



RESEARCH ARTICLE

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COMPUTATION OF ELECTRIC FIELDS INTENSITY IN THE VICINITY OF HIGH VOLTAGE POWER TRANSMISSION LINE

Tahar Rouibah^{1*}, Ilies Rezzag Bara², A.Hakim Bendakir³ and Ahmed N. E. I Ayad⁴^{1, 2, 4}Department of Electrical Engineering, Kasdi Merbah University, Ghardaia Road, P.O. Box 511, Ouargla 30000 DZ, Algeria.³Laboratory of Studies and Modeling in Electrical Engineering, Department of Electrical Engineering, University of Tebessa, Algeria.¹<http://orcid.org/0009-0000-0928-3148>, ²<http://orcid.org/0009-0004-9703-6786>,³<http://orcid.org/0000-0003-3299-7100>, ⁴<http://orcid.org/0000-0002-0238-2204>

E-mail: *rouibah.tahar@univ-ouargla.dz, rezzagbara.ilyes@univ-ouargla.dz, Bendakir_ah@yahoo.fr, ayadnourislam@yahoo.fr

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ABSTRACT

This study aims to assess the electric fields generated near overhead high-voltage transmission lines in light of public concern about possible health effects for those living nearby. The study evaluated the electric fields intensity around a 220 kV power transmission line, while recognizing the conductors have catenary shape in real life, and therefore used real conductors to estimate electric fields for realistic conditions. The quasistatic electric field was computed with an approach based on Coulomb's law and the method of image charges, incorporating the conductor geometries, observer locations, and symmetric images of position. The results showed that specific locations underneath the power transmission line will have electric fields above 5 kV/m and 10 kV/m. When compared to existing safety guidelines and public electromagnetic exposure limits, the findings indicated that the public would not be at significant risk from the electric field levels. However, higher levels of exposure could pose a potential risk for personnel working closely to the transmission lines during long periods, as these individuals are considered to be occupationally exposed. The results provide useful information for public safety assessment and developing mitigation plans around overhead power lines.



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I. INTRODUCTION

Over the past few years, electricity has improved people's quality of life significantly and is now necessary to fulfill basic human needs. Even with many benefits, electricity generation and supply often adversely affect the environment and human health. The increase in the need for energy, due to population growth and economic development, has resulted in transmission systems that operate at very high voltage levels and additional double-circuit transmission lines. Extended or short-duration exposure to electromagnetic fields associated with high-voltage power lines may create health and safety risks, especially for anyone who works near these high-voltage wires [1], [2]. Therefore, it is necessary to reduce the electric field strength around transmission systems, and develop computational methods that accurately calculate the optimal distribution of electric field strength around these systems. The need to reduce electric field strength created around high-voltage transmission lines has led to the precise evaluation and control of electric fields to a major research area in power engineering.

Various analytical and numerical approaches for calculating electric field intensity below high-voltage transmission lines have been introduced [3-6]. One of the more common methods is the Charge Simulation Method (CSM) [7-11]. Essentially, CSM involves substituting the conductors' distributed charge and the polarized charge that appears on dielectric interfaces with a finite set of fictitious discrete charges that reproduce the same potential distribution. This paper describes an example of quasi-static electric field computation that takes place in the area of high voltage transmission lines with a voltage of 220 kV, with consideration for real catenary curves of the conductors. For comparison with the limits of human exposure established by safety standards, the results of the computation are given. To provide more accurate electric field calculation in the area of transmission lines, an application of the Coulomb equation has been utilized.

This application was implemented together with the image charges' method of dependence of electric field on the conductor position, observer position, and its symmetry. The computer program implemented in the MATLAB environment has been developed for assessment of the electric field intensity near overhead power transmission lines.

