Monitoring of electromagnetic pollution inside switchyard substation (case study: El-Hadjar electrical post in Annaba city, Algeria).

Contrôle de la pollution électromagnétique à l’intérieur d’un poste d’interconnexion (cas étudié : poste électrique El Hadjar, Annaba, Algérie).

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ملخص

الهدف من هدا البحث هو تحقيق وصف تجريبي للبيئة الكهرومغناطيسية تحت خطيين كهربائيين 220K v داخل المحطة الكهربائية الحجار. كما تم اقتراح محاكاة تحليلية وعددية لتقييم شدة الحقل الكهرومغناطيسي على ارتفاعات متعددة ابتداء من مستوى الأرض إلى مستويات مقربة من أطوال برج الأسلاك الكهربائية حيت يعتمد فيها بناء نموذج الدارة الكهربائية على الأبعاد الفيزيائية الحقيقية للأبراج. في النهاية يقدم ملخص عام ناتج عن مقارنة القيم المتحصل عليها مع المستويات المرجعية العالمية المنصوص عليها كما تقدم تدابير وقائية لضمان حماية العمال في الوسط المهني.

كلمات مفتاحيه التوافق الكهرومغناطيسي -الحقل الكهرومغناطيسي في الترددات المنخفضة- الخطوط الكهربائية العالية الجهد- التلوث الكهرومغناطيسي- المعايير الدولية.

Résumé

Le but de ce travail est de réaliser une caractérisation expérimentale de l'environnement électromagnétique sous un circuit de deux lignes électriques 220kV implantées à l'intérieur du poste électrique d’El Hadjar nécessitant souvent des travaux de maintenance. Une modélisation analytique et numérique basée sur les dimensions physiques réelles des pylônes est proposée afin d'accomplir cette étude. Les profiles latéraux des champs électrique et magnétique ont étés simulés pour des hauteurs élevées de la garde au sol. Une conclusion résultant de la comparaison des résultats obtenus avec les seuils de référence imposés pour l'exposition professionnelle ainsi que des recommandations a titre préventif pour assurer la sécurité des ouvriers du post sont finalement données.

Mots clés : *compatibilité électromagnétique - champs électromagnétiques basses fréquences – lignes de transmission haute tension – pollution électromagnétique – normes internationales*.

Abstract

The aim of this paper is to carried out an experimental characterization of the electromagnetic environment beneath a selected circuit of two 220Kv power lines inside El- Hadjar electrical post often requiring maintenance. An analytical calculus method is proposed in order to accomplish this study. The model of the circuit of lines proposed was constructed using the actual physical dimensions of the towers. It follows a numerical simulation of the field’s magnitudes for highest ground clearance levels close to the towers. General conclusions arising from the comparison of the results with relevant reference levels in force for occupational exposure as well as recommendations to ensure workers safety are finally given.

Keywords*:* *electromagnetic compatibility - low frequency electromagnetic fields- high voltage power lines - electromagnetic pollution - international standards.*

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1. INTRODUCTION

Static electric and magnetic fields, as well as low- frequency fields, are produced by both natural and man-made sources. The natural fields are static or very slowly varying as the electric field in the air above the earth's surface and the geomagnetic field. Most man-made source are at low frequencies up to 300 Hz.Will The generation, transmission, distribution and use of electricity at 50 or 60 Hz are an integral part of modern civilization, The development and expansion of the power systems worldwide, has increased the electromagnetic field level as well as the bio-organism and human body exposure to the electromagnetic radiation [1]. The human body is a living antenna that can absorb and re-emit power energy, in the environment [2].The physical interaction of time varying electric and magnetic fields(ELF, EMFs) with the human body results in induced electric fields and circulating electric currents, that associated at the endegenous ones, lead to changes in functions of cells and tissues and subtle changes in hormones levels. Because ELF fields can interact with biological systems, interst and concern about potentiel hazards are understandables. In this context various occupational health organizations have established limits for general public and occupational exposures [3-4-5]. Population growth and technological change have led to increase in demand for electrical energy in larger quantities [6]. This causes enhancement of electromagnetic pollution in the urban and the work environment. In area of occupational exposure including workers performing different work tasks, the environment around the power facility falls within the area of increased sensitivity. Overhead HVPL produces electromagnetic fields (EMF), the most efficient way to determine the real effect or danger of EMF from HVPL inside substations is the assessment of these fields by performing experimental and analytical characterization of the electromagnetic environment at workplaces basing on computational model and protocol measurement development. In this context several studies have investigate the occupational exposure at power frequency in substations in power stations and on lines and cables [7], [8] and [9]. Author's publications described exposure to ELFs during work tasks in high voltage substations, the results show that the exposure limits reviewed and published by the international commission on non-ionizing radiations were exceeded in specific work tasks from service plat form [10]. This work extends the previous research work of the authors related to electromagnetic fields inside power substation and investigate occupational exposure inside El-Hadjar electrical post which ensure interconnection between Algeria and Tunisia and located in Annaba city (eastern of Algeria) has been conducted. This substation is categorized according to it location in urban area , the large range of voltages that's covers [220 kV- 90 kV and 60 kV] and its great power resulting in potential risk of occupational exposure to very large electromagnetic fields. There is no specific study to evaluate the amount electric and magnetic field at higher ground clearance levels close to the tower location inside El-Hadjar substations. Will this EMF investigation is a useful as a safety precaution to limit the exposure to these fields especially to live-line workers who are frequently approaching wires. The electric and magnetic fields intensities measured and calculated beneath a selected circuit of two 220 kV transmission lines (Fig.1) often requiring maintenance work show that for the levels 0m, 1m, 1.5m, 1.8m above the ground which represent a sensitive parts of the human body, fields magnitudes are much lower than the safe occupational exposure limits reviewed and published by the International

