GROUND-3D LINKED TO LINE PARAMETERS: A METHOD TO FAULT CURRENT DISTRIBUTION AND EARTH POTENTIAL DETERMINATION

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***Abstract* - In previous work [1,2] the author presents a methodology, based on finite elements method (FEM), to calculate the potential distribution influence on the grounding area. At that time the input of the solver admits as known the split of the system. The aim of this article is to demonstrate the advantages of finite element method (FEM) associated with power systems equations with lumped parameters to intrinsically obtain the distribution of fault current in several offered conductor ways and the potential distribution on the ground, simultaneously. To solve the complex equations system, the methodology adopted was that described by Mesquita [3].**

INTRODUCTION

This work describes a method to calculate the distribution of currents between ground and over head ground wires when a line ground fault occurs in a transmission line as well as the potential grades that had been developed in the earth.

The method described on references [4], [6] is based on:

- Calculation of lumped parameters and use of traditional network studies, with simplifications mainly on the representation of the ground resistance and their mutual;

- Analyses based on empirical graphics.

This kind of phenomena on the last years started to be solved using FEM techniques [1], but even in this case this solution assumes known fault current distribution.

Our proposal is to combine both FEM techniques on the ground and lumped parameters of the over ground network as well the mutual between line and ground cables in the same solution using a global complex matrix.

The computation in the frequencies domain brings a new contribution to the study.

The application of the Incomplete Cholesky Complex-Bi-Conjugate Gradients method (ICCBCG) was identified as the most appropriate, in the face of encouraging results obtained until the moment, as well as existing symmetry in the resultant matrix.

In the developed methodology, the domain is subdivided in two parts:

1. soil and buried elements;
2. electric network, as shown on fig. 1.

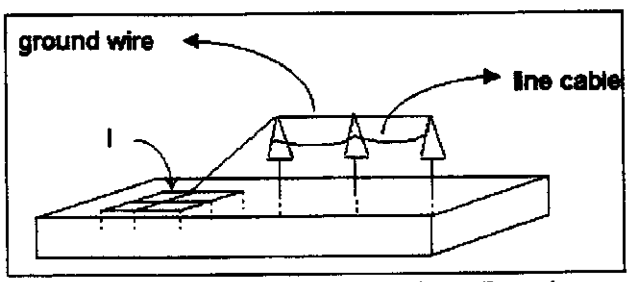


Fig. 1 - Schematic Model of the Study Domain

The matrix that simulates the system will be the composition of the global matrix arising from mathematics formulation for the FEM to the ground system, with the insertion of the network lumped parameters, resulting in a system of equation like:

$$Ax = b \qquad (1)$$

where A is the complex matrix, result of the global matrix composition of the FEM with insertion of lumped parameters of the fault current dispersal system, x is the potential of all domain nodes, and b it is the impress current vector.

This method helps to get more accuracy on results of potential distribution on soil minimising investment on ground grid. As by-product, the used methodology allows the study of transference potentials in metallic elements not directly linked up with the electric system, but which are situated in their influence area (problem domain) like: plumbing, metallic structures, armours, which have contact or which are buried in the soil, in the moment of incident of the line to ground fault.

CONSTRUCTION OF THE COMPLEX MATRIX

Following [4] we can simplify the network model, to the following fig. 2:

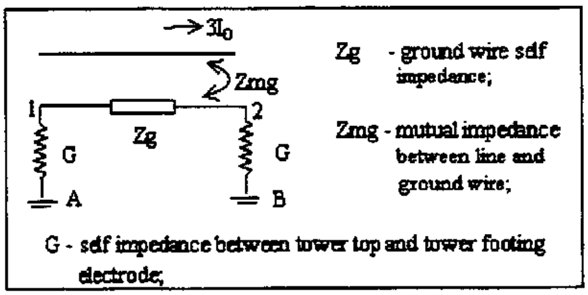


Fig. 2 - Impedance model of lumped parameters.

The points A and B are examples of interface between model with lumped parameter and ground (FEM).

If we change in the above model the Zmg impedance by current generator:

$$Ig = \frac{Zmg}{Zg}(3Io) \qquad (2)$$

the interconnection of two substations can be shown in fig. 3:

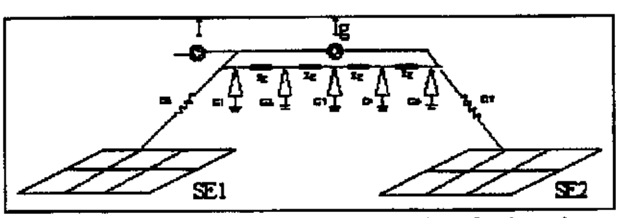
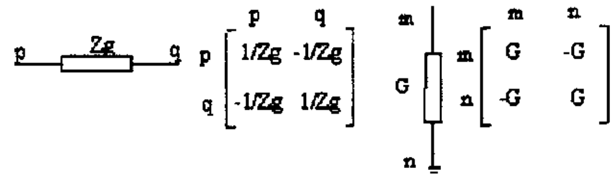


Fig. 3- Interlink of two ground networks of substations.

