Evaluation and Modeling of the Variation of Electromagnetic Field on the Cross Section of a Transmission Line Using Finite Difference Method

Silva O, Jorge Ivan
jsilva6@cuc.edu.co
GIOPEN group researcher, Universidad de la Costa
Barranquilla, 080005, Colombia

Hernández H., Hernan
hhernand16@cuc.edu.co
GIOPEN group researcher, Universidad de la Costa
Barranquilla, 080005, Colombia

Gomez S, Elibardo J
elijosegomez@gmail.com
Account program, Corporación Universitaria Latinoamericana
Barranquilla, 080005, Colombia

ABSTRACT

This paper present a purpose to characterize power lines in order to identify level of operation since the power grid planning. In order to model a power line was required the use of computational tools to generate a mathematical model in MATLAB, which was based on the finite difference method and represent the electromagnetic field (EMF) contribution. The results were contrasted with real and measured values taken from a cross section of a power line that was previously modeled. Statistical analysis showed an accurate estimation of the electric and magnetic field emitted by the line identifying the same shape of the plotted curve and values in an acceptable range.

Keywords-power lines; mathematical model; cross section; electric field; magnetic field.

1. INTRODUCTION

Electrical systems and their active elements during normal operation generate electric and magnetic fields that changes according with the properties of the design, disposition of equipment, current and voltage levels of operation. These results will be used in order to characterize power lines and will be used as a tool to power operators with the aim of reduce legal issues from planning.

The Technical Regulation for electrical installations (RETIE) in Colombia and the International Commission on Non-Ionizing Radiation Protection (ICNIRP), established a permissible range of operation for electrical and electronics equipment such as power lines, communication systems and antennas, however during the installation of new equipment or extending power grid, there is not calculated the contribution of EMF emitted and their changes during operation [1], [2], [3].

There was done a review of regulation and theory of electromagnetic field generated by elements in power system [4], [5], [6]. This information was required to do a process to gather information in order to model a power line using computational tools [7], there was purposed a model considering the conditions of operations of transmission lines of one circuit and were done measurements in a random power line according with the specifications of the model, located in the urban area of Barranquilla, Colombia [8], [9], [10].

Finite difference Method and the load simulation method are the two common methods used to estimate electric and magnetic fields from a specific points in a profile of a power line, these methods are the most used and include as a data base fixed values for which is desired to know the distribution of electric field on a space [11].

A. Finite Difference Method.

Considering the values of the points showed in in figure 1 and using mathematical modeling to approach to an initial condition [12], [13].

$$\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} = \frac{-\rho_s}{\varepsilon} \qquad (Eq.\ 1)$$

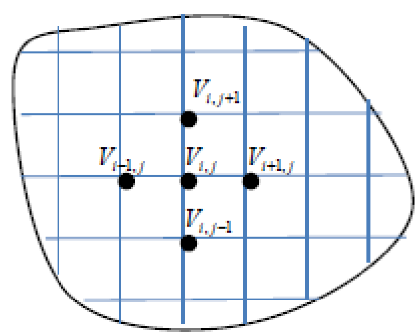

Figure 1. Initial case condition considering voltage at specific points.

For the initial conditions is consider the point (x_0, y_0):

$$\left.\frac{\partial^2 V}{\partial x^2}\right|_{x=x_0} = \frac{V_{i+1,j} - 2V_{i,j} + V_{i-1,j}}{(\Delta x)^2} \qquad (Eq.\ 2)$$

$$\left.\frac{\partial^2 V}{\partial y^2}\right|_{y=y_0} = \frac{V_{i,j+1} - 2V_{i,j} + V_{i,j-1}}{(\Delta y)^2} \qquad (Eq.\ 3)$$

Replacing (Eq. 1 and (Eq. 2 in (Eq. 3 and considering $\rho_s = 0$ [12], [14], it is obtained:

$$V_{i,j} = \frac{1}{4}\left(V_{i+1,j} + V_{i-1,j} + V_{i,j+1} + V_{i,j-1}\right) \qquad \textit{(Eq. 4)}$$

Finally, to estimate the electric and magnetic field is used the second Maxwell equation and the third law of faraday considering time variation respectively.

