LYNCOLE PRESENTS: EARTH GROUNDING FUNDAMENTALS

In the study, analysis, and design of lightning protection systems, earth grounding is perhaps the most difficult variable. This is true because earth grounding systems must be designed individually based on specific site and soil conditions that vary widely from site to site. That information and an understanding of grounding fundamentals is often not readily available to engineers, contractors, and project managers. The focus of this article is to provide the basic information and knowledge necessary to understand and design a safe, effective, and reliable earth grounding system.

Earth grounding is the electrical bonding or connection of equipment to the earth. We ground our equipment to keep it as close to earth's electrical potential as possible. An earth grounding system's performance is directly proportional to the resistance of the interface between it and the earth. While the earth is considered a good conductor of electricity, it is comprised of a multitude of materials varying in resistivity (the ability of the earth to conduct electricity). The resistance of a grounding system is determined by its surface area being in direct contact with earth and the resistivity of the portion of the earth in which the grounding system is buried.

Grounding is critical for several reasons. The first is human safety. A low resistance grounding system will keep equipment near earth's potential, reducing the voltage difference between equipment and "earth." This will reduce the possibility of an accident or fatality during human contact.

Second, grounding is meant, along with Surge Protection Devices (SPDs), to protect equipment from voltage surges and transients. Damage to sensitive equipment from surges caused by lightning, etc., can result in the loss of millions of dollars in damages and downtime.

Finally, grounding offers peace of mind. When a low resistance grounding system is installed, equipment, personnel and financial investments are protected.

The main objectives of a grounding system are to provide:

- Personnel safety and equipment protection by providing a low resistance path to safely dissipate any unwanted charges and potentials.
- A "reference point" approximately equal to the potential of the earth for sensitive equipment.

To be effective, a grounding system must be stable and reliable in all adverse environmental conditions, be maintenance-free, and have a long-life expectancy with no recurring costs.

LIGHTNING PROTECTION

Air terminals, catenaries, down-conductors, bonding connections, surge suppression devices, and grounding are the primary components of a lightning protection system. NFPA 780 "Standards for the Installation of Lightning Protection Systems" explains the design and application of most of these components using mathematical models. This standard explains in detail the placement of air terminals and conductors and lists the types of electrodes that can be used for lightning protection. But there is no actual resistance goal for the performance of the grounding electrodes.

The grounding electrode system can arguably be considered the most important "end point" of the lightning protection system. Without the ground or "end point" the lightning protection system cannot function or protect as designed. The earth grounding system is essentially buried under the surface of the soil and is inaccessible for inspection and maintenance. Since it is the only part of the lightning protection system, which cannot be regularly inspected, it is essential to design the grounding system to perform safely and properly in the soil it is installed.

The grounding system is responsible for dissipating or transferring a high-energy event of a lightning strike into the "natural" earth. The grounding system must be conductive, durable, heat-resistant, and resilient. It should be low enough in impedance to minimize the ground potential rise in the soil surrounding the grounding system and the voltage potentials on all interconnected components.

GROUNDING SYSTEM DESIGN FUNDAMENTALS; SOIL CHARACTERISTICS

Soil characteristics determine the design and physical construction of a grounding system necessary to achieve a desired ohmic resistance. This includes grounding electrodes, electrode spacing, and placement.

The single most important characteristic of concern is the soil's conductivity or its ability to conduct electricity, inversely called soil resistivity. Soil resistivity testing will determine how resistive to electrical current flow the soil is, and ultimately the grounding system layout necessary to achieve a specific earth ground resistance. Factors that affect soil resistivity are its moisture content, electrolyte and metal content, and environmental changes in temperature.

