Electric Fields Intensity Around the new 400kv Power Transmission Lines In Libya

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Abstract:

The electric fields for a realistic recently commissioned 400KV power transmission line systems existing in Libya are presented. The approximate computations will be done using the image method considering a quasi-static, fields and an infinite line sources parallel to a perfectly conducting flat ground plane. The computation domain considered is only the 2D free space in the lateral directions perpendicular to the conductors and at 1 and 4m above ground level. The objective of this work is to investigate how safe is the transmission corridor limits set by the Libyan government and to account for public awareness. The resulted field values considering the line carrying the maximum design load (power) are much less than the exposure level limits recommended by the IRPA/ INIRC (which is 5KV/m) outside the right of way (ROW) edges (±30m off the center-line, the corridor width).

Keywords: High voltage; electric field; transmission corridor; quasi-static fields.

1. Introduction

High voltage power transmission lines in Libya covers and extends nearly to the whole places where industry growing and people live, before 2006 the highest used voltage in Libya was 220 kv. On Sept. 2006 the general electrical company of Libya (GECOL) commissioned the first 400Kv. which extends over 460km from Gumas to Benwaild and Gamra 1 system with, single, and double, circuits with triple bundled conductors The electromagnetic fields generated around high-voltage lines in general have received many investigations concerning their intensities and their influence to human beings. In some places, especially, where people live just under or nearby these lines, the awareness of the affects of the fields produced by these lines becomes a serious problem. Neither the Libyan government nor any other nongovernmental organization has set any level limits to exposure to those electromagnetic fields. The government has set only the corridor width that extends 30 meters from both sides of the center-line of a high voltage transmission lines. The international standards for public exposure limits as set by the *IRPA/ INIRC* [8], is 5kV/m for the electric field. As a start to the calculation of the electric field, the per unit length charges are calculated first using the image method with the potential on the surface of each conductor is known. The quasi-static radial electric field is then calculated using Gauss's law. To simplify the integration of the field components, the radial electric field intensity contributions of each of the conductors constitutes the transmission line system are decomposed into two x- and y-components in a Cartesian coordinate system , this is possible if we assume the power line is along the z-axis figure 1

