GROUND MEASURING TECHNIQUES:

ELECTRODE RESISTANCE TO REMOTE EARTH & SOIL RESISTIVITY

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Abstract: This paper presents different concepts and procedures for ground measuring techniques. A few of the techniques that are discussed are the measuring of resistance to remote earth for a single earth electrode or for an entire earth electrode system, and also the resistivity of the local soil using an earth system tester.

1. Introduction

A good grounding system (also known as an earth electrode system) is important for the protection of an overall system facility. There are many factors that determine how well a grounding system performs. Two major parameters are its resistance to remote earth and the resistivity of the local soil. Each of these values can be measured to help determine and design the best solution for the grounding system.

The resistance to remote earth of the grounding system needs to be at a minimum in order to sustain its effectiveness. A few of the components that make up this resistance are the physical properties of the material used to make the electrode and conductor, all connections made, contact resistance between the electrode and the soil, and the soil resistivity. A complete grounding system might include only one earth electrode, an entire group of electrodes with a grounding grid, or anything in between and beyond. The earth electrodes from any of these types of systems can have their resistance to remote earth determined.

2. Theory vs. Practice

Theoretically, the resistance to remote earth of an earth electrode can be calculated. This calculation is based on the general resistance formula:

$$R = (r \text{ x } L) / A$$

where:

R = resistance to remote earth (W)
r = soil resistivity (W-cm)
L = length of conducting path (cm)
A = cross-ectional area of path (cm)

This general formula is a simplified version of some complex formulas (derived by Professor H. B. Dwight of Massachusetts Institute of Technology) used to calculate the resistance to remote earth for a grounding system. The assumption in the general formula is that the resistivity of the soil is constant throughout the considered area, or averaged for the local soil.

In the practical (real) world, soil resistivity is not constant, properties of electrodes and their connections vary (except with CADWELD™), and complex equations just don't cut it. Therefore, an actual measuring technique is necessary. This technique is done with an earth resistance tester, often called a megger. One example of the earth tester is the ERICO EST301Universal Earth System Tester, seen in figure 1, (please refer to the ERICO EST301 Operating Instructions manual for detailed instructions on its use.) This type of instrument can be used at various stages in the life of a grounding system, once during installation to see if it meets all specifications, and anytime thereafter to observe any possible changes.

Figure 1: ERICO EST301 Universal Earth System Tester

3. Earth Electrode Measurement (Single Electrode)

There exists different measuring techniques for resistance to remote earth of a grounding system. One such technique is the 3-pole earth electrode measurement for a single electrode. This technique uses the electrode under test (EUT), a reference probe, and an auxiliary probe, set in a straight line. Figure 2 shows the single electrode measuring method, and figure 3 shows the single electrode measuring setup for the ERICO EST301 earth tester.