SOIL RESISTIVITY

Soil or earth resistivity is the soil's electrical resistance to the flow of alternating or direct current (AC/DC). The most common unit used is the ohm-meter, which refers to the resistance measurement between opposite faces of a cubic meter of soil. Theoretically, the earth ground resistance of any grounding system or electrode, R, can be calculated using the general resistance formula:

$$R = \frac{\rho}{2 \pi L}\left(\ln \frac{4L}{A} - 1 \right)$$

L = Length of the conducting path (meters)
a = Cross-sectional area of the path (square meters)
ρ = Resistivity of the earth (ohm-meter)

Hence, soil resistivity is a proportional constant that relates the resistance of a grounding system to the length of the conducting path and its cross-sectional area. It is important to measure soil resistivity since resistivity can vary widely in different soil mediums. For example, typical surface soils can vary in resistivity within a range of 100 to 5000 ohm-cm. Moreover, knowing what the resistivity is in surface soil is necessary for an effective grounding design.

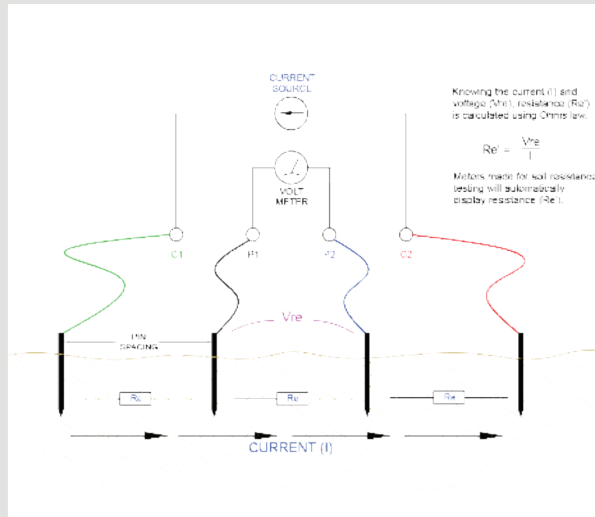
MEASUREMENT

Typically, soil resistivity is measured according to the Wenner Four-Pin Method using a ground resistance meter (Figure 1). Four metal pins are placed in contact with the ground in a straight line and equally spaced. A constant current is then injected through the ground via the meter and the outer two electrodes, labeled C1 and C2.

The potential drop is then measured across the inner two electrodes, labeled P1 and P2. The meter provides a direct ohm reading that is used in the following formula to determine soil resistivity:

ρ = 191.5 x R x A
ρ = Soil resistivity (ohm-cm)
Re` = Ground resistance meter readout (ohms)
A= Distance between electrodes (feet)

The resistivity calculated is the average resistivity of the soil between the surface and a depth equal to the pin spacing



EFFECTS OF MOISTURE, TEMPERATURE, & SALT ON RESISTIVITY

Most soils naturally contain varying amounts of electrolytes. Thus, the addition of moisture will enhance conductive properties; the greater the moisture content in soil, the lower the resistivity. However, the addition of moisture to soils which include granite, sandstone, and surface limestone will have little or no effect in reducing the resistivity.

Temperature, like moisture, can have a significant impact on resistivity. The soil resistivity does not vary much with temperature until the temperature reaches freezing conditions, i.e., 32°F. At this temperature, the moisture in the soil will “freeze-up” and the resistivity will increase.

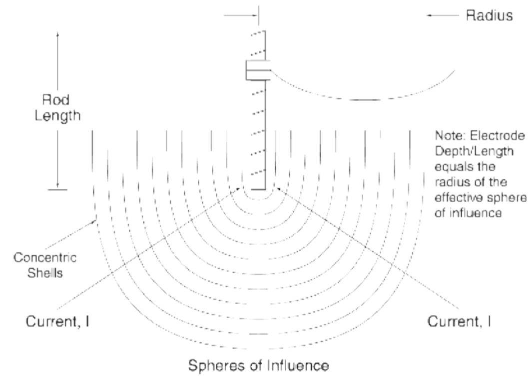
The amount of salts in the ground also influence a soil’s resistivity. In general, the more salts or electrolytes a soil contains, the lower the resistivity.

GROUNDING ELECTRODES

A grounding electrode driven in soil having uniform resistivity will radiate current in all directions. This is the electrode’s sphere of influence on the environment. The ability of the electrode to radiate current is directly dependent on the soil’s resistivity. The higher the resistivity, the less effective the grounding electrode will be in dissipating the current. Therefore, higher resistivity will result in high resistance earth grounds, which are compensated for in a grounding system design strategy.

