

## DEVELOPMENT OF A MATLAB SOFTWARE FOR REAL-TIME MAPPING OF ELECTRIC FIELDS ON TRANSMISSION POWER LINE

Jovanio Junior<sup>1\*</sup>, Rogério Marcos<sup>1</sup>, Carlos Tenório<sup>1</sup>, Alexandre Mateus<sup>1</sup>, Ciro Egoavil<sup>1</sup>

<sup>1</sup>IEEE, Federal University of Rondonia, Brazil

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### ABSTRACT

The main contribution of this article is the mapping of the electric fields in transmission power lines using the Charge Simulation Method (CSM), combined with an embedded system. In this research, a computational routine was written in MATLAB®. The electric field intensity is calculated at a 1 meter height on right-of-way and between towers. The mapping is performed for a space between towers and considers that the maximum arrow of the conductors occurs in the middle of this distance, what provides a computational result where the profile of the electric field can be analyzed. The bundle conductor height varies along the distance between towers in order to improve the values of the calculated field. The results can be seen in different graphics (three-dimensional, bi-dimensional, a slice of the field and others). Charge Simulation Method is a power tool for calculating intensity field of high voltage systems, so this is a motivation for the use of the method. A series of detectors are used to obtain the data of the voltage that is provided to the load. These data are captured by a microcontroller and transmitted to the operational center. Using this data, the measure of the field is possible.

*Keywords:* Charge Simulation Method; Electric fields; Embedded systems; MATLAB®; Transmission line

### 1. INTRODUCTION

Embedded systems are systems which are part of special-purpose devices. Due to the limited duties, these systems can be highly optimized to specific applications. Traditionally, most of these systems are used for control and process measurement, as a side-effect of higher integration of integrated circuits more complex applications can be solved by embedded systems. To be able to solve these problems, embedded systems are commonly equipped with various kinds of peripherals. This includes all the research and development since generation power plant, transmission system and final consumer.

For each kind of transmission line, DC or AC (monophasic, tri-phase and others), the electric field has different characteristics. For an AC transmission line, operating in sinusoidal alternated form, the amplitude of the electric field varies cyclically on the same frequency of the voltage and is perpendicular to the contour surfaces, e.g. line conductors or the soil surface, which is considered as being an infinite plane of null potential. In the case of conductors of a three-phase line, the three spatial components of the electric field are lagged in  $-120^\circ$ ,  $0^\circ$ , and  $120^\circ$ , so that the resultant vector assumes, at every instant, different intensities and directions. The fundamentals for the calculation of the electric field are based on the works of (Deno, 1976), (Fuchs, 1972) and (Sadiku, 2000), which are presented next.

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\* Corresponding author's email: jovaniojunior@ieee.org, Tel. +55-69-8116775

The software developed is applied to electric mesh and analyzes the Brazilian power transmission systems. The agency that manages the power electricity (National Association of Electric Energy, ANEEL, in Portuguese), has determined that, every facility that operates on levels above 138 kV has to have their electromagnetic fields periodically checked in order to guarantee the safety of the installation and workers. In this resolution, released on March 23<sup>th</sup> 2010, the institution declared that every facility that belongs to the national electric system (generation, transmission and distribution) must measure its electromagnetic fields, to guarantee the safety of the installation. In the document, the reference levels for the electromagnetic fields adopted were defined by the World Health Organization (WHO), which are :

- For general public: 4.17 kV/m for the electric field and 83,33 μT for the magnetic field;
- For labor population: 8.33 kV/m for the electric field and 416,667 μT for the magnetic field.

**2. METHODOLOGY/ EXPERIMENTAL**

A MATLAB software was developed to calculate the electric field, using the theory of Charge Simulation Method, in which the only data needed to do the calculus of the field is the transmission voltage. Figure 1 shows the schematic of the project. The data acquired can be transmitted to an operational center by a series of optical cables, which are very efficient to send very large blocks of information, or by a GPRS module, connected to a microcontroller, located into a main information center and to the National Agency of Electric Energy.

