Proceedings of the 10th World Congress on Electrical Engineering and Computer Systems and Sciences (EECSS'24)
Barcelona, Spain - August 19 - 21, 2024
Paper No. EEE 125
DOI: 10.11159/eee24.125

Strategy to Reduce the Electric Field in Transmission Lines, Modifying the Geometry of the Tower and Its Bundle Configuration

Luis Imbachi[1], Mario Rodriguez[2]
[1]University Distrital Francisco José de Caldas
Cl. 68d Bis A Sur #49F - 70, Bogotá DC, Colombia
lfimbachig@udistrital.edu.co; marodriguezb@udistrital.edu.co
[2]Universidad Distrital Francisco José de Caldas
Cl. 68d Bis A Sur #49F - 70, Bogotá DC, Colombia

Abstract – This article presents a methodology designed to reduce the electric field in both single and double circuit overhead transmission lines. To achieve this objective, the computational tool called EMFC-DoubleCTL is used, which was developed in the MATLAB App Designer environment by the CEM Research Group of the Francisco José de Caldas District University. This tool has a friendly and intuitive interface that allows obtaining results with acceptable accuracy and low computational time compared to specialized software in the electromagnetic area. EMFC-DoubleCTL allows adjust parameters associated with the configuration of the three-phase system, the geometry of the line and the bundle of conductors, to subsequently obtain the results of the capacitance matrix, the magnitude of the field in effective value, horizontal and vertical component variant in time and field ellipse. One of the most notable characteristics of the tool is that in many cases, obtaining the results associated with the electric and magnetic field in transmission lines turns out to be tedious, since simulators such as COMSOL require separate calculations and parameterizations for the time and frequency domain. On the other hand, EMFC-DoubleCTL is capable of providing these graphs in a single module, which simplifies the parameterization of the line under study. This methodology is designed to be applied to a case study in which the original geometry of the line will be used and changes will be made both in its geometry and in the bundle configuration of the conductors, in order to evaluate whether these changes allow reduce the magnitude of the electric field in the bonded area expressed in effective value with respect to the original configuration.

Keywords**:** Electric field, transmission lines, geometry, easement area, EMFC-DoubleCTL, MATLAB

1. Introduction

Studying how electric fields generated by overhead transmission lines affect humans and the environment has become increasingly important in electrical engineering and public health. Although the **International Commission on Non-Ionizing Radiation Protection (ICNIRP)** has established exposure limits at low frequencies (*f:* 50/60 Hz) according to the formula $E=(250/f\,[kV])$ [1], the authors of different research works during the last decades, suggest investigating further both the long-term effects of FEM-ELF on living beings and their environment [2]-[3]-[4], as well as the methodologies to reduce the magnitude of said fields. However, these do not exceed the values established by international regulations in some cases[5]-[6]-[7]-[8].

During the last decades, some researchers have developed methodologies that allow reducing the electric field generated by overhead transmission lines, and for which they have considered the variation of different parameters associated with both the geometry of the line and the voltage and current levels [9]-[10]-[11]-[12], and although its effectiveness in some cases has been satisfactory, these could be improved if combined methodologies are used, which consider multiple design variables simultaneously. Therefore, the need arises to develop a methodology that takes advantage of the inclusion of different design variables and optimization algorithms to address this problem.

The methodology proposed in this document is related to the adjustment of the geometry of the line and the configuration of the conductor bundle, in which the effect that each adjustment has separately will be analyzed, and finally, a scenario in which the combined effect of these strategies in order to be able to analyze on a percentage basis whether there is a reduction in the electric field profile in double circuit transmission lines, considering the effect of the guard wires and using a computational tool to perform the calculations and obtain both numerical and graphical results. This tool offers a series of features, among which the following stand out: 1) It was designed with a modular programming architecture. The purpose of this architecture is to include various types of analysis without the need to modify the simulator's core. 2) Offers the flexibility to implement any dual circuit configuration, regardless of the number of conductors per phase, the sequence between the two circuits, and the voltage level. 3) An updated driver database makes it easy to include commercial drivers in the analysis. 4) It has a module to export results in both the time and complex domains. This module also allows you to export the figures generated during the simulation process in vectorized format and files in *.xlsx format. 5) Allows generating additional results, such as the capacitance matrix, the impedance matrix, linear charge densities on the conductors, field ellipses, surface charge densities on the ground surface, and current densities on the ground surface, among others. 6) The interface is friendly, which reduces training times for its manipulation. 7) Offers reduced processing times and low hardware requirements.