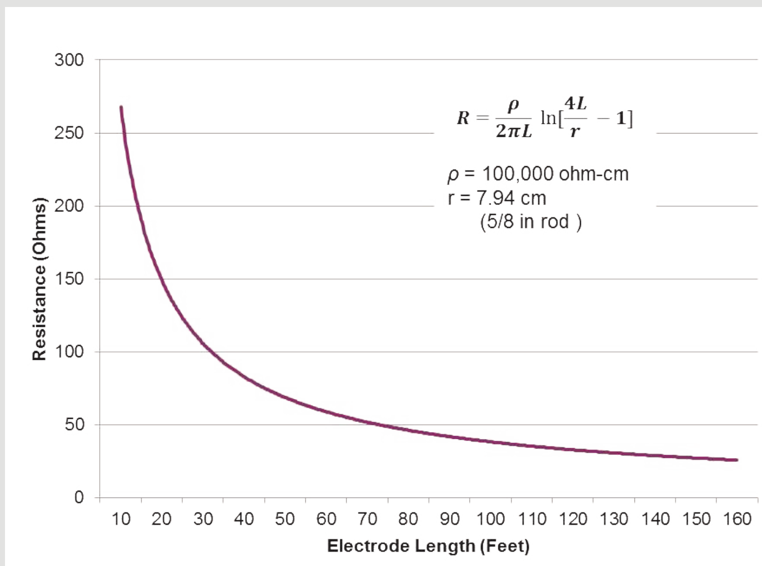
SPHERE OF INFLUENCE & AVAILABLE SPACE

An electrode length L will have a sphere of influence with a radius approximately equal to length L. In a grounding system, if two electrodes are spaced too close to each other, their spheres of influence will overlap, reducing or minimizing the electrodes' ability to dissipate current. To take full advantage of the electrodes' spheres of influence, the electrodes should be at a distance equal to two times the length of the electrode.



LENGTH VS. RESISTANCE

Rod length is one of the factors that determines earth ground resistance in a grounding system. Longer rods, greater than ten feet, have a larger sphere of influence and thus will dissipate more current than shorter rods. This will result in a lower-resistance earth ground in a soil of uniform resistivity.



However, as the rod length increases, the sphere of influence will reach an infinite plateau where the resistance of the earth ground will no longer change. Once the infinite plateau is reached at length L, extending the length of the rod past this length will have little effect in lowering the resistance of the grounding system

RESISTANCE VS. NUMBER OF ELECTRODE SOIL RESISTIVITY

The earth ground resistance of a grounding system is dependent on the number of electrodes placed in the soil. The addition of electrodes will reduce the resistance of the grounding system until, it also reaches an infinite plateau. The plateau is the electrodes' sphere of influence overlapping in the grounding system area. The grounding system area can also be called a counterpoise or grounding grid. The addition of electrodes when the plateau point is reached will not make any significant changes in the earth ground resistance. To further minimize the earth ground resistance in severe areas, it is necessary to increase the grounding system area.

TYPES OF GROUNDING SYSTEMS

There are several types of grounding systems used in the industry today. Some of the most common include driven rods, water pipes, Ufer Grounds and electrolytic rods. Each is briefly described.

DRIVEN RODS & WATER PIPES

Driven rods are usually copper-clad steel rods that are driven into the ground. They are inexpensive and are typically 10 feet long with a 5/8-inch diameter. Driven rods are used as part of grid systems or as isolated equipment grounds. Some of the drawbacks of using driven rods include the following:

- They are easily affected by the environment, aging, temperature, and moisture.
- Their resistance increases steadily with age.
- They are easily damaged during installation. Scratches expose the steel metal to the environment, which will make it susceptible to corrosion attack.
- Driven Rods are inexpensive and are adequate for a short time in good soil conditions; however, they will eventually fail.

