Influence of the Soil Non-uniformity to the Potential Distribution around a Driven Rod

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Abstract: - The computation of the potential distribution in the soil around a driven rod using the Finite Element Method is described in this paper. Two dimensional Finite Element Analysis is used for the computation of the grounding system electric field using the software package OPERA-2d.

Key-Words: - Finite Element Method, OPERA-2d, grounding system, non-uniform soil, potential distribution

1. Introduction

Grounding systems are one of the most important parts of building constructions. The resistance of grounding systems has an essential influence on the building protection. The grounding systems serve multiple purposes. As it is stated in ANSI/IEEE [1] a safe grounding design has two objectives:

- To provide means to carry electric currents into the earth under normal and fault conditions, without exceeding any operating and equipment limits or adversely affecting continuity of service.
- To assure that a person in the vicinity of grounded facilities is not exposed to the danger of critical electric shock.

Grounding systems can consist of one or more vertical or horizontal ground rods, three or more vertical ground rods connected to each other and to all equipment frames, neutrals and structures that are to be grounded. Such a system that combines a horizontal grid and a number of vertical driven rods penetrating lower soil layers has several advantages in comparison to a grid alone. Sufficiently long ground rods stabilize the performance of such a combined system making it less dependent on seasonal and weather variations of soil resistivity. Rods are more efficient in dissipating fault currents because the upper soil layer usually has a higher resistivity than the lower layers. The current in the ground rods is discharged mainly in the lower portion of the rods. Therefore, the touch and step voltages are significantly reduced compared to that of the grid alone.

The analysis of grounding systems subjected to lightning impulse current is complicated; several works are devoted to the subject. Sunde [2] many years ago studied the transient response of grounding structures. Bellaschi et al. [3-5] have given an extensive treatment of driven rods characteristics. The analysis of Gupta [6] is based on empirical results, but som newer approaches are analytical. Mukhedkar et al. [7-9] have developed a model based on circuit theory, Meliopoulos et al. [10-11] and Menter et al. [12] one based on transmission line modelling. More recently, a formulation derived from a full set of Maxwell's equations has been used by Grecv et al. [13-15] and Dawalibi et al. [15-17]. This last approach is relatively rigorous and greatly surpasses the limitations of the previous simplified theories, but is very complicated in use.

2. Software package

OPERA-2d is a suite of programs for 2-dimensiona1 electromagnetic field ana1ysis. The programs use the finite element method to solve the partia1 differentia1 equations (Poisson's, Helmholtz, and Diffusion equations) that describe the behaviour of fields [18].

The solution of these equations is an essential part of designing in several areas: Electrostatics, Magnetostatics and time-varying low frequency magnetic fields. The ability to model non-linear materials is essentia1 to these applications.

The software uses the Finite Element Method (F.E.M.). Since much information is required before the analysis has been be performed, data entry is carried out using a powerful interactive pre-processor. Using the graphica1 interaction within the pre-processor, the space is divided into a contiguous set of triangular elements. The physica1 model may be described in cartesian or cylindrical polar (axi-symmetric) coordinates.

Once the model has been prepared, the solution is achieved using a suitable ana1ysis module. Several modules exist for analysis of the different types of electromagnetic excitation conditions, e.g. static, transient, steady state. The ana1ysis program iteratively determines the correct solution, including non-linear parameters if these are modelled [18].

The result may then be examined using a versatile interactive postprocessor. As with the pre-processor, this is predominantly control1ed by interaction through a graphica1 menu system. Many system variables are available for examination, including potentia1s, currents, fields, forces, temperature. Numerical errors due to non-successful mesh definition are a1so ana1ysed, so that the mesh can be refined to achieve the required accuracy [18].

Finite Element Analysis is the most widely used numerical method for transient and steady state solutions of two and three-dimensional electromagnetic problems. The enormous capabilities of this technique are largely due to considerable advances in computers. Maxwell's equations form the basis of the two-dimensional and three dimensional Finite Element Analysis codes, by taking into account the equation describing the electric scalar potential V

$$\nabla \cdot e \nabla V = -r \ ,$$

where *ñ* is the charge density and *å* is the permittivity.

3. Simulation

The grounding system, which is simulated in this paper, is shown in Fig.1. It consists of a driven rod with a length of 1m. The soil is separated into three cylindrical regions. The inner one is a cylinder with an 1m diameter and a 2m height. The driven rod is placed in region I (into the centre of the circle of the base of the cylinder). The region II, middle cylinder, has a 5m diameter and a 5m height. The region III, i.e. the external cylinder, has a 10m diameter and a 10m height. The arrangement is axi-symmetric, for this reason it is shown in Fig.1 only the half of it.