II. MODELING THE ELECTRIC FIELDS UNDER A POWER LINE INCLUDING THE SAG OF WIRES

II.1 COMPUTATION MODEL FOR A SAGGING CONDUCTOR

Traditional simplified methods for computing electric fields generally make the assumption that power line conductors are infinite, parallel and straight wires located above a perfectly conducting flat ground. However, actual power transmission line conductors have a catenary shape associated with sagging, which is a function of mechanical and environmental parameters. This sagging of the conductors can play a significant role in how the electric field intensity can vary in both magnitude and distribution [12–17], so it must be taken into account for precise field modeling.

The catenary geometry primarily depends on the conductor weight per unit length (w), the horizontal component of tension (H) and the span length (S). In the analysis of the study, each span of the conductor will be decomposed into n equal segments ($s_1, s_2, \dots, s_i, \dots, s_n$), as illustrated in Figure 1, which shows where the conductor sagging and span lay so that there is symmetry across the catenary. The conductor has a maximum height of h at the supports and a minimum height of h_{min} at the mid-point of the span. The sag is defined as follows: provide sag equations the electric charge with line density η will be on each segment carried as defined earlier in the study. The number of simulated charges is chosen to match the number of segments defined for the conductors thereby maintaining the same spatial resolution. The total quantity of simulated charges is selected to equal the quantity of defined conductor segments, which ensures that the spatial resolution remains the same. The catenary equation [18] [19] can be used to describe the arrival position of each segment along the span as it describes the actual curve of the suspended conductor and serves as the geometric basis of calculating the electric field in the proposed model.

$$z(x) = h_{min} + 2a \sin\left(\frac{2x}{2a}\right)^2 \quad (1)$$

with: h is the maximum height, α is related to the mechanical parameters of the line $\alpha = Th/w$, Th is a mechanical stresses in the middle of the line, w is the weight per unit of the length of the line, h_{min} is the minimum height, S is the arrow of the line and L is the length of the line.

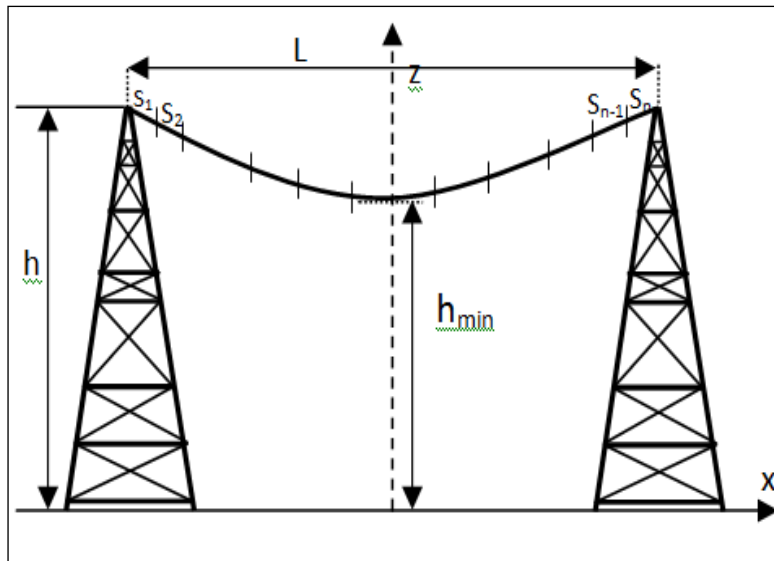


Figure 1: Division of a power line conductor into n segments of symmetric catenary.
Source: Authors, (2026).

II.2 COMPUTATION OF ELECTRIC FIELD INTENSITY

The potential of the static electric field at any observation point $P(x, y, z)$ above the ground plane is determined using the Charge Simulation Method (CSM) alongside Coulomb's law and the image charges method, using the formulation given in references [20–23].

$$\vec{E} = \epsilon \int_r d\vec{E} = \frac{1}{4\pi\epsilon_0} \int_r \frac{q dl}{r^3} \vec{r} \quad (2)$$

where q denotes the elemental of a line charge, dl represents the infinitesimal segment along the conductor, and Γ defines the geometric path of the conductor (catenary curve). $\vec{r}$ is the vector from the conductor element dl to the observer points P in Figure 2.

