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Theoretical and Experimental Analysis of Extremely Low Frequency Magnetic Field in the Vicinity of the Transformer Station of Overhead Power Lines

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Abstract – This paper studies the magnetic fields between the power lines which are finite length and other ones which are infinitely long around the first tower in the proximity of the power transformers. They will be used as a source of disturbance applied to the power line. The method applied in this study was gradual; develop the theoretical formulation of the magnetic fields of these lines which are finite length and other ones which are infinitely long, examine the effects of different couplings between the different neighboring lines and the distribution transformers on behavior of magnetic fields. The method also focused on the experimental results analyzing the magnetic fields which will be used as a source applied to the auditory implants EMC. The theoretical and experimental results were compared and discussed for three power lines (90kV, 150kV and 225kV) near the power station, and it proved the effect of these substations on the simulated and measured results of the magnetic field. The maximum intensities of magnetic fields measured at the height of 1m from the ground for the circuit of three lines close to each substation were significantly lower than the ICNIRP reference levels for occupational and non occupational exposures.

Keywords: Overhead power line, High voltage, Finite electrical line, Semi-infinite electrical line, Magnetic field, Transmission and distribution lines, Biot-Savart law.

1. Introduction

Nowadays, due to the rapid development of countries and with the increase in the rate of energy consumption, power lines in cities are known as a source of electromagnetic pollution. The magnetic field radiation near these lines raises questions for researchers and the public.

In order to answer all these questions, several studies have been carried out to quantify the magnetic field densities generated by power lines and to evaluate the risk of these fields in their environment.

The latter is related to the planning of power lines and is generally evaluated by analytical and numerical methods. Numerical techniques, although powerful, are not well adapted to the evaluation of the dependence of the field strength with electrical and geometric parameters.

An analytical calculation of the magnetic field produced by any electrical lines is developed by Filippopoulos et al. [1]. This calculation is suitable for several geometries; Flat, vertical, or delta arrangement, as well as for hexagonal lines. In [2] adel et al. we study a complete technique to calculate the magnetic field strength at any point on the ground under a complex configuration of power lines. The different configurations of the range of the line are taken into account; namely the unequal pylon heights, the distance between the pylons, with the effect of sagging at different pylon heights and when the transmission lines are not parallel to one another.

Federico et al. [3], proposes a fast procedure for analytically evaluating the magnetic fields of electrical lines, based on complex vectors. The use of complex algebra simplifies the analytical calculations compared to other approaches proposed in the literature. In this context, the expression for complex configurations of three-phase lines is derived in order to calculate the magnetic field of the symmetrical and asymmetric load current lines during a short circuit.

There are also different numerical methods that could be used to calculate the magnetic field around the transmission lines [4-11].

A numerical method under a MATLAB software interface is developed to model and calculate the magnetic field around the transmission lines based on the amplitude law in [6,7,8]. This field is calculated at the arbitrary point around the transmission lines and the safety margin can be easily determined using the results of the software prepared by Robert et al. [6].

Ali et al. [7], develops the Bio-Savart law equations and Maxwell's equations under the Maltlab graphical interface for a vertically-configured 132kV double-ended line. To

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make it easy to calculate the magnetic field for researchers, the method of superimposing multiple conductors was applied. The equations used here are simplified and can be used to manually calculate the magnetic fields radiated in the vicinity of the High Voltage HV power line.

To model the magnetic field produced by the current paths of any shape, the path is divided into a series of small segments of a straight line. In this context, a program proposed by Sanket et al. [8] determines the magnitude and direction of the magnetic field produced by the driver at any point specified. The other programs display the magnetic field at the surface of a specified height. The outputs of the programs are checked by measurements in the laboratory and in relation to situations for which analytical solutions exist.

Biot-Savart's load simulation and Biot-Savart's methods were also adopted to calculate three-dimensional electric and magnetic fields in an exposed modeling environment in [9,10]. This can be used to study white mice exposed simultaneously to electric and magnetic fields emitted by the transmission lines.

The electric and magnetic fields generated by a complex system contain six parallel high voltage lines are calculated by Rachedi et al. [11], using the MULTI PHYSICS COMSOL software.