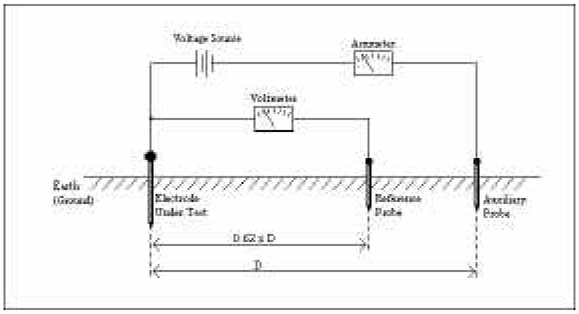

Figure 2: Single Electrode Measuring Method

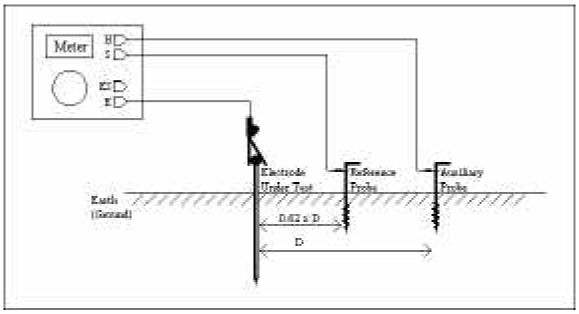

Figure 3: Single Electrode Measurement Setup

After applying a voltage at the designated location in the circuit, the current between the EUT and auxiliary probe is measured, and the voltage between the EUT and the reference probe is measured. Using Ohm's Law, the resistance can now be calculated. This routine is completed by the earth tester. It has been determined that the distance D be approximately 100 feet, and the distance between the EUT and reference probe be 0.62 times the value of D. These values have been tested using the fall of potential method to give optimal results (see figure 4.) But due to the large amounts of uncertainty in all properties of probes and soil, the value of D should be varied for each individual test until reasonably consistent values appear; however, it is recommended that the value of D stay greater than 80 feet. It is also necessary to take a second set of readings at 90^{o} to the original in case of interference from overhead power lines or any underground electrical equipment or metal objects.

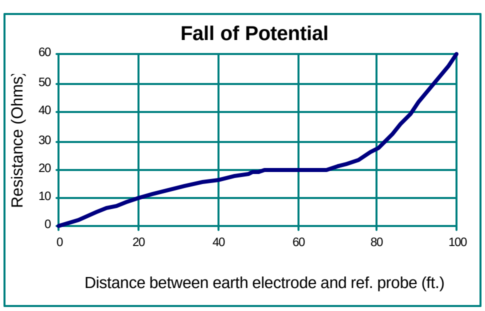

Figure 4: Fall of Potential

4. Earth Electrode Measurement (Multiple Probe System)

A second earthing resistance measuring technique is the process of measuring the resistance to remote earth of a single earth electrode in a multiple electrode grounding system. This technique is used when the earth electrode cannot be disconnected from the rest of the grounding system such as a communication tower installation. When the earth electrode can be disconnected, the previous 3-pole single electrode technique may be used. Caution should always be taken when disconnecting any earth electrode.

The same principles apply to this technique as they did for the single probe technique, the only difference is that for the multiple electrode grounding system, the current is measured with a current transformer around the EUT, (see figures 5 and 6.) After the proper voltage and current values are measured, a simple Ohm's Law equation determines the electrode's resistance to remote earth.

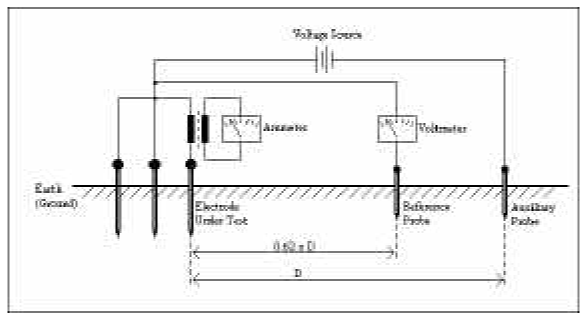

Figure 5: Multiple Electrode Measuring Method

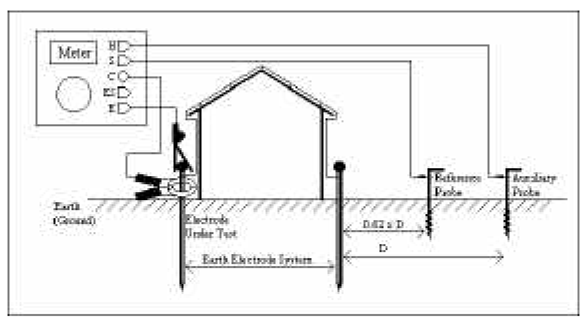

Figure 6: Multiple Electrode Measurement Setup

Once the resistance to remote earth for each electrode in the entire grounding system is determined, one can calculate the resistance to remote earth for the entire grounding system in one of two ways. The first approach is in understanding that the electrodes are in parallel with each other (through the grounding grid and ground itself.) Because they are in parallel, the rule for parallel resistances can be used.

$$R_s = 1 / [(1/R_1) + (1/R_2) + (1/R_3) + \ldots(1/R_n)]$$

where

R_s = *resistance to remote earth for entire grounding system (W)*

$R_{1,2,3\ldots n}$ = *resistance to remote earth for each individual electrode (W)*

However, this rule is not completely accurate in this application because of the extra resistance to remote earth through the grounding grid.

