MODELLING OF ELECTRICAL INSTALLATIONS EARTHING SYSTEMS IN ANSOFT MAXWELL

Vaclav Vycital

Doctoral Degree Programme (3), FEEC BUT

E-mail: xvycit01@stud.feec.vutbr.cz

Supervised by: Petr Toman

E-mail: toman@feec.vutbr.cz

Abstract: This paper discusses the possibilities of modelling of ES in Ansoft Maxwell software. The possible way of definition of the problem with possible modelling difficulties were discussed. The possible error in obtained results by choosing a value of radius of the earth model as well as choosing a value of target percent error in the software by the user is also discussed. The discussion is supplemented with a simplified sensitivity analysis of these input variables and the results are validated by comparing the results with results obtained from simplified analytical formulas.

Keywords: earthing, grounding, power system, electrical installation, Ansoft Maxwell, modelling

1 INTRODUCTION

Electrical installations of all nominal voltages have to be ‘earthed’ to ensure functional and safety requirements of electrical assets [1]. By earthing system (ES) is meant a spatial conductive structure consisting of metallic strips and rods connected together by conductive joints. Even concrete reinforcement [2] is often used as a standalone or as a part of more complicated earthing system. To differentiate between separate parts of earthing system from the whole interconnected system, a term earthing electrode (EE) is introduced here as a term used for one separate rod, one strip etc. The earthing system is usually constructed by many conductively connected basic EEs. The main safety purpose of ES is to provide conductive connection between exposed conductive parts of electrical equipment and the general mass of earth. This is because during a fault there might be an increase of electrical potential on the exposed conductive parts that are accessible to touch by working personnel or by representative of public that might be susceptible to potential difference and might eventually end up in a fatal accident. The ES is installed as a safety measure to reduce potential touch and step voltages and so to decrease the risk imposed by such an installation. ES is always installed in the vicinity and beneath the earthed electrical equipment in the ground.

The quality/safety level of earthing system is evaluated based on the earth potential rise (EPR) of ES during an electrical fault occurrence. Fault current flows from the source through faulty line and ES to the mass of earth and back to the source [3]. The general mass of earth consists of different types of soil with different electrical properties. The flow of electrical current in the soil is facilitated by free ions which number depends on many factors (i.e. water content, type of soil, geological locations, fertilization etc. [4, 5]). However, the resistance of mass of soil is indeed of definite value and is represented by the soil resistivity ρ in Ωm. As the current is passing through the earth, non-negligible voltage drops occur and thus there is a non-uniform current density field spreading from the ES and decreasing in magnitude with increasing distance from the ES. In such a way a concentric equipotential field develops around the ES. Even though the ES is buried in some depth in the earth, scalar potential field also develops on the surface of the earth and this is the field, that is of a main concern when evaluating ES design from the safety point of view. An example of a concrete pole with the ES buried in the ground with the calculated scalar potential field in the ground is depicted in **Figure 1**.

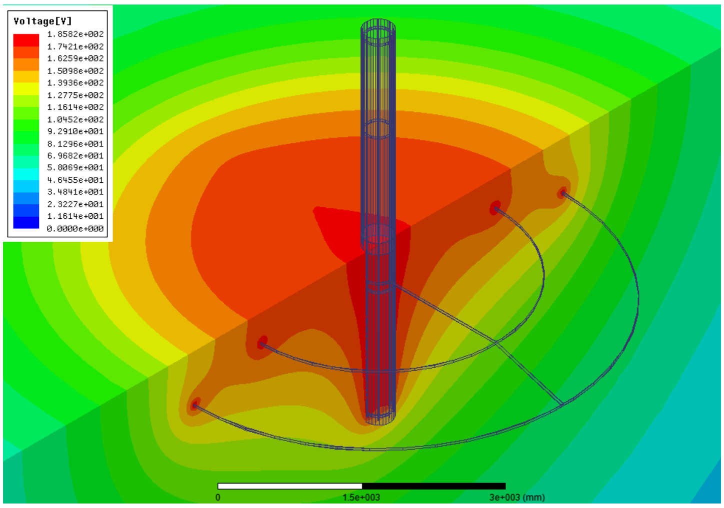

Figure 1: Voltage potential distribution for ES consisting of two peripheral rings and a concrete pole with conductive reinforcement, under fault of 30 Amps situated in homogenous (single layer) soil model with
resistivity of 80 Ωm