`

The methodology developed in this document includes four stages, the first corresponding to the mathematical formulation of the electric field for single and double circuit overhead transmission lines, the second to their implementation in the MATLAB App Designer programming environment, and the third in the choice of study cases defining how to modify the parameters associated with the geometry of the line and the configuration of the conductor bundle, to finally, in the results stage, analyze how effective the proposed methodology is in reducing the electric field in easement area[13].

2.1. Mathematical Formulation

2.1.1. Electric Field Intensity

The analysis considers the ground a perfectly conductive element with utterly flat terrain and infinite lines on the ground's surface. To calculate the electric field intensity **E** generated by the transmission line, the linear charge densities ρ_{L_k}, are determined (where k is the number of conductors in the system, including the guard ones), associated with each one of the conductors and their images based on the Maxwell coefficient matrix and the supply voltages of the conductors [13].

$$[\mathrm{V}] = [\mathrm{P}]\left[\rho_{\mathrm{L_k}}\right] \tag{1}$$

Solving $\left[\rho_{\mathrm{L_k}}\right]$, we obtain:

$$\left[\rho_{\mathrm{L_k}}\right] = [\mathrm{P}]^{-1}[\mathrm{V}] \tag{2}$$

Once the vector of linear charge densities$\left[\rho_{\mathrm{L_k}}\right]$, has been determined from the matrix product between the inverse of the Maxwell coefficient matrix [P] and the phase voltages vector of the system [V], The electric field intensity **E** is determined considering the fundamental conductors and their corresponding images. Taking into account the above, the vertical and horizontal components of the electric field generated by the transmission line for the single-phase case are given by equations (3) and (4), respectively:

$$\mathbf{E}_{\mathrm{x_1}} = \left(\frac{\rho_{L_1}}{2\pi\varepsilon_0}\right)\left(\frac{x - x_i}{(x - x_i)^2 + (y - y_i)^2} - \frac{x - x_i}{(x - x_i)^2 + (y + y_i)^2}\right)\boldsymbol{a_x}\left[\frac{\mathrm{V}}{\mathrm{m}}\right] \tag{3}$$

$$\mathbf{E}_{\mathrm{y_1}} = \left(\frac{\rho_{L_1}}{2\pi\varepsilon_0}\right)\left(\frac{y - y_i}{(x - x_i)^2 + (y - y_i)^2} - \frac{y + y_i}{(x - x_i)^2 + (y + y_i)^2}\right)\boldsymbol{a_y}\left[\frac{\mathrm{V}}{\mathrm{m}}\right] \tag{4}$$

Where x, y correspond to the coordinates of the calculation point, and x_i, y_i are the coordinates of the fundamental conductors and their images. For the three-phase case, both for the single and double circuit, considering the number of conductors in the system as k, the total electric field intensity will be given by equation (5).

$$\mathbf{E} = \left(\sum_{i=1}^{k} E_{x_i}\right)\boldsymbol{a}_{\boldsymbol{x}} + \left(\sum_{i=1}^{k} E_{y_i}\right)\boldsymbol{a}_{\boldsymbol{y}}\left[\frac{\mathrm{V}}{\mathrm{m}}\right] \tag{5}$$

2.2. DoubleCTL Development and Construction of EMFC-DoubleCTL

The construction of the **EMFC-DoubleCTL** computational tool is based on the design of a graphical interface by modules, which represents an improved version of **CEMLT**, since the latter considered only single circuit transmission lines both for obtaining the electric field and magnetic and also the model in transmission line sequence components. In contrast, **EMFC-DoubleCTL** considers the modeling and calculating of electric and magnetic fields in double circuit configurations, representing a significant improvement over the previous version. Fig. 1 shows the graphical interface of the main menu of the application developed in **MATLAB.**

