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Soil Resistivity Testing & Grounding System Design

Part Two of Two

This is the second of two articles discussing soil resistivity testing and grounding system design. The first article discussed soil resistivity testing utilizing the 4-Point Wenner method. This testing determines how well or how poorly the earth conducts electrical current. For more information please refer to Article Part One of Two.

This article focuses on the available options for the ground system design process and the design result. By design process, we mean the method of manipulating the data by formulas, spreadsheets, or software. By design result we mean the actual AutoCAD or instructions showing the locations, models and quantity of grounding electrodes required to achieve the grounding system performance indicated by the design. The sole purpose of the **design exercise** is to make the performance of the ground system predictable upon installation.

The data required for a grounding system design is the soil resistivity information, the ground system performance requirement (5 ohms, etc) and a site map. The map should indicate the lease area, the location(s) of the facility, shelter, tower and all other structures. The map does not need to be precise; we receive everything from AutoCAD's to drawings on napkins.

Geo technical reports are always beneficial to have. Particularly from an installation standpoint, it is good to know that rock is at 3 feet or water at 10. A cautionary point though is that even if the report contains soil resistivity data, it is nearly always unusable for grounding system design. Generally, the soil resistivity data provided is derived from a small sample, which is not good and often the sample is saturated with water, which is worse, prior to testing.

The disadvantage of the sample is that we want to know the resistivity of the whole area, not just the small sample. Also, the natural moisture content and compaction are lost during the collection, shipping and testing process. Corrosion engineers utilize these numbers in their work.

The good news is that all geotech firms that I am aware of can perform the 4-Point Wenner testing during their work at a site. They may charge a few hundred dollars extra and you do want to provide them Lyncole's soil resistivity test procedure. Our test procedure works with all meters (they all operate the same) however you might need to refer to the meter manual for some operational know-how. The Lyncole procedure will ensure enough data is collected that a grounding system can be properly designed.

Remember the **ground resistance formula** from our previous articles, **R = *ρ*/A?** So…., even thought this is a little review from previous articles, how can such a simple formula be difficult to implement with acceptable accuracy? The difficulty is that ***ρ***, the soil resistivity variable "varies" as a function of depth and even horizontally. All the formulas available utilize a single soil resistivity number. They cannot utilize multiple resistivity levels that are absolutely necessary to predict ground system resistance.

The second reason is defining **A**, or the cross sectional area of the grounding system. You can probably visualize that with a single driven rod, the cross sectional area would be pretty simple to define. But, when you add a second driven rod bonded with a buried conductor, etc defining **A** starts getting difficult. When you have multiple driven rods and various ground ring configurations, it get impossible.

Methods of design vary across the board from a Grounding Nomograph (AEMC – Understanding Ground Resistance), simple formulas, not so simple formulas and software programs. The **nomograph** is the simplest form of grounding design.

The nomograph consist of several exponential scales on which by utilizing a straight edge, a resistance objective (5 ohms, etc) and a soil resistivity number (15,000 Ohm-cm, etc) one can determine the length and diameter of a grounding electrode to meet your performance requirement.

The nomograph is **severely limited** in several aspects. One, the range of soil resistivity is effectively limited to around 11,000 ohms-cm. Soils are higher in resistivity than 11,000 ohms-cm nearly everywhere. Two, it can only provide the length/diameter of a **single** grounding electrode. This is inadequate to meet the ground resistance requirement for sensitive equipment. Utilizing the nomograph, achieving 5 ohms in 11,000 ohm-cm soil would take a 100 ft driven rod. Multiple rods in a grid fashion would be a much easier solution but are not an option with the nomograph.

One ground rod length L, radius a	$R = \frac{\rho}{2\pi L}\left(\ln\frac{4L}{a} - 1\right)$

Fig 1 - Simple Ground Resistance Formula

Ground Resistance formulas are available from several sources. The most reliable and thorough source is the IEEE Green Book (Std. 142). Figure 1 is the formula from the Green Book for a single driven rod. You can see that even though this formula may not be very complicated, it is not really that simple. The complexity is required in defining the cross sectional area of the grounding system (**A**) or in this case, a single electrode.