These theoretical and numerical methods must be approved by several experimental studies [12-21]. These measurements of magnetic fields in the vicinity of simple 220 kV and 400 kV simple lines with a flat conductor arrangement, different horizontal distances between the phases and the different heights above ground are presented by Carsimamovic et al. [20]. These measurements are compared with the results of calculations performed with two software programs. In addition, the parameters influencing the measurements of electric and magnetic fields are studied. In [21], the results obtained from the magnetic field measurements were presented to the two power distribution transformers inside and near the 220 KV transmission line. These measures have been taken for transformers with different loads. These results have shown a good indication of the magnetic field value for power distribution transformers inside and around high voltage transmission lines.

The objectives of all these studies were to determine the level of the magnetic field and to evaluate the potential exposure received by future residents. Although these methods are suitable for the theoretical and numerical calculation of the magnetic field, they are not suitable for drawing conclusions about the characteristics of the magnetic field and their dependencies on the n different parameters of the electrical line. The calculation of the field was made on the assumption that the lines are finite or infinite horizontal lines, parallel to one another and at the same time parallel to a flat ground.

The absence of the study of the magnetic field has described the coexistence of the conductor which is of finite length and another which is infinitely long in the situation around the first pylon which is near the transformation station. Moreover, the influence of the arrow due to the weight of the line, the different distances of the power lines and the different angles between the power transmission lines, the different heights of the pylons are neglected.

These hypotheses, lead to a general model where magnetic fields are deformed from those produced in reality. In what follows we will study the characteristic of these fields in the case of the fusion of the conductor which is of finite length and another that are infinitely long, different heights of the conductor and when the energy transmission lines are not parallel to A flat ground, the angles between the transmission lines are different.

The organization of this paper is; in section 2; a new model of the magnetic field produced by the overhead power lines near the power station is given. In section 3, the material and methods applied in this study are presented. In section 4, we present the results and discussion of the magnetic fields produced by three overhead power lines; section 5 summarizes all the results of this study by giving some recommendations for further research.

2. Magnetic Field Models

The electromagnetic fields model generated from electrical infrastructure including overhead power lines and high voltage sub stations is given in Fig. 1.

The magnetic fields due to the power lines are calculated for two scenarios; the first scenario the power lines which are finite length near away from a transformer station, the second scenario the power lines which are infinitely long and far away from a transformer station,

A formulation for calculating magnetic flux density produced by a single current-carrying conductor at any point is given by the Biot-Savart law:

$$d\vec{B} = \frac{\mu_0}{4\pi} I \frac{d\vec{l} \times \vec{u}_r}{r^2} \tag{1}$$

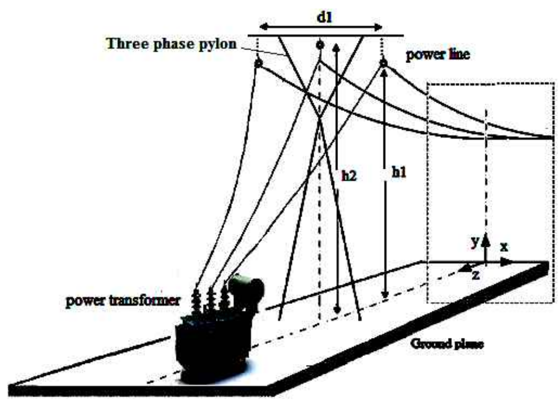


Fig. 1. Overhead power lines model near the power station

Where, dB is the element of the magnetic flux density vector at an observation point P, (T)

μ_0 = Permeability of free space
I = current,(A)
Dl = differential element at the direction of the current., (m)
Idl is the vector of the current element,
r = distance vector between section of conductor dl and an observation point P, (m)
$\vec{r}$ vector from the source point (x, y, z) to the field point
$\vec{u}_r$ is a unit vector in the direction of $\vec{r}$

Magnetic fields are produced by moving charges and thus are proportional to electric currents in a system, irrespective of the voltage used. A flowing current in any conductor, no matter how complicated shape of the conductor, can be broken down into a series of infinitesimally small segments, joined end-to-end. So the following equation of integral form (eq. 2) can be used to calculate the magnetic flux density of a conductor which is finite length (Fig. 2).

$$dB_1 = \frac{\mu_0 I}{4\pi a}\cos\alpha.d\alpha \tag{2}$$

where dB1 is the element of magnetic field produced by the current element I in the conductor element dl at a position r in space, and α is the angle between an observation point and short section of conductor dl.