2 DETERMINATION OF EPR

The EPR and voltage distribution of the ES might be determined by different approaches. In general, it is a task aimed on solution of electromagnetic field (EMF) in three-dimensional space. However, exact solution for the EMF distribution in three-dimensional space was not always possible without some simplification. The need for at least some simplified formulas for EPR determination arose with the worldwide electrification which can be dated back to 1918 [6] or even earlier. Methods used for solution of EMF field in that time were – method of moments, method of image charges, method of average potentials etc. The EPR can be determined through the calculation of the earthing resistance of evaluated ES [3, 7] energized by the fault current [1] as $EPR = R_{ES} \times I_{fault}$. This simplified approach is still accepted by the European standard [1] and also by another international standard on earthing IEEE 80 [8]. Throughout last century many papers were published with an attempt to increase the accuracy of adopted simplified formulas. The possibility of numerically solving the EMF equation in their original - not simplified form became realizable with the developments in computer technology field and a lot of attention was moved in that direction. Today, with emphasis on ES design, the commercially available EMF solving programs can be divided to either general EMF solving programs (Ansoft Maxwell as a sub-package of ANSYS programme, Comsol Multiphysics etc. [9]) or to programs oriented only on the ES designing problems (SKM GroundMat, CDEGS [10]). Some of these software utilize numerical solution of finite element method (FEM) or others use the solution of the Green's function [11].

3 EARTHING SYSTEM CALCULATION AND ANSOFT MAXWELL

Ansoft Maxwell is a general EMF calculation computer program focused on many different tasks ranging from some simple engineering's problems to some more complex problems like optimization of the designs often encountered by scientists. As this programme is designed as a tool for solving general EMF problems, the use for some specific applications requires more experienced user that has to thoroughly consider how the required task will be defined for the programme.

When defining the EMF problem, first of all, the user has to decides if there is any symmetry that might simplify the problem and thus 2D design could be used. Unfortunately, for ES there can´t be found any such simplification and thus 3D design has to be chosen. Then the user has to decides which solution type will be used – either one including only effects form electric field (Electrostatic, DC Conduction, Electric Transient) or one including also the effects form magnetic fields (Magnetostatics, Eddy Currents, Transient). This choice here might be quite tricky and in general the ES problem demands full EMF field solution. However, the choice at this step will determine how difficult will be the definition of the problem and also how difficult will be the solution of this problem by the programme (computation duration, or even if the solutions just converges or not). Many problems might arise here. The Transient solution (electric or magnetic) solves for time varying field and doesn't allow to use Adaptive Mesher. These solution's types might be considered as the most complex ones, however a complicated postprocessing of the solution data might be required to obtain steady state scalar voltage potential field of solved ES problem and also there is a problem with meshing operation (built in Adaptive Mesher cannot be used). Magnetostatics and Electrostatics solution type can be skipped from the possible options because only static dc fields are considered (no charge displacement = no current flow). Only two options have left – Eddy Current and DC Conduction solution type. The Eddy Current solution type might sound much closer to the ES problem, as the excitation here is by ac voltage source and thus development of eddy currents in the model is expected. However, the Eddy Current solution type allows only for current excitation of the model. Even at this point it might seem that this is not a problem because in real situations the fault current magnitude might be much easier to obtain than the faulty voltage (i.e. EPR) on the ES. Unfortunately, the current excitation of the model has to be divergence free. That means, that the actual distribution of the current has to be known before the solution might begin. This conditions together with the limitation of applying current excitation only on planar entities makes use of Eddy Current solution type for ES calculation inadequate, because the exact part of the current will have to be defined for each of the 4 vertical walls and on the bottom of the model of earth. This problem is further explained on the following figures (**Figure 2**, **Figure 3**) where simple ring ES is modelled with two different models of earth (half cube and half sphere). Half sphere might be expected closer to the actual developed potential field from the ES than in case of half cube model, but cannot be used in Eddy Current solution type due to non-planarity of the outer surface of the sphere.

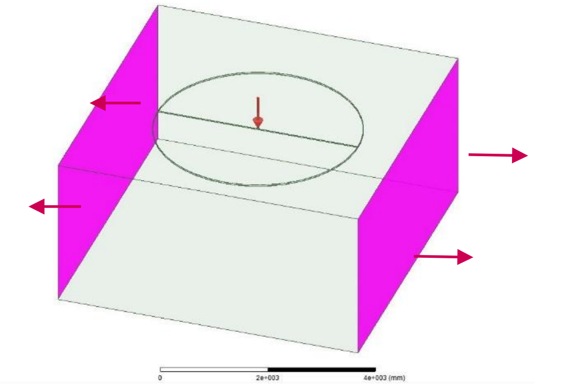

Figure 2: Ring ES in half cube earth model, with indicated current excitations definition for this model (only 2 of 4 vertical walls are highlighted for transparency and simplicity)