Commission on Non Ionizing Radiations 10 against those simulated for highest ground clearance levels namely, [10m-20m] representing the location starting from the maximum sag point and moving toward the tower location often frequented by the maintenance workers were, exceeding the safety limits. The implication of previous results enable us to establish the level of occupational exposure to electromagnetic kV/m and1000µT (ICNIRP, 2010). By pollution from HVPL inside El-Hadjar substation and to recommend possible solutions to ensure workers safety especially during specific maintenance tasks on power lines by making them aware of potential risks and educating them to take protective measures in accordance with international standards [5].

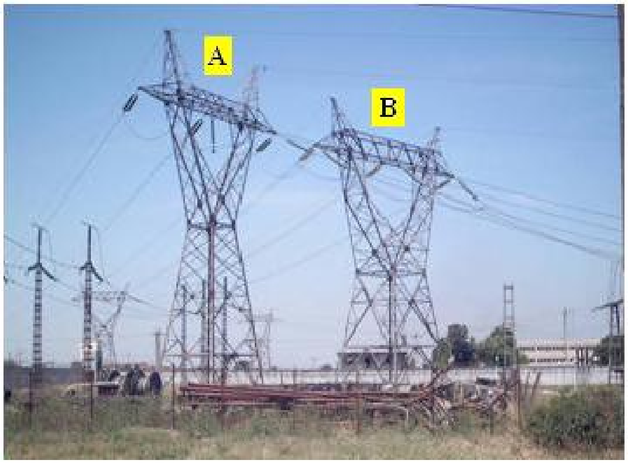


Figure1 : Model studied

2. MATERIAL AND METHOD

2.1 Experimental investigation

In this section of work an experimental characterization of electromagnetic field generated by a circuit of tow 220 KV overhead power lines with flat configuration (Fig. 1) is achieved. Both lines are located next to each other inside El-Hadjar substation which provides interconnection between Algeria and Tunisia. The line (B) is located at 28 m from the line (A), they represent respectively ARCELOR-MITTAL and KHARAZA cities. The operating staff of the substation allowed us with all the electrical and physical data of the both power lines. The current study was conducted by measuring EMFs beneath the selected circuit of two 220Kv transmission lines often requiring maintenance. Experimental investigation is carried out in free space under high voltage power lines in accordance with the IEEE standards [11] using a referenced and calibrated electromagnetic field meter PMM8053B [8-12].The protocol of measurement is shown in figure. 2 and figure 3**.** In order to simulate workers inside substation who are continuously exposed to emitted radiations during normal tasks, field's intensities were measured at the level 1m above the grounds, to avoid the perturbations when measuring. The device is equipped with an isotropic probe mounted on one-meter-high non-conducting tripod. The acquisition of data was done in real time by the computer software package.

