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Experimental and theoretical modelling of the electric and magnetic fields behaviour in the vicinity of high-voltage power lines

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Abstract

This paper consists of an experimental and analytical characterisation of the electromagnetic environment in the medium surrounding a circuit of two 220-Kv power lines running in parallel. The analysis presented is divided into two main parts. The first part concerns an experimental study of the behaviour of the electric and magnetic fields generated by the selected double-circuit at ground level (0 m). While the second part simulates and calculates the field profiles generated by both the lines at different levels above the ground, from 0 m to the level close to the line conductors at 20 m above the ground, using the electrostatic and magnetostatic modules of the COMSOL multi-physics software. The implications of the results are discussed and compared with the International Commission on Non-Ionizing Radiation Protection reference levels for occupational and non-occupational exposures.

Keywords: High-voltage power lines, low-frequency electromagnetic fields, finite element method, electromagnetic compatibility, inductive and capacitive coupling, standards.

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1. Introduction

The electromagnetic fields (EMFs) emanating from high-voltage lines is a topic that has long been a cause for worry due to its influences on the environment, and is well known and analysed in several specialty works [1–5]. Electromagnetic disturbances are limited by the general standards of electromagnetic compatibility: Directives 89/336, 92/31and 93/68/EEC of the Council of the European Community. On the recommendations of CIGRE [6] and the Council of the European Union values , the magnetic induction is limited to 100 µT – for public exhibition and 500 µT for occupational exposure, although the values of the fields power are limited to 5 Kv/m applied to the public, and 10 Kv/m for professionals recommended by Directive 519/1997 of the Council of the European Union. In this work, we present an experimental and numerical modelling of the electric field (CE) and magnetic field (CB) generated by a circuit of two 220-Kv lines running in parallel. The International Commission on Non-Ionizing Radiation Protection (ICNIRP, IEEE) has established a continuous electric field exposure limit of 5 kV/m and a continuous magnetic field exposure limit of 100 µT for the general public at a power frequency of 50 Hz [7, 8]. These limit values are sometimes approached in areas close to large transmission lines, often frequented by electric post workers. Away from the power lines, the field levels are much lower than the proposed limits. As we can see, none of the regulations deal with polarisation of the electric and magnetic field vectors. So, if low levels of fields have no influence on a human body, could we say the same for polarisation of electric and magnetic fields?

2. Materials and Methods

2.1. Model Description

In this paper, an experimental and theoretical characterisation of EMF generated by two 220-Kv three-phase flat configuration overhead power lines is achieved. Both the lines are located next to each other inside El-Hadjar substation, which provides interconnection between Algeria and Tunisia (Figure 1). The two 220-Kv lines (A) and (B) represent, respectively, ARCELOR-MITTAL and KHARAZA city, with a flat configuration. The distance between the phase lines, the clearance of conductors, cable guard, the lengths of lines and the currents in conductors when measuring the field's intensities are given in Table 1.

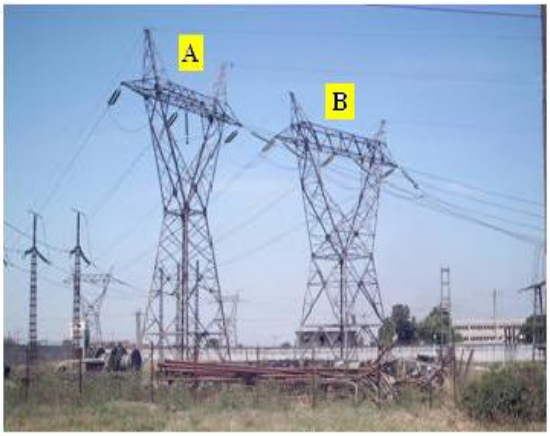

Figure 1. Model studied

Table 1. Pylons geometric and electric data

Directions	Pylon A (220Kv) KHARAZA	Pylon B(220Kv) ARCELOR-MITTAL
Height of the phase 1 [m]	21	21.5
Height of the phase 2 [m]	21	21.5
Height of the phase 3 [m]	21	21.5
Height of the cable guard [m]	25	27
Phase Spacing [m]	07.5	8
Length [km]	76.98	42
Nub of conductors by phase	01	01
Value of current by phase [A]	270	274.2