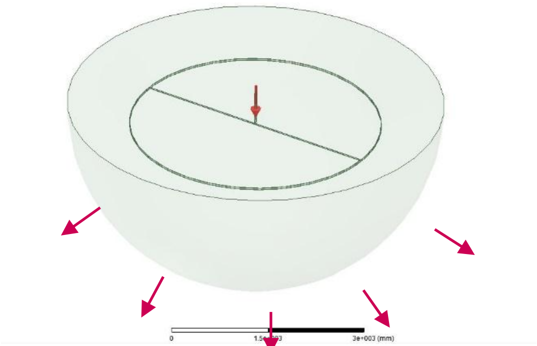

Figure 3: Ring ES in half sphere earth model, with indicated current excitations definition for this model (on the outer surface of the sphere)

The last remaining solution type is DC Conduction. In this solution type the source can be voltage or current and this solution type permits to use the current excitation on non-planar entities, thus the half sphere earth model from **Figure 3** can be used. However, this solution type takes into considerations only the resistive voltage drops caused by the current flow through only resistive medium. This might be the source of discrepancy between the model in Ansoft Maxwell and the real constructed ES due to not counting for ES reactance and eddy current effects. However, the reactance of the ES at low frequencies might be considered negligible compared to resistance [12].

After choosing appropriate solution type, the work steps are quite straightforward. First of all, the 3D and DC conduction solution type is chosen. Then, the ES has to be modelled. This can be done either by built in Ansoft Maxwell graphical CAD interface or by importing the design from third party CAD based software (like AutoCad, Caita etc.). The earth is than modelled as half sphere and the ES model is subtracted from it. Each object is defined its appropriate material properties, i.e. in DC conduction only electrical permittivity and conductivity has to be defined. The boundary condition as well as meshing operations can be kept default as there is no need for any specific definition. Current excitation can be applied on a surface of part of ES that is extended above the earth. If current excitation is used, there has to be defined special excitation 'sink', that is the boundary where all currents flow to (or in DC the terminal of zero potential of the source). After setting the setup (i.e. number of adaptive passes to refine the mesh and the target solution percent error), the solution can be obtained. From the solution matrix, scalar potential field can be obtained (as was depicted in **Figure 1**) as well as the maximum value of the potential field (i.e. = total EPR).

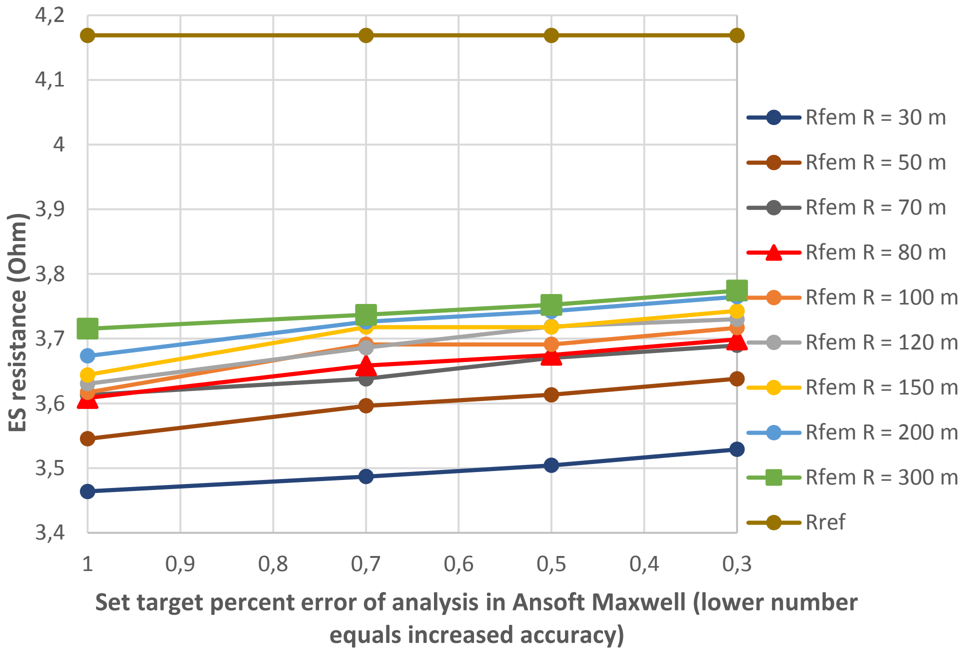

Figure 4: Validation of results obtained from Ansoft Maxwell (Rfem), ES resistance for single ring EE in dependence on set percent error and for different radius of half sphere earth model (Rref. reference ES resistance)