We can modify equation 2 to calculate the magnetic flux density, applicable to the fields emitted from scenario1. The structure is non symmetrical and contains both vertical and horizontal conductors of finite length. In the reference point (x_m=0), the magnetic field is expressed by:

$$B_1 = \frac{\mu_0 I}{4\pi a}\left(\sin\alpha_2 - \sin\alpha_1\right) \tag{3}$$

For this calculation, we use the Biot-Savart Law taking in to consideration the direction of both angles which are shown below in the Fig. 2.

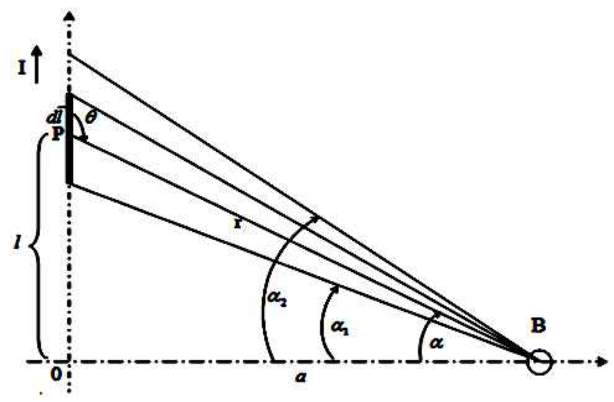


Fig. 2. Magnetic field generation of a finite conductor

The equations used in this paper are simplified in order to make the calculation of magnetic field easier. These formulas can be readily used for the analytical calculation of this field at any point in the vicinity of the finite power line.

$$B_1 = \frac{\mu_0 I_k}{4\pi\sqrt{a^2 + x_m^2}}\left(\sin\alpha_2 - \sin\alpha_1\right) \tag{4}$$

Where a is the distance of the point considered to the direction of conductor and x_{mi} is the measuring point.

The current for a three-phase line are given by:

$$\begin{aligned} I_1 &= I_m\cos(wt+\Phi) \\ I_2 &= I_m\cos(wt+\Phi-120) \\ I_3 &= I_m\cos(wt+\Phi+120) \end{aligned} \tag{5}$$

I_m : maximum current(A)
w : pulsastion (rad/sec)

The magnetic field produced by a power line is radiated in form of vectors; hence it is calculated as the vectorial sum of these fields produced by each conductor current separately. Using the superposition theorem, the magnetic flux density (B1) produced by power line with n conductors in x-y plane (fig.3) is given by

$$\vec{B}_1 = \sum_{i=1}^{N} B_{1i}\sin(\beta_1)\vec{e}_x + \sum_{i=1}^{N} B_{1i}\cos(\beta_1)\vec{e}_y \tag{6}$$

where $\vec{e}_x$ and $\vec{e}_y$ are the unit vectors on x and y axis respectively.

The magnitude of the magnetic field density (B1) is usually characterized by its resultant RMS value, is given by

$$B_1(RMS) = \sqrt{\left(\sum_{i=1}^{N} B_{1i}\sin(\beta_1)\right)^2 + \left(\sum_{i=1}^{N} B_{1i}\cos(\beta_1)\right)^2} \tag{7}$$

When calculating symmetrical magnetic fields and assuming that the conductors are infinitely long (scenario 2), equation 1 is manipulated and simplified to solve the magnetic flux density (B2). The magnetic field of a straight wire infinitely long can be obtained by applying Ampere's law by the following equation (eq.8).

$$B_2 = \frac{\mu_0 I_k}{4\pi\sqrt{\left(h_i - y_m\right)^2 + x_m^2}} \tag{8}$$

where

h_i = the height of the conductor i of the power line.
y_m = the height of measurement point above the ground.

The sum of the magnetic induction vector is given by summing contributions from all n segments

$$\vec{B}_2 = \sum_{i=1}^{N} B_{2ix}\vec{e}_x + \sum_{i=1}^{N} B_{2iy}\vec{e}_y \qquad (9)$$

The resultant magnetic field produced by a power line infinitely long is given by eq. 10.

$$B_2(RMS) = \sqrt{(\sum_{i=1}^{N} B_{2ix})^2 + (\sum_{i=1}^{N} B_{2iy})^2} \qquad (10)$$

The total magnetic fields of the co-existence between the power lines which are finite length and other ones which are infinitely long, is expressed by the sum of two equations, 6 and 9.

$$B_T(RMS) = \sqrt{[\sum_{i=1}^{N}(B_{1i}\sin(\beta_1) + B_{2ix})]^2 + [\sum_{i=1}^{N}(B_{1i}\cos(\beta_1) + B_{2iy})]^2} \qquad (11)$$

We use these equations to analytically calculate the magnetic field of an electrical line and we take into consideration the concept of Biot-Savart law to check the validity of this model for different measurement situations and confirm the practical results of near and far fields.

