EARTH NETWORK RESISTANCE CALCULATION USING 3-D SOLID MODELS

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SUMMARY

Admitting “a priori” the independence of the ground resistance in relation with the earth fault current, a new method to calculate the ground resistance of grounding grids, applying the finite element method for the 3D solid model resolution, is presented in this paper. The results obtained by the method proposed in this paper have been compared with those measured experimentally or evaluated by other methods. Once the ground resistance and earth fault current are known, the grid potential and the touch and step voltages can be calculated.

The main advantage of the method here presented is that it allows analysing symmetrical and non-symmetrical grounding grids in different soils with more than two layers.

INTRODUCTION

Due to the increasing social sensibility in relation to electrical risks in people, the increment of the available powers and the more and more technical exigencies in the electric protection systems, precise and detailed studies of all grounding grids of electric installations are necessary.

Grounding systems are, obviously, the most significant component of an electrical installation from the point of view of equipment security and personnel safety. The reliability and availability of the electrical systems depends on the quality of the design and the construction of the grounding grids.

The main objectives of a grounding system are the following:

- The safety of the people against electrical risks, limiting the possible potential to be acquired by these persons in the case of possible electrical over-voltages.

- The security and continuity of the electrical equipment, in over-voltage circumstances or in incidents.

- The correct operation of the equipment and the protection devices, allowing the default detection and the selection of all the actions oriented to disconnect the installation with damage.

Generally, the calculation methods for modelling of grounding grids consider the following simplifying hypotheses:

- The ground is an infinite medium, with plane surface, isotropic and stratified in layers.

- Electromagnetism laws could be applied to the ground resistance calculation.

- The grounding grid behaviour in the case of normal working frequency may be determined using electromagnetic field analysis techniques for stationary fields (we will not use the propagation times).

- Conductors of the grounding grids are supposed lineal, interconnected and buried near of the ground surface.

The different calculation methods are based in the determination of the electrical potential or in the electrode capacitance.

All the studies of grounding grids determine the ground resistance, the step voltages and touch voltages, using different mathematical techniques, putting into practice simplifying hypotheses that allow modelling the real system in a theoretical one with comparable results. In general, the studies are carried out for symmetry grounding grid and uniform soils [1] or stratified with two or more layers [2-5].

Recently, the study based in finite element method [6] has
been used. The initial method was based in calculate the earth fault current (amperes) starting from a random grid potential, obtaining the ground resistance value as the quotient between voltage and the current. Once the ground resistance had been calculated, the finite element model was analysed again using the real grid potential (calculated as the product of the real fault current and the calculated ground resistance value), obtaining the potentials distribution in the model as well as the touch and step voltages.

This method presented certain difficulties in the selection of the model size (earth distance to be considered from the grid), conditioning the value of the ground resistance. In this case and to obtain acceptable results, models with different dimensions and node numbers has to be proven to evaluate the availability of the application, needing a lot of time and memory of the computer. Another additional problem was the value of the boundary conditions to be applied for the size of the considered model.

To avoid these problems, the new method [6] was developed, allowing the determination of the ground resistance starting of the power loss, or from the stored energy by the electric field. The method had the additional advantage of being independent of the value of the boundary conditions, of the shape and size of the mesh and the kind of soil.

Such a method offers very important improvements to calculate the ground resistance, the step voltages and touch voltages because uses reduced models (short earth distance) but doesn’t resolve the problem of a reduced node number in the interface between the ground electrode and the earth, lowering the precision of the method. To reduce this problem we will apply the finite element method to 3D solid models.

### METHOD

The main advantage of the behaviour simulation of grounding system using the finite element method, by means 3D solid models, in relation with the traditionally in 2D or 3D, is the real and geometrical simulation of the grounding grids. Consequently the method may be applied for every grounding grid kind, with independence of the geometry (diameter of the ground electrode, number and size of the meshes, number of ground rods and of the soil configuration.

For the calculation of contact and pace voltages, we suppose all the earth is infinite and with plane surface. In these conditions, all the equipotential surfaces, far from the ground grid, are supposed to be spherical.

In accordance with that indicated previously, the ground resistance may be calculated as addition:

\[
R_T = R_1 + R_2
\]

Where:

- \( R_1 \): ground resistance of a semi-spherical of radium \( d_1 \) (see figure 1), being \( d_1 \) the earth distance in which one the potentials distribution could be consider spherical.
- \( R_2 \): ground resistance between \( d_1 \) and the infinite.

![Figure 1. Model](image)

The resistance \( R_1 \) can be calculated using the finite element method, simulating the behaviour of the grounding grid by means of 3D model solid and previous calculation of the power lost (carrying out a current flow analysis).

For an arbitrary geometry, the resistance between two electrodes may be expressed, in electrical field terms, as follows:

\[
R = \frac{\int_L E \cdot dl}{\int_S \sigma E \cdot dS}
\]

Where:
- \( S \) is the area surrounding wholly to an electrode.
- \( L \) every arbitrary way between electrodes.
- \( E \) electric field.
- \( \sigma \) conductivity.