2.2. Experimetal Investigation

Experimental measurements for the proposed multi-line power system have been conducted in free space under high-voltage lines in accordance with the IEEE standards [9], in order to achieve an experimental characterisation of the EMF in the vicinity of the model studied. Electric and magnetic field intensities were measurements at 2-m intervals along a direction perpendicular to the power lines, starting from the central pylon A and when moving in an east direction to the centre of pylon B, using a referenced and calibrated EMF meter PMM8053B [10–12]. To avoid the perturbation of intensities of fields, the device is equipped with an isotropic probe mounted on a 1-m-high non-conducting tripod. The acquisition of data was done in real time by a computer software package. The recommended configuration for measurements [13] is shown in Figure 2.

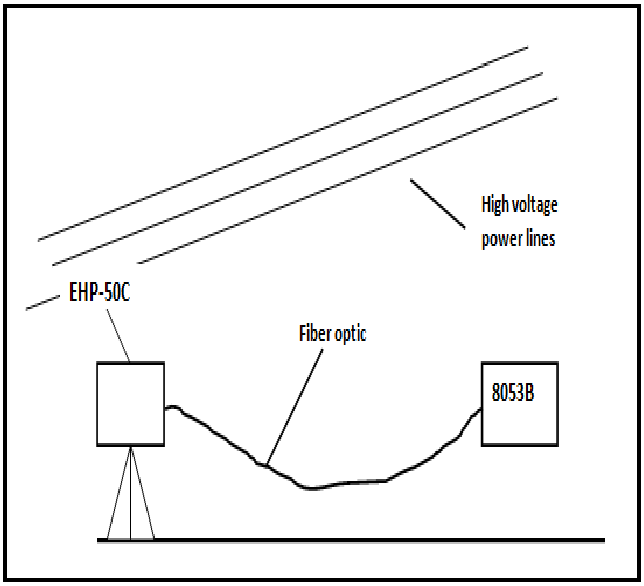

Figure 2. Protocol of measurement of electric and magnetic fields

2.3. Simulation Modelling

The metrology regarding EMFs radiated by high-voltage power lines of large physical size compared to the radius of the phase conductor is very delicate. One can easily get experimental values but it is difficult to say that the results obtained are accurate. Although the electric and magnetic fields generated by power lines are coupled, due to the fact that at power frequency the field varies so slowly in time that Maxwell’s equations are generally converted into electrostatic and magneto-static equations. In order to verify our experimental results, the profiles of fields drawn for the circuit of lines proposed have been simulated at several levels above the ground (0–20 m) using the electrostatic and magnetic-static module. In our case, this simulation is solved by COMSOL multi-physics software, which uses the finite element method [14, 15].

3. Results and Discussion

3.1. Experimental Result

Figures 3 and 4 show the profile of the electric field and the magnetic flux density detected by the EMF measuring instrument according to the distance *x* (in metres) and at 0 m (ground).As can be seen from Figure 3, the maximum value of the magnetic field at the ground level is measured beneath the lines A (1.78 µT) and line B (1.87 µT), and decreases at the middle position of the structure (0.68 µT). In fact, the same phase arrangement causes a greater cancellation of the magnetic field in the intermediate zone between both the lines than if another arrangement is used. The profile of the electric field for the model proposed is shown in Figure 4; the maximum intensity of the electric field (1927.45 V/m) is measured at the middle position of the structure. This can be interpreted by the fact that in the absence of any electrostatic shield, the equivalent capacitance of the capacitors formed by the line's conductors reaches its minimum value and varies proportionally to the concentration of the charge quantities on theme surfaces.