3. Material and Methods

The theoretical results of magnetic field were determined with the Matlab software, using the law of Biot and Savart (eq.1), and taking the same dimensions mentioned in the paper [18].

The simulation process of the magnetic field produced by the overhead power line near the power station can be calculated more accurately with the first and second scenarios. Indeed; the first simulation were made for a power line near the transformer station, the second simulation were made for an overhead power line and without transformer station. The concept of sum of magnetic fields can be used while considering the measuring points near away from the line and the power station.

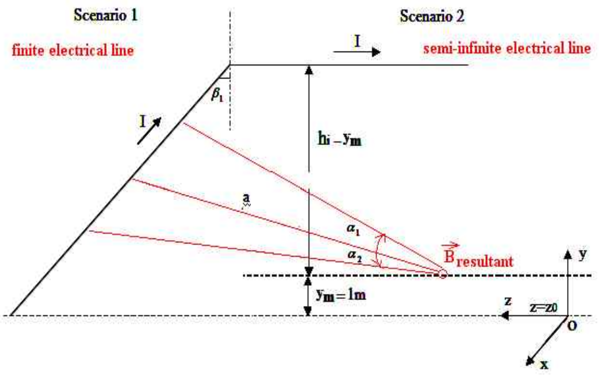


Fig. 3. Theoretical configuration for the calculation of the magnetic fields generated by a finite and semi-infinite electrical line

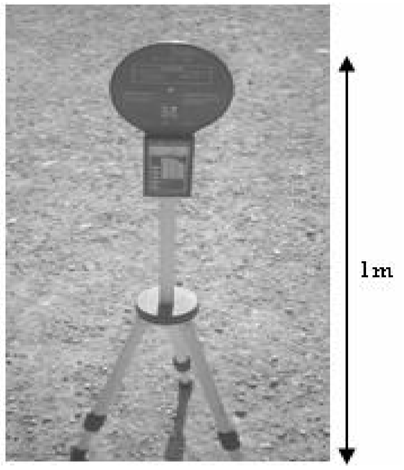


Fig.4. Magnetic field measuring apparatus "HI-3604 ELF Field Strength Measurement System"

Where, hi is the height of the power line, α_1 and α_2 the angles between this orthogonal line from the observation point to segment and the lines joining each end of the segment and observation point.

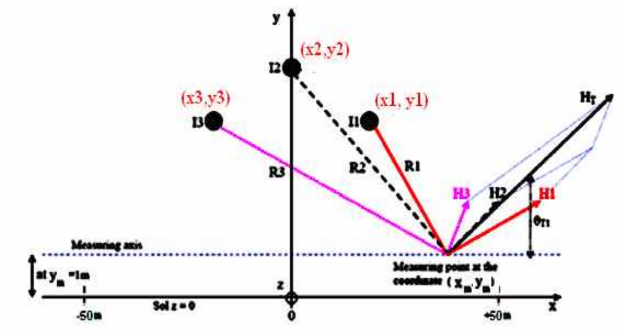
The proposed formulation often requires an accurate measurement model of the amplitude magnetic field intensities, to detect the values of these fields for two considered configurations (single circuit, double circuit) as shown in [18, 19].

The measurements of magnetic field were obtained by the measuring apparatus (Fig. 4) «HI-3604 Extremely low frequency ELF Field Strength Measurement System» associated with 50/60Hz power lines, and made at various hours for the three overhead power lines (90kV, 150kV and 225kV). They were performed in two different situations along the direction (x'Ox); the first, along the overhead power line near the transformer station, the second, along the overhead power line far away from the transformer station, as shown in [18,19].