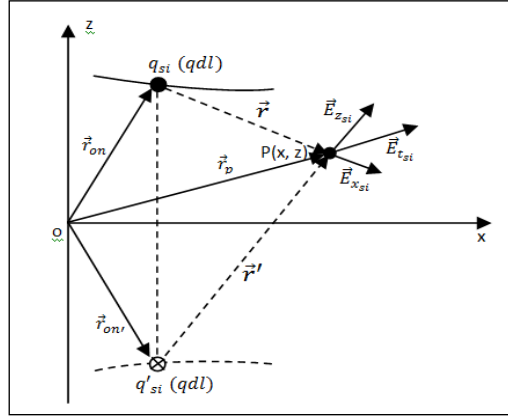


Figure 2: Division of a Method calculation of electric field intensity at the point P.
Source: Authors, (2026).

The resultant electric field vector $\vec{E}$ at point P is equal to the superposition of the electric fields produced by each conductor and its image $\vec{E}'$, as shown in Figure 2. The total electric field vector $\vec{E}$ at the observation point P(x,y,z) is obtained as the superposition of the electric fields generated by each conductor $\vec{E}_k$ and its corresponding image $\vec{E}'_k$ as illustrated in Figure 4.

$$\vec{dE}_{k,k'} = \frac{1}{4\pi\epsilon_0} \frac{+qdl(\vec{r}_p - \vec{r}_{ok})}{(\vec{r}_p - \vec{r}_{ok})^3} + \frac{1}{4\pi\epsilon_0} \frac{-qdl(\vec{r}_p - \vec{r}_{ok'})}{(\vec{r}_p - \vec{r}_{ok'})^3} \quad (3)$$

The simultaneous equations governing the relationship between the line charges and the corresponding conductor potentials enable the determination of the linear charge densities. These equations can be conveniently expressed in matrix form as follows:

$$[V_k] = [P_{kk}] \cdot [q_k] \quad (4)$$

Where: k is a number of conductors, v_k is a potential of conductor k to ground plane, P_{kk} is the potential coefficient of the conductor k and q_k is a line charge per unit length on conductor k. The corresponding potential coefficient values are given as follows:

$$P_{kk} = \frac{1}{2\pi\epsilon_0} \ln \frac{2h_k}{r_k} \quad (5)$$

$$P_{kj} = \frac{1}{2\pi\epsilon_0} \ln \frac{S_{kj'}}{S_{kj}} \quad (6)$$

where: r_k is the radius of conductor k, ϵ_0 is the permittivity of free space, h_k is the height of conductor k above ground, S_{kj} is the distance between conductors k and j, $S_{kj'}$ is the distance between conductor k and the image of conductor j, P_{kk} is the self-potential coefficient of the conductor k and P_{kj} is the mutual potential coefficient of the conductors k and j. The symmetric catenary shape of the overhead conductors is taken into consideration when calculating the intensity of the electric field $\vec{E}$ at an observation point P(x,y,z) beneath k conductors, each energized at a voltage U. The Charge Simulation Method (CSM) in conjunction with the method of image charges is used to evaluate the potential distribution of the static electric field near the power transmission line [24]. For a system with multiple conductors ($m=1,2,\dots,M$), the vector superposition of the individual field contributions from all conductors and their corresponding image charges yields the total electric field intensity at point P.

$$\vec{E} = \frac{1}{4\pi\epsilon_0} \sum_{k=1}^k [\sum_{n=1}^n [\frac{q_{kn}dl(\vec{r}_p - \vec{r}_{onk})}{(\vec{r}_p - \vec{r}_{onk})^3} + \frac{-q_{kn}dl(\vec{r}_p - \vec{r}_{on'k})}{(\vec{r}_p - \vec{r}_{on'k})^3}]] \quad (7)$$

where the conductor element's image and position $\vec{r}_{onk}$ and $\vec{r}_{on'k}$ are determined by the vectors based on the coordinate system.