The second approach used to calculate the resistance to remote earth for the entire grounding system assumes that the resistances to remote earth for each electrode are equal. Then, for the entire grounding system, the resistance to remote earth is 40% lower for a system with only two electrodes, 60% lower for a system with three electrodes, and 66% lower for a system with four electrodes (compared to the resistance to remote earth for one of the equal electrodes.) These values are slightly larger than the values given by the parallel resistance rule.

5. Soil Resistivity

The second major factor in determining how well a grounding system performs, is the resistivity of the local soil. Soil resistivity is the resistance measured between two opposing surfaces of a $1m^3$ cube of homogeneous soil material (see figure 7,) usually measured in Ω–m, or Ω–cm. Soil resistivity has a direct effect on the resistance of the grounding system. The evaluation of the resistivity of the local soil can determine the best location, depth, and size of the electrodes in a grounding system, and can also be used for many other applications. A geological survey uses the soil resistivity to locate ore, clay, gravel, etc. beneath the earth's surface. Depth and thickness of bedrock can also be determined. The degree of corrosion of the local soil also can be obtained from its resistivity value. Due to these many reasons, it is necessary to measure the resistivity of the local soil.

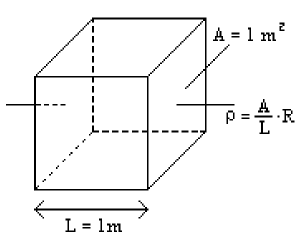

Figure 7: Soil Resistivity Definition Cube

Many different factors have a direct effect on the resistivity of the local soil. A large factor is the type of soil. The resistivity range can go from 1 Ω–cm to the upwards of over 1,000,000 Ω–cm (see figure 8.) Moisture content can be a large factor in determining the resistivity of the local soil. The drier the soil, the higher the resistivity. The soil resistivity remains relatively low (and constant) if the moisture content of the soil is greater than 15% (by weight,) and skyrockets for lower values of moisture content. Another large factor in the determination of soil resistivity is the content of minerals, such as salts or other chemicals. For values of 1% (by weight) salt content, the soil resistivity remains low (and constant,) and skyrockets for lower values of salt content. Finally, compactness and temperature can set the resistivity of the local soil. With temperature, the colder the soil is, the higher the resistivity. Due to seasonal changes where the temperature can change drastically for a particular area, the resistivity of the local soil can also change drastically (see figure 9.) Many of these factors (moisture content, mineral content, compactness, and temperature,) of the local soil can change during the life of the grounding system, and therefore change the resistance to remote earth of that grounding system.

Soil	Resistivity (Ω-cm)	
	lower	upper
Surface Soils	100	5,000
Clay	200	10,000
Sandy Clay	10,000	15,000
Moist Gravel	5,000	70,000
Dry Gravel	70,000	120,000
Limestone	500	1,000,000
Sandstone	2,000	200,000
Granites	90,000	110,000
Concrete	30,000	50,000

Figure 8: Resistivity range for different types of soil

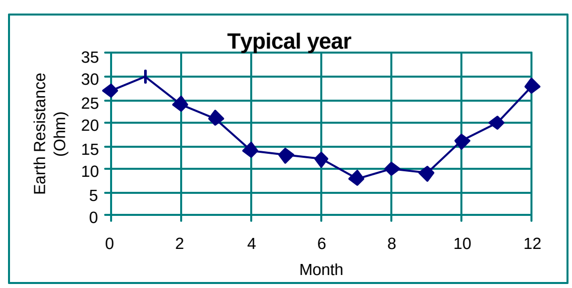

Figure 9: Typical electrode resistance to remote earth in a year

Like the resistance to remote earth of an electrode, measuring the resistivity of the local soil can be done with a specific metering device. The process is sometimes referred to as the four pole (or four-terminal) method (see figures 10 and 11.)