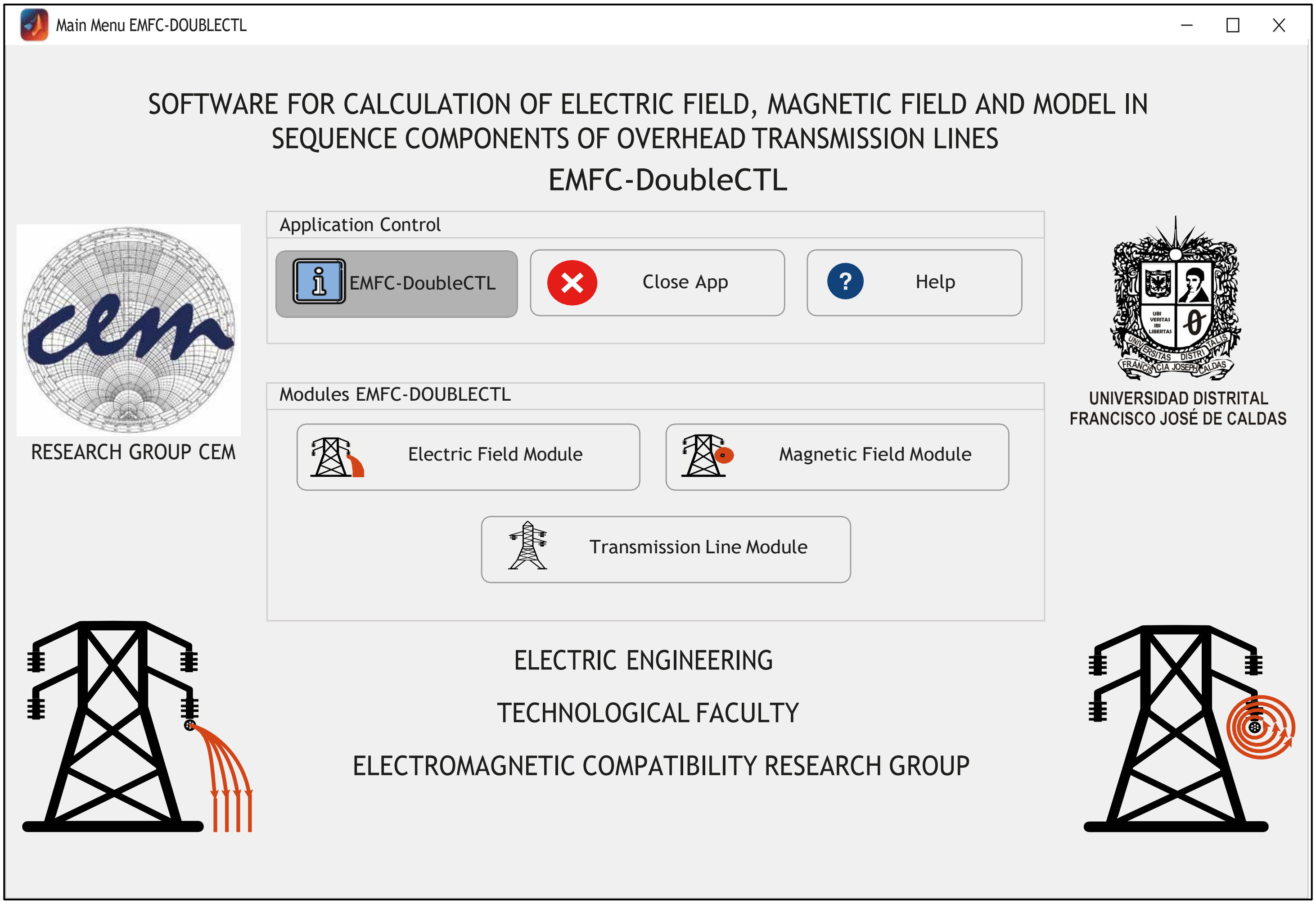

Fig. 1 The graphical interface of the main menu of the application developed in MATLAB.

On the other hand, Fig. 2 shows a flow chart that shows the logical sequence for solving a problem associated with calculating the electric field in single—and double-circuit transmission lines.