Figure 2 is the formula for a total of 6 ground rods in a star configuration. As you **add electrodes** and conductor the formulas get exponentially more complex. Again, it is defining the cross sectional area of the ground system, or **A**. I would certainly characterize Figure 2 as a

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Part Two of Two

Six-point star length of arm L, depth $s/2$	$R = \frac{\rho}{12\pi L}\left(\ln\frac{2L}{a} + \ln\frac{2L}{s} + 6.851 - 3.128\frac{s}{L} + 1.758\frac{s^2}{L^2} - 0.490\frac{s^4}{L^4}\cdots\right)$

Fig 2 - Complicated Ground Resistance Formula

complex formula. Keep in mind that even with this complexity it still does not include the nearly impossible complexity of utilizing various soil resistivity values at different depths. Not only these elements, but real life situations often require the use of radial extensions for grounding systems and other odd configurations that make defining **A** even more complex.

This is where the **software programs** come into play. Notice that I have not shared a formula that considers multiple resistivity layers and the various electrode configurations and forms. These are really the province of some very smart people with doctorate degrees in various engineering disciplines. I do know that through years of Lyncole utilizing software for designs that it works. The formulas are very complex and require multiple iterations to solve. Earlier computers (P2 processors) would literally run for 7-9 hours for more difficult situations. That is the beauty of today's modern computers. They are very efficient at this task which is mainly number crunching a complicated formula. Although we can understand the factors that go into the design algorithms, knowing/repeating them has no value.

Although there are a **few software programs** available for ground system resistance calculations we use a commercially available program (CDEGS) which is produced by Safe Engineering Services of Laval, Canada. We believe that CDEGS does the most accurate ground system design and is also used for our substation work with step and touch calculations as specified by IEEE 80.

Figure 3 is a screen shot from the program illustrating the horizontal layers of differing resistivity values. The program is extremely sophisticated and has the capability of defining up to 32 layers. Our engineers have performed literally thousands of grounding system designs and although we consider grounding a science, there is a lot of operator interface, some judgment and decisions on most designs.

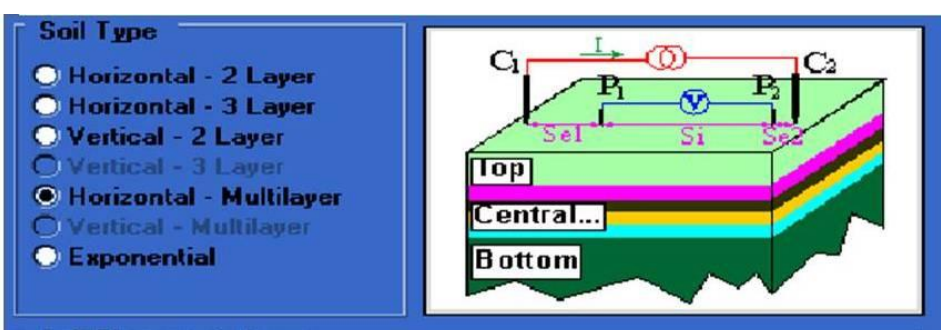

Figure 3 – Soil Resistivity Layers

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Soil Resistivity Testing & Grounding System Design

Part Two of Two

The process starts with the engineer **evaluating** the soil resistivity data. As discussed in previous articles, the more data we have the more confident we feel about a grounding system design. The data will be evaluated for obvious outliers. Sometimes a metallic object (sewer/gas pipe) may be located parallel to the soil resistivity testing. When this happens the data collected along that line of tests will be suspiciously good and should not be used in the modeling. After all the selected resistivity data is inserted, the program will model this section of earth and a result as illustrated in Figure 3. At this point also there are numerous options of how many layers to utilize, whether to use vertical layers or volumes.

After the soil model is developed, the engineer then designs the grounding system **around the constraints** presented by the site, lease area, geotech report, available construction equipment and customer. For instance, if good soil is available at deeper depths, the engineer might use deep electrodes. If the site is inaccessible to drilling rigs, deep electrodes would not be an option.

As we stated in earlier articles, many ground system designs are "geometric" or simply made to be geometrically pleasing and consistent with the facility. In nearly all of these cases, the design is made without regard or thought toward ensuring the ground system performance meets the facility requirement.

We hope that by reading these two articles our readers have a good sense of the importance of the grounding systems and the methodology utilized through the design process. With the various options, you should have the knowledge to select the appropriate one for your situation.

For more information, contact:

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