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Soil Resistivity Testing & Grounding System Design

Part One of Two

This is the first of two articles discussing soil resistivity testing and grounding system design. The hope for the articles is that the readers come away with a good understanding of these processes and why they are important. The result with this understanding is that readers should encourage/require its implementation.

Soil resistivity data is required prior to a site-specific grounding system design. Without it, you can only do a "geometric" design. In other words…, something geometrically pleasing and consistent with the facility footprint. If you want the ground system to meet a specific performance requirement (i.e. 5 Ωs) or know what the performance in ohms will be, it <u>cannot</u> be designed without knowing the resistivity data of the soil. Although we will see 5 Ωs is not always possible, but with soil resistivity data, the design becomes predictable so that you know the final ground resistance to expect after installation.

Soil resistivity testing literally collects data on how well or how poorly the local earth conducts electrical current. Virtually all materials conduct electrical current……, some extremely well, some very poorly and actually some not at all. Gold and copper would fall into the "extremely well" category and dirt would fall into the "okay to very poorly category." Since we expect the grounding system to dissipate electrical current to the earth, it makes sense that we would utilize resistivity data of the local soil in designing the grounding system. The grounding system serves as the connection between both the electrical distribution system and the equipment to earth.

Grounding system design has several benefits. All of them accrue from the fact that the engineering design process results in **predictable grounding system performance**. A major benefit is that this predictability removes the guesswork from ground system performance.

You will know prior to the ground system installation what performance in ohms will be achieved. The design tells you how many electrodes should be used, where they are to be installed, how deep they must be and how large the grounding ring (if required) must be to meet the performance objective.

You also avoid the **unnecessary cost** of overkill and the **unnecessary cost** of having to "fix/enhance" the grounding system when the performance objective is not met. In our experience we have seen the extremes of both. A few years ago, an electrical contractor in Indiana (with excellent soil) installed a huge buried ring/grid of driven rods to ensure that his telecom customer did not need "XIT systems". A single 10 XIT system would have met their 5 Ω requirement. The cost to his customer was about 25 times higher than necessary.

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The reverse situation is installing the grounding system and not meeting the performance requirement. It is always **far more expensive** to "fix", "do it again", "enhance", "improve" or implement other euphemisms that mean it was not done right the first time. No one would be pleased when discovering that the just completed 50X50 foot buried ground ring did not meet the performance objective and had it been 60X60 feet, the objective would have been met.

If you have read our previous articles on **grounding system resistance**, you probably remember that it is determined by the soil resistivity and the size of the grounding system. The scientific, but simple formula is $\mathbf{R = \rho / A}$. With **R** representing the resistance of the grounding system and $\boldsymbol{\rho}$ the soil resistivity and **A** being the effective surface area of the grounding system.

In some situations, the soil resistivity is so high that a 5 Ω grounding resistance is not possible to achieve or certainly not economically feasible. When this happens, it means that $\boldsymbol{\rho}$ is so high, that **A** cannot be made large enough to overcome the high soil resistivity and the grounding resistance objective **R** cannot be met. Even in this case, using a valid grounding system design approach demonstrates to the interested parties that the best effort has been made.

By this point we hope that you have been convinced that soil resistivity testing and the grounding design process are very important. It becomes more important with each new generation of equipment which becomes more sensitive.

Now on to soil resistivity, how it is determined, defined, and measured.

What is **soil resistivity**? As illustrated in Figure 1, it is the resistance to electrical current flow across a **cubic meter of earth**. The current source is bonded to one square meter plates on each side. This ensures the complete volume of earth is available for the current to flow in. The unit of measure is generally ohms-meter and sometimes ohms-centimeter (ohms-meter X 100).

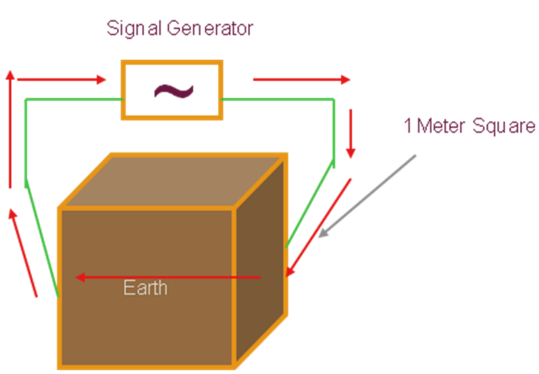

Fig 1 Soil Resistivity Illustration

Resistivity vs. Resistance - Resistivity differs from "resistance" in that it is a measure of resistance per specific volume of material.