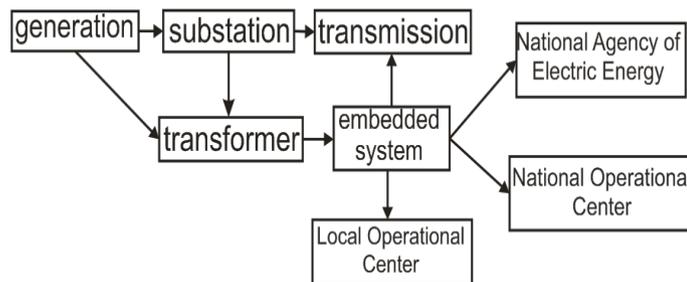


Figure 1 Schematic of the system coupling between the electric network and the embedded system

The regional center of information would have, thus, the values of the electric field of the regional transmission line grid and the national center, along with the Agency, would have information about all of the national transmission energy system. The microcontroller chosen to get the data is the Microchip’s PIC 16F877A. This microcontroller was chosen because it is one of the most good-equipped microcontrollers of the PIC16 family.

**2.1. Characteristics of the electric field generated by transmission lines**

Graphically, the electric field is represented by a vector that spins around a point, which has the other extremity describing an ellipse, as following.

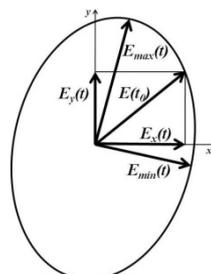


Figure 2 Polarization ellipse of the electric field like a point in space

The electric field vector spins around a point. The potential on this point is described by a phasor, with a real part and an imaginary part, so that it is characterized by its magnitude and angle. The phasorial treatment of the electric field vector is more complicated, since it needs four parameters to describe the two phasorial vectors. The electric field can be described as follows:

- The electric field that has vertical and horizontal components and in each direction, one in a real part and one in an imaginary part, or by its magnitude and angle, defined by:

$$\vec{E} = [\Re(E_x) + j\Im(E_x)]u_x + [\Re(E_y) + j\Im(E_y)]u_y \quad (1)$$

- The electric field composed by a real part that contains a vector with magnitude and angle, and an imaginary part, also represented by magnitude and angle of a vector :

$$\vec{E} = (E_x u_x + E_y u_y) + j(E_x u_x + E_y u_y) \quad (2)$$

- The electric field vector is presented by an ellipse, which is defined by the magnitude of its major axis, angle and the magnitude of its minor axis.

CSM is a consecrated method in technical literature and was used for the mapping of the electric field of the transmission line. In CSM, for a transmission line, the instantaneous complex electric potential of each phase is converted to equivalent fictitious electric charges of each phase. The charges are obtained by the multiplication of the capacitances matrix, which aggregates the mutual and self-capacitances of cables for the potentials matrix. These charges represent the charges of a cylindrical conductor of infinite length that generates the electric field of the real cables. With the charges at hand, the electric field in transmission lines by CSM can be divided in two parts:

1. Calculus of the equivalent charges per unit length of the conductor;
2. Calculus of the electric field produced by these charges.

In order to do the calculus of the electric field in two dimensions, some considerations were made on simulation:

- The charges are calculated considering the variation of the conductors to the soil;
- The conductors are parallel between themselves, homogeneous and have a smooth surface;
- The surface at the soil is flat, infinite, and with zero potential;
- The towers of the transmission line do not distort the electric field.

## 2.2. Calculation of the equivalent charges of the conductors

The CSM is used to convert the potentials into charges, making possible the calculation of the mutual and self-capacitances of the line. The soil is considered an ideal electric conductor ( $\sigma = \infty$ ). The conductors of the transmission line are isolated at a height  $h$  over the soil, so that its electric fields are influenced by its proximity to the soil. If the conductor has a charge  $q$ , there is a charge  $q$  distributed over the soil. The  $-q$  charge can be concentrated in a conductor at a deep  $-h$  from the soil. This conductor is a specular image of the overground conductor.

With the conductors of the phases and their images at hand, the mutual and self-capacitances of the transmission line can be obtained. These values can be allocated in a  $[C]$  matrix. To make this calculation, there is the need to obtain the potential coefficients, group them in a  $[P]$  matrix, and, then, obtain its inverse.

$$[Q] = [C][V] \quad (3)$$

The  $[C]$  matrix is symmetrical and depends only of the geometrical configuration of the

conductors.