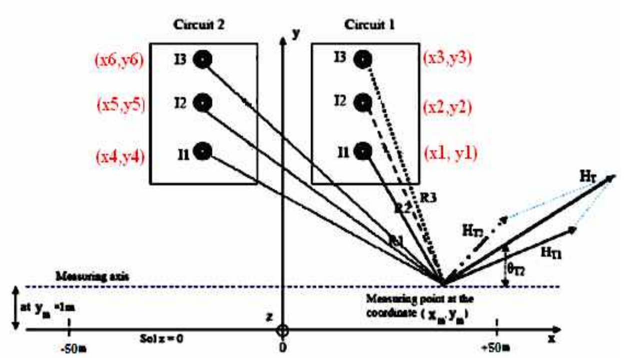
For each configuration, the measuring device is placed along the Ox axis for the two measurement scenarios

4. Results and Discussion

In order to validate our theoretical approach, the simulation of the magnetic fields due to the power lines near and far away from a transformer station was effected with current intensity 180A, by using the Biot-Savart law for a three-phase power line 90kV shown in the figure 5. The values of magnetic field intensity were made for the simple configurations circuit with dimensions (d1=8.5m, h1=24m, h2=25.6m, i=1to3) as shown in Fig. 1.



(a)



(b)

Fig. 5. Transverse section of the power line model single-circuit, b) double circuit

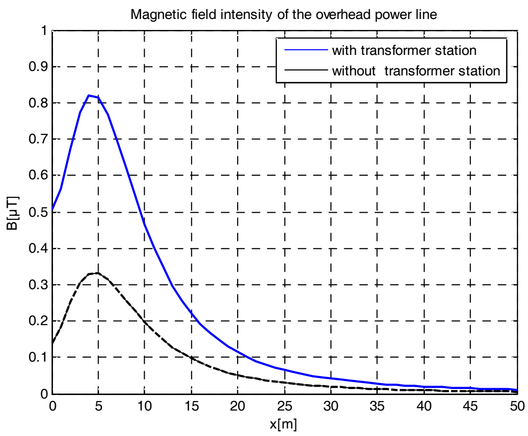


Fig.6. Value of the simulated magnetic field for a simple-circuit 90kV power lines

The simulation and measurement were done to a maximum distance from the tower of 50 m, at a height of y_m=1m from the ground. Consider the magnetic field points of those that are located on the x_m axis of the coordinate system (x,y,z). Those field points should be perpendicular to the zoy plane.

The coexistence of the magnetic fields generated by the power lines and that of the near transformation station can take several forms; addition, subtraction or convolution product. In our paper, we assume that the two fields are added to gether.

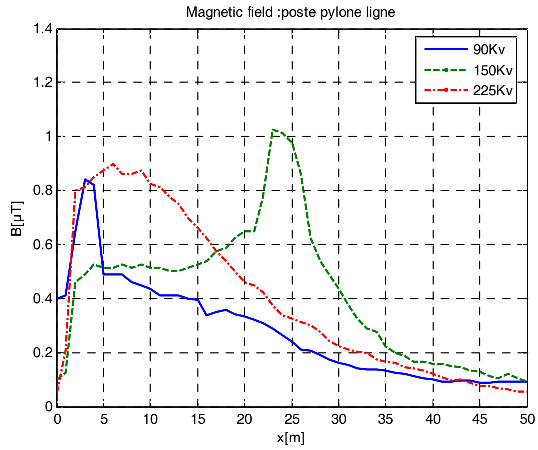


Fig. 7. Value of the magnetic field measured for power lines near a transformer station

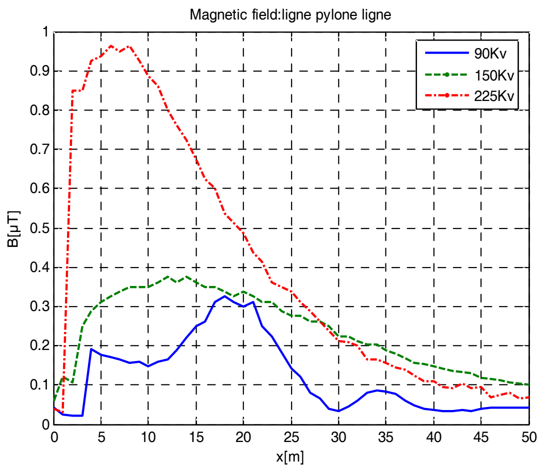


Fig.8. Value of the magnetic field measured for power lines far away from a transformer station

Fig. 6, present the level of simulated magnetic fields according to a distance to the simple configuration circuit when in near and far with the transformer station.

