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Regular paper

Mitigation of the electromagnetic pollution inside El-CHAFIA high-voltage substation (400KV)

The regulatory update concerning occupational and public low frequency exposure published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in 2010 is widely recognized and formed the basis for national regulations in Algeria; this requires verification of compliance with the deriving recommendation. In this paper, the assessment of low frequency professional exposure inside EL CHEFIA 400 kV substation belonging to the Algerian SONALGAZ company is investigated. An analytical characterization of the electromagnetic environment beneath a selected circuit of 400 kV power lines inside the substation often requiring maintenance is outlined.in the second part of the paper, the programs developed based on MATLAB software provide a solution for the analysis and reduction of the electric field intensities for highest ground clearance levels close to the towers, in order to predict live –line- workers safety. General conclusions arising from the comparison of the results with the IEEE and ICNIRP standard levels for occupational exposures as well as recommendations to ensure workers safety are finally given.

Keywords:low frequency occupational exposure, passive shielding, high voltage transmission line,standard limits.

I. INTRODUCTION

Due to their uses in the transport and distribution of electrical energy, power lines are the most abundant sources of "Electro-smog" in the environment. Use of electricity at 50 or 60 Hz are an integral part of modern civilization. Population growth and technological change have led to an increase in demand for electrical energy in larger quantities. This causes enhancement of electromagnetic pollution in the urban and the work environment where the occupational exposure to low frequency electric fields can be quite high and close to or even over the workers' exposure limits published by the International Commission on Non-ionizing Radiation Protection (ICNIRP) [1] for limiting exposure to time-varying EMFs (1 Hz–100 kHz). Constant exposure of humans even to low frequency electromagnetic radiation may be hazardous [2] .The human body is a living antenna that can absorb and re-emit power energy, in the environment [3] .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 endogenous ones, lead to changes in

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functions of cells and tissues and subtle changes in hormones levels. This, in turn, has prompted increased activity in the following areas: the calculation and measurement techniques for the assessment of low frequency public and occupational exposure and the sensitivity of people to different field effects [3-7]. By preventive measures, various legislative institutions (European Parliament, etc.), and learned societies, have established EMF exposure limits for the public and workers. Among these organizations: ICNIRP), WHO and the IEEE standard directive [1], [7-8]. Expectedly, power frequency electromagnetic fields produced inside outdoor substations address environmental impact which may cause negative health effects on the workers if there is no attention during the design stage [9]. During live-line work inside substations high electric fields come when climbing pylons with live circuits and exceeds very much the human exposure limits. The worker exposure level and exposure time depend on the different techniques and positions of the workers. Staff climbing pylons with live circuits experience high electric fields as they climb past the conductors. The fields are highly non-uniform because of the presence of all the steelwork in the pylon and measuring them is made even more complicated because it's almost impossible not to have the person making the measurements distort the field further. So, Considering the widely varying levels of electromagnetic field to which workers may be subjected depending on their job, the CES underlines the relevance of decree No. 2016-1074 of 3 August 2016 , on protecting workers against the risks of electromagnetic fields, and the duty of their employers to characterize the electromagnetic environment of workstations [10], 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 investigated the occupational exposure to power frequency in substations in power stations and on lines and cables [5], [9], [11-13]. Quantitative description of the electrostatic field around EHVDC overhead transmission line has been presented in many papers [2-3], Several investigations have been carried out to reduce field effects based on conventional compensation methods applied in the electric field mitigation near to power lines [14-16]. These methods could be electrical or mechanical. Also, active and passive shield wires are used to mitigate the electric field as an electrical method. [16]. This work extends the previous research work of the authors related to electromagnetic fields inside power substation and investigate occupational exposure inside El-CHEFIA 400Kv electrical post located in El Tarf city (eastern of Algeria). This substation is categorized according to its great power resulting in potential risk of occupational exposure to very large electromagnetic fields. Because most field effects occur close to ground level and are a function of the magnitude of the unperturbed electric field at 1m above ground, the reduction of this field is the mean gool of the electrical shielding method applied in this work. There is no specific study to evaluate and mitigate the electric field at higher ground clearance levels close to the tower location inside this power substation. Will this EMF investigation as useful coordinated action undertaken by the supervisory staff's regulations and our laboratory to predict and limit the exposure to these fields especially Staff climbing pylons who are frequently approaching wires. Genetic algorithm developed in the MATLAB environment is developed for the mitigation of the electric field in the vicinity of 400Kv transmission line using horizontal grid of grounded parallel wires uniformly spaced at constant heigh, that would be another plan at zero potential. The profiles of electric field calculated for several hauteurs above the ground approaching the towers highlight the effect of passive shielding method proposed on changing the value of the electric field intensity and of the space potential from a value without the shield exceeding the limit values imposed by the international standards in areas close to large transmission lines, to a lower value with the shield.

