# Calculation Right of Way Considering Major Effect of Electrical and Magnetic Fields of EHV AC Transmission Lines

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*Abstract*— In EHV AC transmission line can transmit the amount of power safely depends on various limits. Now a day world population are increase and towns are expanding, many buildings constructed near high voltage transmission lines. These transmission lines required the strip (corridor) of land. These strip depends on electric and magnetic field of transmission line.This paper discusses the methods to calculate electric and magnetic field of EHV AC transmission line with single circuit configurations. The sensitivity of EMF on various parameters has been analyzed with the help of mathematical programming in MATLAB software and the results are presented.

***Key words:*** R.O.W. (Right of Way, Electrical Field, Magnetic Field, Horizontal Configuration, Transmission Line

## I. INTRODUCTION

The growing public concern of possible harmful effects caused by electric and magnetic fields difficulties in assessing the related risks have led several governments to set new regulations limiting maximum exposure levels [1],[3]. Because this limitation is necessary to quantify field intensity near high voltage transmission lines having the widest impact [2]. In this paper, emission of electric and magnetic field caused by extra high voltage transmission line are studies.

It is well known that all of the electromagnetic phenomena defining by the general properties can be treated by a few equations called the Maxwell equations, which describes the nature of electric and magnetic fields and the creation of magnetic and electric fields due to electric and magnetic fields changing. Generally, the magnetic and electric field are coupled, and it is necessary to solve Maxwell's equations to obtain those [3], [4]. This methods use the static Maxwell's equations, where the static electric and magnetic fields can be easily calculated.

The relation between the electric and magnetic field levels and the possible induced body currents is often taken as basic restrictions by the international organization like ICNIRP (International Commission on Non-Ionizing Radiation Protection), IEEE (Institute of Electrical and Electronic Engineers), Council of the European Union, WHO (World Health Organization), deals by regulation and recommendation of limits connected to the electromagnetic fields [4], [5]. The compliance to such maximum exposure limits leads to the definition of different Right-of-Way (ROW) widths, which depend on the electric and the geometric parameters of the overhead line. The determination of accurate ROW widths is very important, e.g., in environmental impact assessments or in territory planning, especially when new buildings have to be built near power installations [1], [3].

## II. APPROXIMATE FORMULAS FOR THE ELECTRIC FIELD

Here is the method of calculating electrostatic charges on phase conductors from line dimensions and voltages of line. For an n phase system it will be as shown below.

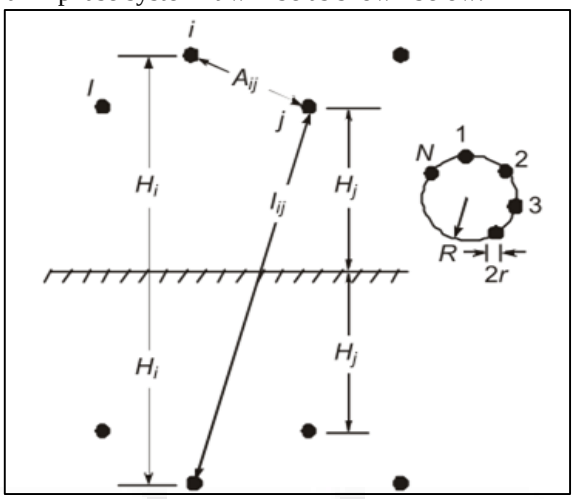


Fig.1: N Phase Configuration for charge calculation [5]

Let q = total bundle charge and V = line to ground voltage then

$$\frac{1}{2\pi\varepsilon_o}[q] = [P]^{-1}[V] = [M][V] \quad \ldots\ldots\ldots (1)$$

Where,

[q] = [q1, q2, q3 ... qn]

[V] = [V1, V2, V3 … Vn] ……. (2)

[P] = n x n matrix of Maxwell's Potential coefficients

$$P_{ii} = \ln\left(\frac{2H_i}{r_{eq}}\right) \text{ and } P_{ij} = \ln\left(\frac{I_{ij}}{A_{ij}}\right), i \neq j \ldots (3)$$

Here,

$H_i$ = height of conductor i above ground,

$I_{ij}$ = distance between conductor i above ground and the image of conductor j below ground, $i \neq j$

$A_{ij}$ = aerial distance between conductors i and j, $i \neq j$

$r_{eq} = R\left(\frac{N.r}{R}\right)^{\frac{1}{N}}$ = equivalent bundle radius,

R = bundle radius,

N = number of sub-conductors in bundle,

r = radius of each sub-conductor, and i, j = 1, 2, 3….. n.

