Tow Layers Soil Resistivity Computation and its Implication on the earth Grid Design

Prepared by:

M. Nassereddine
Abstract:

Performing High Voltage (HV) Works with a multicroft work force creates a special set of safety circumstances. In addition, this paper aims to present vital information to when it is acceptable to use single or two layers soil structure. Also it discusses the implication on the earth grid of the high voltage infrastructure and the safety implication under single or two layers soil structures. A multiple case studies are investigated to show the importance of using the right soil resistivity structure during the earthing system design.

I. INTRODUCTION

High voltage infrastructure necessitates earthing design to warrant the safety and the acquiescence of the system to the confined standards and regulations. Earthing system presents a safe working environment for workers and people passing by during a fault or malfunction of the power system. Soil resistivity structure is one of the main elements that have a burly impact on the design. The change in the soil resistivity structure can pilot to a complex earthing design. By natural, the soil body consists of layers; these layers could be horizontal or vertical. These layers constituents of variable thicknesses, which differ from the parent materials in their texture, structure, consistence, color, chemical, biological and other physical characteristics.

This paper endeavour at presenting a general overview of various ways of determining the soil resistivity structure using the field test data, also it present an overview to when it is acceptable to use single layer or two layers soil structure when it come to earthing design. A case study was conducted and the results are presented.

II. THEORETICAL STUDY

In engineering, soil is referred to as regolith, or loose rock material. Strictly speaking, soil is the depth of regolith that influences and has been influenced by plant roots.

Soil resistivity is a measure of a soil's ability to retard the conduction of an electric current. The electrical resistivity of soil can affect the rate of galvanic corrosion of metallic structures in contact with the soil. Higher moisture content or increased electrolyte concentration can lower the resistivity and increase the conductivity. Soil resistivity values typically range from about 2 to 10000 $\Omega \cdot m$, but more extreme values are not unusual.

Table 1 shows the different type of soil and its typical soil resistivity. It is rare to find an area where it consist of one type of soil, usually the soil structure consist of multiple layers. From a soil resistivity perspective, it is acceptable to use two layers when determining the earth grid assessment.

As the mass of earth play part of any electrical infrastructure, it play the important role in absorbing the fault and malfunction energy of these plants. Soil resistivity structure is the key in this operation, determining the soil resistivity will establish the conductivity of the ground which determines its capability to form an easy path for the fault or malfunction in the electrical system.
Table 1: Typical soil resistivity of various type of soil

<table>
<thead>
<tr>
<th>Type of Soil or water</th>
<th>Typical Resistivity (Ω/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Water</td>
<td>2</td>
</tr>
<tr>
<td>Clay</td>
<td>40</td>
</tr>
<tr>
<td>Ground well and spring water</td>
<td>50</td>
</tr>
<tr>
<td>Clay and Sand mix</td>
<td>100</td>
</tr>
<tr>
<td>Shale, Slates, Sandstone</td>
<td>120</td>
</tr>
<tr>
<td>Peat, Loam and Mud</td>
<td>150</td>
</tr>
<tr>
<td>Lake and Brook Water</td>
<td>250</td>
</tr>
<tr>
<td>Sand</td>
<td>2000</td>
</tr>
<tr>
<td>Morane Gravel</td>
<td>3000</td>
</tr>
<tr>
<td>Ridge Gravel</td>
<td>15000</td>
</tr>
<tr>
<td>Solid granite</td>
<td>25000</td>
</tr>
<tr>
<td>Ice</td>
<td>100000</td>
</tr>
</tbody>
</table>

Resistance is the property of a conductor which opposes electric current flow when a voltage applied as shown in equation 1:

\[ V = I \times R \]  

(1)

Low resistance is known as good conductor and high resistance are known as bad conductor.