III. RESULTS AND DISCUSSIONS

A single-circuit high-voltage (HV) transmission line running at 220 kV is taken into consideration in this study. The system is made up of two overhead ground wires that act as shielding cables and three phase conductors, designated A, B, and C, arranged horizontally parallel to a level ground surface. Figure 3 shows the simplified schematic diagram of this arrangement as well as the geometrical characteristics of the conductors near the suspension tower. The ground wire, which serves as a guard cable, has a diameter of 0.015 meters, while each phase conductor has a diameter of 0.04 meters. The transmission line's span length is 280 meters. With a current magnitude of 150 A per phase, the line runs in a balanced three-phase configuration. The system frequency is 50 Hz, and the earth is assumed to be homogeneous with a resistivity of 100 $\Omega \cdot m$. The electric field intensity is measured at a height of 1.5 meters above the ground, within a horizontal range of ± 30 meters from the line's central axis, or 200 measurement points. This is the definition of the phase voltage configuration. As seen in Fig. 3, the base of the tower, where $x=0$ and $z=0$, is the origin of the Cartesian coordinate system.

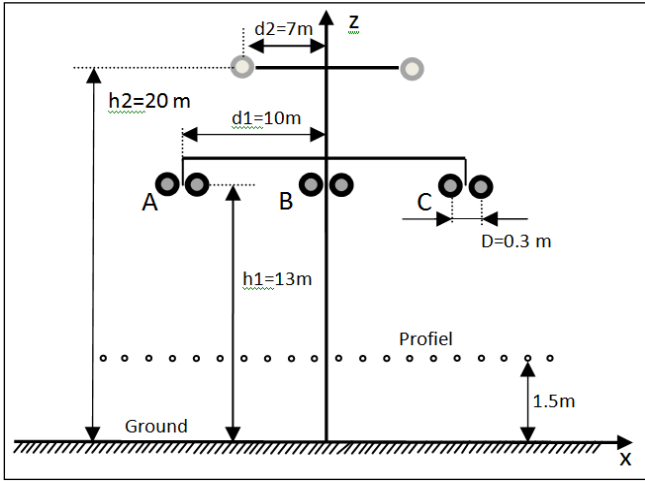


Figure 3: High voltage power transmission lines of 220 kV.
Source: Authors, (2026).

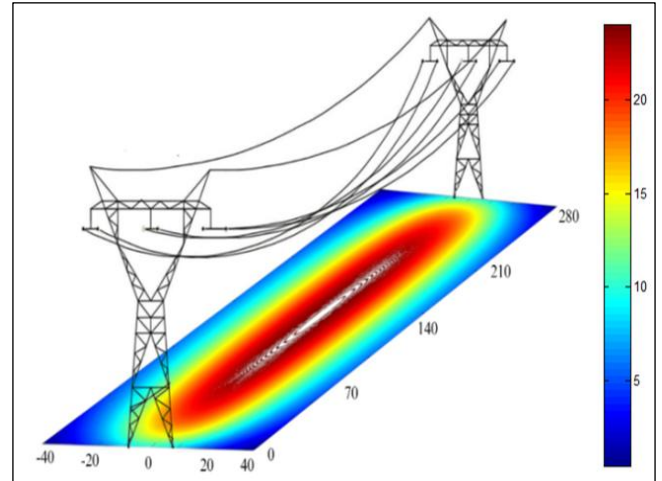


Figure 4: Electric field distribution E_t (kV/m) in the x-y plane at 0.5 m above ground level.
Source: Authors, (2026).