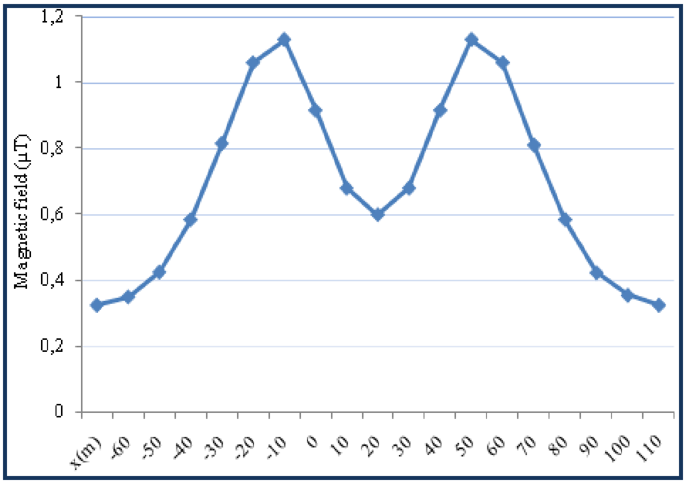

Figure 3. Experimental profile of magnetic field at the 0 m level

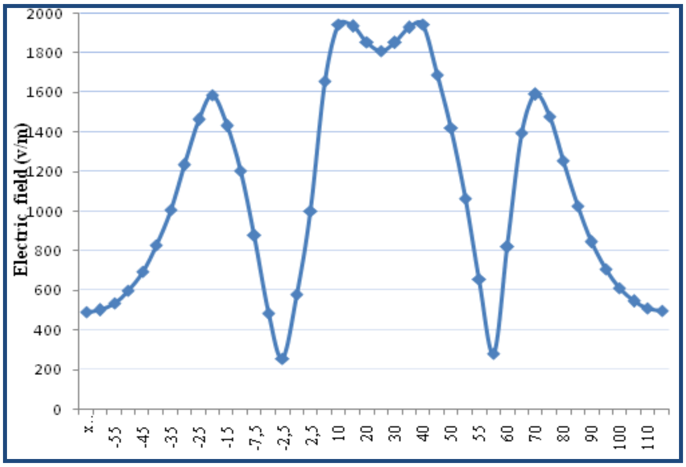

Figure 4. Experimental profile of electric field for the level 0 m

3.2. Analytical and Simulation Results

3.2.1. Behaviour of Electrical Field

Figures 5–7 show the profile of the electric field in the vicinity of the circuit of high-voltage line, depending on the distance to several levels starting with level 0 m, which represents the ground to the level close to the location of the phases (20 m). For good visualisation of the results, we plotted the results on three curves; for the higher levels the electric field strength simulated a rapid increase when capacitive coupling between the two structures decreases by a significant amount. The profile of the electric field simulated at ground level (0 m) is similar to that measured.

