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Modelling Of Electric And Magnetic Fields Under High Voltage Ac Transmission Line

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Abstract: *The main objective of this paper is to calculate the electric field and the magnetic field under high voltage transmission lines. The magnetic fields are produced whenever there is flow of electrons or whenever the electrical equipment is in use. The electric field is produced due to the presence of voltage. The electric field will exist no matter whether the equipment is in use or not. The transmission lines are considered as one of the primary source of these fields in the environment. These fields under high voltage transmission lines cause hazards to living organisms through resistive, inductive and capacitive couplings. So it is necessary to compute these fields under high voltage transmission lines to understand the safer operating practices. The proposed study is the theoretical computation of electric and magnetic field using MATLAB software package.*
Keywords: *Electric field, High voltage transmission line, Magnetic field, Matlab, Safer operating practices***.**

I. Introduction

The electrical energy becomes most essential part of our life. India is the fifth largest electrical energy producer and consumer in the world. This energy is generated far away from utilizing stations and the high voltage power lines are used to transport electrical energy from generating station to demand point. The generating power and utilizing power never gets equal, as a part of generating power disappears as transmission losses. According to the world resource institute, the power loss in India is estimated to be 27%, which is highest in the world. There will be associated low frequency electric and magnetic fields around these lines as the current, which produces circulating magnetic field measured in milligauss (mG) and the high voltage, which produces electric field measured in kilovolts per meter (kV/m).

The magnetic field cannot be shielded, so as a result even underground distribution lines produce EMFs (Electric and Magnetic fields). Whereas, the electric field can be shielded by tress, fence, concrete buildings etc. In case of single phase AC source, the field at any point oscillates forward and backward through straight line, whereas in case of three phase supply, the field actually traces elliptical path. The EMFs are usually stronger near the conductors and diminishes as the distance increases. These fields interact with ground objects through resistive, inductive and capacitive couplings [1].

The static charges are induced on ungrounded conducting objects through capacitive coupling. Circulating currents will be induced on the conducting objects through inductive coupling. Many studies revels that the micro current induced on human body cause serious health issues with respect to field strength and time period of exposure to the field. The maximum acceptable exposure to magnetic field for small living organisms is 0.04 μT and for human about (4-100) μT [2].

EMFs Strength varies based on the following factors,
1. Height of the conductors above the ground.
2. Radius of the conductors.
3. Phase symmetry of the conductors.
4. Position of the phase conductor with respect to other conductors.
5. Position of measuring point with respect to conductor positions.
6. The electric field mainly depends on the magnitude of the conductor voltage and the magnetic field depends on the magnitude of the conductor current.

II. Electric Field Calculation

The voltage in transmission line conductors produce electric field in the region of space between the conductors and between the conductors and ground. The electric field is a vector quantity, it has both magnitude and direction. The electric field at the surface of conductors is responsible for corona effect, which is the ionization of air between the line conductors due to the existence of very strong electric field between them and results in audible noise along with electromagnetic radiation and visible light. Modeling of electric field in the proposed methodology is based on the method of images technique [3], which is a basic problem solving technique in electrostatic engineering. According to the principle of method of images, if an infinitely grounded conducting plane have a charge '+q' at a distance 'r' above the plane, then there will be fictitious charge '–q' at the same distance 'r' under the plane. The potential at any point 'p' in two dimensional plane will be equal to algebraic sum of potential due to these two charges. To compute electric and magnetic field around transmission line some of important parameters are needed such as voltage, current, geometric configuration of conductors. The electric field at any point is equal to force acting on unit positive charge at that point, and the work done in moving the charge between two points is the electric potential difference ΔV.

E is related to ΔV as,

$E=-\Delta V$ (1)

E is called as gradient of V.

$D=\varepsilon E$ (2)

$\varepsilon = \varepsilon_\circ \, \varepsilon_r$ (3)

Where,

D is electric flux density in C m^2,

E is Electric field in V m^{-1}.

ε is permittivity in F m^{-1},

$\varepsilon_\circ$ is permittivity of air or vacuum whose value equals to 8.854×10^{-12} F m^{-1},

ε_r is relative permittivity and for air its value is equals to 1.