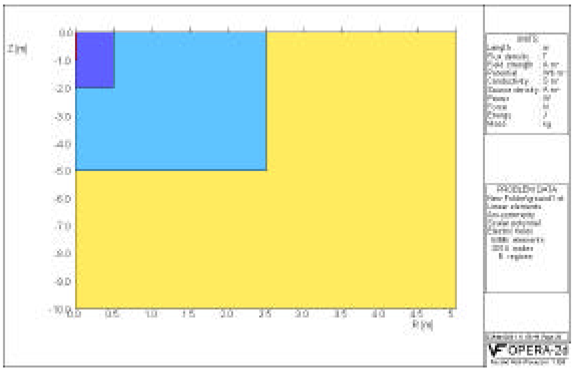

Fig.1. Geometry of grounding system.

In this paper the geometrical arrangement is considered with three different soil parameters. Firstly, a specific conductivity of $0.01\,(\Omega m)^{-1}$ is corresponding to a relative permittivity of 36 ("wet soil") [10, 14, 17]. Secondly, a specific conductivity of $0.001\,(\Omega m)^{-1}$ is corresponding to a relative permittivity of 9 ("dry soil") [10, 14, 17]. And thirdly, a specific conductivity of $0.025\,(\Omega m)^{-1}$ is corresponding to a relative permittivity of 25. The relative permittivities of soil e , of the three investigated cases (A,B and C) for each region are shown in Table 1.

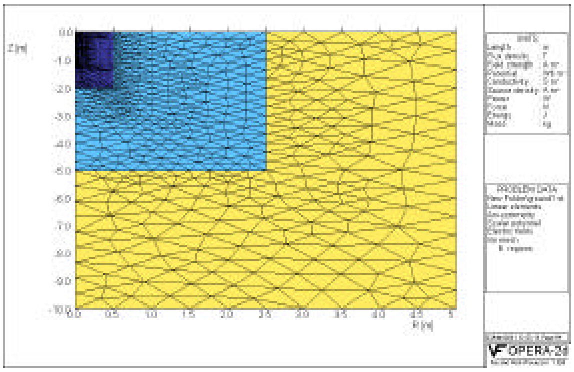

Fig.2. Mesh within the background region.

Fig.2 displays the mesh within the examined regions. The mesh includes 3323 nodes and 6394 triangular elements.

Table 1. Soil permittivity

Case	e_1	e_2	e_3
A	36	25	9
B	36	9	36
C	36	36	9

The density of the equipotential lines in the soil for the case A is shown in Fig.3. The respectively filled zone contour of the potential is shown in Fig.4.

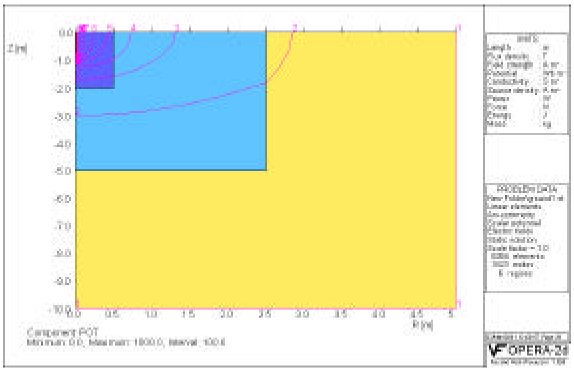

Fig.3. Equipotential lines

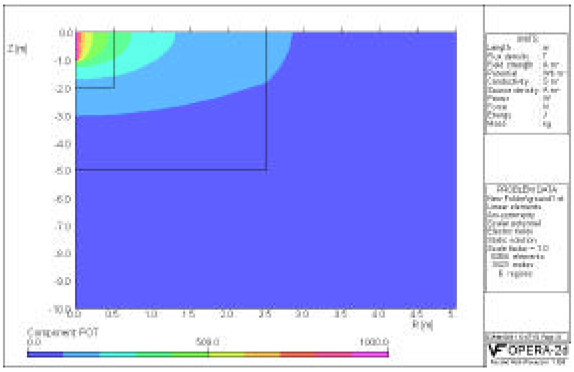

Fig.4. Filled zone contours of potential

The variation of the potential in various directions are shown in Figs.5-7 for case A, Figs.8-10 for case B and Figs.11-13 for case C.

In Fig.5, Fig.8 and Fig.11 is shown the variation of potential versus the horizontal distance from the driven rod for various depths (at 0m, i.e. the surface potential variation, at 75 cm and at 1.5m).

In Fig.6, Fig.9 and Fig.12 is shown the potential upon the depth from the earth surface for various distances from the driven rod (0m, i.e. along the driven rod axis, 75 cm and 1.5m respectively).