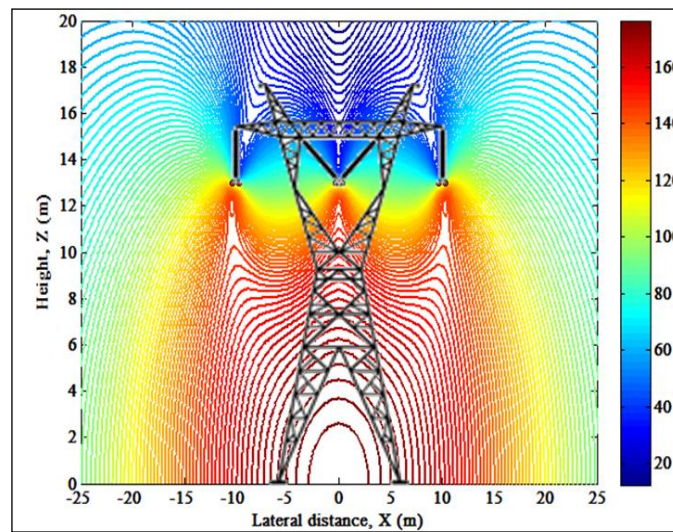


Figure 5: Electric field distribution E_t (kV/m) in the x-z plane above ground level.
Source: Authors, (2026).

Figures 5 and 6 represent the shapes of the electric field distribution in the x-y plane and x-z plane for the 220 kV for overhead power transmission lines. In the x-y plane, the electric field is calculated below the overhead transmission lines at a height of 1.5 m above the earth. In the x-z plane, the strength of the electric field increases and takes a maximum value near the phase conductors. The variation of the electric field intensity, which takes into consideration the change in ground height brought on by conductor sag, is shown in Figure 5 using the 3D method. As the conductors sag, it is evident that the electric field intensity tends to increase. This is primarily because the average clearance between the conductors and the ground surface decreases.

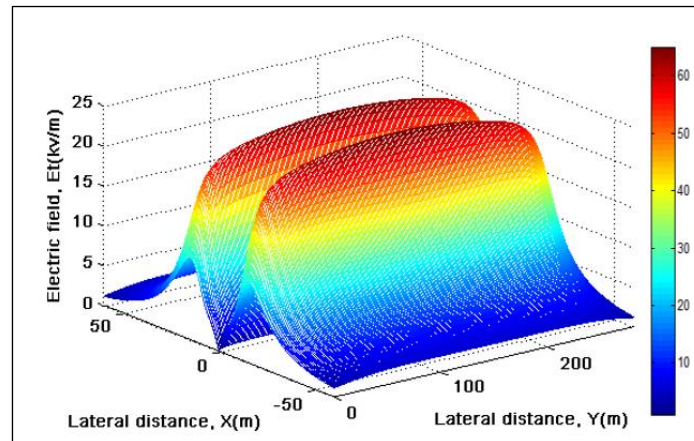


Figure 6: Three-dimensional electric field profile calculated at 1.5 m above the ground.
Source: Authors, (2026).

The electric field's three-dimensional profile is depicted in Figure 6 over a 280-meter span length between the suspension pylons and 50 meters on either side of the power line's center. Only a small region near mid-span has higher electric field values, which rapidly decrease in the direction of the pylons and even more quickly in the direction away from the side conductors. Compared to near mid-span, the electrical field strengths surrounding the pylon are significantly lower.