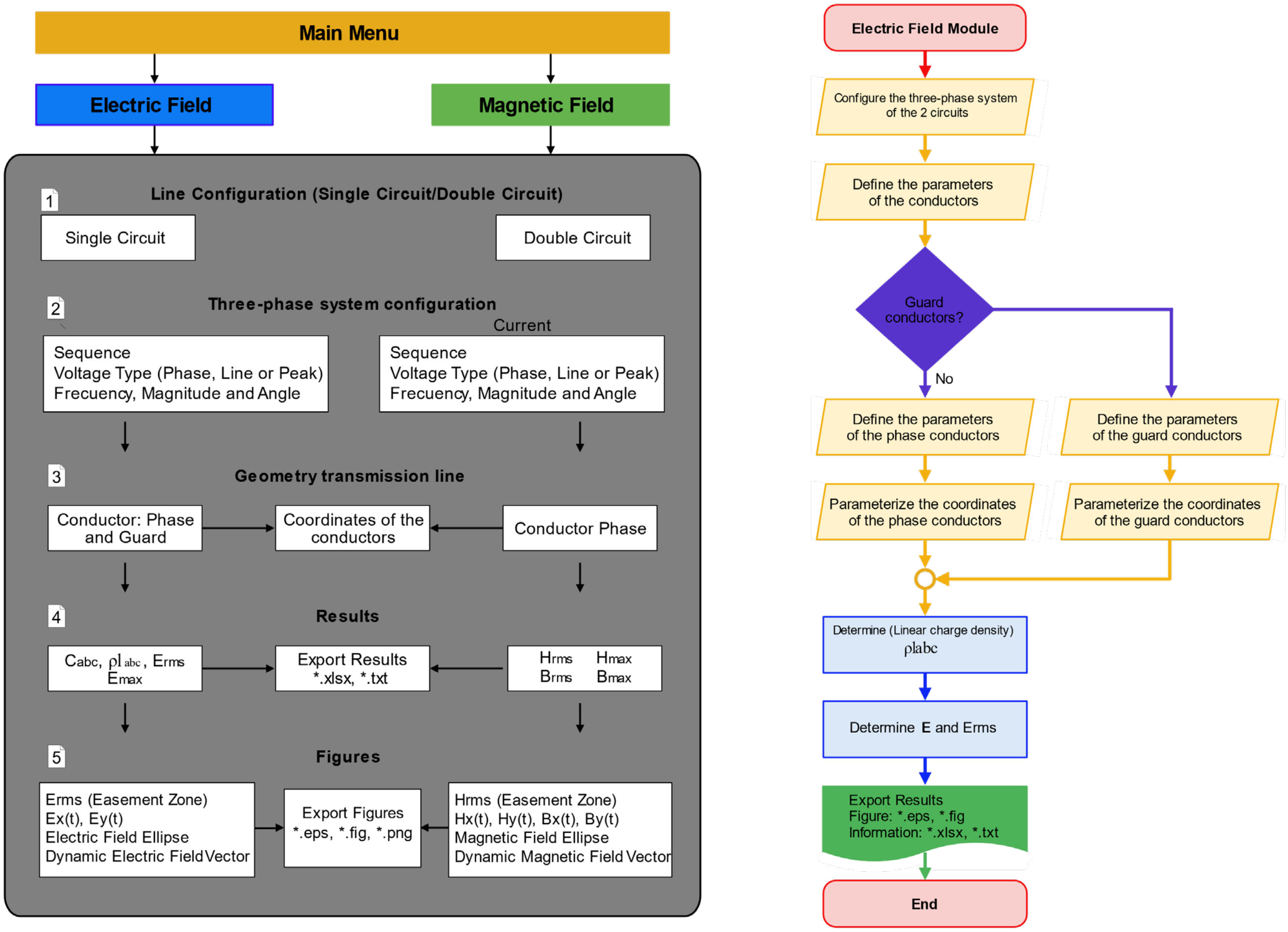

Fig. 2 EMFC-DoubleCTL Tool Block Diagram and Electric field module flowchart

It is important to note that although the tool allows the calculation of both the electric and magnetic fields, the scope of this article is limited only to the calculation of the electric field.