$$E_{i,j} = -\nabla V_{i,j} \qquad \textit{(Eq. 5)}$$

$$B_{i,j} = -\oint \nabla \times E_{i,j}\, \partial t \qquad \textit{(Eq. 6)}$$

The finite differences method assigning values to nodes and applying (Eq. 4, for all the free node to estimate the potential value, then it is repeated the process for all nodes taking as reference the previous value of the iteration. Finally, this procedure is repeated until to reach a minimal error in the iteration process

B. Load Simulation.

The load simulation method employ elements with idealized loads which are located inside of a wire in order to represent the real conditions of power lines. The definition of the region, number of points, number of elements is chosen according the estimation error desired in contrast with real values [15],

The method considers particular solutions using the Laplace and Poisson equation, and taking in consideration that the solution is unique outside of the space occupied by the wire [16]. The solution relates the potential produced by n different loads as is expressed in the following equation:

$$V = \sum_{j=1}^{n} \frac{Q_j}{R_j} \qquad \textit{(Eq. 7)}$$

Where,
Q, corresponds to the load in a point.
R, the distance between the point and the load.
V, is the voltage is the potential produced by the element.

Finally, the contribution of electric and magnetic field as detailed in (Eq. 5 and (Eq. 6. To implement the load simulation method many authors suggest the following procedure:

- Identify zones or partial regions considered as equipotential values.
- Select the type of element suitable for modeling each area.
- Locate all the load points.
- Choose points to validate the values of the surface. Considering, that number of points is equal to the number of load elements.

This paper present results in the research *"Development of gridding method to estimate electromagnetic fields levels on power system elements during steady state."* The results will be chosen to characterize power lines and use the results for future events and similar structures where it is unknown the contribution of electric and magnetic field of a system [17], [18]. The survey is focused on the development of planning strategies with power lines modeling in order to avoid that during new project there could be considered the electromagnetic field propagation in urban and rural areas.

2. METHOD

The methodological process considered consequent stages. There was analyzed the information provided by the power operation and based on the regulatory revision, evaluating the power line considered the recommendations given in the standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines (STD IEEE 644). The evaluation of power line considered the nominal operation and specifications of the power line [2].

Table 1. Technical information of power line evaluated.

Type of power line	Air – Single circuit
Rated Value:	110 kV.
Origin of the line:	Substation A
Year built:	1993
Total distance:	3,8 Km
Type of cable:	AAAC
Area:	827,2 MCM
Number of structures:	34
Type of structure:	Concrete

Subsequently, there was done the development of an algorithm in MATLAB using on which was considered the transverse profile of a power transmission line. This study aims to analyze the variation of EMF respect with the topology used and the physical specifications of the structures in which is installed [2].

The computational modeling developed provide the variation of the properties of the power lines with time one circuit in order to determine electromagnetic fields variation in all points along the power line structure analyzed.

In order to validate the simulation there were considered the measured values in the distribution power line chosen and analyzed previously according with the STD IEEE 644 there were taken into account the following conditions [2]:

- Measurements must be realized at a height of one meter taking as reference the ground. If it is done a measure in other height it must be specified and justified.
- Distance between the meter and the operator must be at least 2.5 meters.
- Approaching to the meter must be registered.
- Asymmetries of the electric field meters can change the direction of the axial components with respect to the vertical coordinate of interest.
- Distance between the meter and objects located during measures must be separated with more than one meter.

Finally, there was done a comparison of power lines topologies in order to evidence the behavior of the model trying to simulate certain condition of operation specified by the operator [19]. This tool will be helpful due to modern and advance software's to simulate electromagnetic fields propagation are very expensive and many power grid planners could use this in order to guarantee a correct operation of equipment. This survey could be also extended to power stations and power transformers.

3. RESULTS

The simulation developed started considering the mathematical model known for the behavior of electromagnetic fields in power lines and start including the parameters of operation of the power line such as the established in Table 1.

The location of the cables on the power line, the height and separation from the reference point also is considered during the modelling process as input data in order to characterize the power line structure. Also could be asked to the power grid operator specific information of power demanded during the last year or in the case of grid planning, the maximum estimated value of power that will be demanded through the power line.