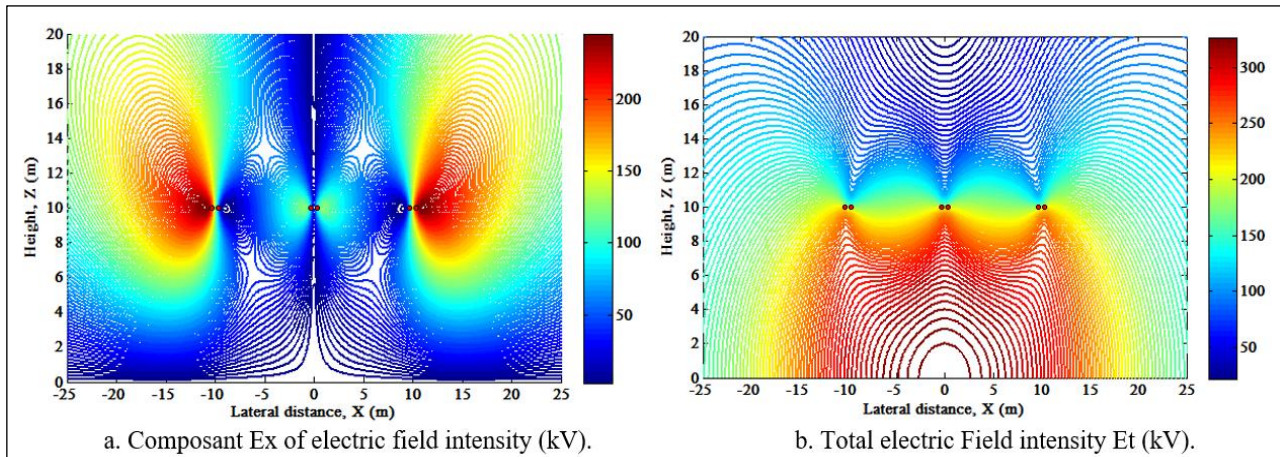


Figure 7: Contour lines plots of the electric field intensity at mid-span.
Source: Authors, (2026).

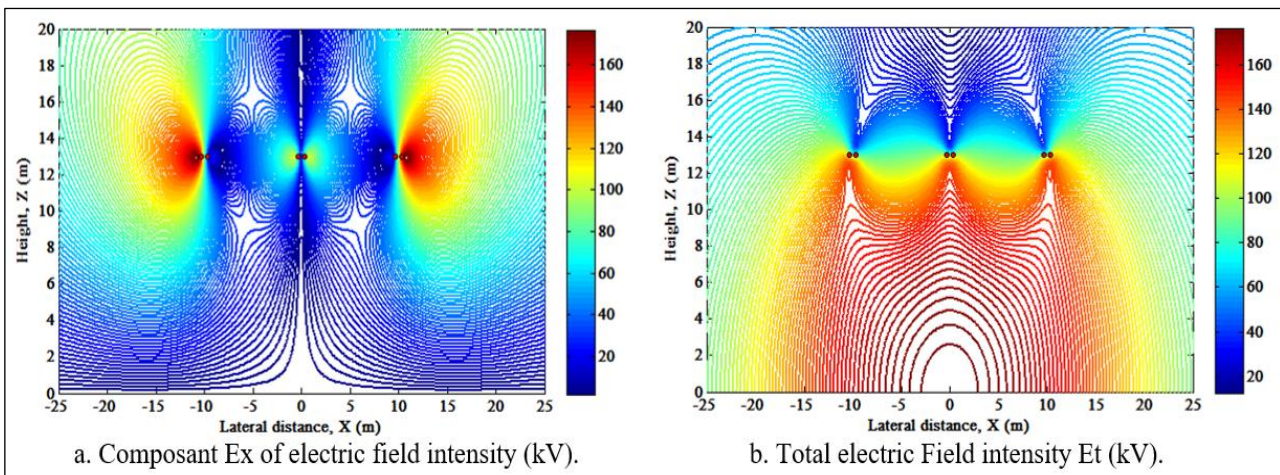


Figure 8: Contour lines plots of the electric field intensity at pylon foot.
Source: Authors, (2026).

Figures 7 and 8 present the contour distributions of the total electric field intensity E_t and its horizontal component E_x for a 220 kV single-circuit power transmission line, evaluated at mid-span and near the pylon. The results reveal a highly non-uniform electric field distribution, with peak values concentrated close to the phase conductors. At mid-span, where conductor sag leads to minimum ground clearance, the electric field beneath the line reaches its highest levels as a result of the reduced conductor-ground distance, producing denser equipotential contours near ground level. In contrast, near the pylon, the increased conductor height results in a significant reduction of the electric field intensity at lower altitudes, while the maximum field values remain confined to the conductor surfaces.

The shielding effect of the overhead ground wires further modifies the field distribution by attenuating the electric field below the line and distorting the equipotential contours. The horizontal electric field component E_x exhibits a symmetrical distribution with respect to the line's central axis, reflecting the balanced three-phase configuration. Its magnitude increases laterally away from the center conductor due to the superposition of fields from adjacent phases and decreases with increasing conductor height near the pylon. Overall, these results indicate that conductor height, line geometry, and the presence of ground wire greatly affect the spatial distribution of the electric field. Therefore, the mid-span area of high-voltage transmission lines is likely to be the area of greatest concern with regards to electric field exposure.