From equation (2), $E = \frac{D}{\varepsilon}$

$$E = \frac{Q}{2\pi\varepsilon_o r^2}\hat{r} \quad (4)$$

Where, $\hat{r}$ is the unit directional vector.

Since, the conductor characteristics such as position of conductors with respect to other conductors, the height of conductors above the ground level, radius of the conductors are known, it is necessary to calculate the spatial position, where the field is to be calculated. The position of measuring point with respect to conductors and with their images are calculated as,

$$r_k = \sqrt{((Xm - D)^2 + (h_k - Ym)^2)} \quad (5)$$

$$r_k^{'} = \sqrt{((Xm - D)^2 + (h_k + Ym)^2)} \quad (6)$$

Where,

r_k is distance between conductor k and measuring point,

$r_k^{'}$ is distance between image of conductor k and measuring point.

Now the unknown parameter in (4) is Q, the charge on the conductor, which can be calculated by the following equations. The Maxwell's potential can be given by,

[V] = [A]. [Q]

$[Q]= [A^{-1}]. [V]$ (7)

Where,

[V] is potential matrix of conductors in kV,

[Q] is charge on conductors matrix,

[A] is Maxwell's potential coefficient matrix, which is the geometric relationship between the charge and the electrostatic potential.

$$A = \begin{bmatrix} a11 & a12 & a13 & ...... & a1n \\ a21 & a22 & a23 & ...... & a2n \\ a31 & a32 & a33 & ...... & a3n \\ : & : & : & : & : \\ an1 & an2 & an3 & ...... & ann \end{bmatrix} \text{F m}^{-1}$$

$aij = \frac{1}{2\pi\varepsilon_0}\ln\frac{2h_i}{r_i}$ where, $i = j$ and $aij = \frac{1}{2\pi\varepsilon_0}\ln\frac{Dij}{dij}$ where, $i \neq j$

r_i is radius of conductor i (m).

h_i is height of conductor i ,above ground (m),
dij is distance of conductor i to j (m),
Dij is distance of conductor i to image of conductor j (m),
dij= $\sqrt{(x_i - x_j)^2 + (h_i - h_j)^2}$ and Dij= $\sqrt{(x_i - x_j)^2 + (h_i + h_j)^2}$
Now the vertical and the horizontal components of electric field can be calculated as,

$$Ex_1 = K * \left[\frac{(Xm - X_1)}{(Xm - X_1)^2 + (h_1 - Ym)^2} - \frac{(Xm - X_1)}{(Xm - X_1)^2 + (h_1 + Ym)^2} \right]$$

$$Ex_2 = K * \left[\frac{(Xm - X_2)}{(Xm - X_2)^2 + (h_2 - Ym)^2} - \frac{(Xm - X_2)}{(Xm - X_2)^2 + (h_2 + Ym)^2} \right]$$

:

$$Ex_n = K * \left[\frac{(Xm - X_n)}{(Xm - X_n)^2 + (h_n - Ym)^2} - \frac{(Xm - X_n)}{(Xm - X_n)^2 + (h_n + Ym)^2} \right]$$

$$Ey_1 = K * \left[\frac{(Ym - h_1)}{(Xm - X_1)^2 + (h_1 - Ym)^2} - \frac{(Ym + h_1)}{(Xm - X_1)^2 + (h_1 + Ym)^2} \right]$$

$$Ey_2 = K * \left[\frac{(Ym - h_2)}{(Xm - X_2)^2 + (h_2 - Ym)^2} - \frac{(Ym + h2)}{(Xm - X_2)^2 + (h_2 + Ym)^2} \right]$$

:

$$Ey_n = K * \left[\frac{(Ym - h_n)}{(Xm - X_n)^2 + (h_n - Ym)^2} - \frac{(Ym + h_n)}{(Xm - X_n)^2 + (h_n + Ym)^2} \right]$$

Where,
n is number of conductors.