II. MATERIAL AND METHOD

A. Geometries used for computation

The model of the 400 kV transmission line under study is presented in Figure 1, providing a detailed representation of its geometry, and key design parameters.

Figure 1: 400KV triangular configuration

The Table 1 mentioned the parameter of the model in the study case.

Table 1: Model parameters

Height of conductors (h)	Phase spacing (s)
h_1=h_3=26 m h_2=32,5 m	S_1= 8 m S_2= 20 m S_3= - 4 m
Height of shield wires (H_s) = 15 m	S= 5 m r_{sh}= 0,42cm

B. 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 [10]. 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:

$$V = V_r + j\,V_i \qquad (1)$$

The charges Q on the conductors are determined with the matrix equation through the line voltage V, and the Maxwell potential coefficientsbased 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 400KV line 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 phases as shown in (figure. 1) and is given by the following expression.

$$E_i = \frac{q_{ri}+jq_{ii}}{2\pi\varepsilon_0} \frac{2Y_i}{(X_i-X_M)^2+(Y_i-Y_M)^2} \qquad (5)$$

Where q_{ri} and qii are the real and the imaginary parts of the charge on conductor ($Xi–X_M$) and ($Y_i–Y_M$) 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 (*i, j, k, i', j'* and *K*'...):

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

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.

C. Electric Field Shielding Calculations

Because most field effects occur close to ground level and are a function of the magnetite of the unperturbed electric field at 1 *m* above ground, the reduction of this field is the primary objective of the shielding method presented in this section. The shielding method changes the value of the electric field intensity and the space potential from a value without the shield to a lower value with the shield. The electric field shielding calculation is obtained by combining the two-dimensional calculations for the electric field without.

Shield wires and for the shielding factor *SF* efficiency shielding *SE* in the uniform field defined as:

$$E_s = E_u \, . SF \qquad (7)$$

Were *Es*is the electric field at ground with the shield present and Eu is the unperturbed electric field without the shield. Also, the shielding efficiency, *SE*, me be defined, as shown in equation 8:

$$SE = 1 - SF = \frac{E_u - E_s}{E_u} \qquad (8)$$

Combining equations 7 and 8 fields

$$E_s = E_u \, (1 - SE) \qquad (9)$$

Passive shielding method applied for a road under a high voltage transmission line consists of using an infinite grid of parallel grounded wires uniformly spaced at constant heigh under lines phases can provide effective shielding under it. The parameters of these arrangements are the wire radius height *H* and spacing *S*. This concept assumes that the field is induced by high voltage conductors far from the grid and the ground. A perfect shield over a plane would be another plane at zero potential. The shielding efficiency of an infinite grid, *SE* ∞ is given in the following equation: the shielding efficiency of an infinite grid, *SE* ∞, as defined in figure 2 is given by this equation:

$$SF\infty = \frac{2\pi H/S}{ln\frac{2H}{R} + \left[ln\frac{e^{2\pi H/S} - e^{-2\pi H/S}}{4\pi H/S} \right]} \qquad (10)$$

This equation is presented in the form of dimensionless curve in (figure 2) that given a desired shield efficiency, the design values of wire size R, high H and spacing S may be iteratively introduced [17].