To determine [C] matrix, the potential coefficients of the cable have to be calculated by the following equations:

$$p_{ii} = \frac{1}{2\pi\epsilon_0} \ln \frac{2h_i}{r_i} \quad (4)$$

$$p_{ij} = p_{ji} = \frac{1}{2\pi\epsilon_0} \ln \frac{D'_{ij}}{D_{ij}} \quad (5)$$

$$D_{ij} = D_{ji} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (6)$$

$$D'_{ij} = D'_{ji} = \sqrt{(x_i - x_j)^2 + (y_i + y_j)^2} \quad (7)$$

When the phases of a transmission line have a conductor with a bundle of sub-conductors, positioned uniformly over a circle of radius  $R$ , an equivalent conductor can be adopted with an equivalent radius. This equivalent radius can be interpreted as being a radius of a fictitious cylindrical conductor that has the same charge  $q$  of a cylinder of same dimension, and that produces the same electric field that the bundle of sub-conductors. The equivalent radius can be obtained by the following equation, in which  $n$  is the number of sub-conductors that forms the bundle and  $r$  is the radius of a sub-conductor.

$$r_{eq} = R^n \sqrt{\frac{nr}{R}} \quad (8)$$

### 2.3. Calculation of the electric field

Having the charges per unit length of the conductors, it is possible to obtain the total electric field generated by the superposition of the effects of the conductors and their images. Applying Gauss' Law in the integral form in the case of an infinite length conductor, in which  $d$  is the distance between the point and the conductor and  $\vec{u}_r$  is the unit vector at the radial direction, it comes that :

$$E = \frac{q}{2\pi\epsilon_0 d} \vec{u}_r \quad (9)$$

The phasorial components, in the horizontal direction,  $E_{xi}$ , and in the vertical direction,  $E_{yi}$ , represent the intensity of the electric field at point  $(x,y)$ , generated by the  $i$  conductor and its image, are calculated by the following equations :

$$E_{xi} = \frac{q_i}{2\pi\epsilon_0} \left[ \frac{X}{(X)^2 + (Y)^2} - \frac{X}{(X)^2 + (Y')^2} \right] \quad (10)$$

$$E_{yi} = \frac{q_i}{2\pi\epsilon_0} \left[ \frac{Y}{(X)^2 + (Y)^2} - \frac{Y'}{(X)^2 + (Y')^2} \right] \quad (11)$$

on which  $X = x - x_i$ ,  $Y = y - y_i$ ,  $Y' = y + y_i$ .

For  $k$  conductors, the electric field is the sum of the contribution of all the conductors of the phases and of the lightning rod cables, if these are grounded. Mathematically:

$$E_{xtotal} = \frac{1}{2\pi\epsilon_0} \sum_{k=1}^n q_k \left[ \frac{X}{(X)^2 + (Y)^2} - \frac{X}{(X)^2 + (Y')^2} \right] \quad (12)$$

$$E_{ytotal} = \frac{1}{2\pi\epsilon_0} \sum_{k=1}^n q_k \left[ \frac{Y}{(X)^2 + (Y)^2} - \frac{Y'}{(X)^2 + (Y')^2} \right] \quad (13)$$

### 3. RESULTS

The software developed can work in two modes: online and offline. The online mode is the one in which the operator can couple the software with the mesh, to get real-time information about the electric field. A simulation was run to validate the program. The data used on the simulation follow the reference to Figure 3, (Camargo, C.C.B, 2009).

- Bundle of conductors : 2 X 636 MCM per phase – 26/7, grosbeak;
- Self-supporting tower, III, plane type;
- Distance between phases : 7.50 meters;
- Minimum height of the conductor in the tower : 21.00 meters;
- Minimum distance conductor-ground : 11.65 meters;
- Distance between conductors : 0.45 meters;
- Distance between towers : 378 meters;
- Number of isolators :  $16\left(5\frac{3}{4}.10''\right)$  ;
- Lightning rod cables: 3/8', EHS class B. Two cables forming an angle of 30o in relation to the external phases and at a height of 4.56 meters in relation to the plane of the phases;
- Right-of-way: 50 meters.

It is important to highlight that the height difference in the space between towers was considered in the simulation, what gives more credibility to the software, expressed by a higher quality to the results.