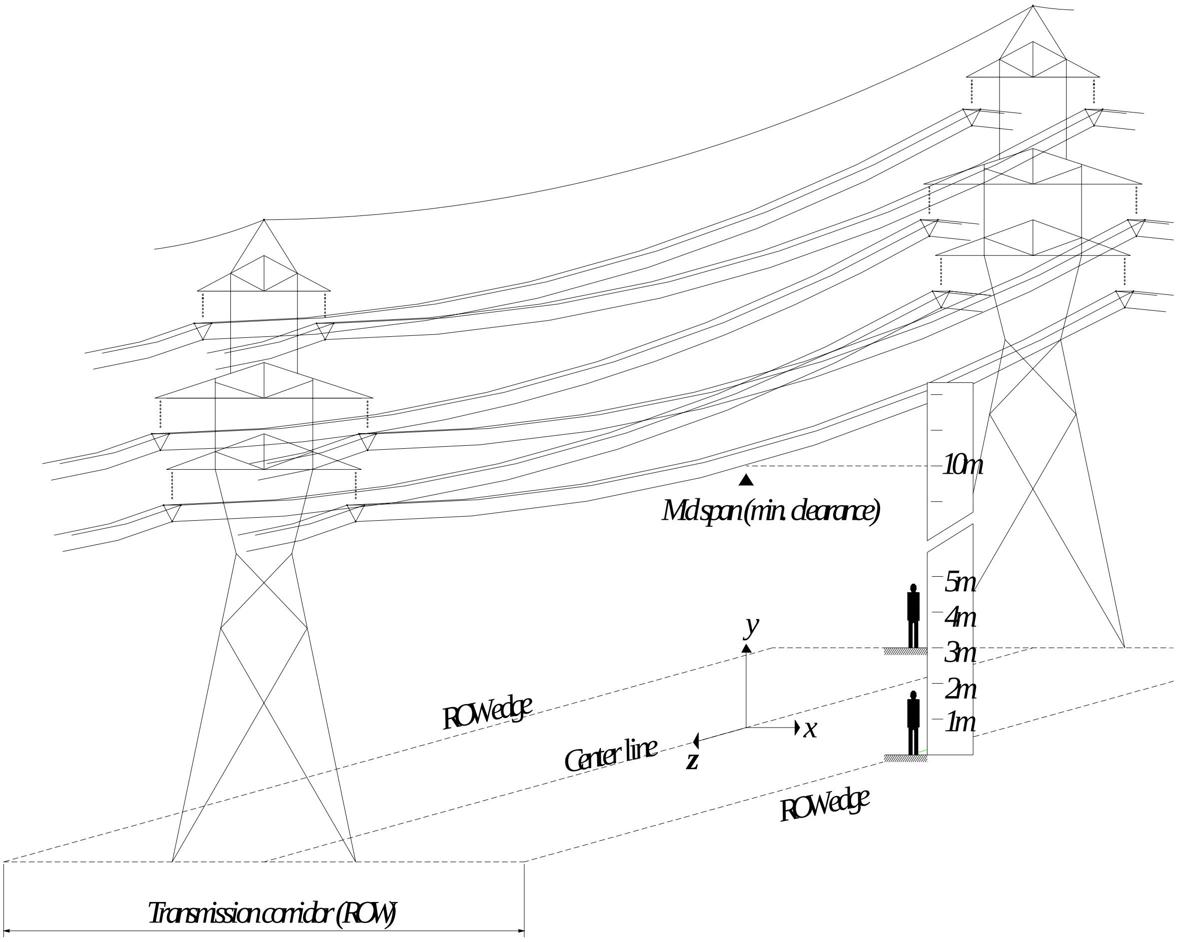

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Figure (1): 3-phase, 3-bundled conductors double circuit TL system, computation space illustration and general problem idea.

2-Background theory

From Gauss's law the total electric flux through a closed surface is equal to the charge enclosed

$$\oiint_s \vec{D} \cdot \vec{ds} = Q' \qquad (1)$$

Where

D is the electric flux density

Q is the total electric charge enclosed by the closed surface s

Considering an imaginary cylindrical surface of length l around a thin charged wire along the z -axis and integrating over its boundaries according to equation (1) yields the radial electric field of equation (1) as follows,

$$\oiint_s \vec{D}\cdot\vec{ds} = \int_0^{2\pi}\int_{-l/2}^{l/2} \varepsilon_o E_\rho \overrightarrow{a\rho}\cdot\rho d\varphi dz\overrightarrow{a\rho} = 2\pi\varepsilon_o \rho l E_\rho \qquad (2)$$

Thus,

$$2\pi\varepsilon_o \rho l E_\rho = Q'$$

or,

$$\vec{E} = \frac{Q}{2\pi\varepsilon_o \rho}\overrightarrow{a\rho} \qquad (3)$$

where:

Q, is the linear charge density. The electric field vector of equation (3) can be represented in the Cartesian coordinates by the x- and y-components as follows,

$$\vec{E} = \frac{Q}{2\pi\varepsilon_o \rho}\overrightarrow{a\rho} = E_\rho \overrightarrow{a\rho} = E_x \overrightarrow{ax} + E_y \overrightarrow{ay} \qquad (4)$$

The total electric field vector is then the vector sum of both field vectors caused by the charge $Q(t_o)$ and its image, $-Q(t_o)$, through the ground plane in the $z = 0$ plane. At the time instance t_o, and from the vector identity, $\nabla \times (\nabla A) = 0$, we can satisfy equation 1 by equating the E-field with the electrostatic scalar potential $\Phi(x, y, z = 0, t_o)$ that is a function of the spatial coordinate system as follows[1,2,3],

$$\vec{E} = -\nabla\Phi \qquad (5)$$

The components of the gradient of the scalar potential can be expressed in the cylindrical coordinate system as follows,

$$\nabla\Phi = \frac{\partial\Phi}{\partial\rho}\overrightarrow{a\rho} + \frac{1}{\rho}\frac{\partial\Phi}{\partial v}\overrightarrow{a\varphi} + \frac{\partial\Phi}{\partial z}\overrightarrow{az} \qquad (6)$$

