

# Advanced Computer Methods for Grounding Analysis

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**Summary.** In this work we present the foundations of a numerical formulation based on the Boundary Element Method for grounding analysis developed for the authors in last years. Furthermore, a revision of main applications of this numerical approach to some problems in electrical engineering practice is shown.

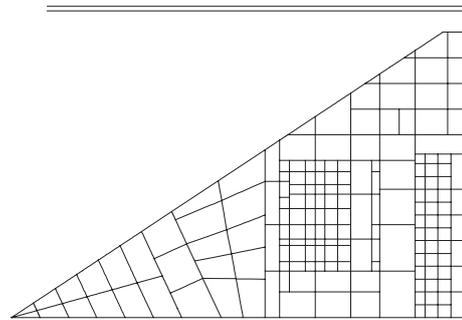
Main goals of an earthing system are to safeguard that persons working or walking in the surroundings of the grounded installation are not exposed to dangerous electrical shocks and to guarantee the integrity of equipment and the continuity of the power supply under fault conditions. Thus, the equivalent resistance of the electrode should be low enough to assure the current dissipation mainly into the earth, while maximum potential differences between close points on the earth surface must be kept under certain maximum values defined by the safety regulations [1–3].

Although the electric current dissipation is a well-known phenomenon, the computing of grounding grids of large electrical substations in practical cases present some difficulties mainly due to the specific geometry of these grids [4, 5].

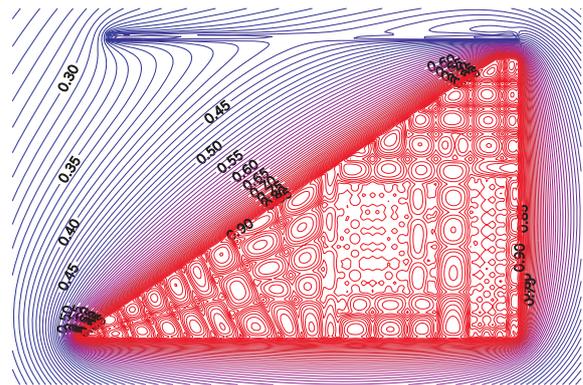
In the last years, the authors have proposed a numerical approach based on the transformation of the Maxwell’s differential equations onto an equivalent boundary integral equation. This integral approach is the starting point for the development of a general numerical formulation based on the Boundary Element Method which allows to derive specific numerical algorithms of high accuracy for grounding analysis embedded in uniform soils models [6]. On the other hand, the anomalous asymptotic behaviour of the classical computer methods proposed for earthing analysis can be rigorously explained identifying different sources of error [4]. Besides, the Boundary Element formulation has been extended for grounding grids embedded in stratified soils [7, 8].

This methodology has been implemented in a CAD tool for grounding systems comprising all stages of the analysis: the preprocessing, the computing and the postprocessing, including the calculation of the characteristic safety parameters [9]. Furthermore, high-efficient convergence acceleration techniques have been also derived improving the earthing analysis for the case of layered soil models [10]

In 2005, the authors proposed a methodology for the analysis of a common and very important en-



**Fig. 1.** Grounding grid plan and situation of the two railway tracks in the surroundings of the electrode.



**Fig. 2.** Potential distribution ( $\times 10$  kV) on the earth surface due to the energization of the grounding grid considering the phenomena of the transferred potentials by the tracks.

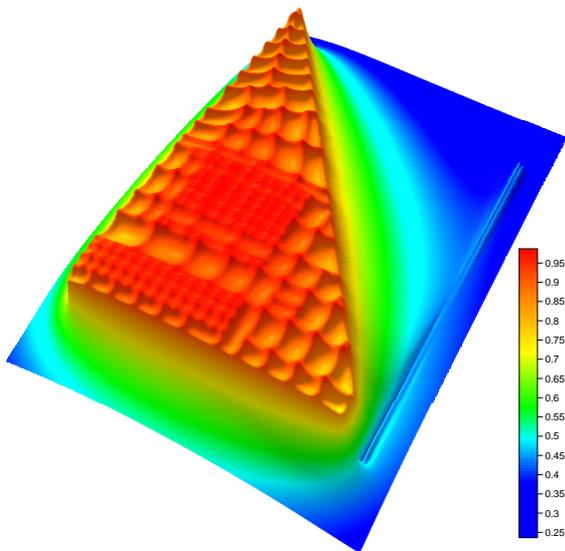
gineering problem in the grounding field: the problem of transferred earth potentials by grounding grids [11]. “Transferred earth potentials” refer to the phenomenon of the earth potential of one location appearing at another location with a contrasting earth potential. This transference occurs, for example, when a grounding grid is energized up to a certain voltage (typically, the Ground Potential Rise) during a fault condition, and this voltage—or a fraction of it—appears (or it is “transferred”) out to a non-fault site by a buried or semiburied conductors: communication or signal circuits, neutral wires, metal pipes, rails, metallic fences, etc., leaving the substation area.