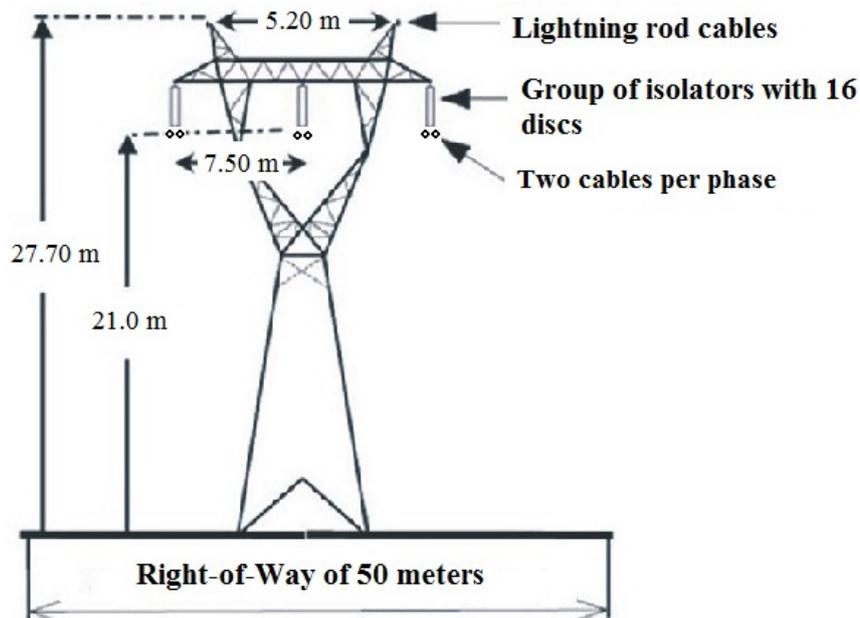


Figure 3 Model of the first structure used to run the simulation

The Figures 4 and 5 show the results of the simulation for the model of tower in Figure 3.