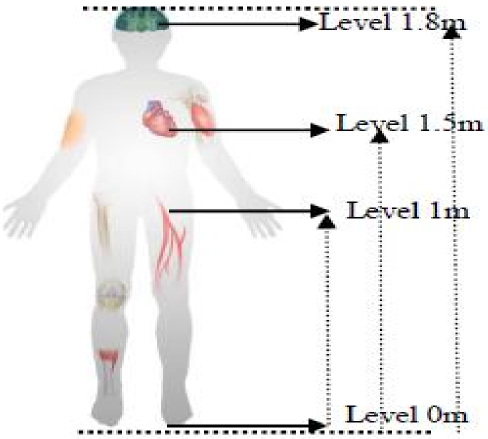


Figure 2: Sensitive levels of human body exposure

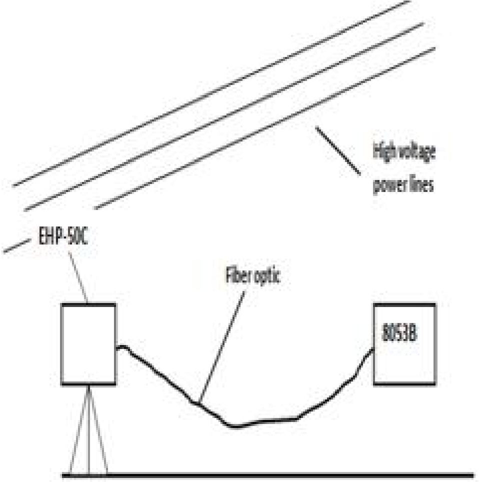


Figure 3: Protocol of measurement

2.2 Analytical model

The metrology regarding electromagnetic fields radiated by high voltage power lines with large physical size compared to the radius of the phase conductor is very delicate. One can easily get experimental values but it is very difficult to say that the results obtained are accurate. In order to validate our experimental results, an analytical characterization of the fields in the vicinity of the circuit of lines proposed has been made. Though the electric and magnetic fields generated by power lines are decoupled, due to the fact that at power frequency field varies so slowly in time that Maxwell’s equations are generally converted into the electrostatic and magneto-static equations. Figure 4 shows the analytical model developed basing respectively on Gauss and Ampere laws for the electric and magnetic field calculation using the actual physical dimensions of the towers for monitoring electromagnetic charges quantities dissipated in the vicinity of the circuit of lines proposed. Fields magnitudes are calculated at the levels 0m, 1m, 1.5m and 1.8m above the ground which present the sensitive’s parts as organs and major functions (head, heart, pelvis and feet) of the human body (Fig. 2) in case of power frequency fields exposure.

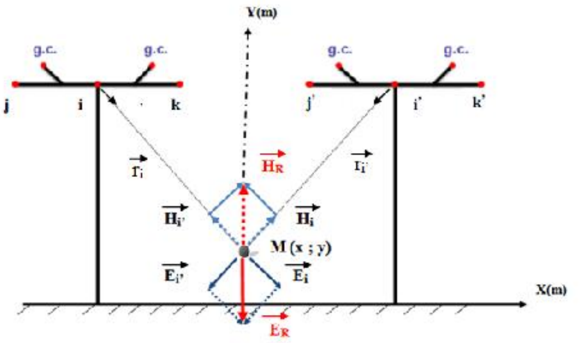


Figure 4: Analytical model for EMF calculation

2.2.1 Electric field calculation

For the calculation of the electromagnetic fields under the power lines, phase's conductors are considered as finite line charges. Electric fields in proximity to high voltage transmission lines are calculated assuming that there is no free charge in space. The earth is assumed to be a perfect conductor. Each conductor, of transmission line, including wires at ground potential, must be characterized by a real and imaginary voltage given by:

$$V = V_r + jV_i \qquad (1)$$

The charges **Q** on the conductors are determined with the matrix equation through the line voltage **V**, and the Maxwell potential coefficiens based on the coordinates of the phase conductors and the ground wires.

$$[Q] = [P]^{-1}.[V] \qquad (2)$$

Where, [*V*] is the phase's potential matrix (toward the earth) and [*P*] is the potential coefficients matrix in the form of:

$$P_{ij} = a \ln \frac{D'_{ij}}{D_{ij}} \qquad (3)$$

$$P_{ii} = a \ln \frac{D'_{ij}}{r_{oi}} \qquad (4)$$

Where:

D_{ij} = The distance between the conductors i and j

D'_{ij} = The distance between the conductors i and the image of the conductor j

r_{oi} = The radius of the conductors i

For the circuit of two 220 KV lines proposed, the calculation of the lateral profile of electric field at a point M above the ground level is a considerable simplification of the general method of the field calculation based on Gauss's law.

In fact, the electric field at a point M above the ground is the resultant of fields generated by the line's A and B phases with the same order as shown in figure 4 and is given by the following expression.

$$E_i = \frac{q_{ri} + jq_{ii}}{2\text{®£}_o} \frac{2Y_i}{(X_i - X_M)^2 + (Y_i - Y_M)^2} \qquad (5)$$

Where q_{ri} and q_{rj} are the real and the imaginary parts of the charge on conductor (X_i – X_M) and (Y_i – ? are respectively the horizontal and vertical distances between conductor, i, and the point, M, where the field is calculated. The total field at point M is obtained summing the contributions of all the conductors of the two 220KV lines (i, j, k, i', j' and K'...):

$$\left.\begin{array}{l}\vec{E}(M)=\sum_{m=i}^{k'}\vec{E}_{m}(M)\\ \vec{E}(M)=\sum \vec{E}_{(i,j.....k')}(M)\end{array}\right\} \qquad (6)$$

Were, , E $_i$ (M) is the electric field generated by the phase charge (m= i, j... k') at the point, M, where the field is calculated.

2.2.2 Magnetic field calculation

Because of the quasi-static nature of the electromagnetic behavior at the industrial frequencies, the magnetic field of three phases' lines is generated only by the current circulating in the conductor. The intensity of magnetic field around conductors is obtained by application of ampere's law, then by superposition of the partial results. The magnetic field at point M with coordinates ($X_{M\,?}$ Y_M) at a distance, from a conductor with a current, has the following Vector notation:

$$\overrightarrow{H}_i=\frac{I_i}{2\circledR r_i}\vec{\text{¤}}_i \qquad (7)$$

Where $\overrightarrow{\emptyset_1}$ is the unit vector in the direction of the product of the vector current and the vector segment $\overrightarrow{r_1}$ The resultant magnetic field at the point M is the sum of all the contributions of the two 220KV lines phase's currents:

$$\overrightarrow{H}(M)=\sum_{m=i}^{k'}\overrightarrow{H}_{m}(M) \qquad (8)$$

2.3 Numerical simulation

The electromagnetic fields were also analyzed basing on numerical simulation for several ground clearance levels namely, [10m-20m]. These ground clearance levels represent the location starting from the maximum sag point and moving toward the tower location, levels often frequented by the maintenance workers during specific tasks. A powerful program was employed for reaching this purpose known as COMSOL, MULTIPHYSICS MODELING AND SIMULATION. It is a finite element analyzer and solver software package for various physics and engineering applications, especially coupled phenomena. Because electric and magnetic fields EMFs are alternating the simulation is time dependent