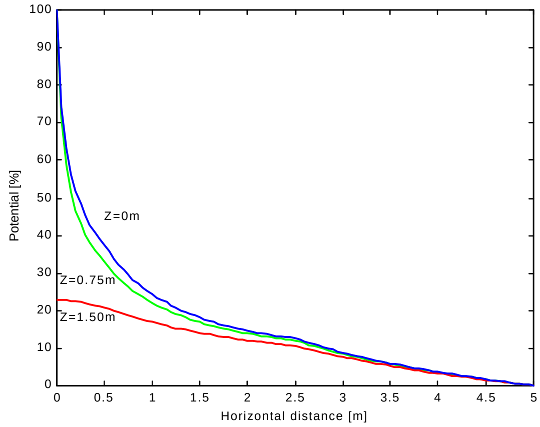

Fig.5 Potential vs. horizontal distance (case A)

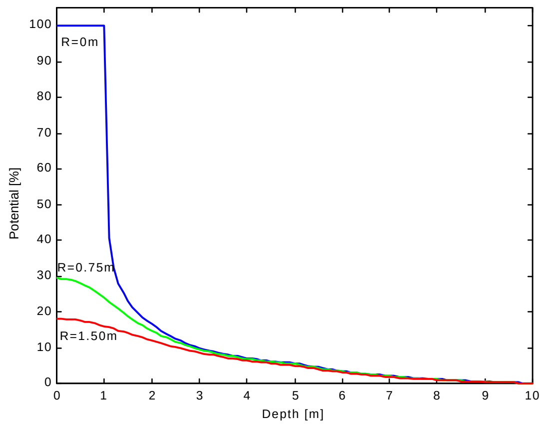

Fig.6 Potential vs. depth (case A)

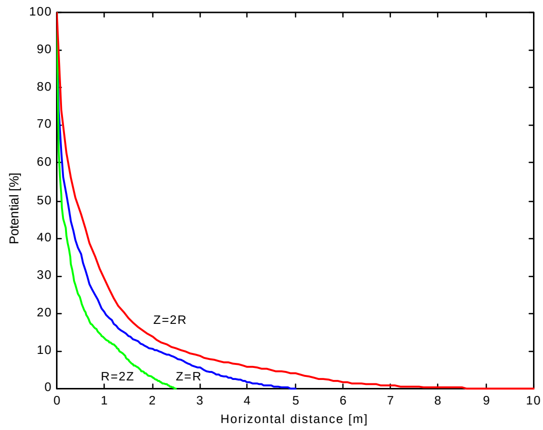

Fig.7 Potential vs. diagonal distance (case A)

In Fig.7, Fig.10 and Fig.13 is shown the potential versus the diagonal distance from the point (0,0) for three cases (along the lines characterized by the equations Z=2R, Z=R, and Z=R/2 respectively).

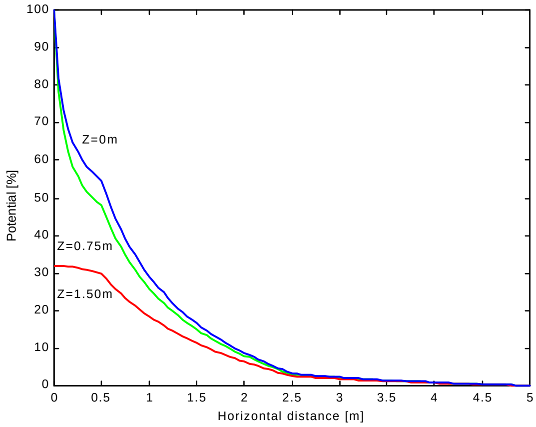

Fig.8 Potential vs. horizontal distance (case B)

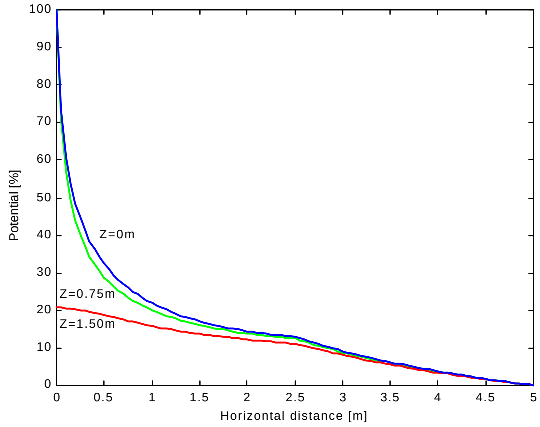

Fig.11 Potential vs. horizontal distance (case C)