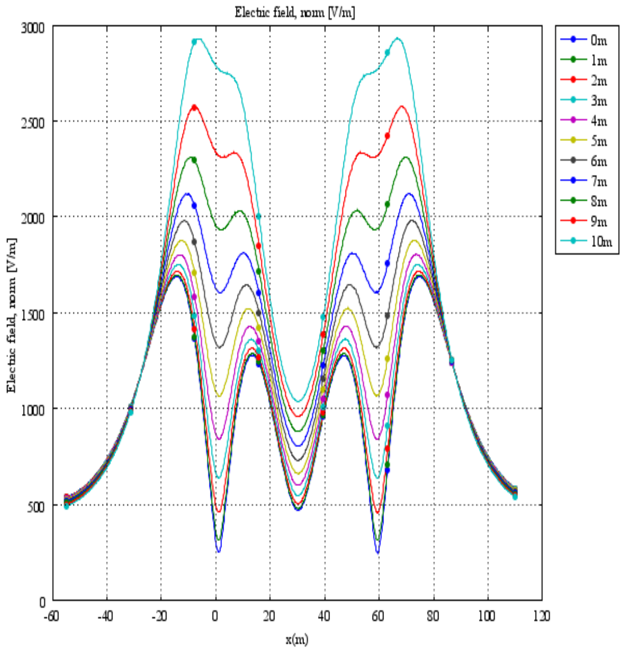

Figure 5. Profile of electrical field for the levels between 0 and 10 m

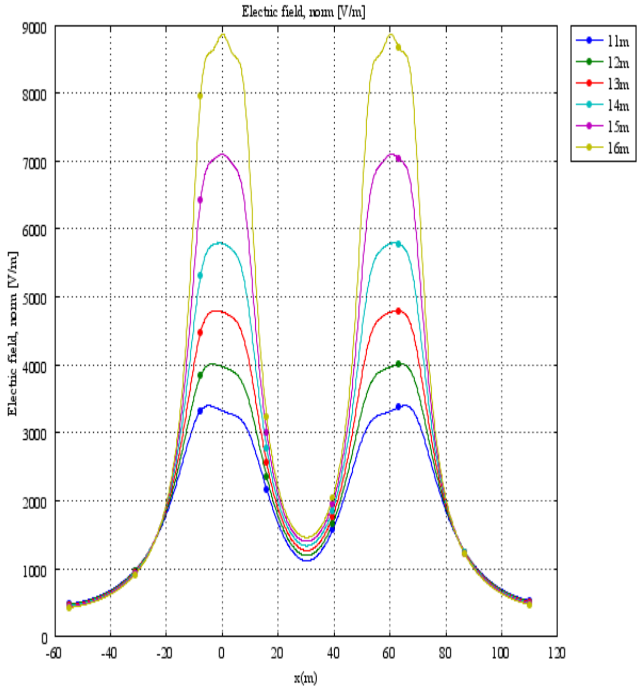

Figure 6. Profile of electrical field for levels between 11 and 16 m

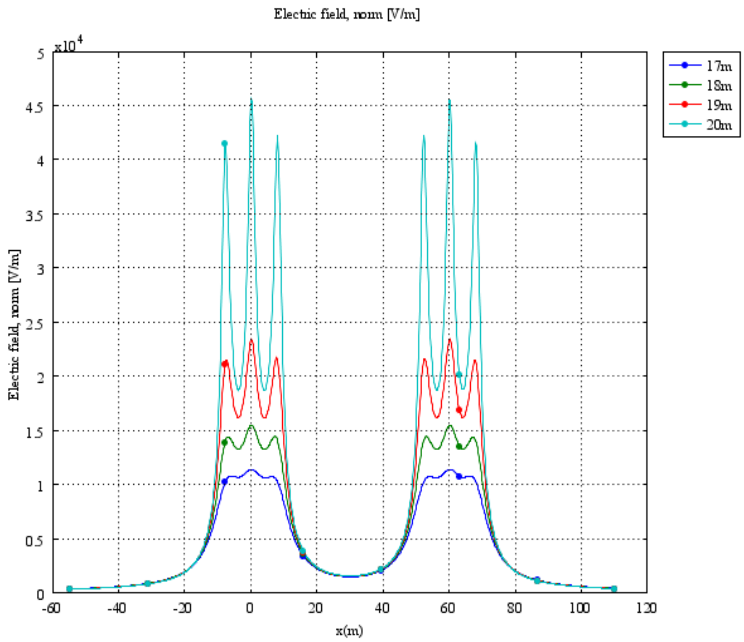

Figure 7. Profile of electrical field for the levels between 17 and 20 m

3.2.2. Behaviour of Magnetical Field

The same numerical modelling of the magnetic field profiles has been shown in the three curves in Figures 8–10. The magnitudes of the magnetic field increase close to the line conductors at the same time the inductive coupling between the two 220-Kv lines decreases from the level of 11 m .There is a slight difference between the values of the magnetic field simulated and measured at ground level; this difference does not have to be attributed to the module of calculus but to the simplifying assumptions and process of each technique.