$K = \frac{Q}{2\pi\varepsilon_0}$.

$$\vec{Ex} = \sum_{n=1}^{n} \vec{Ex}_n \quad (8)$$

$$\vec{Ey} = \sum_{n=1}^{n} \vec{Ey}_n \quad (9)$$

The resultant field is,

$$\vec{E} = \sqrt{\left(\vec{Ex}^{\,2}\right) + \left(\vec{Ey}^{\,2}\right)} \quad (10)$$

The electric field in the proposed work was calculated based on the following assumptions, the earth was assumed to be perfect flat surface, the conductor sag was not considered, the conductors were assumed to be parallel to each other and parallel to the earth surface. The earth was assumed to be perfect conductor as reluctance of air under 50 Hz transmission line is greater than the earth resistance, which is usually 100-1000 ohm-m.

The electric field interacts with all matters including living organisms. When a conducting object is subjected to electric field, the electric field interacts with charges in the object. The field can be resolved into two components, the tangential component and the normal component. Only the normal component is responsible for induction of charges on the object and the tangential component get vanishes to satisfy the boundary conditions of the electric field. When the object is grounded then the total current (the short circuit current) flows to ground. For example, the cyclist under high voltage transmission line feels sudden shock when they touch the metal part of the cycle. Since the cycle is completely insulated above ground through rubber tires, the electrostatically induced voltage and current cause sudden shock when it gets low resistance path to ground like human body .

The short circuit current on the object can be calculated as follows,

$$\text{Isc} = j\,\omega\,\varepsilon_0\,\vec{E}\,\text{S} \tag{11}$$

Where,

$\vec{E}$ is the field strength at point of measurement.
S is the surface area of object under exposure to electric field.

To calculate the open circuit voltage, the short circuit current was given to Norton equivalent circuit, the simple electric circuit representation of the conducting object above ground. As shown in the Fig.1, the conducting object under transmission line was represented as a circuit having current Isc, and the object to ground capacitance, Cog. The object to ground resistance, Rog (the leakage resistance), which was assumed to be high. Usually the resistance varies based on the moisture content of the ground. The resistance decreases at wet ground and it affects the open circuit voltage on object.

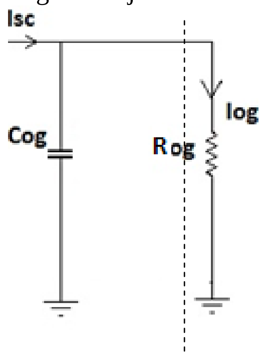

Fig.1 Norton equivalent circuit.

$$\text{Vog} = \text{Isc}\ \frac{1}{j\omega Cog + \dfrac{1}{Rog}}\ \text{V.} \tag{12}$$

On considering the ground, to be completely dry land, the open circuit voltage becomes function of the short circuit current and the object to ground capacitance.

$$\text{Vog} = \text{Isc} \times \frac{1}{j\omega\text{Cog}}\ \text{V.} \tag{13}$$

III. Magnetic Field Calculation

The magnetic field is generated by moving charges in a conductor or a wire [4-5], usually the 50 Hz current flowing through transmission and distribution lines produce 50Hz time varying magnetic field. The magnetic field also a vector quantity having proper magnitude and direction. The magnetic field strength is measured in terms magnetic lines of force acting per unit area and it is expressed in units of gauss (G) or milligauss (mG). (The tesla (T) is the unit of magnetic flux density preferred in scientific publications, where 1.0 gauss equals one ten-thousandth of a tesla (0.1 mT) and 1.0 mG equals 0.1 microtesla [µT]).

Many studies have been carried out to compute magnetic field around transmission lines [6-8].The strength of the magnetic field depends on the magnitude of current and purely independent of voltage strength, it is not mean that the low voltage line has field lesser than high voltage line, the only reason is the high voltage line carries high current. If the low voltage line carries the same current then the magnetic field will be same around both the lines. The uniformity of magnetic field is purely depends upon the proximity of source, the magnetic field generated by transmission lines are quite uniform over ground, at the same time the field generated by electric and electronic appliances decreases rapidly over distance. Calculation of magnetic field is based on some of assumptions such as, the earth is assumed to be flat, the conductors are assumed to be parallel to each other and parallel to earth surface, the current is assumed to be balanced current, which means the magnitude of current in all phase conductors are same, this is usually possible when the load on all phase conductors are maintained in balance under operation.