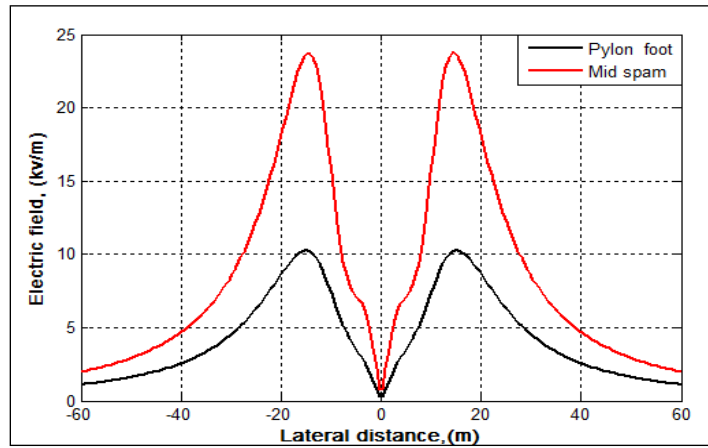


Figure 9: Electric field profile at 1.5 m above the ground.
Source: Authors, (2026).

The distribution of the electric field beneath the power transmission line at a height of one meter above the ground is shown in Figure 8, which is assessed at the mid-span and at the foot of the pylon for different lateral distances along the transmission corridor. As one gets farther away from the transmission line's centerline, the electric field intensity gradually diminishes. At mid-span, where the phase conductors reach their lowest elevation above the ground, the maximum field values are seen over a small area. The conductors are positioned higher as the observation point gets closer to the pylons, increasing their clearance from the ground and, as a result, lowering the maximum electric field magnitude.

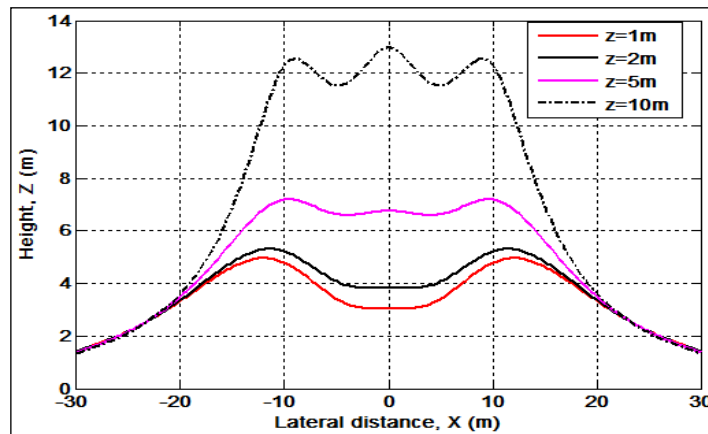


Figure 10: Electric field profile for different heights of observation point.
Source: Authors, (2026).

The calculated electric field intensity at various observation points (P) above the ground is shown in Figure 9. It is clear that as the observation point's elevation increases, the peak electric field value rises noticeably. The electric field strength increases in proportion to the height above the ground, which brings the observation point closer to the phase conductors.