2.3. Study cases

What was mentioned above, below are the characteristics of the case study chosen for this article:

2.3.1 Case No. 1

Case 1 corresponds to the transmission line under construction for the interconnection project between Peru and Ecuador. In Peru, the project consists of 500 kV double circuit towers, which start from the Piura Nueva substation and move to the Frontera substation [14]. Each transmission line phase comprises 4 ACAR 800 MCM aluminum alloy conductors separated by 40 cm in the conductor bundle and two guard cables. The conductors are supported in metal lattice structures, self-supporting vertical configuration type [14]. Fig. 3 presents the arrangement of the conductors in the transmission tower. Likewise, Table 1 presents the characteristics of the phase conductors and the parameters of the Piura Nueva-Frontera transmission line.

Table 1 Characteristics and parameters of the Piura Nueva-Frontera line

Line configuration	**Line r.m.s voltage [kV]**	**Maximum line current [kA]**

Double Circuit	500	1.8
Number of sub conductors	**Sub Conductor spacing [cm]**	**Frequency [Hz]**
4	40	60
Cable type and gauge KCMIL	**RMG phase conductor [mm]**	**Type of line**
ACAR (18/19) 800	11.90	Vertical

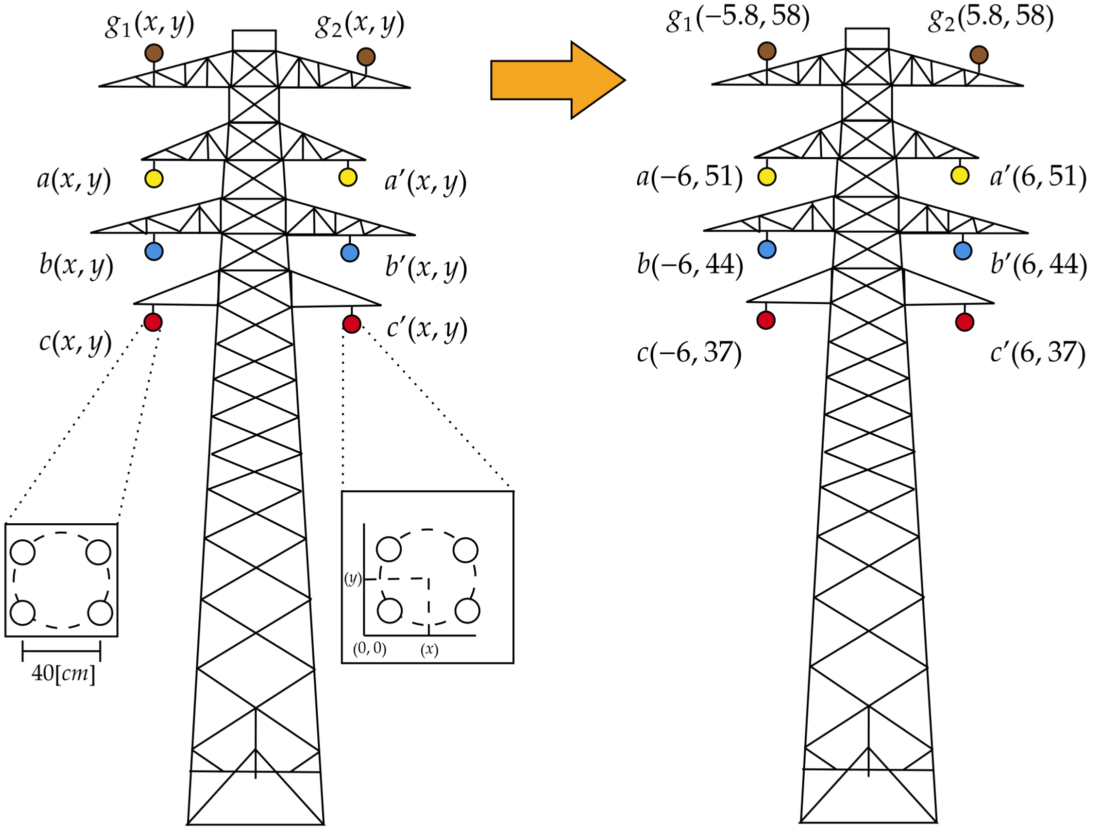

Fig. 3 500 [KV] transmission tower. Coordinates in meters

For this case study, 6 scenarios are analyzed which involve changes in 3 aspects such as the geometry of the line, the conductor bundle configuration and the phase sequence. These changes are mentioned below:

2.3.1.1 Scenario 1 of Case Study 1

In this scenario, the original configuration shown in Fig. 3 and with the characteristics of Table 1

2.3.1.2 Scenario 2 of case study 1

In this scenario, an asymmetric movement in the geometry of the line is considered, modifying the height of the conductors of circuit 2 by 1m, but preserving the original height of the conductors of circuit 1.