Resistance is a point to point measurement. For example, the resistivity of the copper material making up a 4/0 AWG conductor will remain the same along a 100 foot section. However, the resistance of the 4/0 AWG conductor when measured from one end to the 50 foot point would be one half the value when measured along the entire 100 foot section.

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So **what determines soil resistivity**? The first factor is the type of soil. Generally speaking, sand and gravel conduct poorly and clays conduct well. The IEEE documents provide a table which I will not repeat, but they show a very broad range of resistivities for a specific type of soil.

For instance, clays vary from 200 to 10,000 ohms-centimeter, or a factor of 50. Limestone can vary between 500 to 400,000 ohms-centimeter or a factor of 800. With such ranges, just knowing the soil type is not sufficient information for the design of a grounding system.

What causes the broad ranges? The soil itself serves as the starting point for resistivity. From that point, the resistivity varies as a function of the moisture content, the electrolyte content and the temperature. Generally speaking, the more of each, the lower the resistivity will be. However, each pretty quickly reach a point of diminishing returns at which time more (moisture, electrolytes or temperature) provides little/no additional benefit or reduction in resistivity. When soil freezes, the resistivity becomes exponentially higher.

Essentially, none of these factors can be changed in the field. It is what it is. The soil resistivity testing tells you all you need to know. It does not matter why the resistivity is what it is, it only matters that we define the number for resistivity as precisely as possible.

Often much ado is made about "**reaching the water table**" with the grounding system. Sometimes that might improve grounding resistance and sometimes it might not. One thing is always true, for a grounding system design, you can only depend on real data provided by real testing and a design based on real data, not anecdotes. One might spend a fortune reaching the water table and get no benefit.

Years ago, one of our customers purchased a 400 foot XIT system to reach the water table. This was a classified government project and we were not involved in the design or installation but the cost was very significant. I suspect we would have suggested something else (less expensive) with an engineered design based on soil resistivity data.

Another time we were asked to analyze/test the grounding at a telehotel on the Florida coast. The local consultant had designed a ground ring of about 70 feet with several driven rods.

He was convinced that it was less than 1 ohm resistance because of the "brackish" water table at 5 feet (and invalid ground system testing). We found the ground system resistance to be in the 45-50 ohm range. Soil resistivity testing showed high resistivity soil, not good soil as the consultant thought.

We have found this situation on several occasions and believe that the "brackish" water is often stripped of electrolytes when filtered through the earth in these situations. Remember that distilled water has no electrolytes and therefore is has high resistivity. Again, this is the reason we believe in testing to define the actual resistivity and not depend on anecdotes.

Testing - To determine resistivity of the soil is a simple concept. It takes a special purpose meter, probes, hammer, coils of conductors, measuring tape, paper/pencil and very often some sweat. As we have discussed, you can consider soil as a semi-conductive material.

The soil resistivity test meter is known as a "4-Pole Meter" and functions as a **current source.** It generates enough voltage (most up to a max of 48) to generate the current the meter or operator selects. The resistance the meter sees exists in the conductors (minimal) and the probes-to-earth interface (lots).

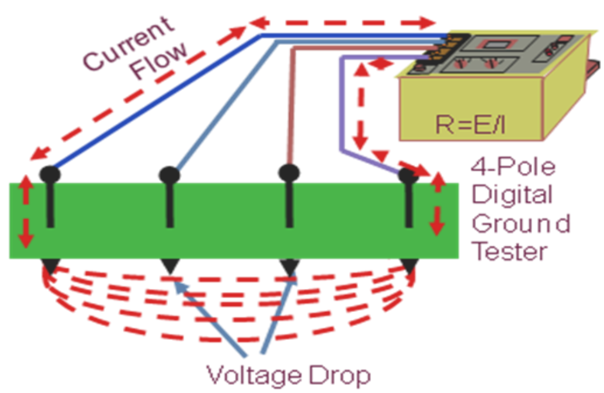

Fig 2 Soil Resistivity One-Line Diagram

Figure 2 shows a basic electrical one-line diagram of the testing configuration. **Probes -** Typically probes are 18 inches long and made of stainless steel. Their purpose is to establish an electrical contact between the meter and earth. They allow the meter to inject the current and measure the resulting voltages.

Probe Spacing - Probes are driven into the earth in a straight line, in equal spacing. Generally we start at 5 feet spacing. The four probes would be installed at 0, 5, 10 and 15 feet.

