

Factors Affecting the Apparent Soil Resistivity of Multi-Layer Soil

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Abstract: The accuracy of power system grounding analysis is critically dependent on the actual resistivity of local surrounding system. In this paper the factors affecting the apparent soil resistivity of multilayer soil are investigated. Such these factors are:-

- (1) The number of layers of soil structure (double and three layers are considered in this paper) and their arrangement.
- (2) The thickness of each layer.
- (3) The reflection factor between each layer.

The studies are done for different types of soil such as clay, sand and rocks, different formulas are used. An experimental model is used in the laboratory to study experimentally the effect of the above factors on apparent soil resistivity. A scaling factor is used into consideration due to the differences between model measurements. These differences are:-

- i- The layers thickness.
- ii- The distances between the electrodes used in testing.
- iii- The compactness between soil grains in the field is more than that in the laboratory.

The obtained experimental result are compared with the calculated values and also with the results obtained by the others.

Key Words: Soil resistivity; Apparent soil resistivity; Multilayer; Reflection factor

INTRODUCTION

To design the most economical grounding systems for large substations it is necessary to obtain accurate value of the resistivity on the site. The soil at the most sites is non-uniform. Different methods are used to compute the apparent resistivity of multi-layer soil structure and compared to actual measurement^[1-4]. IEEE suggested formula to calculate the apparent soil resistivity seen by the earthing system, in case of there are two layer soil environment with upper layers thickness H, in which ground rods penetrate the more conductive lower layer, that is for $\rho_1 > \rho_2$ where the grid is buried in the upper layer ρ_1 but the ground rods are partly in ρ_2 and partly in ρ_1 ^[2].

In this paper different soil structures are characterized by the following:

- i. Double layers soil characterized by first layer of resistivity ρ_1 has thickness h and second layer resistivity of ρ_2 with infinite thickness
- ii. Multilayer soil structure (three layers structure or more) characterized by first layer resistivity of ρ_1 with thickness h, second layer of resistivity ρ_2 has a thickness of h' and third layer of resistivity ρ_3 with infinite thickness

FACTORS AFFECTING THE APPARENT SOIL RESISTIVITY

Many factors affecting the apparent soil resistivity and the ground resistance seen by the grounding system. In this paper the factors affecting the apparent soil resistivity of multilayer soil are investigated. The grounding system taken as an example in calculating the resistance seen by the ground contains 50mX50m grid of 300 meter total length and eight 10 meter driven rods.

I. Double Layer Case

In this study two layer soil environment with upper layer thickness H in which ground rods penetrate the more conductive lower layer, In such case where $\rho_1 > \rho_2$ and the grid is buried in the upper layer ρ_1 , but the ground rods are partly in ρ_2 and partly in ρ_1 the apparent soil resistivity ρ_a could be calculated by the relation^[1]

$$\rho_a = l_2(\rho_1 \cdot \rho_2) / (\rho_2(H - h) + \rho_1(l_2 + h - H)) \quad (1)$$

Where l_2 is the average value of rod length, ρ_1 and ρ_2 are the soil resistivity of upper and lower layers and H is the thickness of upper layer. According to IEEE^[1,5] the ground resistance of rods and the mutual resistance between the grid and rods are calculated with the use of an apparent soil resistivity. Fig(1,2) shows the relation between the upper layer thickness and the apparent soil resistivity, rods resistance (R_2), mutual resistance (R_{12}) between the grid and rods and the grounding system resistance (R_{total}).

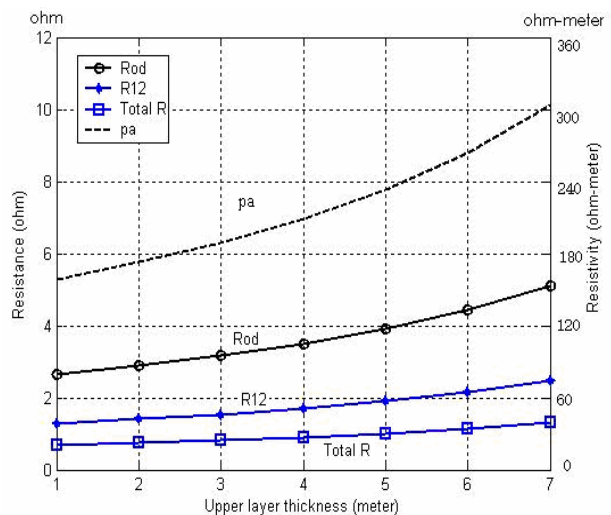


Fig.(1) Relation between upper layer thickness, the apparent soil resistivity, rods resistance, mutual resistance and the grounding system resistance ($\rho_1=600, \rho_2=150 \Omega.m$)