According to Fig. 6, the level of magnetic field decreased depending on the distance, field reached a maximum value when it comes close to the power lines and a minimum value when in far away to these lines. We also noted the influence of the transformer station on the magnetic field calculated for a simple configuration circuit and the existence of the latter increases the level of fields and the bad impact on the environment.

Measurements were made at different times of the day with current intensities varying between 150A and 200A in order to detect the values of the magnetic field strengths for the two geometric configurations considered as shown in Fig. 5.

Figs. 7 and 8 show the level of magnetic fields measured in function of the distance for the single circuit power lines configurations (90kV, 150kV and 225kV).

Theoretically the magnetic fields decrease depending on the distance, and it is noted in Fig. 7, when we get close to the transformer station; the magnetic field intensity increases in function of the distance especially on the interval [15-30m]. This can be explained by the effect of the transformer station on the measured field strength generated by the overhead power lines. Indeed, the measured field strength is the sum of both fields produced by the electric line and transformer station. This is not similar with the theoretical result.

We also note when the voltage level increases, the effect of the transformer station does not appear.

Figs. 9 and 10 show the level of magnetic fields measured in function of the distance for three double circuit power lines configurations (90kV, 150kV and 225kV).

In Figs. 9 and 10, we notice the effect of the transformer station on the level of the field produced by the electrical lines on the interval [15-35m]. Hence, we confirm that the transformer station is a source of disturbance for the overhead power lines.

The results measured for single and double configuration circuits show the effect of the transformer station on the calculation for the near and far fields. When the voltage level increases for the double circuit configuration, the effect of the transformer station appears.

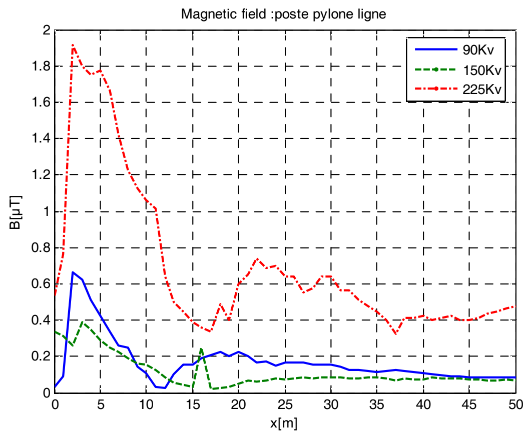


Fig. 9. Value of the magnetic field measured for power lines near a transformer station

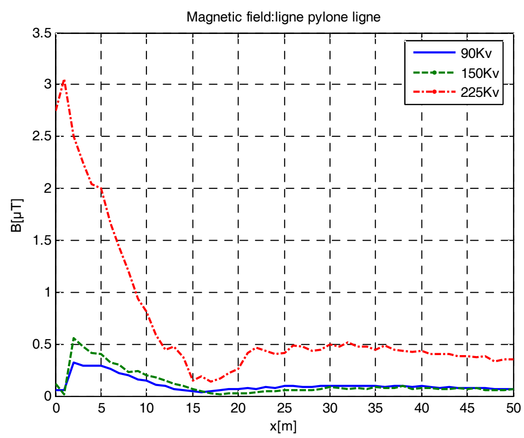


Fig. 10. Value of the magnetic field measured for power lines far away from a transformer station

These overhead power lines ensure the coverage of the current for citizens living in urban areas. However, these lines have negative effects. In fact, they are sources of electromagnetic disturbance on the environment, but the level of this disturbance does not exceed the international standards set for 100μT the magnetic field near the transformer station.

5. Conclusion

This paper studies the magnetic fields produced by overhead power lines and its associated equipment (90kv, 150kv and 225kv).The co-existence of these lines (finite and infinite lines) which are considered as sources of pollution to the environment by its electromagnetic radiation. The measured results of the magnetic field proved the effect of the power station on the calculation of these fields produced by these overhead power lines, and also, supported good satisfaction between all results given by simulation and measurement.

The characteristics of the magnetic field with n various parameters of the power line; simple and double configuration, merging of finite and infinite lines near the power station can be recommended for the analysis of this field with complex configuration involved and employed like support in the planning of the electrical systems in Tunisia.

The intensities of the magnetic field close to earth are well below the limits set by international standards (100μT for the magnetic field), and proved the confirmation of standards compliance to the limits of human exposure to ELF fields in the case of the inside area of town of Tunisia.

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