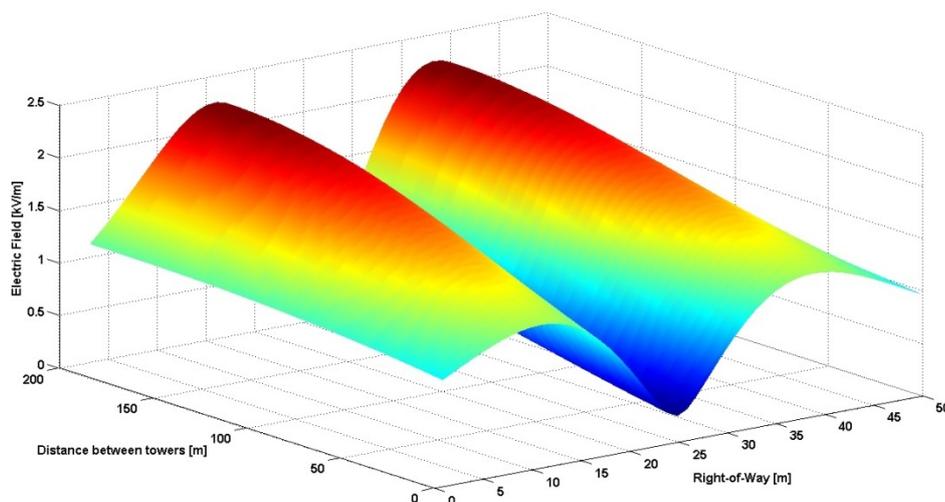


Figure 4 Electric field for the first configuration of tower

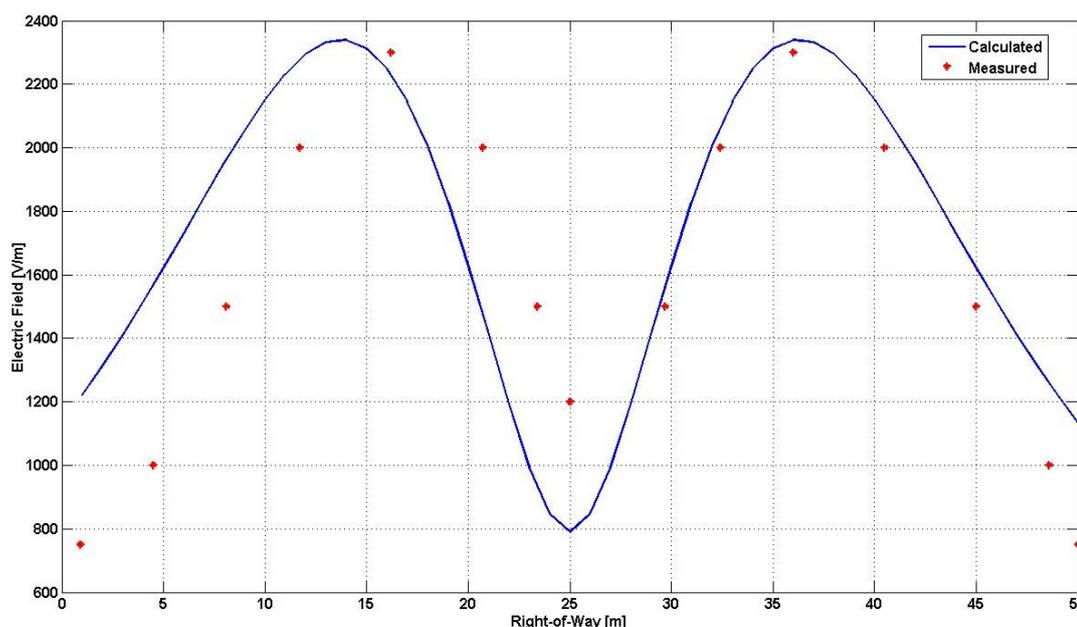


Figure 5 Comparison between calculated values, obtained with the program, and measured values

In Figure 5 it can be seen that the values of the electric field at the ends of the right-of-way do not exceed the maximum values stipulated by international rules (IRPA, International Radiation Protection Association/International Non-Ionizing Radiation Committee), which establish limits to professional people (10 kV/m, in full time work, 30 kV/m, short time work. All values are in rms, (IRPA, 1993)) and for the local population (5 kV/m, until 24 hours/day, 10 kV/m, to few hours/day. All values are in rms, (IRPA, 1993)). Those limits are important for safety of the people in the surrounding areas and for the power structure. In Figure 5, the maximum values do not exceed 2.4 kV/m and at the end of the right-of-way, they are less than 1.3 kV, which means that the values of the electric field does not exceed the limits set by standard.

#### 4. DISCUSSION

Comparing the obtained results with other conceptualized texts (Fuchs, R.D, 1972), (Camargo, C.C.B, 2009), (Domingues, et. al, 2003), it can be noticed that the values are coherent. It is highlighted that the magnitude of the electric field varies with the height of the conductors. At the middle of the distance between towers, the intensity of the field is maximum, because the height between cable and soil is minimum, in the case of flat terrains, as can be seen in the results.

It is also important to emphasize that the distance between conductors increase the capacitive effect between them decreases. It is the reason for the reduction of the electric field values in the simulation.

#### 5. CONCLUSION

The values of the electric fields not exceed the values established on international rules, what provides safety to the surroundings of the towers analyzed. The main contribution of this paper is the development of an embedded system that can monitor the electric fields in real-time. Although the calculations are implemented for two-dimensional fields, the program is able to calculate all the two-dimensional slices of the fields along the distance between towers and, with these slices together, it can generate a 3-D graph of the profile of the electric field. The software can be used in two modes: online and offline. The online mode can be coupled to the electric network, so that the competent agencies can observe the electrical field levels of the facilities.

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#### 7. REFERENCES

- DENO, D. W., 1976. Transmission line fields. *IEEE Trans on PAS*, Vol. 95, 5, pp. 1600-1611, September/October. 1976.
- Fuchs, R.D., 1972. Fuchs, *Transmissão de Energia Elétrica*. 2nd ed. São Paulo.
- Sadiku, M.O.S., 2000. *Elements of Electromagnetics*, 3rd ed. New York. Oxford University Press.
- Camargo, C.C.B., 2009. *Transmissão de Energia Elétrica: Aspectos Fundamentais*. 4th ed. Editora UFSC.
- Domingues, 2003. Mapeamento de Campos Eletromagnéticos em Linhas do Sistema de Transmissão de FURNAS (138 kV-765 kV). In: *XVII - SNPTEE, 2003, Uberlândia*. XVII – SNPTEE.
- International Radiation Protection Association, 1993. International Non-Ionizing Radiation Committee – *Protection of Workers from Power Frequency Electric and Magnetic Fields: A Practical Guide*. Geneva, International Labour Office, 1993 (Occupational Safety and Health Series nº 69).
- Microchip's datasheet of PIC 16F87XA.
- Sanches, J., Canton, Maria P., 2007. *Microcontroller Programing: The Microchip PIC*. Florida.
- Bates, M., 2006. *Interfacing PIC Microcontrollers: Embedded Design by Interactive Simulation*. Oxford.
- Perez, F.E.V, Areny, R.P., 2009. *Microcontroller: Fundamentals and Applications with PIC*. Florida.