Figure 2 and

Figure 3 represent the simulated values of magnetic and electric field in the selected power line. The simulation load method and the application of Faraday Law were used in order to model the power line and obtain the electromagnetic field estimated to the power line in study.

After modelling the electromagnetic field contribution of the power line were measured real values of operation in the power line modeled in order to validate the approximation of the modelling. This results are presented in Table 2.

Table 2. Measured value of a transmission line selected to study.

Distance	Electric Field (V/m)	Magnetic Field (uT)
-30	0,8	0,5
-25	8,4	0,7
-20	16,1	0,9
-15	36,7	1,3
-10	57,4	1,8
-5	56,0	2,3
-1	54,7	3,2
0	54,5	6,0
1	38,0	6,4
5	24,9	2,4
10	11,7	1,9
15	7,1	1,4
20	2,4	1,040
25	1,9	0,719
30	1,3	0,609

Then, there was done a comparison between measured values and simulated valued in order to identify the approach between the results. There was used scattered plots and statistical analysis in order to validate the proximity of the modelling process taking into account that the mathematical model require the power, voltage, current and frequency of operation of the power line in the specific moment. Figure 4 present the contrasted results and can be observed the same exponential behavior of both graphs. The results obtained give an economical option in order to

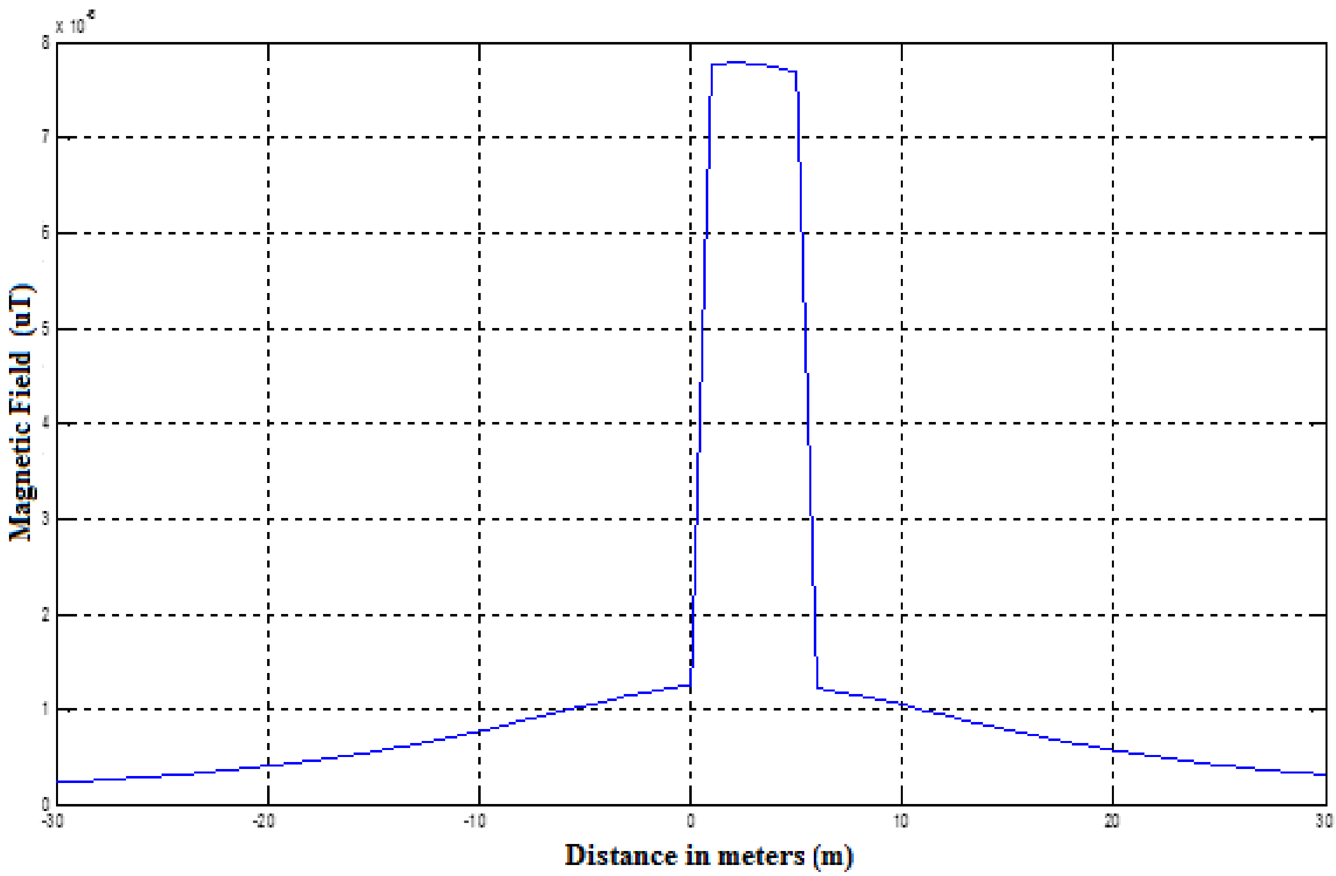

Figure 2. Simulated magnetic field value in a cross section of a power line.

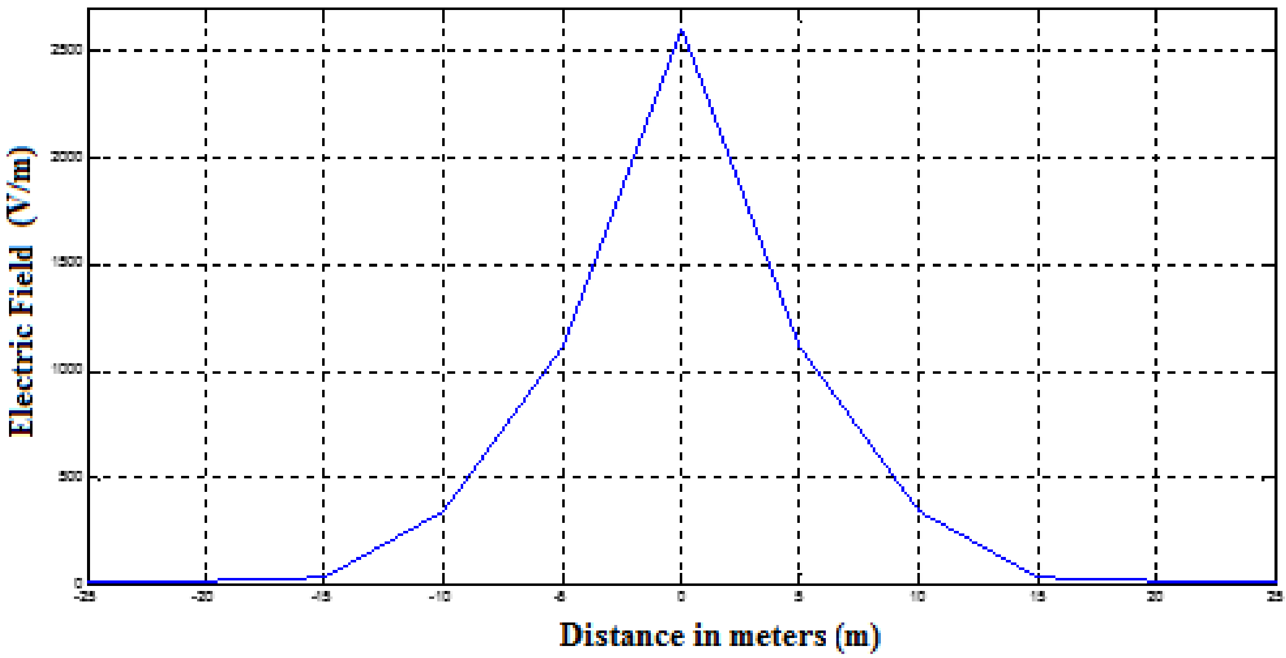

Figure 4. Simulated electric field values in a la cross section of a power line.

