ELECTRIC FIELD MAPPING IN HIGH VOLTAGE SUBSTATION USING THE FINITE ELEMENTS METHOD

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ABSTRACT

This paper aimed to study the behaviour of electric field and its influence within and in the vicinity of a high voltage substation, since the presence of electric fields intense can produce interactions with living organisms from harmful effects by long-term exposure. The study was performed by means of computer simulation using the software COMSOL Multiphysics®, which is based on Finite Element Method (FEM). With results of the simulations was possible to weigh if the values obtained meets the levels of electric field recommended by legislation. Was also possible to determine the voltage induced in a metallic tube in soil and in one human, the touch voltage and step voltage on the patio of the substation. The results of simulations were shown to be coherent, and they may serve as an aid in the evaluation process of electric field of complex structures.

INTRODUCTION

The possible effects on human health due to exposure to electric and magnetic fields of extremely low frequency (range between 3 Hz and 3 kHz) have generated a growing concern of public opinion in recent years [1], is already accepted that exaggerated exposures to sources of electric and magnetic fields can be harmful to health [2], however, the studies are not yet conclusive regarding the determination of a safe level of exposure nor as to the actual severity of the effects on living organisms.

In Brazil, with the objective of regulating the exposure to such fields, settled down in Article 4 of Law nº 11.934, of May 5, 2009, which will be adopted the limits recommended by the World Health Organization - WHO for occupational exposure and the general population to electric, magnetic and electromagnetic fields generated by systems which they operate in the range up to 300 GHz. In Table 1 are presented the limits recommended by the WHO [3].

TABLE 1
EXPOSURE LIMITS RECOMMENDED BY WHO

	Electric Field (V/m)	Magnetic Field (μT)
General public	4,17	83,33
Occupational population	8,33	416,67

Since such law went into effect, many companies are passing or passed in the near future, for process of adapting the legislation. In this context, is of great importance that efficient techniques can be applied to assess the intensity and distribution of electric fields order to be able of establish safe zones near energized electrical arrangements, such as substations. The assessment can be performed both experimentally via measurements in loco, more common today, or via computer simulations.

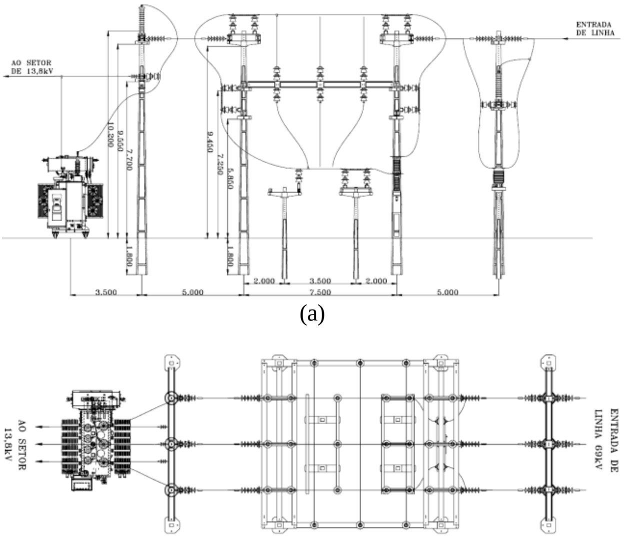
Thus, the objective of this work is the application of a computational method for evaluating the distribution of the electric field of a high voltage substation. The computational simulations are based on the Finite Element Method (FEM). It is intended, from simulations, evaluate the distribution of the electric field on the patio and in the vicinity of the substation, aiming to ascertain whether the values obtained meets the levels of electric field recommended by law. The work also aims to investigate the potential induced in metallic pipes in the soil and in one human located in the substation patio, with the results of the simulations will be possible determinations of touch voltage (between the metal pipe and the ground) and voltage step in the substation patio.

DEVELOPMENT OF THE GRAPH MODEL

The first step for performing the simulation is to build the graphical model of the arrangement to be simulated, the modelling was done on the platform simulation. The software has limited 3D modelling tools and difficulty working with complex geometry, which led the model to produce a very large computational effort, forcing the realization of some simplification in simulated arrangement.

For calculation purposes, equipment as isolators, circuit breakers, PTs and CTs were modelled as cylinders with same length and the same cross section of the real equipment, the transformer was represented as a parallelepiped. Note that, the simplifications do not cause significant error provided it is not necessary exact determination of the electric field exactly on the element simplified, as the interest of the study is the electric field distribution around the substation patio, the simplifications can be performed.

Thus, was simulated a model of substation from 69/13,8 kV, with one transformer and single bus, the physical arrangement of the substation in question is shown in Figure 1.