The resistance R depends on the resistivity of the conductor (medium) as shown in equation 2:

\[ R = \frac{\rho \times L}{A} \]  

(2)

Where

- \( \rho \) is the resistivity of the conductor (medium)
- L is the length of the conductor
- A is the cross section area

Figure 1 demonstrates the different soil structure that can impact on the electrical design. Based on IEEE 80 standard, 2 layers structure is sufficient for conducting an acceptable design. [1]

- Curve (A) represent homogenous resistivity
- Curve (B) represent low resistance layer overlaying higher resistivity layer
- Curve (C) represent high resistivity between two low resistivity layer
- Curve (D) represents high resistivity layer overlaying a lower resistivity layer
Curve (E) represents low resistivity layer over high resistivity layer with vertical discontinuity

![Figure 1: IEEE 80 soil structure](image)

**Soil Resistivity Structure field Test**

The most three popular methods to perform soil resistivity test are: [2]
- Wenner Method
- Schlumberger Array
- Driven Rod Method

The wenner method is the most popular one due to the following reasons:
- Wenner method is capable of obtaining the data from deeper layers without driving the test pins to those layers
- No heavy equipment is needed to perform this test
- The results are not greatly affected by the resistance of the test pins
- The results are not affected by the holes created by the driving test pins

Figure 2 shows Wenner method arrangement

**Soil Resistivity Structure Computation**

Interpretation and computation of the soil model structure using the measured data is one of the most difficult parts, it is important to derive a soil model analogous to the real one. The most frequently used soil resistivity structures are the uniform model and the two layers model. According to IEEE 80, two layers SRS are often a good approximation of many soil structures. This computation can be achieved manually or by using aided computer software. A uniform SRS should only use if the variation in measured apparent resistivity is low, this have a rare occurrence in practice. If a large variation occur, the uniform soil is unlikely to yield accurate
results. According to IEEE standard, more accurate representation of the actual soil conditions can be obtained by the use of two layers SRS model.

\[
\rho = \frac{\rho_1 + \rho_2 + \ldots + \rho_i}{N_i}
\]

(3)

Where
- \( \rho_i \) is the apparent soil resistivity measured at different distance
- \( N_i \) is the number of soil resistivity test

Another approach was established in determining the uniform soil resistivity as shown in equation 4:

\[
\rho = \frac{\rho_{\text{max}} + \rho_{\text{min}}}{2}
\]

(4)

Where
- \( \rho_{\text{max}} \) is the maximum apparent resistivity value measured
- \( \rho_{\text{min}} \) is the minimum apparent resistivity value measured

It is not recommended the use of equation 4 for a ground grid without ground rods

The characteristics determination of the 2 soil layer soil structure is more complicated, the two layers soil model can be approximate by using graphical methods described in Sunde’s chart, figure 3 illustrate the chart.

The two layers structure consists of the characteristics shown in table 2:
Table 2: Two layers soil resistivity

<table>
<thead>
<tr>
<th>Layers Number</th>
<th>Resistivity (Ohm.m)</th>
<th>Thickness of layers (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\rho_1$</td>
<td>$H$</td>
</tr>
<tr>
<td>2</td>
<td>$\rho_2$</td>
<td>Infinite</td>
</tr>
</tbody>
</table>

SRS and Earthing Design

Fine interpretation of the soil structure is very important to ease the earthing design, and achieve the adequate design with low cost. For example, if high soil resistivity presented on top and low resistivity on bottom, it is effective to drive the electrode to reach the low resistance layer. During the homogenous resistivity approach, the entire earthing system will be exposed to one type of soil resistivity; this could lead to error especially if the change in soil layers resistivity is large. Also the safety compliance assessment will use the average computed soil value; this could be deviated from the actual top soil value.
During the two layer approach, the electrode will be exposed to different soil resistivity which represents more realistic approach, also the safety assessment will address the top layer resistivity which in its turn represent more practical situation. Understanding the soil layers resistivity support the designer in determining the type of earth grid that yield to adequate solution, bellow is couple of cases under different soil structures:

- Low resistance layer overlaying higher resistivity layer, mesh grid have better influent than driving electrodes into the high resistivity layer
- High resistivity layer overlaying a lower resistivity layer, deep electrode to reach the lower resistivity layer will enhance the performance of the earth grid

There is little available software that can be used to compute the soil resistivity structure using the field test, CDEGS is one of these softwares, figure 4 shows an output computation for a field test using RESEP in CDEGS engineering software, it details the depth, the upper layer and the bottom layer of the soil structure, CDEGS follow IEEE procedures.