Water pipes or mains are used as earth electrodes. The drawbacks to using a water pipe ground are:

- They are difficult to test and impossible to maintain.
- Plastic inserts or O-rings destroy the circuit integrity.
- Cold water pipes produce condensation which encourages corrosion.

Water pipes should never be used as a single grounding source. They are an unreliable grounding source which can be destroyed by a simple plumbing upgrade. Instead, water pipes should be used in conjunction with driven rods or a grounding grid system in compliance with NEC 250.

UFER GROUNDS & ELECTROLYTIC RODS

Ufer grounds consist of copper wire grids that are incorporated into the building's concrete foundation during construction. Ufer grounds are impossible to test and maintain since the conductor, typically 4/0 AWG stranded cable, disappears into the foundation. Thus, time and gradual removal of moisture can cause changes in foundation integrity and ground resistance.

Electrolytic rods are 100% copper tubes filled with natural earth salts. To be effective, "active" electrolytic rods must have holes drilled near the top and bottom of the rod. The holes near the top act as "breather" holes and allow air to enter. The hygroscopic salts in the tube absorb the moisture from the air and form an electrolytic solution. This solution is then deposited into the backfilled soil environment by "weeping" action through the bottom holes, creating electrolytic roots. The electrolytic roots further lower the resistance of the ground by ionizing the surrounding soil. For example, sodium chloride (NaCl), changes physically from a solid to an aqueous state producing the following ions:

$NaCl(s) \Rightarrow Na^{+} + Cl^{-}(aq.)$

In general, the reaction that changes the physical state of any salt can be described as:

$MX(s) \Rightarrow M^{+} + X^{-}(aq.)$
M^{+} = Metal cation
X^{-} = Nonmetal anion

This solution creates electrolytic roots that dissipate electrical current. The active electrolytic rod never needs to be recharged or refilled with salts as with most chemical systems. This allows it to be maintenance-free. Another advantage is the ability of the ionizing salts to lower the freezing temperature of the moisture, allowing the system to be effective in "freezing" conditions.

When these types of systems are installed, a hole is augured into the ground. The rod is then placed into the hole which is backfilled with Lynconite II®. This makes electrolytic rods reliable unlike driven rods.

DESIGN PROCESS

The design process for a grounding system begins with a site survey of the installation area. The survey must include soil resistivity analysis, at several depths, relevant site plans, a topographic analysis and a boring core sample if available. This data will indicate any physical barriers such as rock, high-resistivity soil, or underground piping. Once the information is obtained, a design can be initiated. Our discussion will begin with the simplest scenarios and equations.

SINGLE VERTICAL ROD DESIGN

The earth ground resistance for a single electrode, such as a driven rod or electrolytic rod, can be calculated from the following formula:

$$R = \frac{\rho}{2 \pi L} \left(\ln \frac{4L}{A} - 1 \right)$$

L = Length of the conducting path (meters)
a = Cross-sectional area of the path (square meters)
ρ = Resistivity of the earth (ohm-meter)

Nomographs are available in various IEEE publications and provide basic information for simple designs. In a grounding design, there are many geometric configurations to consider when calculating resistance, i.e., 90° bends and conductor length. Formulas for different grounding configurations can be found in the IEEE Standard 142 Green Book. Hand calculating the formulas may result in errors; it is recommended that computer software be used to design a grounding system. By using a computer, the designer is able to investigate multiple grounding system configurations to obtain the target resistance. This will save time since the computer will perform the computations of a grounding configuration in fractions of manual time.