From this figure it is noticed that increasing the upper

layer thickness from 1 to 7 meter increases the apparent soil resistivity, rods resistance, mutual resistance between the rods and connecting grid and the grounding system resistance in case of $\rho_1 > \rho_2$ by 90%

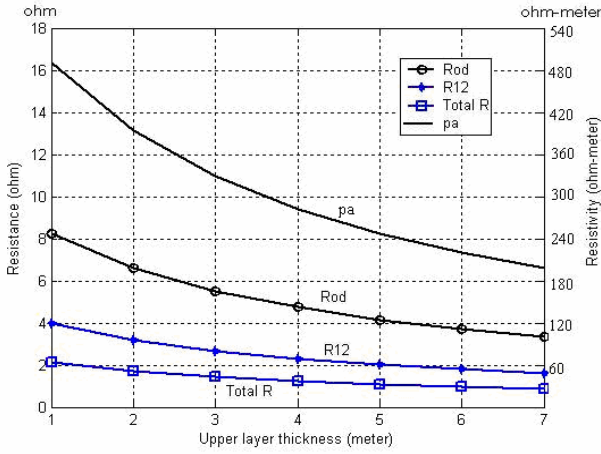


Fig.(2) Relation between upper layer thickness and the apparent soil resistivity, rods resistance, mutual resistance and the grounding system resistance ($\rho_1=150, \rho_2=600 \Omega.m$)

In case of $\rho_1 < \rho_2$ increasing the upper layer thickness from 1 to 7 meter reduces the apparent soil resistivity, rods resistance, mutual resistance between the rods and connecting grid and the grounding system resistance in case of $\rho_1 > \rho_2$ by 60%.

To investigate the effect of the reflection factor on the apparent soil resistivity, rods resistance, mutual resistance and grounding system resistance, the value of ρ_1 / ρ_2 is changed between 5 and 0.2 and the reflection factor k is calculated according to relation

$$K = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1} \quad (2)$$

Fig.(3) shows the relation between the reflection factor and the apparent soil resistivity, rods resistance, mutual resistance between the grid and rods, also the ground resistance seen by the grounding system, these values are calculated according to IEEE^[7].

$$R_1 = \left(\frac{\rho_1}{\pi l_1} \right) \left(\ln \left(\frac{2l_1}{h} \right) + k_1 \left(\frac{l_1}{\sqrt{A}} \right) - k_2 \right) \quad (3)$$

$$R_2 = \left(\frac{\rho_a}{2n\pi l_2} \right) \cdot \left(\ln \left(\frac{8l_2}{d_2} \right) - 1 + 2k_1 \left(\frac{l_2}{\sqrt{A}} \right) \cdot (\sqrt{n} - 1)^2 \right) \quad (4)$$

$$R_{12} = \left(\frac{\rho_a}{\pi l_1} \right) \left(\ln \left(\frac{2l_1}{l_2} \right) + k_1 \left(\frac{l_1}{\sqrt{A}} \right) - k_2 + 1 \right) \quad (5)$$

$$R_g = \frac{R_1 R_2 - R_{12}^2}{R_1 + R_2 - 2R_{12}} \quad (6)$$

Where R_1 and R_2 are resistance of all ground rods and grid conductors respectively and R_{12} is the mutual resistance between the group of grid conductors and group of ground rods, n =number of ground rods placed

in parallel in area A, d_2 is the diameter of the driven rods in meter, A = area covered by the rods in m^2 , K_1, K_2 are constants related to the geometry of the system and could be calculated from the relations where X is length to width ratio

$$K_1 = 1.41 - (0.04) \cdot X \quad (7)$$

$$K_2 = 5.5 + (0.15) \cdot X \quad (8)$$

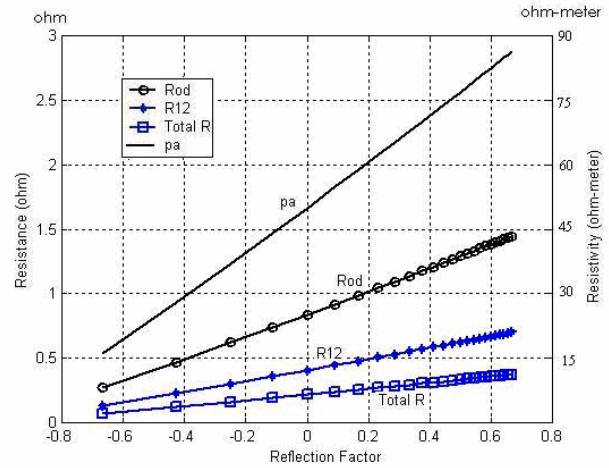


Fig.(3) Relation between reflection factor and the apparent soil resistivity, rods resistance, mutual resistance and the grounding system resistance ($\rho_1=50, \rho_2=10$ to $250 \Omega.m, H=5m$)

From this figure it is noticed that increasing the reflection factor from -0.7 to 0.7 increases the apparent soil resistivity, rods resistance, mutual resistance between the rods and connecting grid and the grounding system resistance by 500%.