Ampere circuital law states that the line integral of B around any closed path is equals to the current enclosed in that path.

According to Ampere circuit law,

$$\oint B.dl = \mu_0 I \qquad (14)$$

$$\vec{B} = \frac{\mu_0 I}{2\pi r} a_r \qquad (15)$$

Where,

a_r is unit directional vector,

r is distance between conductor and measuring point,

$$Bx_1 = -R^*\left[\frac{(h_1 - Y_m)}{(X_1 - X_m)^2 + (h_1 - Y_m)^2}\right]$$

$$Bx_2 = -R^*\left[\frac{(h_2 - Y_m)}{(X_2 - X_m)^2 + (h_2 - Y_m)^2}\right]$$

:

$$Bx_n = -R^*\left[\frac{(h_n - Y_m)}{(X_n - X_m)^2 + (h_n - Y_m)^2}\right]$$

$$By_1 = R^*\left[\frac{X_1 - X_m}{(X_1 - X_m)^2 + (h_1 - Y_m)^2}\right]$$

$$By_2 = R^*\left[\frac{X_2 - X_m}{(X_2 - X_m)^2 + (h_2 - Y_m)^2}\right]$$

:

$$By_n = R^*\left[\frac{X_n - X_m}{(X_n - X_m)^2 + (h_n - Y_m)^2}\right]$$

Where,

$$R = \frac{\mu_0 (I_{rj} + jI_{ij})}{2\pi}$$

I_{rj} is real part of current through jth conductor,

I_{ij} is the imaginary part of current through jth conductor,

The current at specific conductor can be given by,

$I_a = I_m \cos(\omega t + \phi_a)$

$I_b = I_m \cos(\omega t + \phi_b)$ where, $\phi_b = \phi_a + 120^0$

$I_c = I_m \cos(\omega t + \phi_c)$ where, $\phi_c = \phi_a - 120^0$

The rms value of current in each conductor,

$I_{ra} = \frac{I_m}{\sqrt{2}} \cos(\omega t + \phi_a)$ and $I_{ia} = \frac{I_m}{\sqrt{2}} \sin(\omega t + \phi_a)$

$I_{rb} = \frac{I_m}{\sqrt{2}} \cos(\omega t + \phi_b)$ and $I_{ib} = \frac{I_m}{\sqrt{2}} \sin(\omega t + \phi_b)$

$I_{rc} = \frac{I_m}{\sqrt{2}} \cos(\omega t + \phi_c)$ and $I_{ic} = \frac{I_m}{\sqrt{2}} \sin(\omega t + \phi_c)$

$$Bx_n = B_{rx} + jB_{ix} \tag{16}$$

$$By_n = B_{ry} + jB_{iy} \tag{17}$$

$$\vec{Bx} = \sum_{n=1}^{n} \vec{Bx}_n \tag{18}$$

$$\vec{By} = \sum_{n=1}^{n} \vec{By}_n \tag{19}$$

The resultant field is given by,

$$\vec{B} = \sqrt{\left(\vec{Bx}^{\,2}\right) + \left(\vec{By}^{\,2}\right)} \tag{20}$$

IV. Results And Discussion

In the proposed methodology, the electric field and the magnetic field were computed around three phase double circuit 132kV line. The lattice tower structure is shown in the Fig.2. The electric and magnetic field at any point of interest in the Cartesian coordinate plane can be computed, on considering the center of transmission tower as reference axis (0, 0). The center of tower at ground corresponds to the point X=0, Y=0.