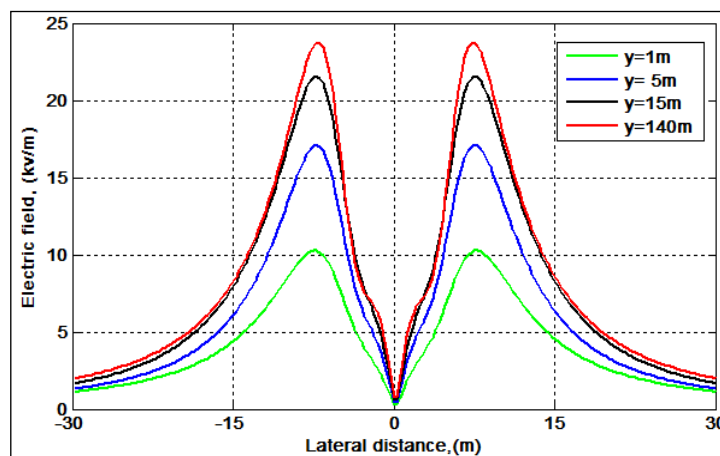


Figure 11: Electric field profile distribution at height $z=1.5\text{m}$ in the x-y plane.
Source: Authors, (2026).

Figure 10 illustrates the variation of the electric field intensity with height above the ground surface at different lateral distances along the y-direction. It is evaluated at 1 m, 5 m, 15 m, and 140 m for the 220 kV transmission lines. The electric field strength rapidly diminishes beyond the central region (at about $x=\pm 30$ m), becoming comparatively low and insignificant at greater lateral distances. The calculated electric field strength for the given study is then compared with the limits of exposure specified by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) for power frequency electric fields with a frequency of 50 Hz. As per the ICNIRP guideline limits for electric field strength for public exposure at 50 Hz, it is restricted to 5 kV/m, whereas it is increased to 10 kV/m for occupational exposure illustrate in Table 1.

Analysis of electric field strength as calculated through simulation reveals that the maximum strength is found at mid-span of the 220 kV transmission line at points where the phase conductors are closest to the ground. Though maximum strength locally observed is in excess of 5 kV/m for a very small area lying directly below the phase conductors, electric field strength reduces significantly with increase in distance from the transmission line and height from the ground. It is found that electric field strength at points of probable public access is below the ICNIRP guideline limits for public exposure. This is devoid of any risk of health hazards that could occur among the public at large. It is evident from the results that electric field strength for personnel approaching or exceeding the ICNIRP guideline limits for occupational exposures is of considerable importance for implementation of proper safety standards for such work.

Table 1: Exposure limits to low frequency electric and magnetic fields (50 Hz) ICNIRP.

Exposure Type	Electric Field Intensity E (kV/m)	Magnetic Flux Density B (μ T)
General Public	5	100
Occupational	10	500

Source: [1].

IV. CONCLUSIONS

This study used an approach based on Coulomb's law in conjunction with the method of image charges to successfully implement a numerical model for calculating the electric field vector in the vicinity of overhead power lines. This model produces accurate and reliable results regardless of distance by appropriately accounting for the electric field's dependence on conductor position, observer location, and mirror images. According to our simulation results, there are some locations close to high-voltage transmission lines where the electric field intensities are higher than the maximum exposure limits set by standard specifications for both the general public and occupational workers. Importantly, the study also confirms the well-known fact that the intensity of an electric field decreases dramatically with increasing distance from the source. In the end, this paper aims to dispel common misunderstandings about the exposure levels to electric field close to overhead transmission lines. Informing public safety assessments and directing future mitigation strategies, the findings offer useful information that can help document possible health risks linked to these exposures more accurately and effectively.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Tahar Rouibah, A. Hakim Bendakir and Ahmed N. E. I Ayad.

Methodology: Tahar Rouibah, Ilies Rezzag Bara and A. Hakim Bendakir.

Investigation: Tahar Rouibah and A.Hakim Bendakir.

Discussion of results: Tahar Rouibah, Ilies Rezzag Bara, A. Hakim Bendakir and Ahmed N. E. I Ayad.

Writing – Original Draft: Tahar Rouibah.

Writing – Review and Editing: Tahar Rouibah and Ahmed N. E. I Ayad.

Resources: Tahar Rouibah.

Supervision: Tahar Rouibah, Ilies Rezzag Bara and Ahmed N. E. I Ayad.

Approval of the final text: Tahar Rouibah, Ilies Rezzag Bara, A. Hakim Bendakir and Ahmed N. E. I Ayad.

VI. ACKNOWLEDGMENTS

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