Equating the similar components of equations (4) and (5),

$$\vec{E} = -\frac{\partial\Phi}{\partial\rho}\overrightarrow{a\rho} = \frac{Q}{2\pi\varepsilon_o \rho}\overrightarrow{a\rho} \qquad (7)$$

or,

$$-\frac{\partial\Phi}{\partial\rho} = \frac{Q}{2\pi\varepsilon_o \rho} \qquad (8)$$

$$E_\varphi = 0 \qquad (9a)$$

$$E_z = 0 \qquad (9b)$$

$$\Phi = -\int \frac{Q}{2\pi\varepsilon_o \rho} d\rho$$

$$\Phi = \frac{-Q}{2\pi\varepsilon_o}\ln\rho \qquad (10)$$

equation (10) relates the scalar potential to the linear charge density, Q. In this analysis the interest is focused on the potential difference, or voltage, rather than absolute potential. Thus, from Figure (1a), the potential difference between a point $a(x_a, y_a, z = 0)$, at a radial distance ρ_a, and another, $b(x_b, y_b, z = 0)$, at a distance, ρ_b, with the positive reference at point a, is

$$\Phi(a) - \Phi(b) = \frac{-Q}{2\pi\varepsilon_o}\ln\rho_a - \left(\frac{-Q}{2\pi\varepsilon_o}\ln\rho_b\right)$$

$$= \frac{Q}{2\pi\varepsilon_o}\ln\frac{\rho_b}{\rho_a}; \qquad \text{with } \rho_b > \rho_a \qquad (11)$$

It is evident that the constant potential surfaces at each point are circles whose centre is the axis of the line charge oriented parallel to the z-axis. From figure(1a,b), the

potentials at the two points $a(x_a, y_a, z = 0)$ and $b(x_b, y_b, z = 0)$, due to the line charge Q and its image $-Q$ are

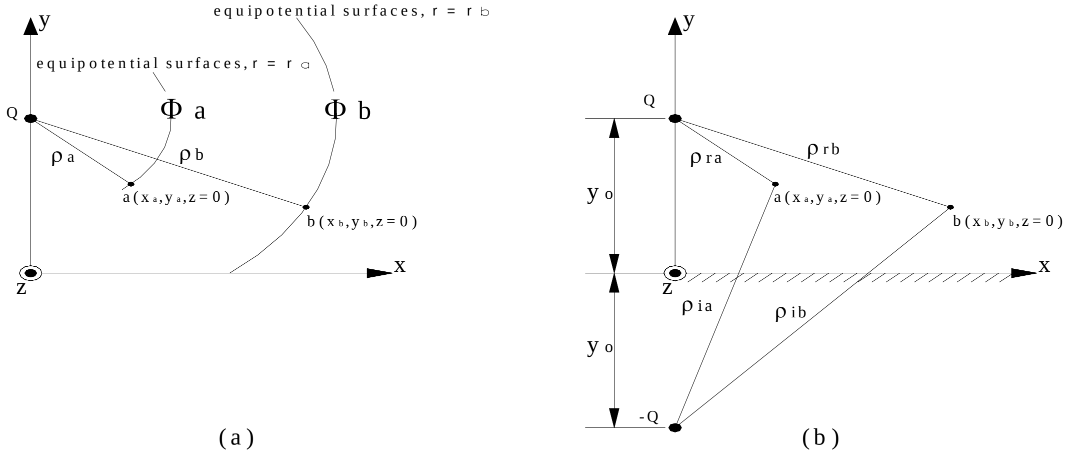


Fig.(1a,b): Geometry for fields of single line charge. a) single line charge with no image. b) single line charge and its image.

$$\Phi(a) = \Phi_{+Q}(a) + \Phi_{-Q}(a) = \frac{-Q}{2\pi\varepsilon_o}\ln\rho_{ra} + \frac{Q}{2\pi\varepsilon_o}\ln\rho_{ia} \qquad (12)$$

$$\Phi(b) = \Phi_{+Q}(b) + \Phi_{-Q}(b) = \frac{-Q}{2\pi\varepsilon_o}\ln\rho_{rb} + \frac{Q}{2\pi\varepsilon_o}\ln\rho_{ib} \qquad (13)$$

respectively, and the potential difference between them is,

$$\Phi_{ab} = \Phi(a) - \Phi(b) = \frac{Q}{2\pi\varepsilon_o}\ln\left(\frac{\rho_{rb}}{\rho_{ra}}\frac{\rho_{ia}}{\rho_{ib}}\right) \qquad (14)$$

