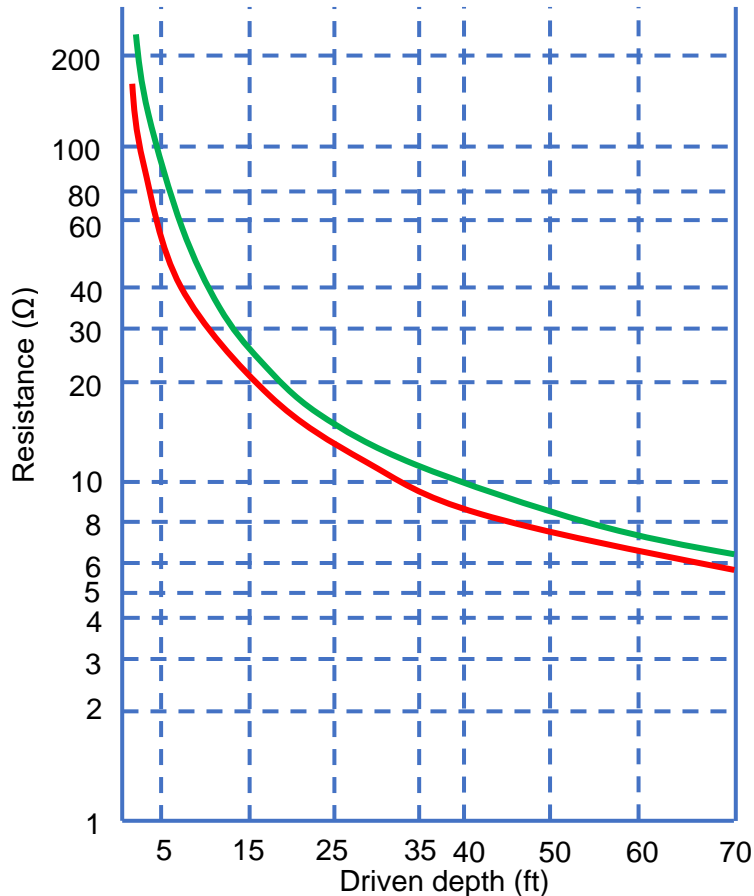


Figure 3. Ground resistance vs. depth of ground rod

Soil Resistivity Effect on Ground Electrode Resistance

Resistance of grounding electrodes depends not only on the depth and surface area of grounding electrodes, but also on soil resistivity. Soil resistivity is the major factor that affects what the resistance of a grounding electrode will be, and to what depth it must be driven to get low ground resistance. The soil resistivity changes widely throughout the world and changes seasonally. Soil resistivity is largely

affected by its content of electrolytes that consist of moisture, minerals, and dissolved salts. A dry soil has big resistivity if it contains no soluble salts, as indicated in Table 1.

Table 1. Cross comparison of different soil resistivity

| | Resistivity (Ω -cm) | | |
|---|-----------------------------|---------|---------|
| | Minimum | Average | Maximum |
| Loam, gumbo, clay | 340 | 4060 | 16300 |
| Cinders, waste, ashes, brine | 590 | 2370 | 7000 |
| Same, with varying proportions of sand and gravel | 1020 | 15800 | 135000 |
| Gravel, sand, stones with little clay or loam | 59000 | 94000 | 458000 |

Factors that Affect Soil Resistivity

Two soil samples, when completely dry, can become very good insulators, having a resistivity higher than 109 Ω -cm. Soil sample resistivity changes fast until roughly 20% or higher moisture content is reached as shown in Table 2. The soil resistivity is also affected by temperature. Table 3 presents the variation of resistivity of sandy loam that contains 15.2% moisture, with temperature changes from 20°C to -15°C. Resistivity changes from 7,200 to 330,000 Ω -cm in this temperature range. Since soil resistivity directly relates to moisture content and temperature, it can be assumed that the resistance of any grounding system will change throughout the different seasons of the year. These variations are presented in Figure 4.

Table 2. Moisture effects on soil resistivity

| Moisture content (% by weight) | Resistivity (Ω -cm) | |
|-----------------------------------|-----------------------------|------------|
| | Top soil | Sandy Loam |
| 0 | <109 | <109 |
| 2.5 | 250000 | 150000 |
| 5.0 | 165000 | 43000 |
| 10.0 | 53000 | 18500 |
| 15.0 | 19000 | 10500 |
| 20.0 | 12000 | 6300 |
| 30.0 | 6400 | 4200 |

Table 3. Temperature effects on soil resistivity

| Temperature | | Resistivity (Ω -cm) |
|--------------|--------------|-----------------------------|
| $^{\circ}$ C | $^{\circ}$ F | |
| 20 | 68 | 7200 |
| 10 | 50 | 9900 |
| 0 | 32 (water) | 13800 |
| 0 | 32 (ice) | 30000 |
| -5 | 23 | 79000 |
| -15 | 14 | 100000 |

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Figure 4. $\frac{3}{4}$ in electro

or curve 1, and

Since temperature and resistivity increase at greater distances below the ground surface, it means that a grounding electrode must be made with the ground rod driven down a considerable distance below the surface of the ground. The best results are obtained if the ground rod reaches the water table.

In certain areas, ground resistivity is so high that low-resistance grounding can be accomplished only at high expense and with an elaborate grounding arrangement. In these cases, it may be beneficial to use a ground rod system of limited size and to decrease the ground resistivity by periodically increasing soil soluble chemical content. Table 4 presents the substantial resistivity reduction of sandy loam by an increase in chemical salt content.