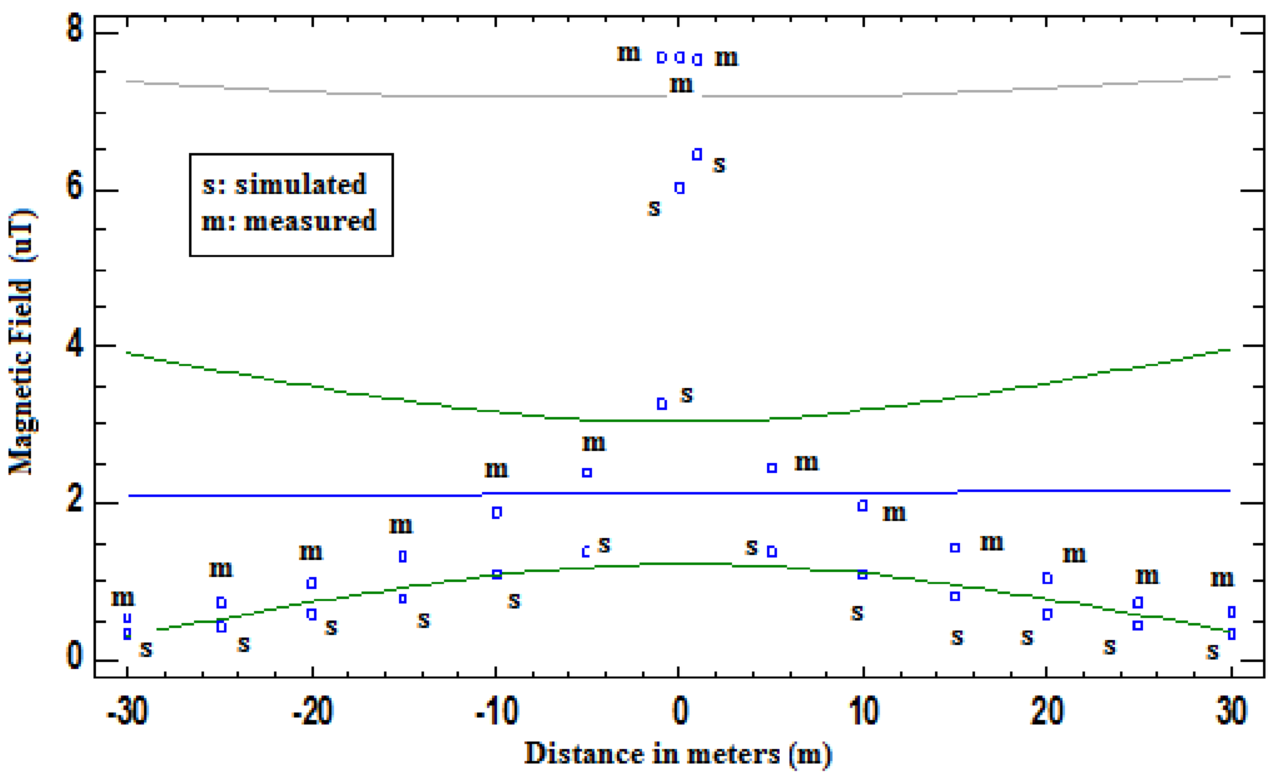

Figure 3. Scatter plot of the obtained results.

validate the design of power lines and to take into account by power grid planners during the design due to it is a mandatory requirement established by the ICNIRP and also in Colombia is established in the RETIE.

In many cases, the software's that develop these estimations are very expensive and power grid planners of the countries are not able to support their maintenance and licenses which implicate that the costs of the designs become higher to the grid operator, increasing the cost of final users in many cases. This modelling process could be helpful in countries and regions where are promoted the designs that must require as mandatory the ICNIRP recommendation for non-ionizing radiation and that must be required since the planning process [20].

Also there is projected to continue the survey making comparison with different topologies of the structure in order to identify which types of cable arrangement provide the less amount of electromagnetic field propagation in order to reduce the non-ionizing radiation generated by the air transmission lines used nowadays.

4. CONCLUSIONS

A power line using mathematical modeling based on finite element method was represented in MATLAB. The use of measured values allowed the validation of the model, obtaining results in a range of permissible errors as was shown in Figure 4 during the statistical analysis and comparison.

This solution will provide information about the electromagnetic field behavior considering the nominal values of operation of power line such as power, current, voltage and frequency. Also there are compared real values with simulated values in order to guarantee an acceptable approach between them.

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