Now if the two points, $a(x_a, y_a, z = 0)$ and $b(x_b, y_b, z = 0)$, are moved to confine with the mid-plane, the earth surface, then $\rho_{ra} = \rho_{ia}$ and $\rho_{rb} = \rho_{ib}$; and from equation (14), it results that the mid-plane is an equi-potential surface (zero potential difference). So if we restrict point b to lie in the mid-plane, the ground plane, then the potential at point b is zero (assuming zero reference at the earth's surface). Then the potential difference between points $a(x_a, y_a, z = 0)$ and $b(x_b, y_b = 0, z = 0)$, is

$$\Phi_{ab} = \frac{Q}{2\pi\varepsilon_o}\ln\left(\frac{\rho_{ia}}{\rho_{ra}}\right) = pQ \qquad (15)$$

where,

$$p = \frac{1}{2\pi\varepsilon_o}\ln\left(\frac{\rho_{ia}}{\rho_{ra}}\right) \qquad (16)$$

is a constant and it is a function of the radial distances and increase as the point moves towards the charged line.

3-Computation model

A two dimensional (2D) computation model is shown in Figure (2), where the magnitude value of the computed field quantity is traced in the x-y dimensional space (z=0 plane). The figure shows a cross-sectional view of a line system consisting of one conductors and its image through a perfectly conducting ground plate. Assume a linear charge density per unit length on the conductor and assume that the conductor diameter is small compared to the spacing between the conductors for a multi-conductor model. Then for a system of *n*-line charges with line voltages v_1, v_2, v_3, ………… v_n, the line charges are related to the line voltages by this system of linear equations [1,3,4]

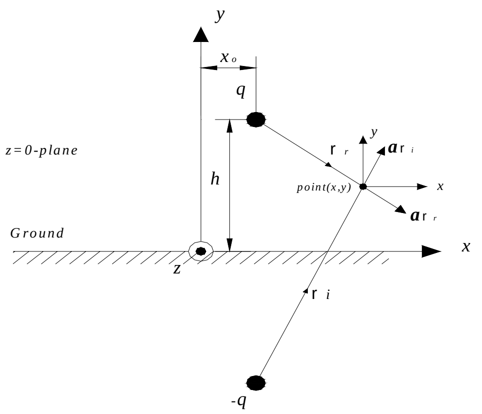


Fig.(2): single high voltage line model for radial electric field computations in the z=0 plane.

$$\begin{bmatrix} p_{11} & p_{12} & p_{13} & & p_{1n} \\ p_{21} & & & & \\ p_{31} & & & & \\ & & & & \\ & & & & \\ p_{n1} & & & & p_{nn} \end{bmatrix} \begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ \\ \\ q_n \end{bmatrix} = \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ \\ \\ v_n \end{bmatrix} \qquad (17)$$

or in more compact form;

$$[P][Q] = [V] \qquad (18)$$

where,

$$; \; p_{ij} = \frac{1}{2\pi\varepsilon} \ln\left(\frac{|\rho_i|}{|\rho_r|}\right)$$

constants when the point *p(x,y,z=0)* is on the conductor's surface.

q_i ; Charge on conductor *i*.

V_i ; potential on the *i*th conductor relative to ground.

The charges on each of the conductors per unit length are then,

$$[Q] = [P]^{-1}[V] \qquad (19)$$

The electric field from each conductor is radial and falls off inversely as the distance,

$$\vec{E} = \frac{q}{2\pi\varepsilon_o \rho} \overrightarrow{a\rho} \qquad (20)$$

the total vector electric field is then can be combined vectorially with the fields from the other conductors in the Cartesian coordinate system as follows [3]

$$\vec{E}(x,y,z=0) = \sum_{i=1}^{i=n} \frac{q_i}{2\pi\varepsilon_o}\left[\frac{(x-x_i)}{(x-x_i)^2+(y-y_i)^2}\right]\overrightarrow{ax} + \sum_{i=1}^{i=n} \frac{q_i}{2\pi\varepsilon_o}\left[\frac{(y-y_i)}{(x-x_i)^2+(y-y_i)^2}\right]\overrightarrow{ay}$$