2.3.1.3 Scenario 3 of Case Study 1

In this scenario, the original configuration of a 4-conductor bundle is preserved, but now the height and separation between the phases is varied. Considering that these changes should not represent significant inconveniences from the structural point of view of the tower, the changes associated with this geometry correspond to modifying, in circuit 2, the height of the phases by 1m and horizontally moving each of the phases by 1m, preserving the original geometry for circuit 1

2.3.1.4 Scenario 4 of Case Study 1

In this scenario, a meticulous change is made to the bundle configuration of the conductors, transitioning to a configuration of 3 conductors per phase. However, the conductor gauge remains the same, supporting a current of 861A. It's important to note that despite these adjustments, the design of the line remains unchanged in terms of energy transmission capacity and conductor sizing. This meticulous approach ensures the stability and reliability of the system.

2.3.1.5 Scenario 5 of case study 1

In this scenario, a modification is considered in the phase sequence of circuits 1 and 2 of the transmission line, taking as reference the positive sequence (a, b, c) in the case of circuit 1, while for circuit 2 the following sequence (c, b, a)

2.3.1.6 Scenario 6 of case study 1

In this scenario, the adjustments made in scenarios three, four and five shown above are combined.

The results obtained in EMFC-DoubleCTL for the field at point P (0,1) [m] are presented in Table 2.

Table 2 The results obtained in EMFC-DoubleCTL for the field at point P (0,1) [m]

Electric Field Intensity [V/m] (Scenario 1 of Case Study 1)			
Magnitude/Angle	**Horizontal component of the field [RMS]**	**Vertical component of the field [RMS]**	**Field Magnitude [V/m] "RMS"**
Magnitude [V/m]	0	1961.72	1961.72
Angle [°]	0	-78.01	
Electric Field Intensity [V/m] (Scenario 2 of Case Study 1)			
Magnitude [V/m]	0.60	1922.09	1922.09
Angle [°]	84.46	-77.94	
Electric Field Intensity [V/m] (Scenario 3 of Case Study 1)			
Magnitude [V/m]	1.31	1919.76	1919.76
Angle [°]	-73.65	-77.71	
Electric Field Intensity [V/m] (Scenario 4 of Case Study 1)			
Magnitude [V/m]	0	1811.40	1811.40
Angle [°]	0	-77.14	
Electric Field Intensity [V/m] (Scenario 5 of Case Study 1)			
Magnitude [V/m]	35.8197	606.5621	607.6188
Angle [°]	120	-150	
Electric Field Intensity [V/m] (Scenario 6 of Case Study 1)			
Magnitude [V/m]	30.0146	509.0844	509.9684
Angle [°]	120	-150	

Finally, Fig. 4 shows the profile of the norm of the electric field intensity in the easement area at a height of 1m from the ground level, that is, at a point (0,1) for the six scenarios. This is done to graphically observe how the changes made affect both the configuration of the conductor bundle and the geometry of the line.