When using two layers soil structure to determine the grid resistance, it is important to determine the reflection factor K, equation 5 shows the computation of the reflection K

\[ K = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1} \]  

(5)

Where

- \( \rho_2 \) is the bottom layer soil resistivity
- \( \rho_1 \) is the top layer soil resistivity

The earth grid consist of single electrode, multiple electrodes, mesh grid or combination of mesh and electrodes. Two types of formulas exist to compute the earth grid:

- Formulas for single layer soil structure. [3] contain information in regards these equations
- Formulas for two layers soil structure. These formulas are shown bellow

As conversed earlier, soil structure consists of multiple layers. For several soil structures, in order to yield an acceptable design, two layers shall be used throughout the earth grid resistance calculation. Applying two layers soil structure during the earth grid calculation could be concluded using two methods:

- Calculate an apparent soil resistivity that can be used in the same equations mentioned in [4], the apparent soil resistivity utilise the characteristics of the two layers structure as shown in equations 6 and 7
- Calculate the earth grid resistance using equations 8 to 13

For the first method, there are two formulas as shown bellow:

For a negative reflection coefficient K
\[ \rho_a = \frac{\rho_1}{1 + \left( \frac{\rho_1}{\rho_2} - 1 \right) \times \left( 1 - e^{-\frac{-1}{4(d+2h)}} \right)} \]  

(6)

For a positive reflection coefficient K

\[ \rho_a = \rho_2 \left( 1 + \left( \frac{\rho_2}{\rho_1} - 1 \right) \times \left( 1 - e^{\frac{-1}{4(d+2h)}} \right) \right) \]  

(7)

Where

- \( d \) is the depth of the top layer
- \( h \) is the grid depth

The calculated apparent soil resistivity will be applied in the single layer equations when determining the grid resistance.

For the second method, the calculation is divided into three types:

- Mesh Grid calculations
- Electrode calculations
- Combination of mesh and electrodes

This paper discusses the electrodes calculation process.

\[ R_1 \] represents the resistance related to the top layer, \( R_2 \) represents the resistance related to the bottom layer

\[ R_1 = \frac{\rho_1}{h - h_g} g_0 \frac{F}{N} + \frac{\rho_1}{h} \phi \]  

(8)

\[ R_2 = \frac{\rho_2}{l + h_g - h} g_0 \frac{F}{N} \]  

(9)

The total resistance can be found by considering \( R_1 \) is parallel to \( R_2 \)

Where

- \( g_0 \) is a function can be found using equation
- \( a \) is the radius of the driven rod
- \( h_g \) is the depth of the grid from the ground level
- \( h \) is the depth of the top layer
- \( F \) is the factor for the N rods, can be found using equation
- \( l \) is the length of the electrode
- \( \phi \) is a function as shown in equation
\[
g_o = \frac{1}{2\pi} \left[ \ln \frac{2l}{a} - 1 + \ln \frac{2}{(4\ln 2)h_k} \right] \\
F = 1 - \left( N - \frac{1}{\sqrt{N}} \right) \frac{R_j}{R_i} \\
\phi = \frac{1}{2\pi} \left( \ln \frac{1}{1 - k} \right) \\
\sqrt{\left( \frac{N}{F} - 1 \right) \left( \frac{l + h_k}{h} \right)^2 + 1} \\
\frac{R_s}{R_j} = \sqrt{l} \left( 0.5^3 + \left( \frac{l}{l + 0.5r} \right)^3 \right)^{\frac{1}{3}} \\
\]

Figure 4: CDEGS computation of the SRS

Figure 5 represents the earth potential rise for 5 case studies, the EPR under two layers represent more practical case, it is clearly shown that in case studies number 1, 3 and 5, the use of uniform
soil structure will lead to unsafe condition. Case study 2, the use of uniform soil will lead to over engineering for the earth grid design.

III. CONCLUSION

This paper highlights the importance of using two layer soil structures when it comes to determine the earth grid resistance and EPR. In the five case studies, only in case study number 5, apparent soil resistivity method can be approved. Using apparent soil structure in cases 1, 3 and 5 will lead to more expensive system, using the apparent soil structure in case study 2, leads to non compliance system.

Also it shows that apparent soil resistivity structure can be used when small deviation occur in the field test data as illustrated in case study number 4

References