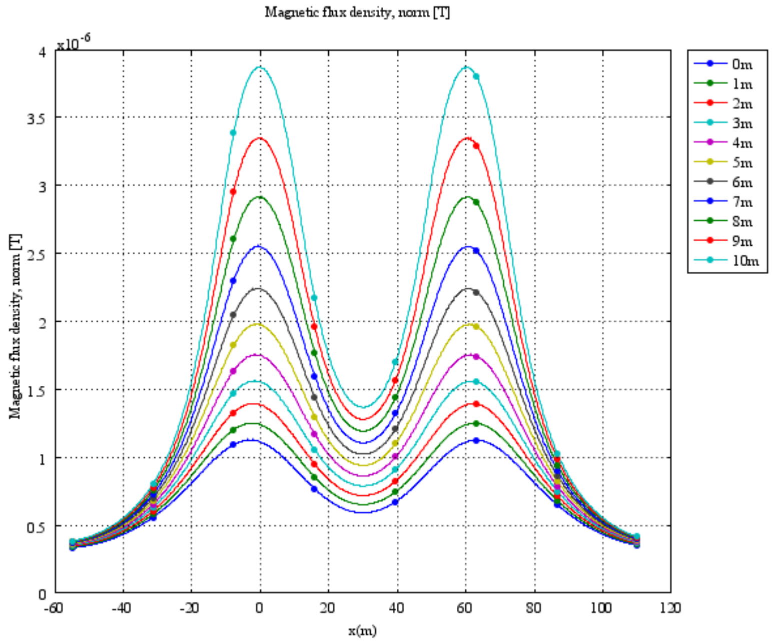

Figure 8. Profile of magnetic flux density for levels between 0 and 10 m

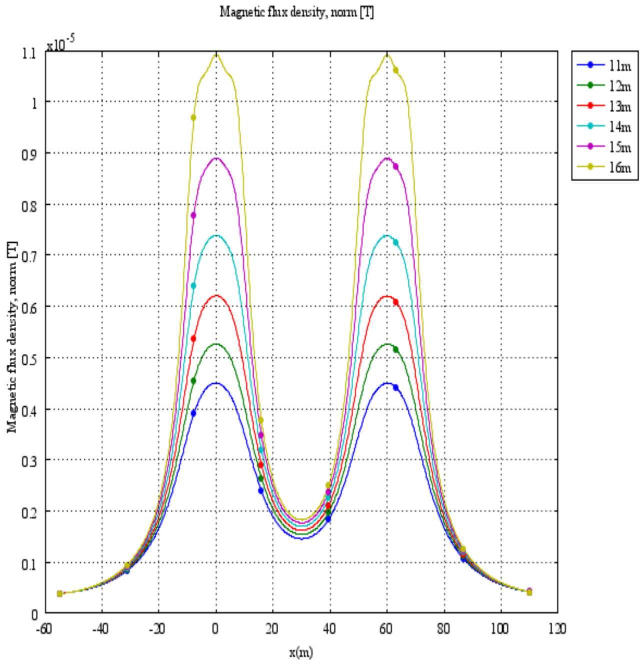

Figure 9. Profile of magnetic flux density for levels between 11 and 16 m

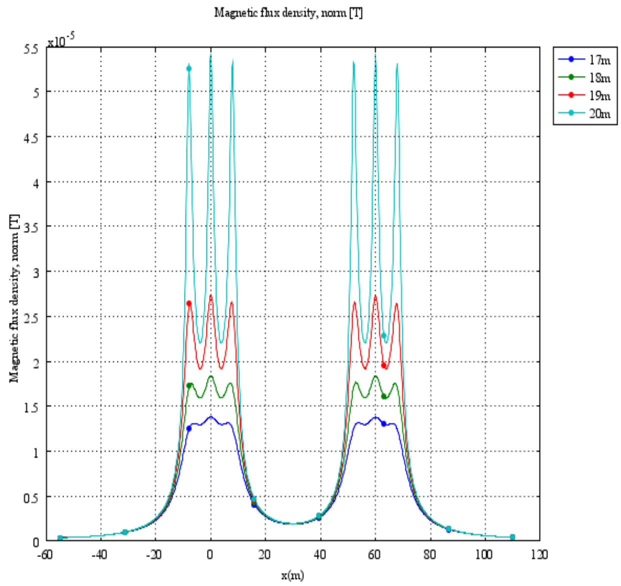

Figure 10. Profile of magnetic flux density for levels between 17 and 20 m

4. Discussion and Conclusion

The analysis of the results presented in this work shows that the profile of the electric and magnetic fields obtained digitally is in very good agreement with those obtained experimentally for the first-level curve (0 m). Consequently, finite element analysis using the COMSOL multi-physics software is a numerical process that can be recommended for analysis of complex circuit configurations, including levels close to the line phases. Experimental measurements for the other levels are 1–20 m in the framework of a research project in collaboration with the SONELGAZ (an Algerian company for production of electricity).Drawing on the ICNIRP's standards, we project to set our own national standards for exposure to EMFs, in order to achieve a regional database on the characterisation of the high-voltage power lines as a source of electromagnetic disturbances.

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