The construction of the Matrix is done including in the FEM matrix [G] the nodes introduced by the links with the lumped parameters. To do that the impedance of the interconnections between the tower top and the ground electrode, and the self impedance of the over ground wire will be treated as one dimension elements to be included in the main matrix as shown bellow:



$$\begin{array}{c|cc} & p & q \\ \hline p & 1/Zg & -1/Zg \\ q & -1/Zg & 1/Zg \end{array} \qquad \begin{array}{c|cc} & m & n \\ \hline m & G & -G \\ n & -G & G \end{array}$$

Tower interconnections series impedances.

Elements of parallel impedance.

$$\begin{array}{c} \\ m \\ n \\ p \\ q \end{array}\begin{array}{cccc} m & n & p & q \\ \end{array}$$

$$\begin{array}{c|cccc} & m & n & p & q \\ \hline m & G & -G & & \\ n & -G & G & & \\ p & & & 1/Zg & -1/Zg \\ q & & & -1/Zg & 1/Zg \end{array}$$

[G] after lumped elements included.

The tower connections with the over ground wires will be considered as resistive so the final matrix will be symmetric with complex elements. This algorithm is the inclusion of an element in an already built Y matrix [5]:

SOLUTION METHODOLOGY

As described by Mesquita when the matrix A is symmetric and complex, we can use Incomplete Choleski method before applying the CBCG, making the ICCBCG (Incomplete Choleski Complex Bi-Conjugate Gradients). These solutions introduce reductions compared to direct inversion of the matrix using usual technics with lumped parameters and network studies.

EXAMPLE AND RESULTS

In the first approach we will use the simplified example of figure 4, with DC current of 1500 A on point 2.

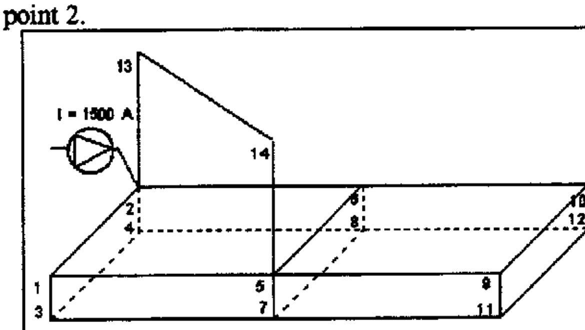


Fig. 4 - Example Scheme

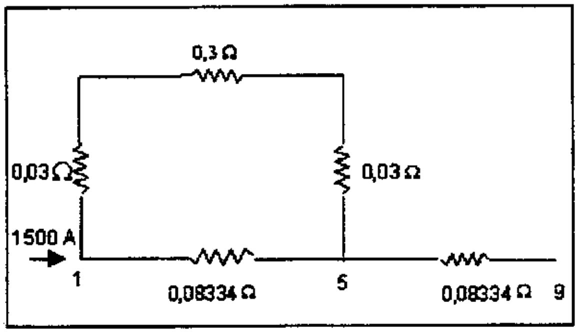


Fig. 5 - Equivalent Model

The solver had considered the elements between the points 2-13, 13-14, and 14-5 as lumped values, and the rest of domain had been simulated with FEM and ICCG (Incomplete Cholesky Conjugate Gradients) solution because with DC current, the matrix becomes real. The results are shown below:

$V_1 = 226.48$ V	$V_2 = 226.53$ V
$V_3 = 226.45$ V	$V_4 = 226.47$ V
$V_5 = 124.99$ V	$V_6 = 124.97$ V
$V_7 = 124.97$ V	$V_8 = 124.98$ V
$V_9 = 0$ V	$V_{10} = 0$ V
$V_{11} = 0$ V	$V_{12} = 0$ V
$V_{13} = 218.07$ V	$V_{14} = 133.45$ V

For verification lets take an equivalent system where the FEM domain will be simulated by lumped parameters too.

Considerations:

- Distance between two points: 1m
- Soil Resistivity: $r_{solo} = 1/12\ \Omega.m$
- Resistances: element between points 2-13: 0,03 Ω
  element between points 13-14: 0,3 Ω
  element between points 14-5: 0,03 Ω

Then,

$$R_{solo} = \rho/s = 1/12 * 1 = 0{,}08334$$

The current is uniformly distributed in the 1-2-3-4 area.