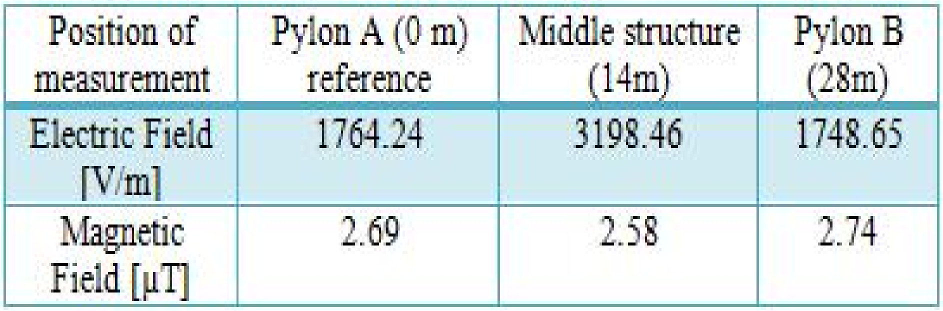
3. RESULTS AND DISCUSSION

3.1 Experimental Results

Tables 1 and 2 summarize the measurement results of the electric and magnetic fields at 1m height above the ground, made respectively under a single 220KV and two 220KV transmission lines. Theoretically the low frequency electromagnetic fields have relatively low spatial ranges and field's strengths are inversely proportional to the distance from the source. To argue ours experimental results, we based on the two fundamental principles related to electromagnetic compatibility of high voltage transmission lines which are the effect of electric field to induce currents in the wires parallel to the field lines (capacitive coupling) and the effect of magnetic field to induce a voltage in the loops perpendicular to the field lines (inductive coupling). As can be seen from experimental results mentioned in table 1, the intensities of electric field (EF) intensities measured at the center of the pylons A and B are respectively (1764.24V/m) and (1748.65V/m), the difference between these values is due to the tower heights and terrain deviation from flat earth. The EF maximum value (3198.46V/m) is relieved at middle position of the structure (15m) and depends on the spacing between the phase conductors. This can be interpreted by the fact that in absence of any electrostatic shield, the equivalent capacitance of the capacitors formed by the line's phases reaches its maximum value and varies proportionally to the concentration of charge's quantities on them surfaces. We can conclude from the experimental results recorded that the electric field strength is significantly higher under two power lines compared to the single power line (Tab. 2)

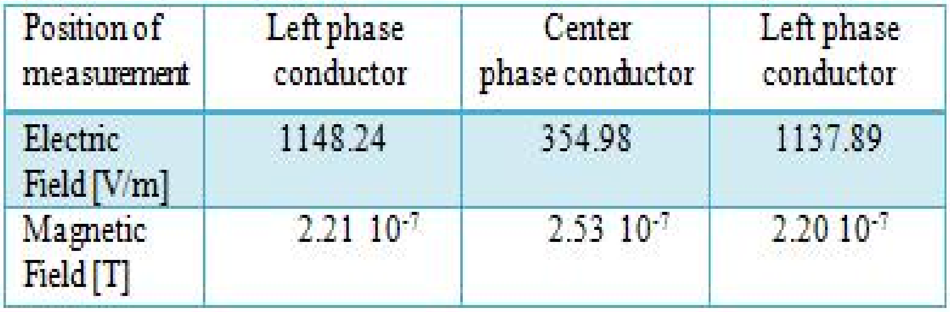
The maximum values of the magnetic field are measured beneath the line A (2.69 µT) and the line B (2.74 µT) and decrease at middle position of the structure (2.58µT) as mentioned in (table.2), in fact the same phase arrangement causes a greater cancellation of the magnetic field in the intermediate zone between both lines than if another arrangement is used. It appears from experimental results that the circuit of two 220KV power lines with great power generates higher magnetic field strength compared to the single 220KV power line (Tab. 2).

Table 1: Measurement results of the electric and magnetic fields at 1m above the ground under two power lines



Position of measurement	Pylon A (0 m) reference	Middle structure (14m)	Pylon B (28m)
Electric Field [V/m]	1764.24	3198.46	1748.65
Magnetic Field [µT]	2.69	2.58	2.74

Table 2 : Results of the electric and magnetic fields at
1m above the ground under single power lines



Position of measurement	Left phase conductor	Center phase conductor	Left phase conductor
Electric Field [V/m]	1148.24	354.98	1137.89
Magnetic Field [T]	$2.21\ 10^{-7}$	$2.53\ 10^{-7}$	$2.20\ 10^{-7}$

3.2 Analytical Results

Figures 5, 6, 7 and 8 present respectively the 3D distribution of electric and magnetic fields for the model studied and their presentation in X-Y plane for the selected levels above the ground (0m, 1m, 1.5m and 1.8m). The axis (Oz) represents the field’s magnitudes and the other axes (OX) and (OY) represents the distances x (m) and y (m) in the vicinity of the circuit considered.