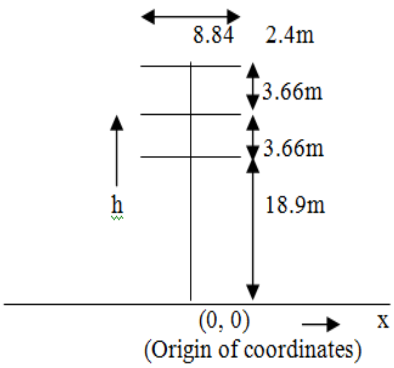

Fig.2 The 132kv tower structure

The electric and magnetic field strength for 132kV symmetric double circuit transmission power line was computed about the line of clearance of 30 m right of way and about different heights above the ground. The height of lowest conductor is about 18.9m above the ground. The electric field at different height above the ground was computed as shown in the Fig.3 and Fig.4.The electric field strength increases as the height above ground increases and also the field strength decreases as the radial distance increases. The asymmetry in result is due to the asymmetry in phase relationship between conductors. This study is based on two scenarios, one is at ground level about 1m and 5m height above the ground another is about 10m and 15m above the ground. This will helps to predict the nature of field at ground level and at certain height where live-line workers are supposed to work.

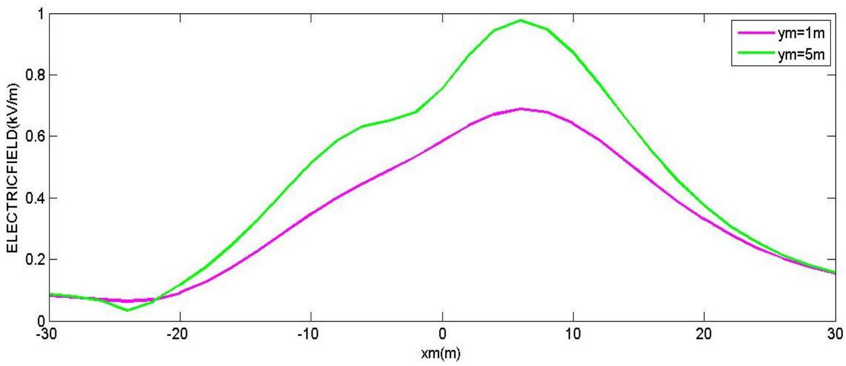

Fig.3 Electric Field at height 1m and 5m above ground.

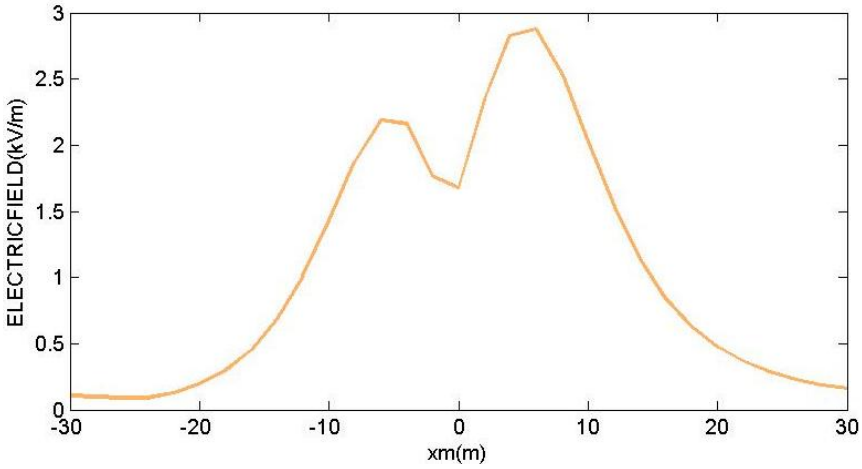

Fig.4 Electric field at height 15m above ground.

The time varying magnetic field interacts with conducting objects cause time varying electric field and current in that object. The change in electric field again cause change in magnetic field, the relation between them can be predicted by Maxwell's equation. The change magnetic field induces voltage on conducting objects called Faraday's law of electromagnetic induction. When this field interacts with living organic matters cause some short term and long term health effects.