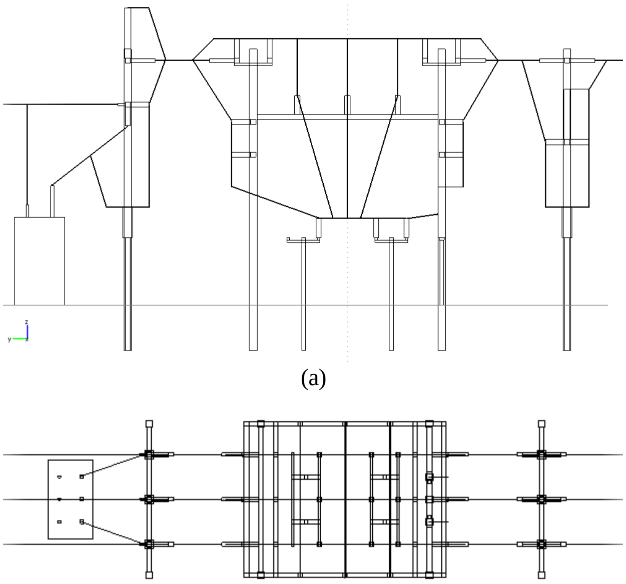


(a)

(b)

Figure 1 - Substation from 69/13, 8kV simulated, (a) side sectional view and (b) top view.

In Figure 2 is shown the results of the modelling graph performed to represent the substation computationally.



(a)

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Figure 2 - Graphic model constructed and used in the simulation, (a) side sectional view and (b) top view.

ATTRIBUTION OF PHYSICAL FEATURES AND SIMULATION

After modelling physical, were determined the greatness and constants physical that characterize each material constituting the simulated system. Most values are present in the library's own simulator, however some values were taken from literature. All the constants used are shown in Table 2.

TABLE 2
CONSTANTS ASSIGNED TO MATERIALS PRESENT AT SIMULATION

Material	ε_r - Relative Permittivity	σ - Electrical Conductivity (S/m)
Air	1,00	0,00
Earth	50,00 [A]	$1,00 \times 10^{-3}$ [B]
Human	60,00 [C]	0,50 [C]
Concrete	2,10	0,00
Glass	4,20	$1,00 \times 10^{-14}$
Iron	$1,00 \times 10^{99}$	$1,12 \times 10^{7}$
Aluminum	$1,00 \times 10^{99}$	$3,77 \times 10^{7}$
Steel	$1,00 \times 10^{99}$	$4,03 \times 10^{6}$

[A][4], [B][5], [C][6]. The others were taken from COMSOL Multiphysics®.

The human model used was taken from [6] where the author considers the human body as a cylinder that has height = 1,75 m and base radius = 0,14 m. The conductivity σ = 0,5 S/m and relative permittivity, ε_r = 60, used are related to the characteristics of saline fluid that permeates the body. Furthermore, is also considered that the potential induced within the cell and into the nucleus is the same in the body outside the cell.

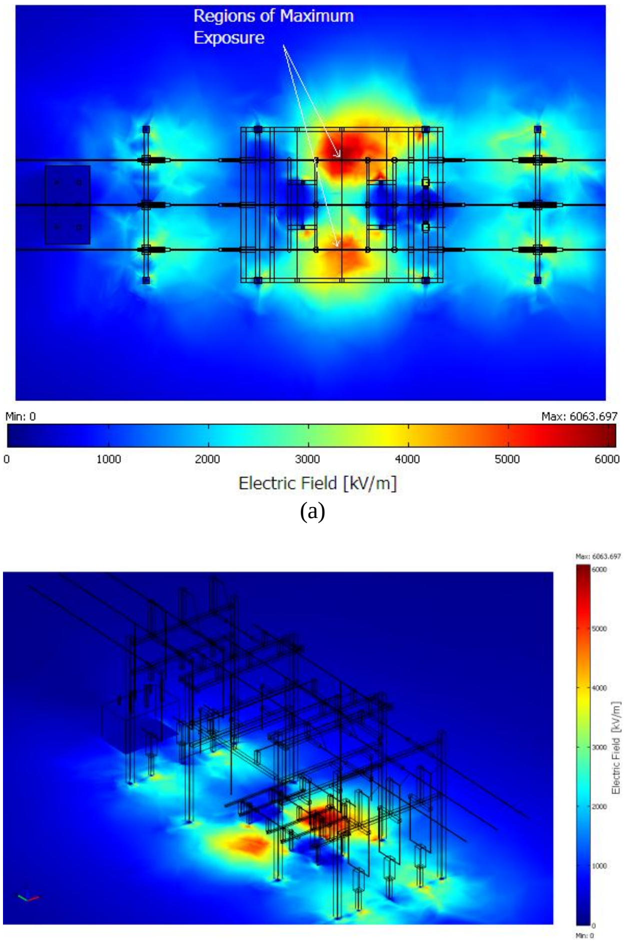
After this step, is necessary to define the differential equations and the boundary conditions that describe the problem and finally, run the simulation, at this stage the software uses the Finite Element Method for finding approximate solutions of the equations at the nodes of a mesh that is generated previously in a process known as discretization, the results are shown by the software in various ways, such as, color map, equipotential lines, graphics, tables, etc., and from these results is carried the analysis necessary to the interests of study.