As can be seen in figures 5, the intensities of the electric field calculated at the level 1m above the ground for example, reach them maximum values at the middle position of the structure (2995 V/m) and the fields strengths decrease under the pylons centers (1760 V/m).
At the same time, the maximum values of the magnetic field (Fig.7) calculated are higher under the pylons A and B and lower at the middle of the structure (15m). At 1m high above the ground for example the corresponding values are respectively (2.73µT and 2.41 µT). The profiles of magnetic field raised in this figure for the four levels (0m, 1m, 1.5m and 1.8m) above the ground highlight the highest inductive coupling between the two structures when approaching the conductor’s area. Figures 6 and 8 visualize respectively the capacitive and inductive coupling between the two structures in the plane X-Y, they highlight the effect of the hights above the ground on the distribution of the electric and magnetic field in the vicinity of the both 220KV lines.There is a slight difference between the experimental and analytical field intensities (6%), this difference does not have to be attributed to the model of calculus, but to the simplifying assumptions and to the process of each technique. The values of fields calculated for the levels 0m, 1m, 1.5m and 1.8m above the ground remain very inferior to the maximum limit(5 KV/m) established by the ICNIRP standards [5].

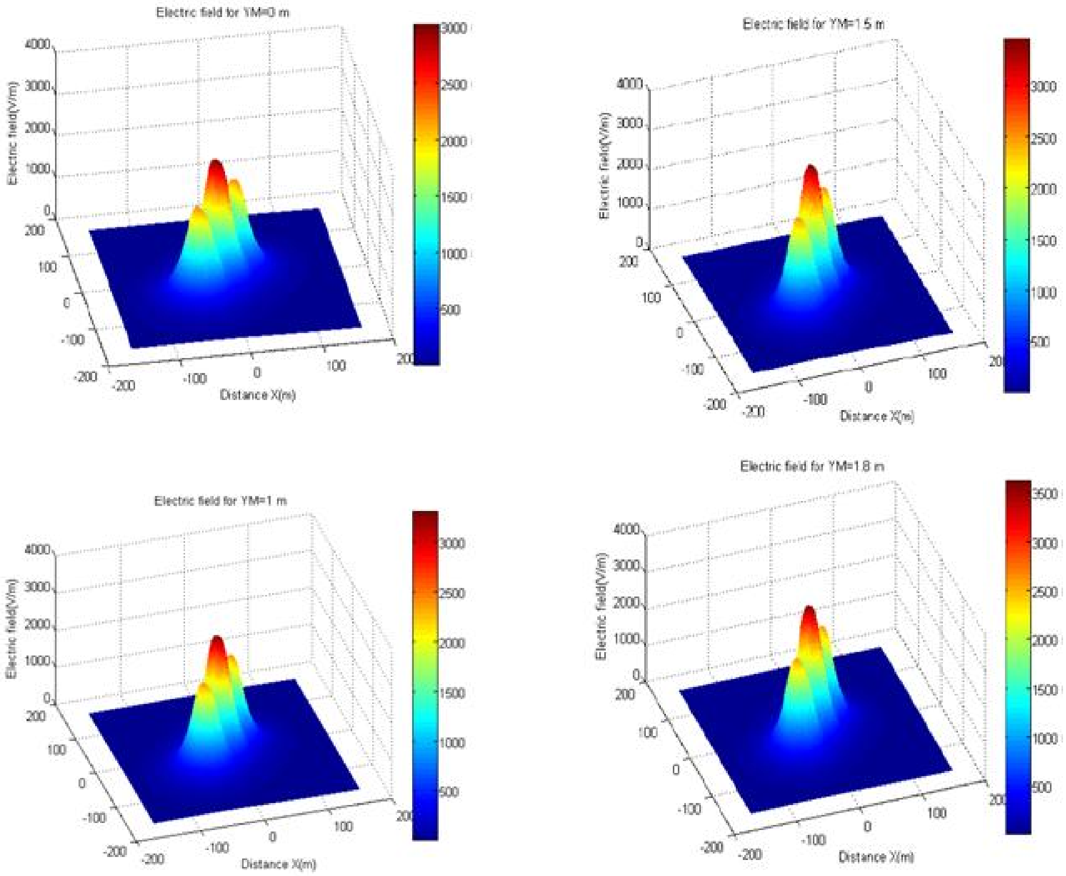


Figure 5: Electrical field distribution for 4 levels (0m, 1m, 1.5m, and 1.8m)