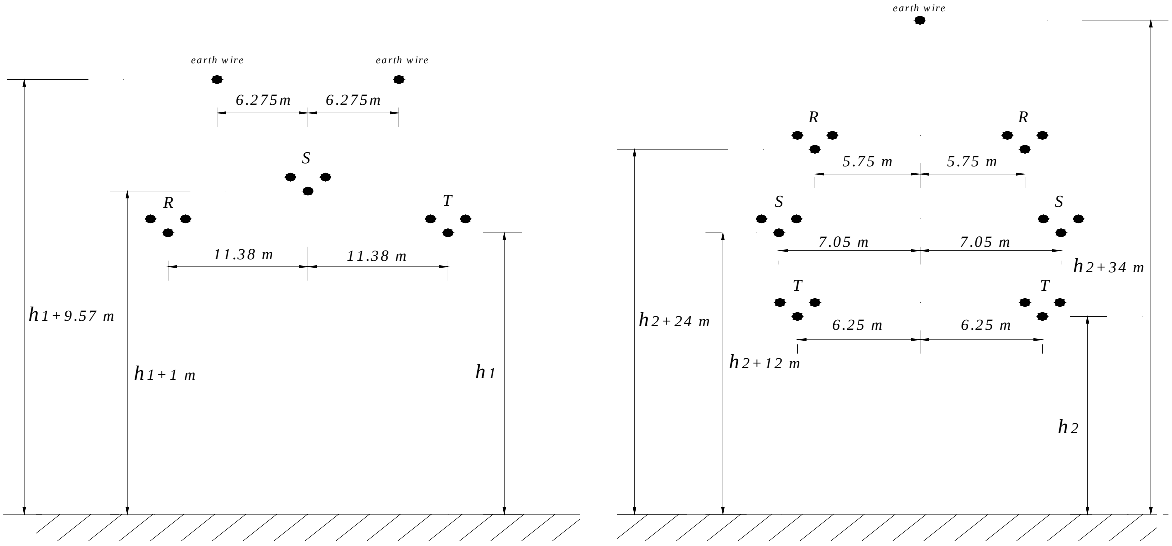
(21)

The magnitude of the electric field at any point in the space of z=0-plane can then be computed as :

$$|E| = \sqrt{E_x^2 + E_y^2} \qquad (22)$$

4. Results and discussion

The electric field intensity generated by a 50Hz, 400kV single- and double-circuits power transmission lines are analyzed and computed in the aforementioned way. The computations where done for 1.0 and 4.0m above ground in the z=0 plane (mid-span) for the two real line systems shown in Figure (3). The computer program results are shown in Figures (4a,b) for the electric field intensities of the single and double circuits. The field quantities were assumed quasi-static fields and computed on this basis at discrete time instances corresponds to a maximum value along a full time period. The electric field intensity was calculated for different minimum possible clearances of 8, 10, 12, 14, and 16 meters.