Our advice is to calculate the ground resistance from the power loss by means of the following expression:

\[
R_1 = \frac{\text{grid potential}^2}{\text{power loss}}
\]

At the same time, the power loss is determined by means of the following expression:

\[
P = \int_V E \cdot J \, dV = \int_V \sigma E^2 \, dV
\]

The boundary conditions may be of any different value, because the ground resistance only depends of the soil constitution and grid geometry.
The resistance $R_2$ can be calculated applying the expression (2) to calculate the resistance of a semi-spherical resistor of $d_1$ internal radium and infinite external radium. In this condition the expression (2), is transformed in the following expression [7]:

$$R_2 = \frac{1}{2\pi \sigma} \left( \frac{1}{d_1} \right)$$

(5)

Once we have determined the ground resistance and the fault current is known, we determine: a) the grid potential and b) the touch and step voltages. The touch voltage and step voltages can be obtained:

- Directly, measuring the nodal potentials in the finite element model, or preferably
- Using our own program, in C language, which reads the potentials in the different nodes of the model and evaluate the points where the touch and step voltages are maximal

Figure 2 shows the kind of mesh used (grid B in the section Results of this paper) for the analyzed model.

Figure 2. Mesh (180 degrees of the model)

Figure 3 shows the distribution of potentials in the model (grid B in the section Results of this paper).

Figure 3. Distribution of potentials (180 degrees of the model)

Figure 4 shows the potential variation with the distance (measured starting from centre of the grid) according to the central axis of the grid and when the earth fault current is of 200 A (grid F in the section Results of this paper).

Figure 4. Potential

RESULTS

The method described in the previous section has been applied to calculate the ground resistance of the following grounding grids (in all the grids the section of the ground electrodes is 70 mm²):

A) Grid of 12 x 8 m with two meshes of 8 x 6 m and 6 ground rods of 2 m, buried to 0.6 m in a soil stratified in two layers. The first layer with a depth of 0.2 m and conductivity $\sigma = 1/3000 \ \Omega^{-1}m^{-1}$ and the other with conductivity $\sigma = 1/22 \ \Omega^{-1}m^{-1}$.

B) Grid of 6 x 4 m with six meshes of 2 x 2 m, without ground rods, buried to 0.5 m depth in a soil of conductivity $\sigma = 0.005 \ \Omega^{-1}m^{-1}$.
C) Grid 2.5 x 4.5 m with four meshes of 1.25 x 2.25 m and 6 ground rods of 2 m, buried to 0.7 m in a soil stratified in two layers. The first layer with a depth of 0.015 m and $\sigma = 0.000166 \, \Omega^{-1} \text{m}^{-1}$ and the other layer with conductivity $\sigma = 0.053 \, \Omega^{-1} \text{m}^{-1}$.

D) Grid of 3 x 3 m, without ground rods, buried to 0.5 m in a soil of conductivity $\sigma = 0.01 \, \Omega^{-1} \text{m}^{-1}$.

E) Grid of 6 x 6 m, without ground rods, buried to 0.5 m depth and soil of conductivity $\sigma = 0.01 \, \Omega^{-1} \text{m}^{-1}$.

F) Grid of 4 x 2 m with two meshes of 2 x 2 m, without ground rods, buried to 0.5 m in a soil of conductivity $\sigma = 0.01 \, \Omega^{-1} \text{m}^{-1}$.

G) Grid of 6 x 4 m with four meshes of 3 x 2 m, without ground rods, buried to 0.5 m depth in a soil of conductivity $\sigma = 0.015 \, \Omega^{-1} \text{m}^{-1}$.

H) Grid of 20 x 20 m with 16 meshes of 5 x 5 m, without ground rods, buried to 0.5 m in a soil of conductivity $\sigma = 0.01 \, \Omega^{-1} \text{m}^{-1}$.

I) Grid of 24 x 24 m with 9 meshes of 8 x 8 m, without ground rods, buried to 0.5 m in a soil of conductivity $\sigma = 0.01 \, \Omega^{-1} \text{m}^{-1}$.

Table I shows the values obtained (for each geometry), by means of method proposed and those measurement experimentally or calculated by other methods [1].

<table>
<thead>
<tr>
<th>Grid</th>
<th>Method proposed (Ω)</th>
<th>Experimental measures (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.98</td>
<td>1.00</td>
</tr>
<tr>
<td>B</td>
<td>16.30</td>
<td>16.80</td>
</tr>
<tr>
<td>C</td>
<td>2.40</td>
<td>2.50</td>
</tr>
<tr>
<td>D</td>
<td>14.43</td>
<td>15.00</td>
</tr>
<tr>
<td>E</td>
<td>8.18</td>
<td>8.70</td>
</tr>
<tr>
<td>F</td>
<td>14.36</td>
<td>14.90</td>
</tr>
<tr>
<td>G</td>
<td>5.67</td>
<td>5.40</td>
</tr>
<tr>
<td>H</td>
<td>2.35</td>
<td>2.40</td>
</tr>
<tr>
<td>I</td>
<td>2.10</td>
<td>2.00</td>
</tr>
</tbody>
</table>

The soil resistivity has been measured using the Wenner’s method and the ground resistance using the method of the two auxiliary ground rods.

Taking into consideration these last results, we can see that in all cases the mistakes made using the method exposed in this paper are less than 6%.

CONCLUSIONS

A new technique for ground resistance calculation using finite element method has been presented in this paper.

The results obtained, by means of method presented in this paper, are sufficiently good if are compared with those experimentally measured.

The method herein exposed is independent of the grid geometry and soil configuration.

The method is specially appropriated to calculate the ground resistance of asymmetric grid and multilayer soil.

The soil resistivity has been measured using the Wenner’s method and the ground resistance using the method of the two auxiliary ground rods.

The ground resistance is obtained once know the power loss in the “finite element model”. Once the ground resistance is known the grid potential and later on the touch and step voltages can be calculated.

REFERENCES


