Solid Foundation

Building an Outside Grounding System to Support Lightning Protection

BY LAWRENCE ARCAND

The foundation for any lightning protection system is an effective outside grounding system. Without a well-designed outside system, all other components of a protection system, including inside bonding and surge protection, cannot function properly. All electrical infrastructure, whether it is located overhead or below grade, is constantly subjected to direct or indirect lightning potentials, which will induce surge currents on the conductors and/or the cable sheaths. Grounding systems provide the means by which to dissipate harmful surges to earth, thus preventing these surges from entering and damaging sensitive equipment. With the advent of today's microprocessors and sensitive electronics, facility managers are finding that most conventional grounding systems offer inadequate protection. Grounding systems designed today must have lower resistance values, higher energy dissipation characteristics and must fit within the tight confines of rights of way or property limits.

There are four basic steps involved in obtaining an effective outside grounding system:

1. Soil Resistivity Testing
2. System Design
3. System Installation
4. System Testing

Soil Resistivity Testing

The first step is to establish the on-site soil resistivity conditions. You wouldn't design a building foundation without first measuring the bearing properties of the soil, similarly, you can't design a grounding system without first measuring the soil resistivity. Resistivity is a measure of the soil's ability to conduct electricity. It can vary by several orders of magnitude from area to area; therefore, it is important to get specific data for the location where the system will be installed. The Wenner method is one of the most common methods utilized for measuring soil resistivity. Soil resistivity tests can be performed by specialty testing companies or can be completed in-house using a 4-pole ground resistance test set and some basic instructions. ASTM (American

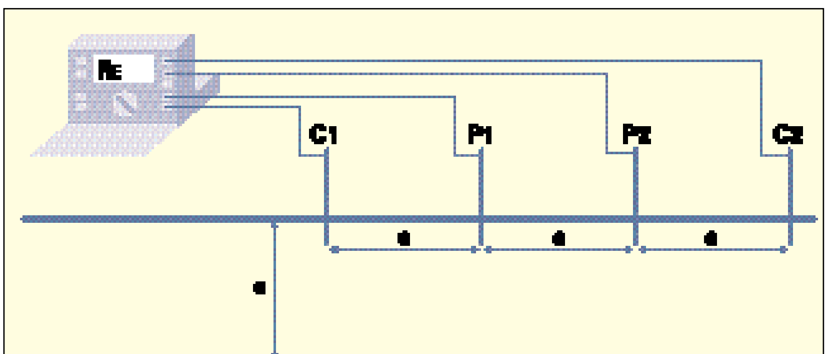


Figure 1 The Wenner Method

Society for Testing and Materials) – Test Method G57-95a provides a good guideline for the methods of collecting soil resistivity data, including the Wenner method.

The Wenner method, shown in Figure 1, involves placing four probes in the earth at equal spacing. The probes are connected with wires to the ground resistance test set. The test set passes a known amount of current through the outer two probes and measures the voltage drop between the inner two probes. Using Ohms law, it will output a resistance value, which can then be converted to a resistivity value using the equation:

$$p = 2\pi aR$$

where: p = soil resistivity
a = spacing between probes
R=resistance value measured by the test set

Soil resistivity values will vary depending on the soil type (Table 1), temperature (Table 2) and moisture content (Figure 2). As a result, it is important to obtain enough data to allow engineers to design a system that will maintain a consistent resistance value throughout the seasons. Typically, data is collected to depths of 1 to 10 meters with additional testing required for difficult sites.

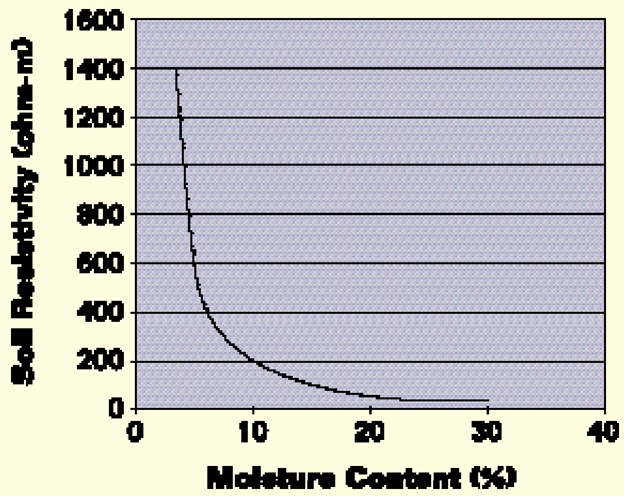


Figure 2 Soil Resistivity – Moisture Content

System Design

Once the data is collected, the second step is the design of the grounding system. Building a grounding system without a design is like throwing darts in the dark. Doing the design upfront ensures the grounding system will achieve the target resistance value and possess the desired dissipation characteristics.