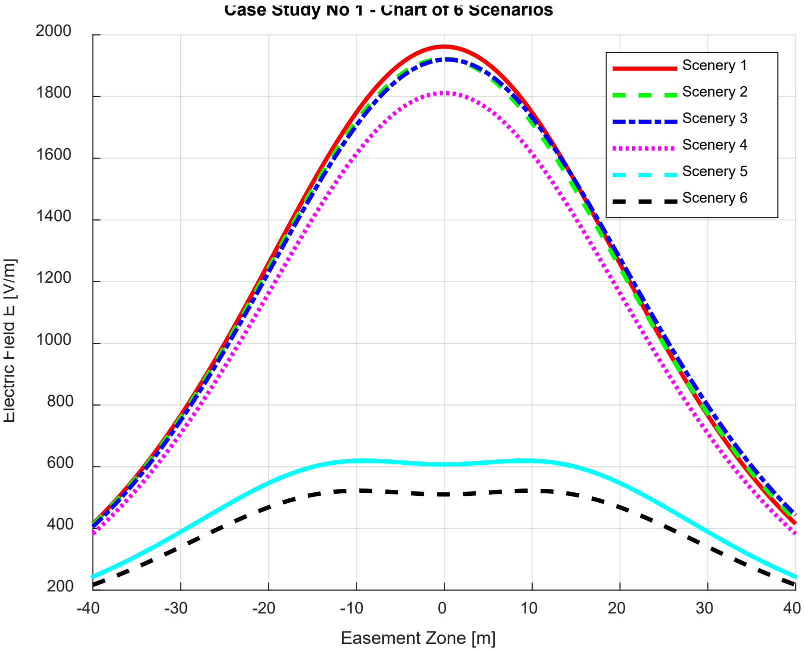

Fig. 4 Results of the Electrical Field Profile in the Easement Zone

Fig. 4 allows us to show that the effect of changing the configuration of the bundle of conductors, the geometry and the phase sequence is positive in terms of reduction of the electric field in the bonded zone since, with respect to the initial configuration, the Scenarios 2, 3 and 4 allow the field to be reduced by 1.98%, 4.00% and 7.66% respectively, while scenario 5 allows it to be reduced by up to 69.02%, but it is important to highlight that scenarios 4 and 5 are the ones with the least changes implies from the point of view of civil and structural works. However, scenario 6 shows us that if it were possible to combine the advantages of scenarios 2, 3, 4 and 5, quite significant improvements could be achieved in the electric field profile in the easement area.

4. Conclusion

The development of this research made it possible to demonstrate the impact that the configuration of the conductor bundle, the geometry of the line and the sequence of phases have on the electric field profile in the easement zone, which was positive, and although the changes made As for the beam configuration, they are based on the sizing of the conductors, the adjustment made in the geometry is not supported by any strategy or theoretical foundation, which is why future work related to this article aims to design a methodology that takes advantage the optimization algorithms and the high-level and open access programming language "Julia", which is a relatively new language, since public access to it was presented in 2012, so the research that has made use of this tool is very few, particularly in the area of electrical engineering, the works [15] and [16] can be highlighted, which are oriented towards efficient energy management. Therefore, the objective is to implement an optimization model that allows us to obtain an optimal configuration of conductors and in this way guarantee that the designs of transmission lines that intend to control the electric field in the easement zone have a foundation in this work a well-founded theory. It is important to note that to the best of our knowledge this is the first time that Julia will be applied to electric field reduction problems in overhead transmission lines.

Tools such as EMFC-DoubleCTL allow teachers and students to obtain precise results in quite a short time and perform analysis of problems that are theoretically complex from the point of view of calculations and that require carrying out many simulations for a problem. In particular, which the CEM Research Group plans to develop some free access applications in the future that allow students and researchers to solve problems associated with the area of Electromagnetic Compatibility in a simple and fast way.

5. References

[1] ICNIRP, "Recomendaciones para limitar la exposición a campos electricos,magneticos y electromagneticos (hasta 300 GHz)," *Health Phys.*, p. 48, 1977, [Online]. Available: http://www.icnirp.org/cms/upload/publications/ICNIRPemfgdlesp.pdf

[2] A. Sendera, J. Adamczyk-Grochala, B. Pikuła, M. Cholewa, and A. Banaś-Ząbczyk, "Electromagnetic field (50 Hz) enhance metabolic potential and induce adaptive/reprogramming response mediated by the increase of N6-methyladenosine RNA methylation in adipose-derived mesenchymal stem cells in vitro," *Toxicol. Vitr.*, vol. 95, no. April 2023, 2024, doi: 10.1016/j.tiv.2023.105743.

[3] M. A. Molina-Montenegro, "Electromagnetic fields disrupt the pollination service by honeybees," *Sci. Adv.*, vol. 9, no. 19, 2023, doi: 10.1126/sciadv.adh1455.

