Potential Distribution on the Surface of Multi-Layer Earth Structure

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Abstract — In this paper the software packages OPERA-2d and CDEGS have been used in order to simulate grounding systems. Moreover the potential distribution in the soil around a driven rod is computed by using analytical equations. The comparison of the results acquired both from the equations and the simulation demonstrates the influence of the earth structure to the potential distribution on the surface of the earth. In addition the effectiveness of the simulation methods is proved.

I. Potential Distribution On Soil Surface

Assuming homogenous and isotropic soil, the potential at any point on the surface at a distance x from the current source is given by the formula [1]:

$$V_o(x) = \frac{\rho_o \cdot I}{2 \cdot \pi} \int_0^{\infty} e^{-\lambda \cdot |z|} \cdot \mathrm{J}_o(\lambda \cdot x) \cdot \partial\lambda \tag{1}$$

where J_o is the Bessel function of the first kind of zero order. However, the soil is almost always non-homogenous [2]. Tagg [1] proposed a model of a two-layer soil consisting of a surface layer of resistivity ρ_1 of thickness h_1 overlaying a second layer of resistivity ρ_2. The potential due to a current flow at a point on the surface is given by the equation [1]:

$$V(x) = \frac{\rho_1 \cdot I}{2 \cdot \pi \cdot x} \cdot [1 + 2 \cdot x \cdot \int_0^{\infty} \frac{k_1 \cdot e^{-2 \cdot \lambda \cdot h}}{1 - k_1 \cdot e^{-2 \cdot \lambda \cdot h}} J_o(\lambda \cdot x) \cdot \partial\lambda] \tag{2}$$

k_1 is the coefficient of reflection given by: $k_1 = \dfrac{\rho_2 - \rho_1}{\rho_2 + \rho_1}$.

Takahashi and Kawase [3] have developed a method for the calculation of the surface potential considering a multi-layer structure for the earth. According to their model the potential at any point x on the earth surface for an injected current I is described by the following equations [3]:

$$V_N(x) = \frac{\rho_1 \cdot I}{2 \cdot \pi \cdot x} \cdot [1 + 2 \cdot x \cdot \int_0^{\infty} \frac{K_{N1} \cdot e^{-2 \cdot \lambda \cdot h_1}}{1 - K_{N1} \cdot e^{-2 \cdot \lambda \cdot h_1}} J_o(\lambda \cdot x) \cdot \partial\lambda] \tag{3}$$

For $1<i<N$-1 the coefficient of reflection k_i for two sequential layers is given by the formula: $k_i = \dfrac{\rho_{i+1} - \rho_i}{\rho_{i+1} + \rho_i}$.

Additionally, for $N>2$ and $1<S<N$-2 the factor K_{NS} is given by: $K_{NS} = \dfrac{k_S + K_{NS+1} \cdot e^{-2 \cdot \lambda \cdot h_{S+1}}}{1 + k_S \cdot K_{NS+1} \cdot e^{-2 \cdot \lambda \cdot h_{S+1}}}$ and $K_{NN-1} = k_{N-1}$.

II. Simulation

Grounding systems consisting of a 1m single driven rod buried in different soil types are simulated by using the software packages PC Opera and CDEGS. The obtained results are compared with results from the application of equations: a) (1), considering that the soil is homogeneous and its resistivity is equal to the average resistivity ρ, b) (2), considering that the soil has two layers with parameters ρ_1, and h_1 for the first layer and ρ_2 for the second layer, these parameters have been estimated by using the genetic algorithm developed in [2] c) (3), considering a multi-layer earth structure The variation of the surface potential versus the horizontal distance from the rod for one of the examined grounding systems is shown in Fig. 1. For this case the values of the soil parameters for each equation are:

a) $\rho = 240\ \Omega \cdot m$,

b) $\rho_1 = 135\ \Omega \cdot m$, $h_1 = 1.5m$, $\rho_2 = 2000\ \Omega \cdot m$,

c) $\rho_1 = 100\ \Omega \cdot m$, $h_1 = 2m$, $\rho_2 = 500\ \Omega \cdot m$, $h_2 = 2m$, $\rho_3 = 800\ \Omega \cdot m$, $h_3 = 2m$, $\rho_4 = 1000\ \Omega \cdot m$.

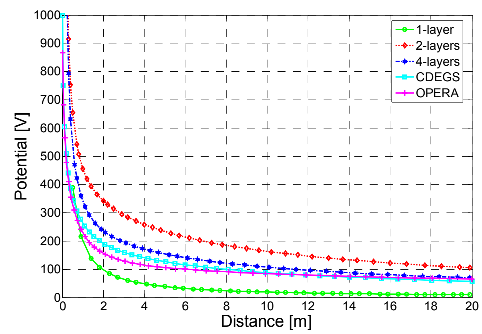

Fig. 1. The variation of surface potential versus the horizontal distance from the rod

III. Conclusions

The non-uniformity of the soil must be taken into consideration during the design of a grounding system. Thus the non-uniformity of the soil greatly affects the potential distribution on the surface of the earth.

The usage of simulation packages can provide valuable assistance to the estimation of the surface potential developed on the ground, regardless of the grounding system's geometry, considering the fact that the closed-form mathematical formulae for multi-layer analysis are subjected to limitations (they can be used only for point, vertical or horizontal electrodes). Moreover, the simulation results are in good agreement with the results obtained by (3).

IV. References

[1] G. F. Tagg, *Earth resistances*, George Newnes Limited, London, 1964.

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[3] T. Takahashi and T. Kawase, "Analysis of apparent resistivity in a multi-layer earth structure", *IEEE Transactions on Power Delivery*, vol. 5, No. 2, April 1990, pp. 604-612.