The basic formula used for the design of a grounding system is:

$$R = p \times f$$

Resistance = Soil Resistivity x Function (based on type, size, shape and layout of system)

Typically, the target resistance is dictated by company standards. Less than 5 ohms is a common value used in the telecommunication industry. Soil resistivity is a known value based on site conditions, and "f" is a function based on the shape, size, type and layout of the electrode. A good design engineer will ensure that the components of the grounding system are configured to achieve the desired results using the most efficient methods.

Some basic formulas that are used to determine electrode resistance can be found in the *IEEE Green Book (IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems)*, Chapter 4, Table 13. Figure 3 illustrates sample formulas from Table 13.

Traditional grounding methods include ground rods, copper wire and ground plates or grids. All of these techniques can be effective in certain circumstances; however, they are of limited value for more resistive, difficult sites. One recent advancement for solving grounding problems is the use of conductive concrete products. These products consist of special blends of carbon and cement to form a conductive grounding material. The conductive concrete is used as a backfill around traditional rods and wire to offer greater surface area to the electrodes, thus lowering resistance and impedance and offering higher capacitance. Conductive concrete allows engineers to design an effective grounding system in even the most difficult soil conditions, where traditional systems just don't work.

Soil Type	Resistivity (ohm-m)
Clays	10-150
Sandy Clays	150-600
Pure Sand	600-5000
Gravel	5000-30,000
Shale/Slate	400-1,000
Limestone	1,000-5,000
Sandstone	5,000-50,000
Granite	1,000 -80,000

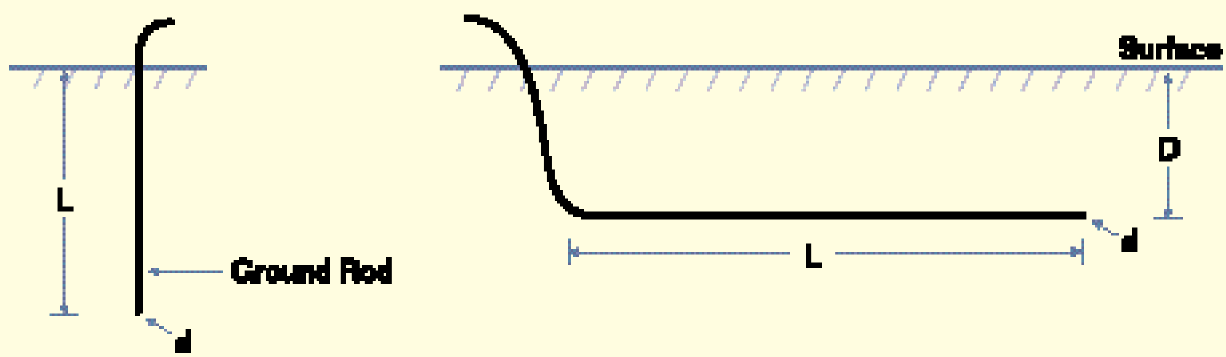
Table 1

Temperature	Soil Resistivity
20˚ C	72 ohm-m
10˚ C	99 ohm-m
0˚ C	130 ohm-m
0˚ C (ice)	300 ohm-m
-5˚ C	790 ohm-m
-15˚ C	3,300 ohm-m

Table 2

System Installation

Once the design is finalized, Step 3 begins. System installation may involve excavation equipment, drilling rigs or simple shovels and ground rod



Vertical Electrodes (i.e. Ground Rods)

$R = p\ x\ [(2\pi L)^{-1}\ \ln(4L/d - 1)]$

Horizontal Electrodes (i.e. Counterpoise)

$R = p\ x\ [(4\pi L)^{-1}\ (\ln 4L/d) + (\ln 4L/D - 2 + s/2L - s^2/16L^2 + s^4/512L^4....)]$

Figure 3 Illustration of basic formula used to determine electrode resistance.

drivers. Care must be taken to ensure that the system is installed exactly as described in the design. Because digging is involved, it is crucial to have all the buried utilities marked prior to digging. It is advisable to have the engineer or a supervisor onsite during installation to ensure construction is carried out according to the prescribed design.