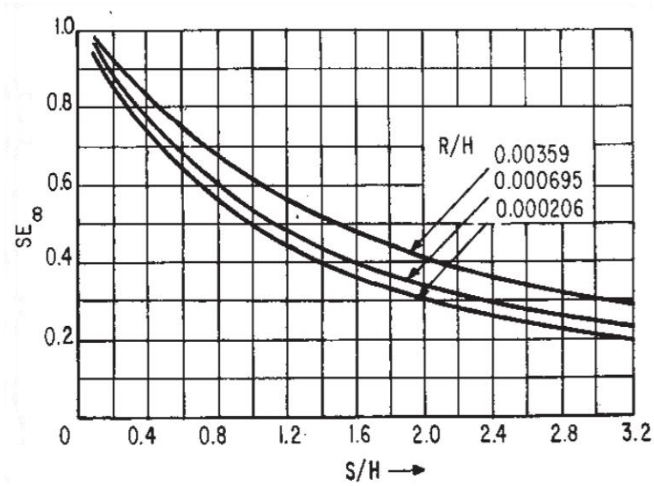


Figure 2: Shielding efficiency for an infinite grid of horizontal shield wires [17].

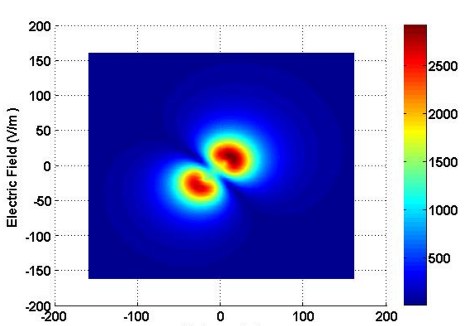
III. RESULTS AND DISCUSSION

A. Analytical Results

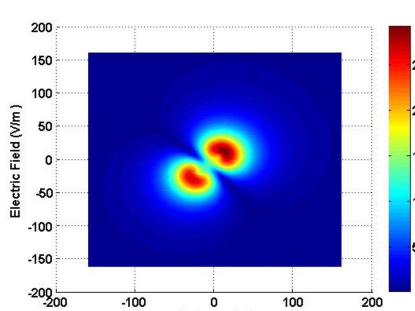
1) Electric Field without shield:

Figure3, visualizes the distribution of the electric field generated by the 400 KV transmission line in the plane X–Y, it highlights the effect of the heights above the ground on the distribution of the capacitive charge quantities emitted by the line. As can be seen in Figure3, the intensities of the electric field calculated increase were increasing the levels above the ground because most field effects occur close to ground level and are a function of the magnitude of the unperturbed electric field at 1m above ground. The values of fields calculated for the levels 0 m, 1 m, 1.5 m, and 1.8 m remain very inferior to the maximumlimit (5 kV/m) established by ICNIRP standards.

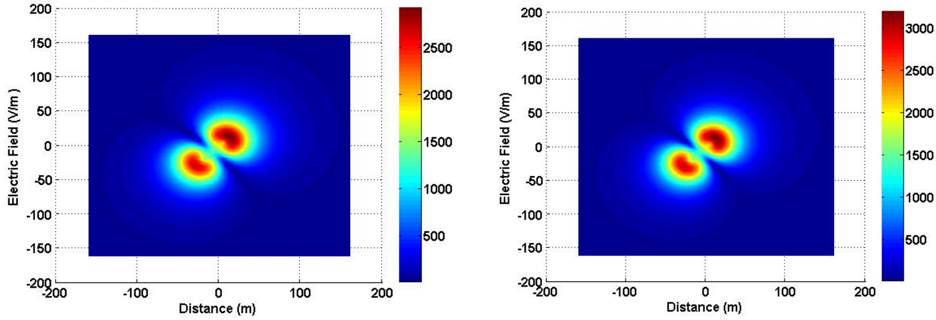
We can see from these figures that for the higher levels in direction of the towers the electric field strength increases and reach maximal values (3500v/m for YM= 1.8 m) the unperturbed electric field intensity increases far from the ground.