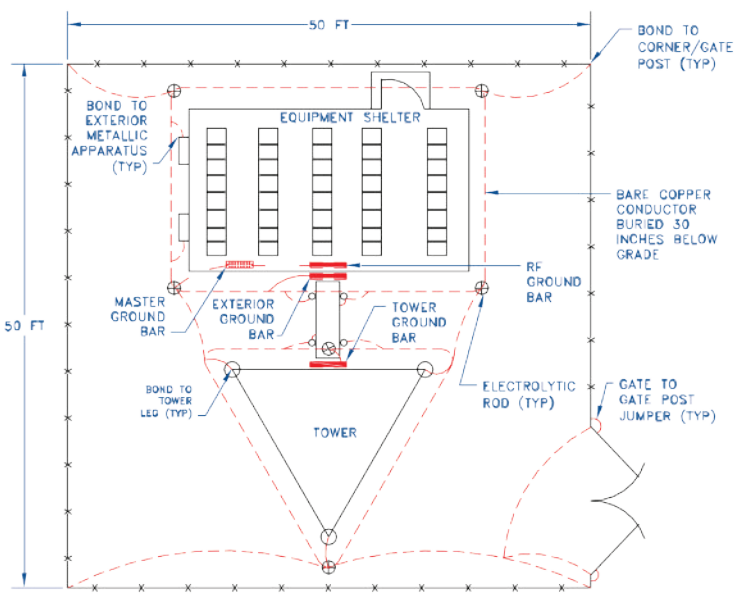
Some programs require only resistivity data and grounding system dimensions. These programs can develop a soil resistivity profile from the raw field data which is then used in the design. Using a three-dimensional coordinate system, a geometric arrangement can be programmed from the site dimensions incorporating

The program then uses a matrix to compute the earth ground resistance. Several different arrangements can be explored until the target resistance is reached.

SAMPLE PCS APPLICATION

Figure 4 shows a grounding design for a personal communication system (PCS) telecommunications site. Typically, these sites require earth ground resistances of 10 ohms or less. Electrolytic rods are commonly used since they are more reliable and stable in harsh environments and because the earth ground resistance is low and improves over time. Telecommunications providers understand that even short duration equipment outages can cost immensely in repairs and customer loyalty.

The design was modeled using proprietary software. The design has shelter and tower counterpoises with the conductor buried 30 inches below grade. Electrolytic rods are placed at each corner of the shelter counterpoise. Two additional electrolytic rods are placed in specific locations along the tower counterpoises, one directly below the tower ground bar and the other on the opposite side of the counterpoise.



The ground bars and tower/ice bridge legs are bonded to the counterpoises with the shortest and straightest bonding conductors possible. The design in these soil conditions will provide a stable, highly dependable system with the required less than 10-ohm ground resistance.

Grounding for the PCS site requires knowledge of grounding fundamentals. For example, using 10' electrolytic rods, the rods must be spaced at least 20' apart (2L) in order to take full advantage of the rods' sphere of influence. Ground conductors must be buried below the frost line and connected to the rods in a counterpoise arrangement – this ensures system integrity. Finally, the PCS grounding system in Figure 4 is an example installation. It is stable, reliable, safe, maintenance-free and long lasting without recurring costs. The use of electrolytic rods is the heart of any grounding system for telecommunications.

CONCLUSION

Grounding requires a knowledge of soil resistivity, the impact of electrolytic rods and the effects of environment on resistivity. These characteristics ultimately determine the grounding layout to obtain the "target" earth ground resistance. In general, increasing the moisture and salt content of soil will decrease its resistivity. However, lowering the temperature of the environment, i.e., 32°F, will increase its resistivity.

There are several types of grounding methods, water pipes, Ufer, driven rods and electrolytic rods, that will offer the earth ground reference. Electrolytic rods have the advantage of producing their own electrolytes, since moisture is absorbed by the salts in the rod. The electrolytes then "weep" out of the bottom, creating electrolytic roots that lower the resistance of the grounding system.

The first step in any grounding design is to obtain accurate soil resistivity data. Second, it is necessary to determine which grounding configuration will accomplish the specific resistance within the installation area. This can be determined by using formulas (IEEE Standard 142, Green Book) or nomographs for calculating the resistance of a single vertical rod. If the target earth ground resistance is not achieved it is necessary to use multiple rods or another arrangement. The use of computer software to determine a grounding configuration is recommended.

It is recommended that all engineers, builders and managers employ a company specializing in grounding system design and with a proven and verifiable history of experience. Grounding is a scientific process and one on which human safety and equipment protection are critically reliant.