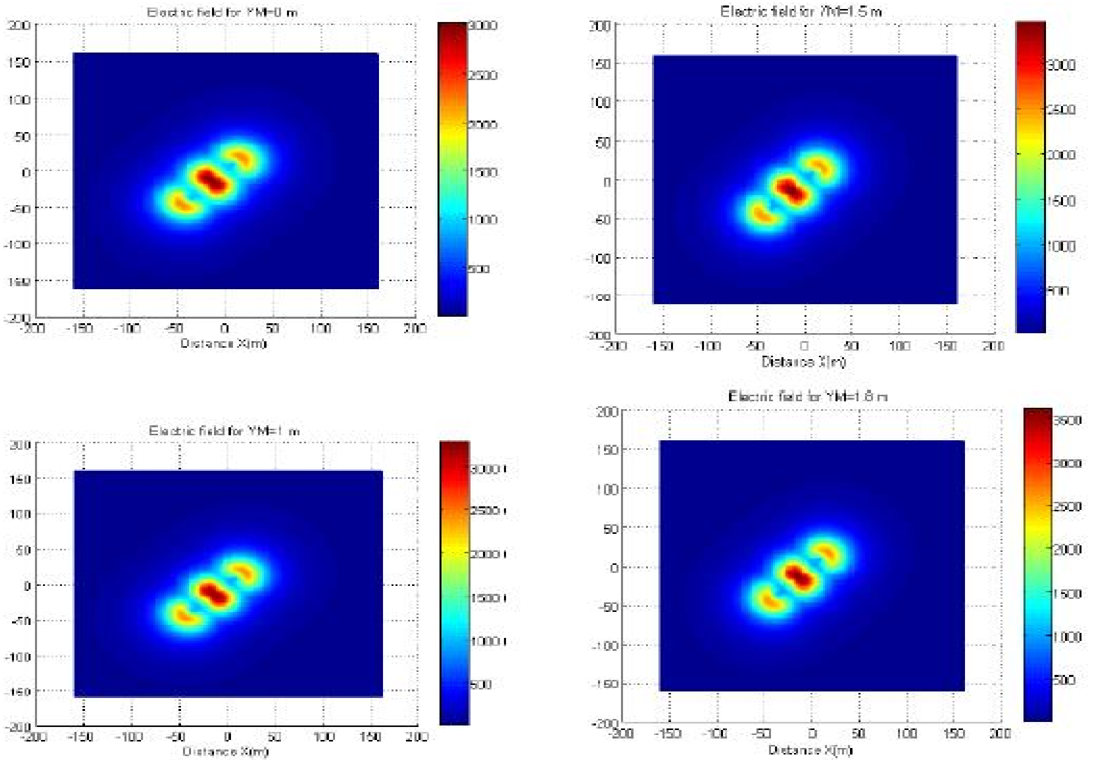


Figure 6: Electrical field distribution, plane X-Y, for 4 levels (0m, 1m, 1.5m and 1.8m

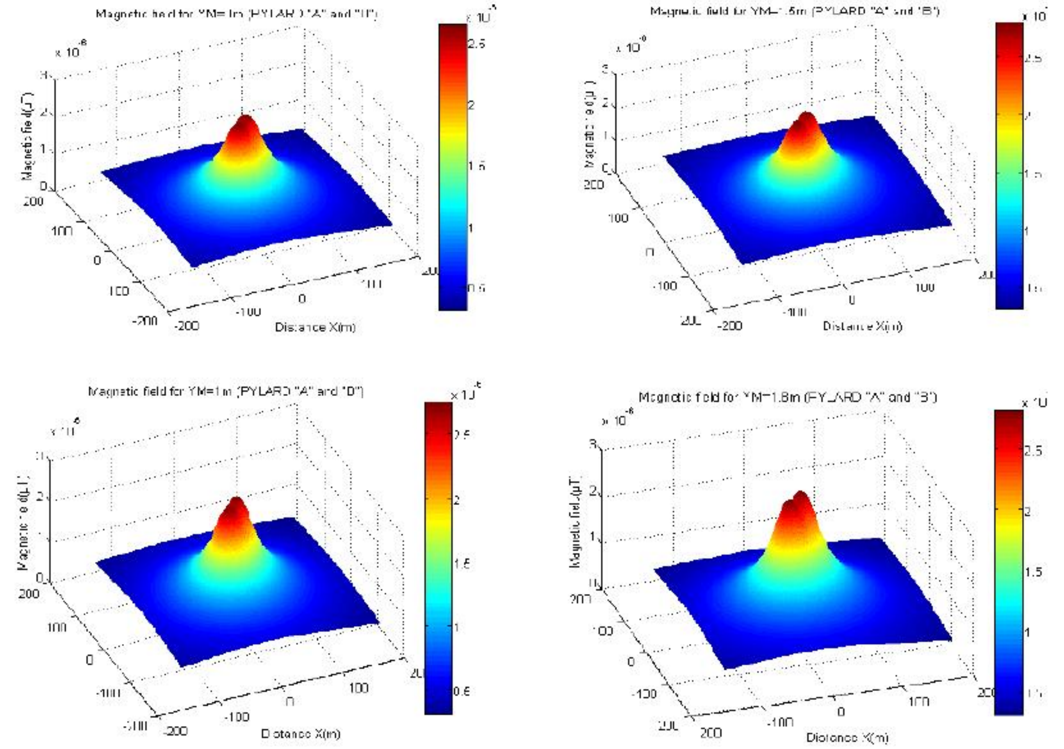


Figure 7: Magnetic field distributions for 4 levels (0m, 1m, 1.5m and 1.8m)