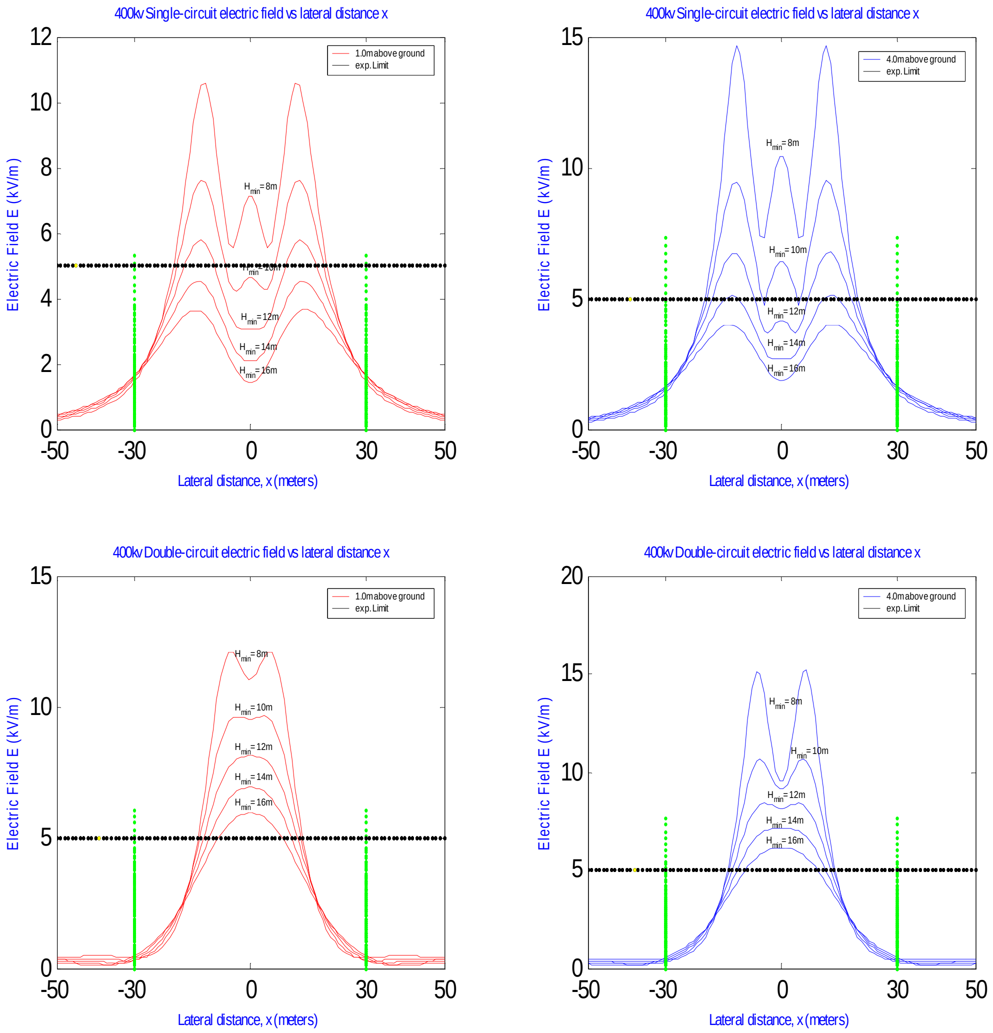
a ***b***

Fig.(4): a) singl-circuit, 400kv 3-conductors/phase, 2-earth wires; b) Double-circuit, 400kv 3-conductors/phase, 1-earth wire. Bundled conductors are equispaced by *s=40cm*.

For the single circuit line configuration system, the results shows a maximum electric field values within the transmission corridor of 10.568kV/m and 14.6275kV/m at 1 and 4m above ground respectively. The maximum electric field outside the transmission corridor is less than 1kV/m which is more than 80% below the exposure limit set by the *IRPA/ INIRC*.

For the double circuit line configuration system, the results shows a maximum electric field values within the transmission corridor of 12.0603kV/m and 15.1336kV/m at 1 and 4m above ground respectively. The maximum electric field outside the transmission corridor is less than 2kV/m which is more than 60% below the exposure limit set by the *IRPA/ INIRC*. The table below shows the maximum field values within and outside the transmission corridor.

Max. Field quantity	**Single circuit at** y *meter* **above ground**		**Double circuit at** y *meter* **above ground**		**For single circuit at** -30 > X > +30		**For double circuit at** -30 > X > +30	
	1m	4m	1m	4m	1m	4m	1m	4m
E*(kV/m)*	10.568	14.6275	12.0603	15.1336	1.6342	1.6259	0.4718	0.5099



a b

Fig. (4): a) EF under single & double circuits 400kV TLs, *1m above ground.*
b) EF under single & double circuits 400kV TLs, *4m above ground*.

5. conclusion

According to the *IRPA/INIRC* for EMF reference level limits for general public exposure, the previous results showed a safe areas surrounding the ±30m transmission corridor. It is only in the corridor area where field intensities are maximum, and some appropriate precautions are expected to be taken to minimize or avoid exposure. The results shows a noticeable decrease of the field values by an increase in the minimum clearance of the line conductors. The electric field intensity exceeds the general public exposure level limit (5*kv/m*) for some minimum clearances in the corridor area .

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