Meter Operation - The meter forces current through the first probe, the earth, and the fourth probe and back to the meter. Because the earth is semi-conductive, a voltage drop develops. The meter also measures this voltage across the second and third probe. The meter then knows the amount of current flowing and the voltage that the current develops (two of the three unknowns in ohm's law) and simply reads out the **resistance** in ohms.

Since the result is in ohms (a resistance) and we are looking for **ohms-meter (a resistivity),** a characteristic of the soil, a conversion must be performed. The following formula converts the resistance reading to ohms-meter.

$$\rho = \text{Probe spacing (feet)} * \text{meter reading} * 1.915$$

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If our reading was 9.80 ohms at the 5 feet probe spacing, then our resistivity would be 93.835 ohms-meter. An important concept to remember is that the 93.835 ohms-meter is the average resistivity between the **surface and a depth of 5 feet** (equivalent to the probe spacing).

From the Figure 2 you can see that as the current **leaves probe #1**, it forms a reverse funnel. All the current leaves the small area of the probe and immediately starts expanding, flowing through the widest cross-sectional area available (more parallel paths) before it starts "funneling" in to collect at the 4th probe on its way back to the meter. The area with the "widest cross-sectional" is where we want to measure the voltage drop because the current is flowing through not only the shallow earth, but also the deepest it can reach with the probe spacing being used.

Now we know the average resistivity down to 5 feet, but we need a lot more information on other depths. You will learn in the subsequent article that all of this resistivity data goes into a sophisticated software program. The program literally builds a resistivity model of the earth that we are testing. This earth model is then used to design the grounding system. It is understandable that the more information we have the more confidence we would have in the computer model **accurately predicting** the performance of the grounding system.

Because a large grounding system will utilize soil at depths much greater than typical electrode depths, information much deeper than the 5 foot depth needs to be known. After performing the 5 foot test, we repeat the test with probe spacing of 10, 15, 20, 30, 40, 60, 80 and out to a minimum of 100 feet. At each probe spacing we determine the average soil resistivity between the surface and a depth equivalent to the probe spacing.

How Much Testing – One line (probe spacing of 5, 10, 15, 20, etc feet) of testing is not enough. We prefer a minimum of 3 lines within the typical site. Starting in one corner, we would at least test down one side, then at a 45 degree angle, then at a 90 degree angle. Figure 3 indicates the typical test locations.

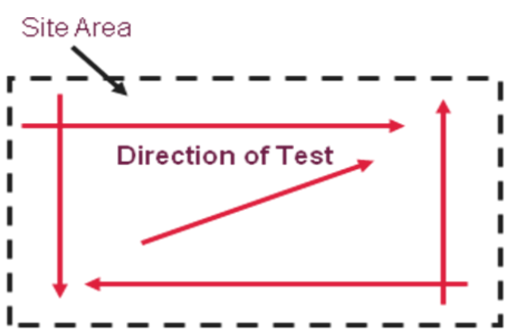

Fig 3 Typical Soil Resistivity Test Plan

There are two reasons for this. One, as we discussed, the **more data** we have for the modeling program the more confidence we have in the prediction of grounding performance. Second, if a metallic pipe had been buried down one side of the site, the results will be seriously compromised on that line of testing. Remember that current will take the path inversely proportional to the impedance it sees. If a nice metallic pipe is available, not much current will flow through the earth that we are testing. One of the first things an engineer will do prior to designing a site is to perform a sanity check on the soil resistivity data to see if any of it might be compromised and degrade the grounding design.

Figure 3 shows testing within a site. Often this may not be possible and also there will be sites where the area is not large enough to obtain all the test data we would like. It is often a compromise. We have encountered sites that have no place to test. In this case we will go to the nearest open space and also test any driven rods we might encounter. We do everything possible to obtain as much data as possible.

An important reason not yet mentioned for performing the soil resistivity testing is that soil resistivity never remains consistent with depth. In our experience, the resistivity of the soil will always get either better or worse with depth. If the soil resistivity is better with depth, the ground system resistance can be improved by installing deeper electrodes. If the soil resistivity gets worse with depth, deeper electrodes will be unlikely to lower the resistance.

The last item to mention is the testing current in all meters is a reversing DC. True DC polarizes the grounding and provides inaccurate readings. The frequency of most meters is 128 hertz. This frequency was selected because it is not a harmonic of power frequencies. The better meters have variable test frequencies so that adjustments can be made when interference is encountered.

We hope this article has shed some light on soil resistivity testing. It is an absolutely necessary step if you are designing grounding systems for sensitive electronics or other applications requiring a low resistance. Any design without specific soil resistivity testing is nothing more than a guess.

For more information, contact:

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