The danger that can imply this potential transference to people, animals or the equipment is evident, especially because in some cases it is produced in un-

expected and non-protected areas [2]. While the prevention of these hazardous voltages has been traditionally carried out by combining a good engineering expertise, some crude calculations and even field measurements, an accurate determination of the transferred earth potentials by grounding grids can be currently performed by using computer methods: in [12], the authors proposed a numerical methodology for the case of uniform soil models, and the generalization for stratified soil models was published in [13].

Figure 1 shows the plan of the grounding grid of an electrical substation and the situation of two tracks in the surroundings of the electrode, as an application example of transferred earth potential analysis. The grounding grid has 408 cylindrical electrodes (diameter: 12.85 mm), it is buried 0.80 m. and its maximum dimensions are  $145 \times 90 \text{ m}^2$ . The resistivity of the soil is  $60 \Omega\text{m}$  and the GPR considered is 10 kV. There are also two tracks—with a length of 130 m (diameter: 94 mm)—buried 0.10 m. Figures 2 and 3 show the potential distribution on the earth surface computed by using a Boundary Element formulation for transferred earth grounding voltages in uniform soil models. In both graphs, it can be observed the modification of the potential mapping on the earth surface due to the presence of the tracks and the voltage level induced on them.

Finally, most recently the authors have proposed a methodology for the analysis of grounding grids buried in soils which present some finite volumes with very different conductivities. In our opinion, these kinds of numerical models should allow for example the computational modeling of earthing systems of underground compact substations [14].



**Fig. 3.** TOTBEM Postprocessing module: 3D visualization of the potential distribution on the earth surface.

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## References

1. IEEE Std. 80, *IEEE Guide for safety in AC substation grounding*. New York, 2000.
2. IEEE Std. 142, *IEEE Recommended practice for grounding of industrial and commercial power systems*. New York, 2007.
3. J. G. Sverak, “Progress in step and touch voltage equations of ANSI/IEEE Std 80. Historical perspective”, *IEEE Trans. Power Del.*, **13**, (3), 762-767, July 1998.
4. F. Navarrina, I. Colominas, and M. Casteleiro, “Why do computer methods for grounding produce anomalous results?”, *IEEE Trans. Power Del.*, **18**, (4), 1192-1202, Oct. 2003.
5. D. L. Garrett and J. G. Pruitt, “Problems encountered with the average potential method of analyzing substation grounding systems”, *IEEE Trans. Power App. Syst.*, **104**, (12), 3586-3596, Dec. 1985.
6. I. Colominas, F. Navarrina, and M. Casteleiro, “A boundary element numerical approach for grounding grid computation”, *Comput. Meth. Appl. Mech. Eng.*, **174**, 73-90, 1999.
7. I. Colominas, J. Gómez-Calviño, F. Navarrina, and M. Casteleiro, “Computer analysis of earthing systems in horizontally and vertically layered soils”, *Elect. Power Syst. Res.*, **59**, 149-156, 2001.
8. I. Colominas, F. Navarrina, and M. Casteleiro, “A numerical formulation for grounding analysis in stratified soils”, *IEEE Trans. Power Del.*, **17**, (2), 587-595, Apr. 2002.
9. J. París, I. Colominas, X. Nogueira, F. Navarrina, and M. Casteleiro, “Numerical simulation of multilayer grounding grids in a user-friendly open-source CAD interface”, *Proceedings of the ICETCE-2012*, IEEE Pub., New York, 2012.
10. I. Colominas, J. París, F. Navarrina, and M. Casteleiro, “Improvement of the computer methods for grounding analysis in layered soils by using high-efficient convergence acceleration techniques”, *Adv. Engrg. Soft.*, **44**, 80-91, 2012.
11. Nichols N., Shipp D.D., “Designing to avoid hazardous transferred earth potentials”, *IEEE Trans. Ind. Appl.*, **1A-18**, 340-347, July 1982.
12. I. Colominas, F. Navarrina, and M. Casteleiro, “Analysis of transferred earth potentials in grounding systems: A BEM numerical approach”, *IEEE Trans. Power Del.*, **20**, (1), 339-345, Jan. 2005.
13. I. Colominas, F. Navarrina, and M. Casteleiro, “Numerical Simulation of Transferred Potentials in Earthing Grids Considering Layered Soil Models”, *IEEE Trans. Power Del.*, **22**, (3), 1514-1522, July 2007.
14. I. Colominas, J. París, X. Nogueira, F. Navarrina, and M. Casteleiro, “Grounding Analysis in Heterogeneous Soil Models: Application to Underground Substations”, *Proceedings of the ICETCE-2012*, IEEE Pub., New York, 2012.