To study the effect of depth of laying of grid on the ground to apparent soil resistivity, mutual resistance and rods resistance. The laying depth of the grid is changed between 0 and 1.5 m. Fig.(4) shows the relation between the ground resistance, apparent soil resistivity, the mutual resistance and rods resistance and the laying depth of the grid.

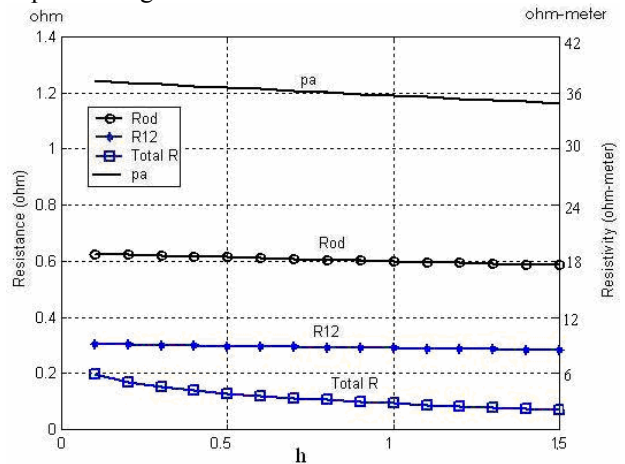


Fig.(4) Relation between depth of laying of grid and the apparent soil resistivity, rods resistance, mutual resistance and the grounding system resistance ($\rho_1=50, \rho_2=30 \Omega.m$)

From this figure it is noticed that increasing the depth of laying grid slightly change rod resistance and mutual resistance but it make enormous reduction to the total resistance of ground system 64% (from 0.196 Ω to .069 Ω) and also reduces the apparent soil resistivity seen by the grounding system by 7%

II. Multi-layer Case

In the analysis carried out in this paper any number of layers could be reduced to two layers. As example in 3-layers, two layers will be reduced to one layer as follows:

Evaluating initial apparent soil resistivity between first and second layer represented by ρ_{12} could be calculated by the relation^[8-11]

$$\rho_{12} = 2(\rho_2 - (\rho_2 - \rho_1) \cdot e^{-js}) - (\rho_2 - (\rho_2 - \rho_1) \cdot e^{-2js}) \quad (9)$$

$$\text{Where } J = \frac{\delta}{2H}, \delta = \frac{\ln(\rho_1 / \rho_2) - \ln(0.0176)}{3.5}$$

ρ_1 and ρ_2 are the resistivity of first and second layer respectively, s is the space between probe electrodes of measuring the soil resistivity and H is thickness of first layer.

From the experimental work done by the authors it is found that the best space between electrodes is between 10m to 15m as given in Fig.(5)

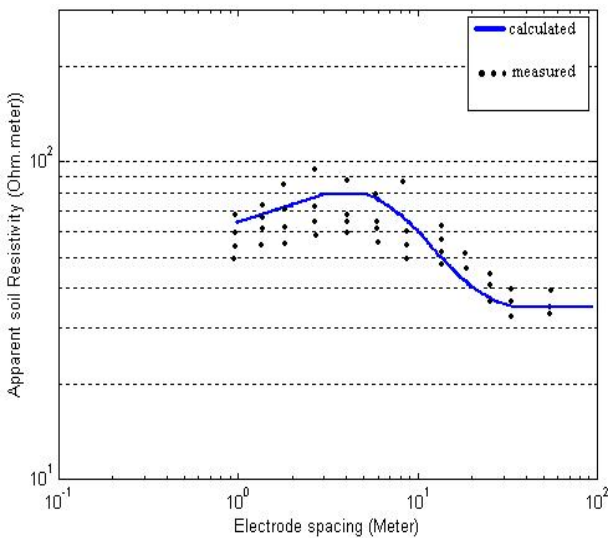


Fig.(5). Soil resistivity of three layer soil

To obtain the apparent soil resistivity of the three layers consider ρ_{12} is resistivity of one layer and then obtain the total apparent soil resistivity

$$\rho_a = l_2(\rho_{12} \cdot \rho_3) / (\rho_3(H' - h) + \rho_{12}(l_2 + h - H')) \quad (10)$$