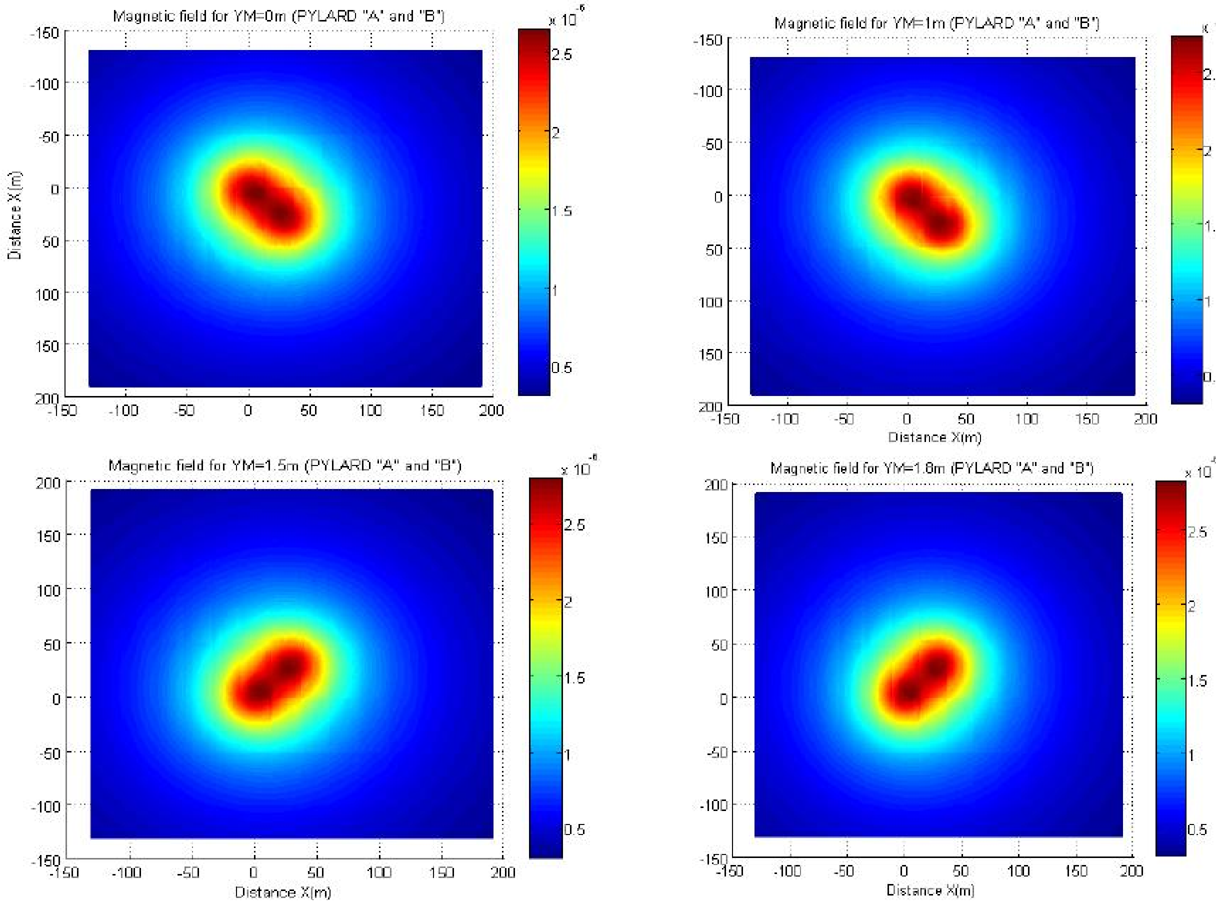


Figure 8: Magnetic field distribution, plane X-Y, for 4 levels (0m, 1m, 1.5m and 1.8m

3.3 Numerical results

Simulation results, using COMSOL, for EMF intensity are shown in figures 9 and 10. Electric potential of ground was assumed to be zero. In this simulation, all results were obtained during one period at 50Hz, starting with level (0m) which represents the ground to the level close to the location of the lines' phases (20m).When approaching the conductor‘s area the simulated electric and magnetic fields intensifies increase rapidly by against the capacitive and inductive coupling between the two structures decreases with a significant amount. As the reported data has confirmed and according to the ICNIRP standards, the EMFs values are in danger zone. Moreover, location close to the tower is also a risky region for workers during maintenance tasks.