RESULTS AND DISCUSSIONS

The Figure 3 shows the simulation result in the form of electric field distribution in a plane situated at a height of 1.5 meters in relation to substation patio, the points of maximum exposure are highlighted.

To the point of highest exposure the value of the electric field obtained in the simulation was 4,3 kV/m, exceeding the limit imposed by legislation for the general population which is of 4,17 kV/m, however for a substation should be considered the exposure limit for occupational population of 8,33 kV/m. Therefore, the substation in question meets the limits imposed by legislation with respect to exposure to electric fields.

The graphs in Figure 4 represent the electric field along axes located at 1,5 m above the ground, located in paths particular of substation: on the bus, near to the transformer and the periphery of the patio under the transmission lines.



(a)

(b)

Figure 3 - Distribution of the electric field on a plane situated at a height of 1,5 m in relation to substation patio,(a) top view end (b) perspective view.

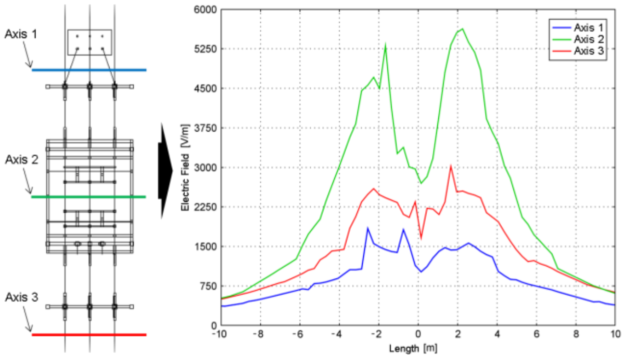


Figure 4 - Electric field along axes located at 1,5 m above the ground, located in specific paths of substation indicated by respective axes.

The RMS values of the electric field were calculated for the major point of intensity in three distinct axes and are presented in Table 3. Note that in none of the paths the value of the electric field exceeds the allowed limits, and that the path that has the highest exposure to the field is that one under the bus, because this is the region where the equipment it's the lowest height in relation to the ground, as expected.

TABLE 3
RMS VALUES OF ELECTRIC FIELD OBTAINED IN SIMULATION

Local	Maximum Value (kV/m)	Limit (kV/m)
Substation Patio	4,30	8,33
Axis 1 - Under the bus	4,00	
Axis 2 - Vicinity of transformer	1,30	
Axis 3 - Periphery patio	0,91	

Additionally were calculated the values of potential induced in a human, in a metal pipe, made of steel, with a radius of 10 cm, to 1.5 m below ground, and also the step voltage and touch voltage between the metal duct and soil, all values were obtained for location the point of greatest exposure, highlighted in the upper part of Figure 3 (a) and are shown in Table 4.

TABLE 4
RMS VALUES OF POTENTIAL INDUCED OBTAINED IN SIMULATION

Results	Maximum Value (V)
Potential induced in metallic duct	35,40
Potential induced in one human	2248,60
Voltage step	10,60
Touch voltage	169,70

The results represent admissible values and close to typical values of potentials induced by electrical arrangements that operate in the voltage range simulated.

CONCLUSIONS

The results showed that for the arrangement simulated the electric field values are in accordance with the requirements of legislation. However, the signalling of the regions of maximum exposure would be an excellent measure, because it is a simple procedure and low cost that would obviate the prolonged stay of workers in these regions, thus mitigating the cumulative effects of exposure to the field on them.

The simulation method developed in this work can be used as a valuable adjunct in the evaluation process of the electric field of complex structures. Simulations can be performed to guide concessionaries in the estimation of the electric field of future installations even before they are built.

Different scenarios of arrangements of equipment can be analysed so as to reduce, as much as possible, the value of the electric field. Furthermore, the method makes it possible to analyse the electromagnetic interference produced by substation in neighbouring utilities, such as gas or water piping.

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