[4] J. Martel, S. H. Chang, G. Chevalier, D. M. Ojcius, and J. D. Young, "Influence of electromagnetic fields on the circadian rhythm: Implications for human health and disease," *Biomed. J.*, vol. 46, no. 1, pp. 48–59, 2023, doi: 10.1016/j.bj.2023.01.003.

[5] S. A. Ghani, M. S. A. Khiar, I. S. Chairul, N. H. Rahim, and S. N. M. A. Hashim, "Effects of parameter adjustment on the electromagnetic field of an overhead power transmission line model," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 30, no. 2, pp. 643–650, 2023, doi: 10.11591/ijeecs.v30.i2.pp643-650.

[6] M. S. H. Al Salameh and S. M. K. Alnemrawi, "Ant Lion Optimization to Minimize Emissions of Power Transmission Lines," *Prog. Electromagn. Res. M*, vol. 110, no. May, pp. 171–184, 2022, doi: 10.2528/PIERM22040605.

[7] A. L. Paganotti, R. R. Saldanha, A. C. Lisboa, M. M. Afonso, M. Q. Melo, and M. A. O. Schroeder, "Methodology for minimizing electric field at ground level from transmission lines using sensitivity analysis," *J. Microwaves, Optoelectron. Electromagn. Appl.*, vol. 20, no. 4, pp. 702–713, 2021, doi: 10.1590/2179-10742021V20I4254763.

[8] J. C. Bravo-Rodríguez, J. C. Del-Pino-López, and P. Cruz-Romero, "A survey on optimization techniques applied to magnetic field mitigation in power systems," *Energies*, vol. 12, no. 7, 2019, doi: 10.3390/en12071332.

[9] J. S. Acosta and M. C. Tavares, "Optimal selection and positioning of conductors in multi-circuit overhead transmission lines using evolutionary computing," *Electr. Power Syst. Res.*, vol. 180, no. October 2019, p. 106174, 2020, doi: 10.1016/j.epsr.2019.106174.

[10] R. Wang, J. Tian, F. Wu, Z. Zhang, and H. Liu, "PSO/GA combined with charge simulation method for the electric field under transmission lines in 3D calculation model," *Electron.*, vol. 8, no. 10, pp. 1–18, 2019, doi: 10.3390/electronics8101140.

[11] A. Carsimamovic, A. Mujezinovic, Z. Bajramovic, I. Turkovic, M. Kosarac, and K. Stankovic, "Origin and mitigation of increased electric fields at high voltage transmission line conductors," *Int. J. Electr. Power Energy Syst.*, vol. 104, no. January 2018, pp. 134–149, 2019, doi: 10.1016/j.ijepes.2018.06.049.

[12] R. Djekidel, S. A. Bessedik, P. Spiteri, and D. Mahi, "Passive mitigation for magnetic coupling between HV power line and aerial pipeline using PSO algorithms optimization," *Electr. Power Syst. Res.*, vol. 165, no. July, pp. 18–26, 2018, doi: 10.1016/j.epsr.2018.08.014.

[13] L. I. Guerrero, F. J. Rubio, M. R. Barrera, and D. Giral-Ramírez, "Electric and magnetic field calculation software in transmission lines," *Int. J. Electr. Comput. Eng.*, vol. 12, no. 6, pp. 5697–5706, 2022, doi: 10.11591/ijece.v12i6.pp5697-5706.

[14] M. San, J. De La, V. San, J. La, and C. Casitas, "Línea De Transmisión 5OoKv Subestación Piura Nueva -Frontera," 2019, [Online]. Available: https://info.proinversion.gob.pe/wp-content/uploads/2023/01/Brochure-LT-Piura-Nueva-Frontera.pdf

[15] K. Gao, G. Mei, F. Piccialli, S. Cuomo, J. Tu, and Z. Huo, "Julia language in machine learning: Algorithms, applications, and open issues," *Computer Science Review*, vol. 37. Elsevier Ireland Ltd, Aug. 01, 2020. doi: 10.1016/j.cosrev.2020.100254.

[16] O. D. Montoya, C. A. Ramírez-Vanegas, and J. R. González-Granada, "Dynamic active and reactive power compensation in distribution networks using PV-STATCOMs: A tutorial using the Julia software," *Results Eng.*, vol. 21, Mar. 2024, doi: 10.1016/j.rineng.2024.101876.