Where H' is the thickness of first and second layers. The relation between the reflection factors and apparent soil resistivity, grid resistance, mutual resistance and rods resistance is given in Fig.(6). The reflection factor is defined in this case as

$$K' = \frac{\rho_3 - \rho_{12}}{\rho_3 + \rho_{12}} \quad (11)$$

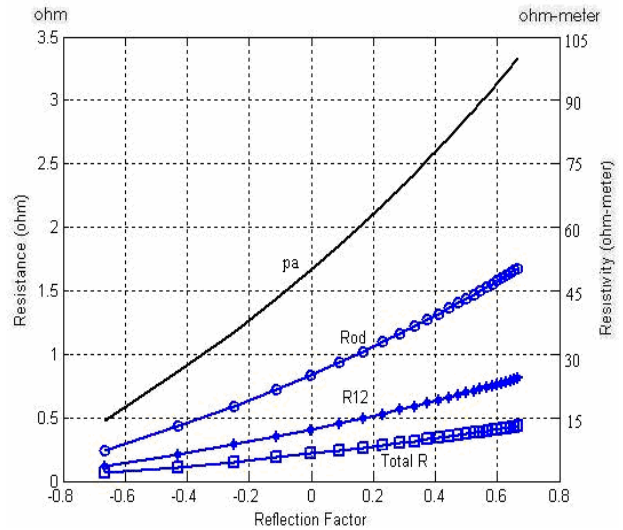


Fig.(6) Relation between reflection factor and the apparent soil resistivity, rods resistance, mutual resistance and the grounding system resistance ($\rho_1=60, \rho_2=50, \rho_3=10$ to $250 \Omega.m, H=2, H'=4$)

From this figure it is noticed that there are proportional relation between reflection factor and the apparent soil resistivity, rods resistance, mutual resistance between the grid and rods and the grounding system.

Changing the reflection factor from -0.7 to 0 increase the apparent soil resistivity by 300% and changing the reflection factor from 0 to 0.7 increase the apparent soil resistivity by 200%

Similar relation is obtained between grid depth in first layer and apparent soil resistivity, grid resistance, mutual resistance and rods resistance, Fig.(7) shows this relation

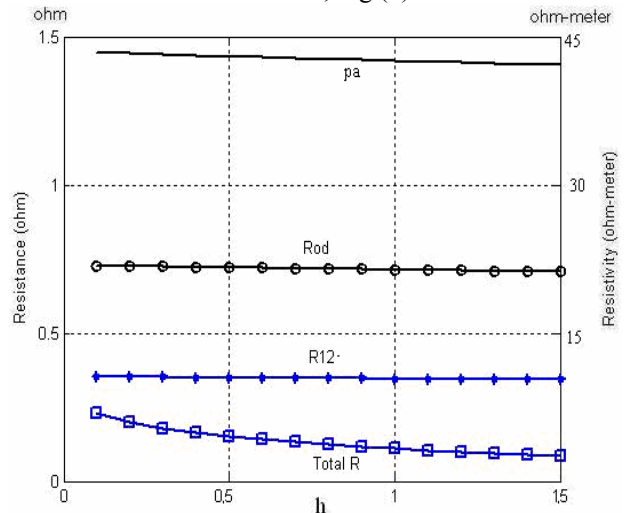


Fig.(7) Relation between depth of laying of grid and R_2, R_{12}, R_{total} and ρ_a ($\rho_1=60, \rho_2=50, \rho_3=40 \Omega.m, H=2, H'=4$)

From this figure it is noticed that increasing the depth of laying grid slightly changes rod resistance and mutual resistance but it makes enormous reduction to the total

resistance of ground system 64% (from 0.228 Ω to .083 Ω) and also reduces the apparent soil resistivity seen by the grounding system by 3%

CONCLUSIONS

- (1) There are proportional relation between apparent soil resistivity and upper layer thickness in case of $\rho_1 > \rho_2$ and the relation become inverse proportional in case of $\rho_1 < \rho_2$.
- (2) Increasing the depth of buried grid reduces the total ground system resistance by 64% and slightly affect the apparent resistance.
- (3) Change in reflection factor affects the apparent soil resistivity especially when it changes from negative to positive value for 3 layer soil.
- (4) Apparent soil calculated and measured are very close to each other.

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