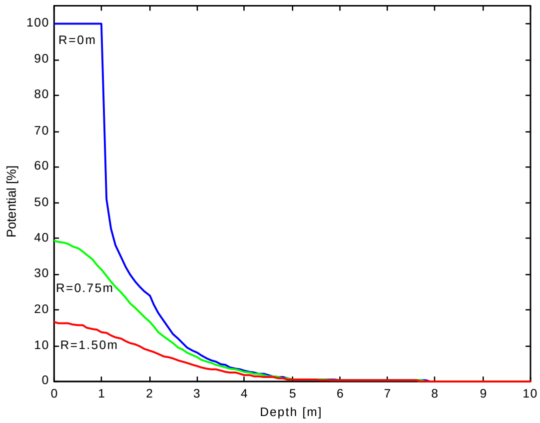

Fig.9 Potential vs. depth (case B)

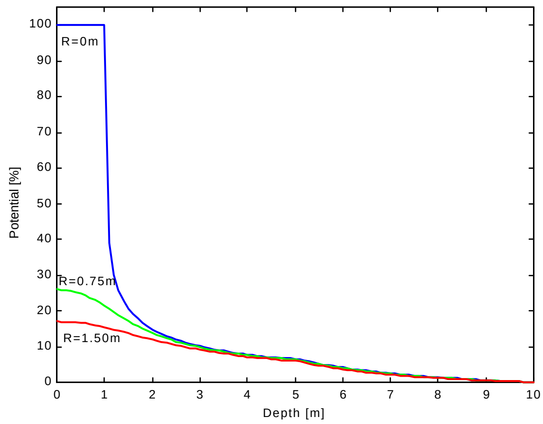

Fig.12 Potential vs. depth (case C)

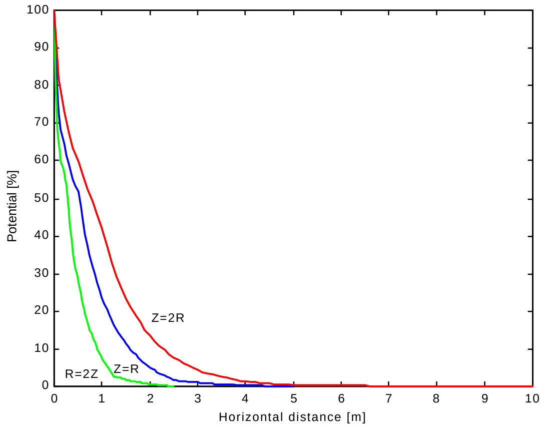

Fig.10 Potential vs. diagonal distance (case B)

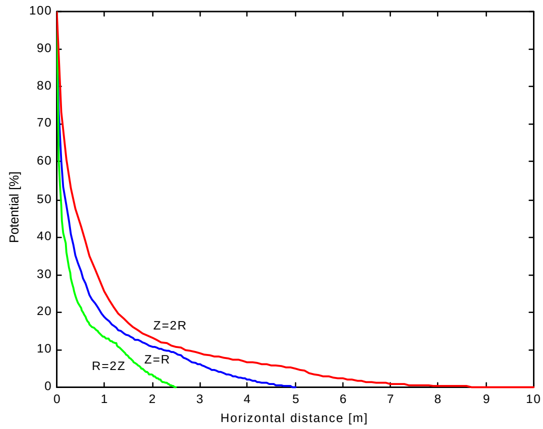

Fig.13 Potential vs. diagonal distance (case C)

In Figs.5, 6 and 7 it is shown that in the first region, the earth surface potential decreases slowly as the distance increases because the conductivity is high. In the other two regions, the potential decreases rather rapidly because of the low values of the conductivities in these regions. Similar behavior of the potential is shown in Figs.8-13 depending on the values of the conductivities in the different regions.

It is obvious that as lower value has the conductivity of the ground, the density of equipotential lines become higher, Figs.3, 4.

In Figs.8-13, it is observed that the slope of the potential changes at the boundary of the regions. The passage from an area with high conductivity value to an area with lower conductivity value increases the slope of the potential, as the potential decreases rapidly.

4. Conclusions

Grounding systems have been investigated in a non-uniform ground. It is observed that for various values of resistivity, the decreasing of grounding conductivity increases the density of the potential lines (the potential decreases faster). The passage from an area with high conductivity value to an area with lower conductivity value causes the equipotential lines to become densier. The higher density of the equipotential lines is located close to the boundary of the two regions, in the region with the lower conductivity. The potential decreases rapidly, causing in this way high value of step voltage.

It is also, concluded that the ground potential is very sensitive in the conductivity and the non-uniformity of the ground, something which must be taken into serious consideration during the designing of a grounding system. OPERA-2d has been proved as a very useful tool to this design.

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