Traditional systems are installed in trenches as per the design layout. Ground rods are typically spaced along a length of counterpoise wire. Conductive concrete electrodes are most commonly installed in a horizontal configuration; however, they can also be installed vertically.

When installing conductive concrete in a horizontal application, trenches are excavated 18 inches wide and approximately 30 inches deep (dependent on local codes). The bare copper wire is laid straight down the middle, and it is encased in conductive concrete. The conductive concrete is installed dry, and it absorbs moisture from the surrounding soil and sets up like regular concrete. The conductive concrete is applied evenly to a thickness of 2 inches over the copper electrode, and then the trench is backfilled.

For vertical electrode applications, a hole is drilled to the designed depth and diameter. The conductor is placed down the hole, and it is filled using a slurry mixture of conductive concrete and water. Care must be taken to fill the hole from the bottom up to displace any water or mud.

Grounding system connections of wire-to-wire, wire-to-rod, or wire-to-plate located below grade should be made using exothermic welds. An exothermic weld provides a molecular bond between the two materials and eliminates the potential for the connection to weaken due to corrosion, loosening, or any other problem associated with mechanical or compression connections. Exothermic welds are fast and cost-effective; however, extra care must be taken to ensure they are done properly and safely.

System Testing

Finally, testing of the grounding system, Step 4, is important to determine whether ground resistance targets are met. Typically, grounding professionals should be called to perform the ground resistance tests, as each test must take into account on-site conditions in order to avoid obtaining erroneous data. Testing can be accomplished using clamp-on resistance testers, fall of potential methods, or by simply calculating the probable resistance. Detailed procedures for accurate testing can be found in ANSI IEEE Standard 81.

Three-pole ground resistance testing (commonly referred to as fall of potential testing as illustrated in Figure 4) is used to measure the resistance value of a grounding system or ground electrode in situ. In order to get accurate results, the electrode or system being tested must be isolated from all other grounding sources including the AC mains neutral. This test works by passing current between the grounding system and an outer probe. An inner probe is then moved to various locations and the test set measures the voltage drop and converts that number to a resistance value. The resistance values are plotted for the different locations and should form a curve with a flat region, which represents the actual resistance value of the grounding system. Fall of

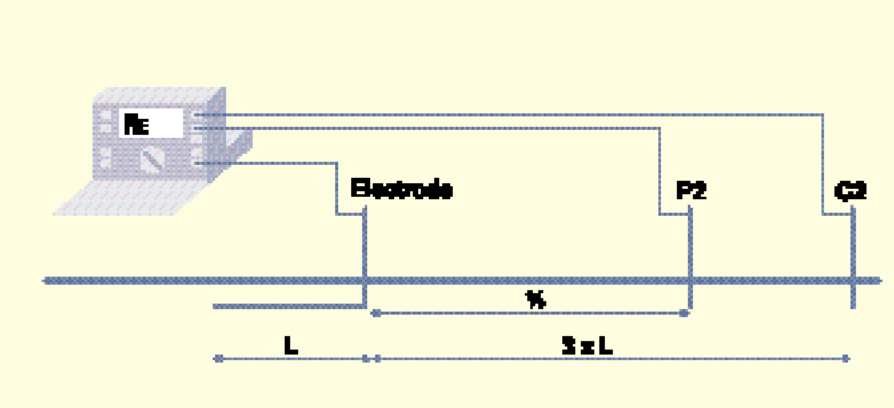


Figure 4 Fall of Potential Testing

potential testing is very accurate for new installations or those that are completely isolated from any other ground source.

The clamp-on method is a much faster technique to use. However, it requires a good understanding of the system under test in order to obtain accurate readings. This test may be conducted while the grounding system is still attached to the AC power neutral or other grounding sources.

Conclusions

Attention to good grounding techniques helps establish a solid foundation on which to build an effective lightning protection system. Without addressing grounding, these protection systems are inadequate. This article outlines the basic testing, design and installation techniques that can be used to establish a good outside grounding system. Recent advancements in grounding technology utilize conductive concrete materials. These systems offer the lower resistance values and higher dissipation characteristics required to protect today's more sensitive electronics. A grounding professional qualified to test and design grounding systems is a valuable asset to ensure that every location has adequate protection against harmful lightning surges.

Lawrence Arcand, P.Eng., is the manager of engineering at SAE Inc. Grounding Systems. He has been involved in the design and implementation of numerous grounding systems throughout North America. Visit the SAE Inc. web site at www.saeinc.com.