It can be obvious, that by changing the radius of half sphere earth model the obtained EPR will be increasing due to adding thicker resistive medium in the current path (between surface on ES and outer surface of half sphere with 'sink' excitation – the whole conductive path). However, also the current density is decreasing because the volume of resistive medium encountered by the current flow further from the source is also increasing. Thus, the radius of the earth model will have an impact on the obtained total EPR but will be approaching its limit maximum value that would have been developed in an infinite radius earth model. Another input parameter that might influence the determined EPR is the value of set target percent error of the mesh refining. The target percent error value determines the level of finesty of the finite element mesh that is generated and refined in iterative adaptive passes by Ansoft Maxwell built in Adaptive Mesher. Thus, in this paper the setting of the target percent error and the value of radius of the earth model was examined. The results are depicted in **Figure 4**. To validate the results obtained from Ansoft Maxwell, the total ES resistance of the modelled ES was determined using the Ohm's law (as Rfem = EPR / ExcitationCurrent) and this value was compared with ES resistance obtained from simplified analytical calculation according to [13], where for ring EE the following formula is defined (ring buried at depth of z and with diameter of D with soil resistivity ρ), (Rref for D = 6.5 m, z = 0.8 m, ρ = 50 Ωm)

$$Rref = \frac{\rho}{2\pi^2 D}\left(\ln\left(\frac{8D}{d}\right) + \ln\left(\frac{\pi D}{2z}\right)\right) \tag{1}$$

4 CONCLUSION

In this paper the possibilities of modelling ES in Ansoft Maxwell software were discussed. It was found out that the best suitable way of modelling ES in this software is by using 3D solution design together with DC conduction solution type. This definition of the ES problem also preserves the simplicity of the solution so that this task can be performed also by a less experienced user. To validate the obtained results, an analysis of the influence of the changing earth model radius and also the set target percent error of the analysis was performed. From the results it can be seen, that the radius of the earth model should be at least 10 times greater than the longest ES dimension). Increasing the radius of the earth model beyond this value does not have such a great impact on the results. Adjusting the target percent error can increase the accuracy of the results, however together with the earth model radius this is also increasing the required time for the solution. Also, the computer hardware requirements are increasing by increasing requested RAM memory. Increasing percent error is in many situations worse as this have major impact on the required time, that might be from half a minute up to several hours of computation time. (in the presented results for not very complicated model it usually takes only up to few minutes, on average computer). However, for obtaining detailed potential distribution the percent error should to be adjusted. Increasing the radius of the earth beyond 300 m yielded for some designs to an invalid field solution. The difference of approximately 10-15% between Rfem and Rref solution might be also due to the horizontal strip in the middle of the ring EE as the formula (1) is defined for only separate ring EE (solution was for model of ES same as on **Figure 3**). An inspection of the obtained potential field data by the user is still recommended.

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REFERENCES

[1] *Earthing of Power Installations Exceeding 1 kv a.c.*, CENELEC Standard EN 50522:2010, 2010.

[2] Kočvara, A.: Uzemňování elektrických zařízení (in Czech, Earthing of Electrical Equipment), Prague, Czech Republic, Knižnice elektro 1995.

[3] Rüdenberg, R.: Grounding principles and practice I – Fundamental considerations on grounding currents. *Electrical Engineering*, vol. 64, no. 1, pp. 1-13, 1945.

[4] Tagg, G.F.: Earth resistances. London, Great Britain, The Whitefriars Press, 1964.

[5] Jinliang, H., Rong, Z., Bo, Z.: Methodology and technology for power system grounding. Noida, India, John Wiley & Sons, 2013, ISBN 978-1-118-25495-0.

[6] Peters, O.S.: Ground connections for electrical systems, *National Bureau of Standards*, Technological paper 108, 1928.

[7] Dwight, H.B.: Calculation of resistances to ground. *Electrical Engineering*, vol. 55, no. 12, pp. 1319-1328, 1936.

[8] *IEEE Guide for Safety in AC Substation Grounding*, IEEE Standard 80, 2015.

[9] Gutiérrez, S., Sánchez, C.N., Alvarez, J., Soberanes, J.D.: A comparative analysis of finite element programs for their implementation in a graphic tool of insulated power cables. In: *IEEE International Autumn Meeting on Power, Electronics and Computing (ROPEC 2017)*, Ixtapa, Mexico, 2017.

[10] Dawalibi, F.P., Donoso, F.: Integrated analysis software for grounding, EMF, and EMI. *IEEE Computer Applications in Power*, vol. 6, no. 2, pp. 19-24, 1993.

[11] Zhong-Xin, L., Weijiang, Ch., Jian-Bin, F., Jiayu, L.: A novel mathematical modelling of grounding system buried in multilayer earth. IEEE Transaction on Power Delivery, vol. 21, no. 3, 2006.

[12] Papalexopoulos, A.D., Meliopoulos, A.P.: Frequency dependent characteristics of grounding systems. *IEEE Transaction on Power Delivery*, vol. PWRD-2, no. 4, 1987.

[13] Osolsobě, J., Zapletal, M.: Uzemnění a bezpečnost. (In Czech Earthing and safety), Prague, Československá akademie věd, 1964.