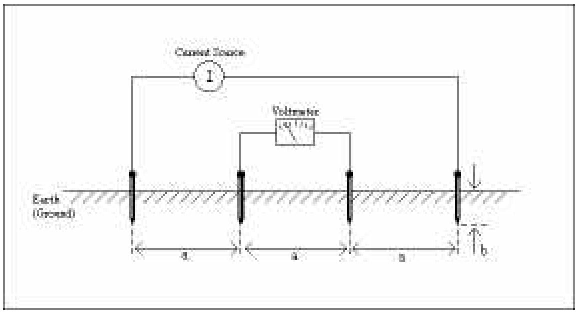

Figure 10: Soil Resistivity – Four Pole Method

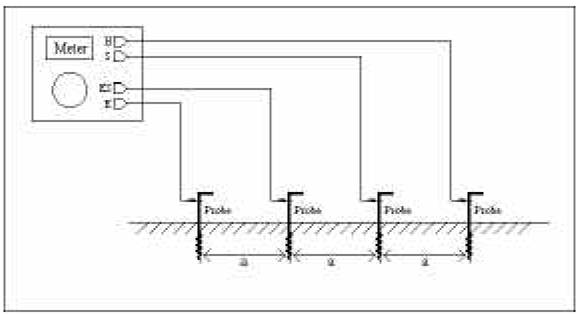

Figure 11: Soil Resistivity – Four Pole Setup

Four small electrodes (auxiliary probes) are placed in a straight line at intervals of a, to a depth of b. A current is passed through the outer two probes, and the potential voltage is then measured between the two inner probes. A simple Ohm's Law equation determines the resistance. From this information, it is now possible to calculate the resistivity of the local soil by using the Equally Spaced (or Wenner Arrangement) method.

$$r = [\, 4 \times p \times a \times R \,] \,/\, [\, 1 + ((2 \times a) / SQRT (a^2 + 4 \times b^2)) - (a / SQRT (a^2 + b^2)) \,]$$

where

r = *resistivity of the local soil (W-cm)*
a = *distance between probes (cm)*
b = *depth of probes into the ground (cm)*
R = *resistance determined by the testing device (W)*

For most practical circumstances, a is twenty times larger than b, where we can then make the assumption that b=0, and the formula becomes simply:

$$r = 2 \times p \times a \times R$$

These values give an average resistivity of the soil to a depth of the value of a. It is recommended that a series of readings be taken at different values of a, as well as in a 90^o turned axis, so that the measuring results are not distorted by any underground pieces of metal (pipes, ground cables, etc.) These final values should be plotted, so that a consistant value be determined.

6. Improving the Grounding System

If it is determined that a grounding systems resistance to remote earth is not low enough, there are several ways that it can be lowered. The first approach would be to lengthen the electrodes, which puts them deeper into the ground. If it is difficult to drive ground rods keep into the ground, a horizontal "crows foot" approach using copper tape, may be used. Another approach would be to use multiple ground rods. The National Electrical Code (NEC 1996) states that if one electrode is being used and it's resistance to remote earth is greater than 25Ω, then only one additional electrode needs to be installed. A final way to help lower the resistance to remote earth for a grounding system, is to treat the soil with some type of ground enhancing material (i.e. GEM™, salt, chemical rod, etc.) The thickness of the electrode used plays only a small part (and it is not very economical) in helping to reduce the total resistance to remote earth of the grounding system.

7. Conclusion

It is important for a facility to have a good grounding system. The safety of all personnel and equipment is at stake. In order to be sure that a good grounding system is in place, it is necessary to maintain a low resistance to remote earth of all the electrodes, and a low resistivity of the local soil. There are different methods for obtaining these measurements. Due to variations in electrodes and soil, a number of measurements should be taken and evaluated for a consistancy.

It is the intent that this paper be used as a guide for descriptions and definitions of different ground measuring techniques for electrode resistance to remote earth and soil resistivity. Detailed instructions on the use of any earth testing device should be fully read and understood before they are used. There always exists the possibility of ground faults in a system, and step and touch potentials. It is important to note that before attempting to test any grounding system, all safety precautions be taken.

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