(a)



(b)

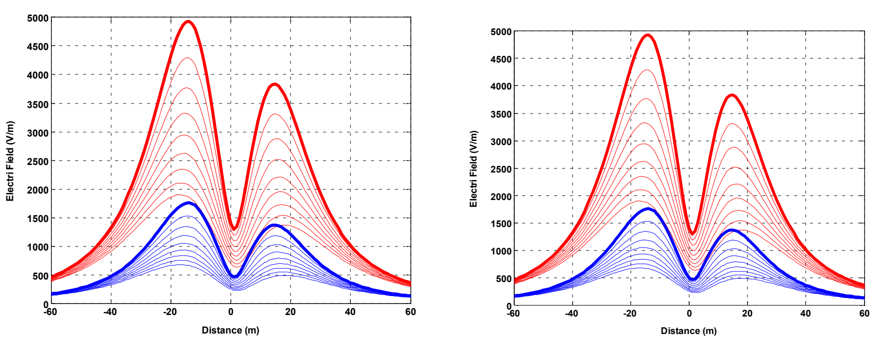


(c) (d)

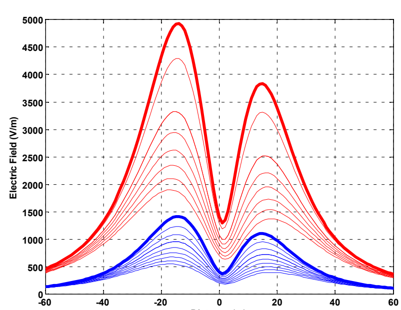
Figure. 3: Electrical field distribution, plane *X-Y*, for 4 levels: (a) Y_m= 0*m*, (b): Y_m=1*m*, (c):Y_m=1.5*m* and(d) Y_m= 1.8*m*.

2) **Electric Field shielding calculations**:

The shield wires are arranged under the 400 kV line's conductors. In this study shield wire selection is given by a minimum number of wires with a small size for economy and low visual impact. The approach is to use passive shields of single, double and triple configurations, which are positioned underneath the phases conductors and connected together at one end where they are grounded. Where the shield wire radius is r_{sh}, the spacing between shield wires is *S* and the height from shield wires to ground is*Hs*.



(a) (b)



(c)

Figure4: Electric field shielding with: (a) One wire, (b) Tow wire and (c): Three wire.

Figures 4shows the calculated profile of the electric field in the vicinity of the circuit of 400 *kV* high voltage power line studied with and without shield wires depending on the distance to several levels above the ground (0*m*) in direction of the towers often frequented by the live –line –workers when climbing towers. For a good visualization of the results and to highlight the effect of increasing the number of shield wires on the reduction of the electric field intensities we plotted the results on separate curves. It can be seen from these figures that without the shield wires the computed electric field intensities at several levels above the ground in direction of the pylons are higher than the electric field computed with the presence of the shield wires.

The maximum electric field value decreases with the increase of the number of shield wires for the single, double and triple configuration of the shield wires the percentages reduction are respectively 47%, 62% and 71%. Also from the previous figures, the lateral profile of electric field relieved for theheights (0m-10m) is highest for single shield wire configuration and lowest for three shield wire configurations. This is because in the case of an infinite grid the field is induced by high voltage conductors far from the grid and the ground. Then a perfect shield over a plane would be another plane at zero potential

IV. CONCLUSION

This work has investigated the prediction of live-line workers inside El -CHEFIA 400*KV* electrical post located in El Tarf city (eastern of Algeria). This substation is categorized according to its great power resulting in potential risk of occupational exposure to very large electromagnetic fields. The algorithm developed in MATLAB environment is developed for the characterization of the electric charges' quantities for the levels 0 m, 1 *m*,1.5 *m*, and 1.8 *m* which affect the human body in case of power frequency fields exposure. The profiles of electric field calculated for severalheights above the ground often frequented by climbing workers during different tasks of maintenance, highlight the effect of passive shielding method proposed on changing the value of the electric field intensity and of the space potential from a value without the shield exceeding the limit values imposed by the international standards in areas close to large transmission lines, to a lower value with the shield.

Drawing on the ICNIRP's standards and in co-operation with partners concerned, critical activities have been identified and handled to set our own national standards for occupational exposure to electromagnetic fields, that will be at the disposal of partners concerned to ensure the safety of people and mainly to guarantee the maximal level of safety for live -line workers inside high voltage substations.

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