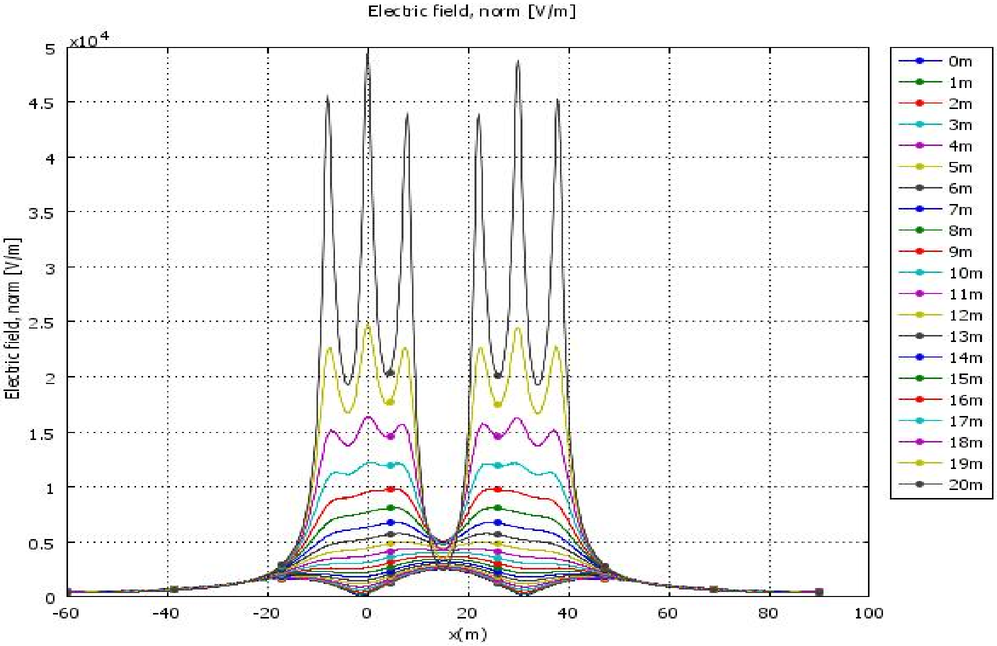


Figure 9: Simulated electric field for the levels 0m to 20m

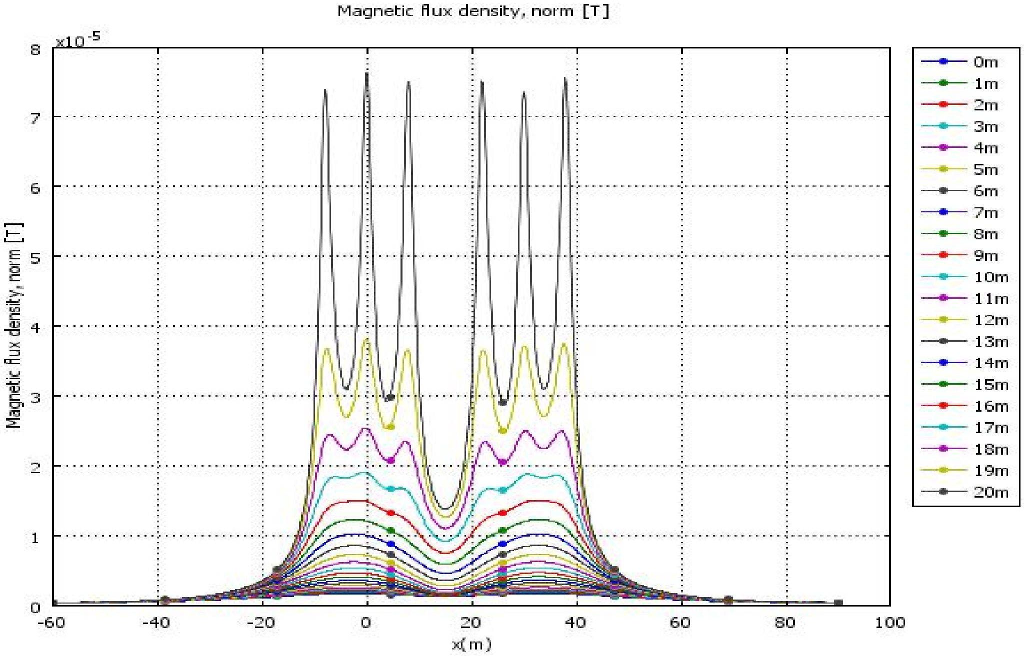


Figure 10: Simulated magnetic fields for the levels 0m to 20m

4. CONCLUSION

This paper present a monitoring and diagnoses of the electromagnetic fields inside an electrical post of interconnection, consisting in several ranges of voltages [220 KV, 90 KV, 60 KV and 30 KV].The purpose is to systemize the knowledge about the repartition of electric and magnetic charges quantities beneath a Multi-line power system often requiring maintenance in order to see the level of exposure that the workers are facing.**T**he results show that for the levels above the ground representing the human body in case of occupational exposure, the electric and magnetic field strength values are substantially within recognized ICNIRP guidelines, suggesting that they are not dangerous and therefore no cause for concern among the working personnel. The results also present the levels that could be dangerous to the live- line worker. According to the simulated field's strength values at ground clearance close to the tower, these exceed the reference level for safe occupational exposure. This could endanger workers body when approaching conductor's area for a long period.

People performing work tasks in and around power facilities may be informed and educate to take protective measures against exposure to EMF field in order to make them aware of electromagnetic field potential risks. For example a security program could be established to protect maintenance staff inside substations when performing repairs on line's phases often presenting coupling by inductive and capacitive crosstalk. **I**n our monitoring protocol and in agreement with SONELGAZ, we will conduct regular inspections of these exposure levels, but in view of the previous results we recommend to think in simple and accessible solution to keep these values in international standards. **A**s shortcoming with regards to limit of exposure to EMF in Algeria, this study is important and the results could be a benchmark for the evaluation of electromagnetic pollution from HVPL in order to elaborate normative and to implement protection techniques of the public and professional against strong electromagnetic fields (EMF) at power frequency and the related electromagnetic radiations (EMR).

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