So, we have the solution of the equivalent model of figure 5:

	Traditional Method	ICCBCG
V1	226.5 V	226.48 V
V5	125.0 V	124.99 V
V9	0.0 V	0.0 V

To the other result we will use the example of the fig. 6:

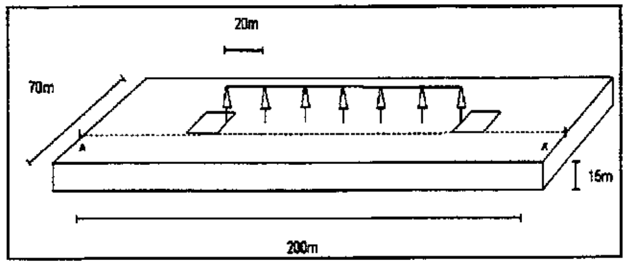


Fig. 6 - Example domain

The ground rods located on the four corners of the mesh and of the towers (one rod per tower) are 6.0 m long, the mesh is buried at 0 m level, and the soil is stratified in three layers as follows:

0m -3m: 100 Ω.m
-3m -9m: 400 Ω.m
-9m -15m: 1300 Ω.m

Fig. 7 shows the equipotential lines due to a total ground fault (I= 40 A) imposed to the left-side mesh.

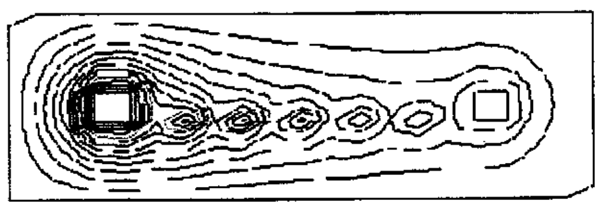


Fig. 7 - Equipotential lines

Fig. 8 shows the potential profile in the direction (A-A') as shown in fig. 6, and the fig. 9 shows the potential surface at 0m level.

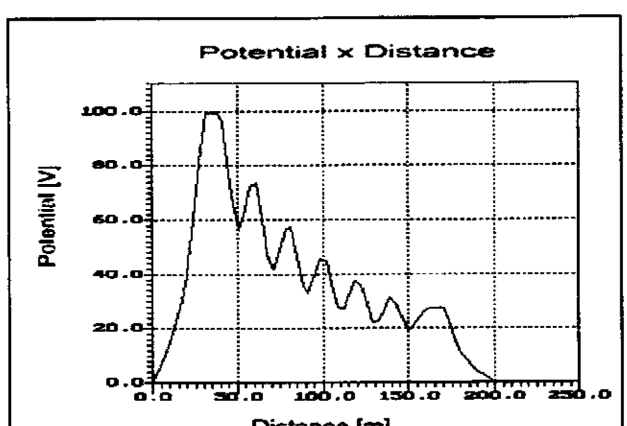


Fig. 8 - Potential profile

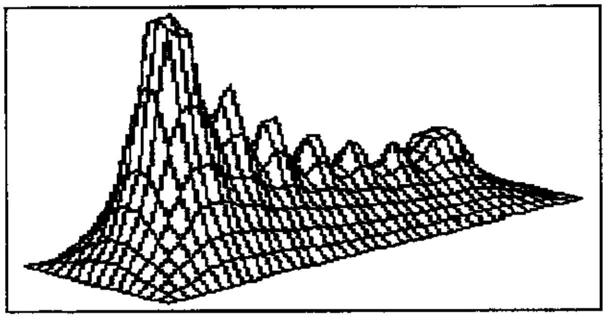


Fig. 9 - Potential Surface

First tests on ICCBCG using the example of fig. 4, changing the connection impedance to:

- Impedances: element between points 2-13: 0,03 Ω
  element between points 13-14: 0,3j Ω
  element between points 14-5: 0,03 Ω

The results are:

$V_1 = 236.47 + 28.25j$ V	$V_2 = 236.52 + 28.27j$ V
$V_3 = 236.44 + 28.25j$ V	$V_4 = 236.46 + 28.25j$ V
$V_5 = 124.98 - 0.02j$ V	$V_6 = 124.96 - 0.01j$ V
$V_7 = 124.96 - 0.01j$ V	$V_8 = 124.97 + 0.01j$ V
$V_9 = 0.0 + 0.0j$ V	$V_{10} = 0.0 + 0.0j$ V
$V_{11} = 0.0 + 0.0j$ V	$V_{12} = 0.0 + 0.0j$ V
$V_{13} = 231.66 + 38.44j$ V	$V_{14} = 129.84 -10.19j$ V

For verification, we use an equivalent model, using normal circuit technics and the results are:

	Traditional Method	ICCBCG
V1	236.50 + 28.27j V	236.47 + 28.25j V
V5	125.0 + 0.0j V	124.98 - 0.02j V
V9	0.0 + 0.0j V	0.0 + 0.0j V

CONCLUSION

The results show that the implementation of the global matrix gives results in an acceptable precision compared with direct methods of circuit calculation. This way of calculation doesn't come to substitute other methods, but to look more carefully the locations where problems are detected.

The great advantage is to obtain the division of currents between over-ground-cable and soil intrinsically resulting a more easy iterative analyses to the elements on ground.

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