According to the study [9], the risk of childhood leukemia among children living in homes with distance greater than 60m from power lines are analyzed. An increased risk of 69% for leukemia was found for children living around 200m of power lines, about 23% was found for children living around 200 to 600m of power lines. Some other studies measure risk by using magnetic field strength as exposure measure revels that 0.3 to 0.4 μT leads to double risk of leukemia. In the proposed methodology we found the magnetic field strength about line of clearance of 30m in double circuit 132kV transmission line

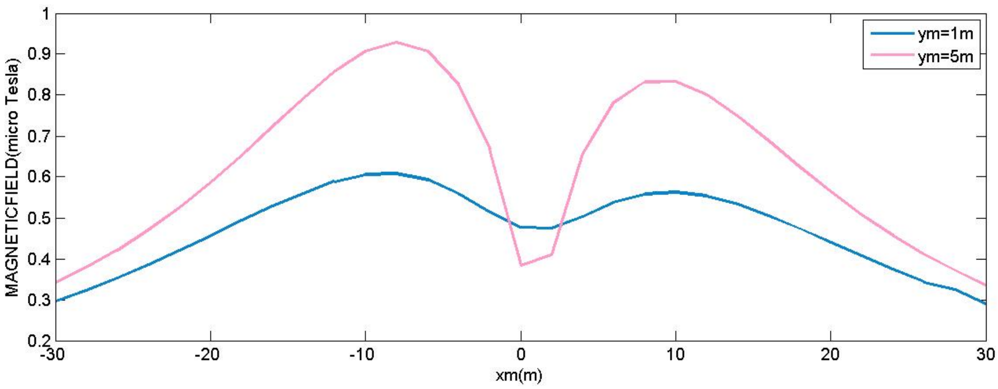

Fig.5 Magnetic field at 1m and 5m above ground.

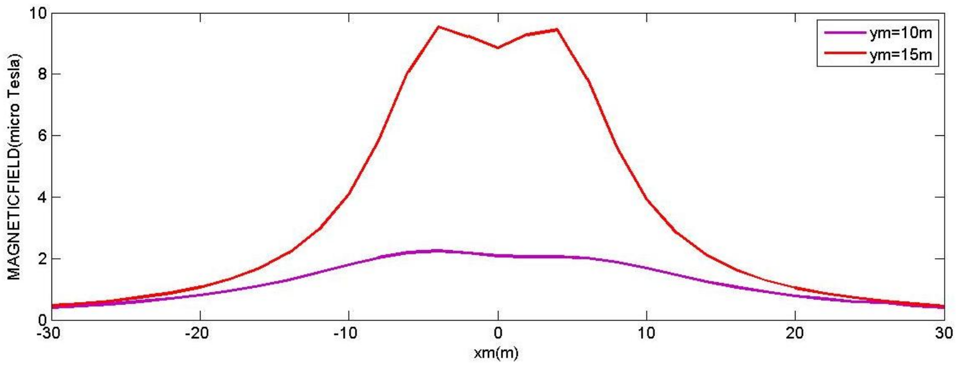

Fig.6 Magnetic field at 10m and 15m above ground

The maximum field strength of 0.608 μT obtained at 1m height above ground, at 5m above ground the maximum field strength of 0.9075 μT was obtained as shown in the Fig.5. For height of 10m and 15m the maximum magnetic field strength obtained as 2.25 and 9.5 μT respectively as shown in the Fig.6. These results revels that, as the height increases the magnetic field strength also increases. Since magnetic field cannot be shielded by concreate walls, constructing houses near high voltage transmission line cause some serious health issues. The line men working on transmission towers and lines are subjected to these fields might cause short term effects depending upon the time period of exposure to field.

V. Conclusion

The software program developed in the proposed methodology provides better understanding of electric and magnetic field strength under 132kV tower structure. Based on this study preventive measures can be taken by the peoples who are under vicinity to high voltage transmission lines. The long term health effects such as cancer due to this low frequency electric and magnetic fields are still under debate and research but still these fields interacts with conducting objects on ground through resistive, capacitive, and inductive couplings. When living organism such as human beings are supposed to be in contact with ungrounded or poorly grounded conducting object such as fence, vehicle, etc. cause momentary shock or serious shock based on the field strength, area of exposure of conducting object to field, and the resistance of the body which conducts the short circuit current to earth.

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