Since the line voltages are sinusoidally varying with time at power frequency, the bundle charges q 1 to q n will also vary sinusoidally. Consequently, the induced electrostatic field in the vicinity of the line also varies at power frequency and phasor algebra can be used to combine several components in order to yield the amplitude of the required field, namely, the horizontal, vertical or total vectors.

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## III. CALCULATIONS OF ELECTROSTATIC FIELD FOR SINGLE CIRCUIT

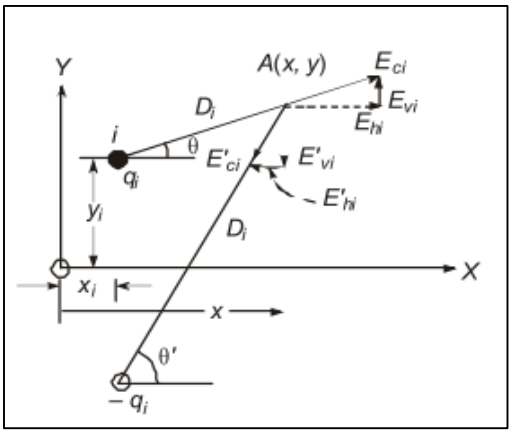


Fig. 2: Calculation of E. S. Field components near the line [5].

Let us consider first a 3-phase line with 3 bundles on a tower and excited by the voltages.

$$[V] = V_m[\sin(\omega t + \varphi), \sin(\omega t + \varphi - 120^o), \sin(\omega t + \varphi + 120^o)] \ldots\ldots (4)$$

The field vector at A due to the charge of the aerial conductor is with

$$D_i^2 = (x - x_i)^2 + (y - y_i)^2, \quad E_c = \left(\frac{q_i}{2\pi\varepsilon_0}\right)\left(\frac{1}{D_i}\right) \ldots\ldots\ldots (5)$$

Horizontal components of electric field are

$$E_h = E_c\cos\theta = \frac{q_i}{2\pi\varepsilon_0}\frac{(x-x_i)}{D_i^2} \ldots\ldots (6)$$

Similarly due to image charges of the conductor

$$D_i'^2 = (x - x_i)^2 + (y + y_i)^2, \quad E_c' = \left(\frac{q_i}{2\pi\varepsilon_0}\right)\left(\frac{1}{D_i'}\right) \ldots\ldots\ldots (7)$$

$$E_h' = E_c'\cos\theta = \frac{q_i}{2\pi\varepsilon_0}\frac{(x-x_i)}{D_i^2} \ldots\ldots (8)$$

Total horizontal component is, adding vertically

$$E_{hn} = V_m[J_{h1}\sin(\omega t + \varphi) + J_{h1}\sin(\omega t + \varphi - 120^o) + J_{h1}\sin(\omega t + \varphi + 120^o)] \ldots (9)$$

## IV. CALCULATIONS OF ELECTROMAGNETIC FIELD FOR SINGLE CIRCUIT

Based on Maxwell's method of images, we will calculate the magnetic field generated at any point in space in the vicinity of the 3-phase line. In most applications, the field intensity at ground level is the most important quantity. But the equations derived will be very general.

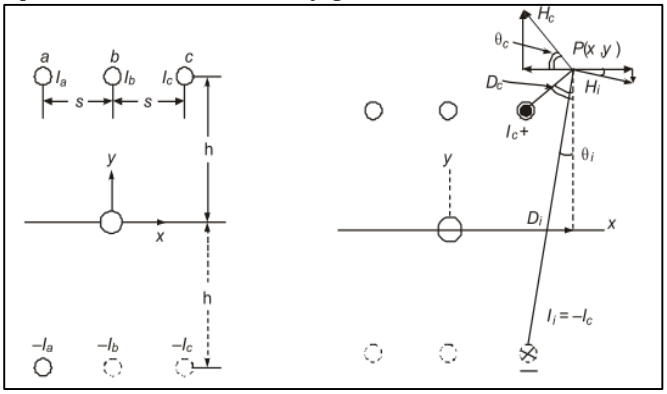


Fig. 3: Overhead conductors with their images for calculation of EM fields

Figure 3 shows the 3 overhead conductors and the ground surface replaced by image conductors below the ground surface. This assumes that the ground surface is a flux line. The origin of a coordinate system is placed on the ground underneath the centre-phase. The conductors are at height h above ground and the phase separation is s. At the point P (x, y), the components of magnetic field are as follows:

– Due to the conductor current

$$H_c = \frac{I}{2\pi D_c}, where\ D_c = \sqrt{(x-s)^2 + (y-h)^2} \ldots (10)$$

Horizontal components of the field are shown in equations (11)

$$H_c\cos\theta_c = \frac{I.(y-h)}{2\pi((x-s)^2+(y-h)^2)} \ldots (11)$$

– Due to the image current

$$H_i = \frac{I}{2\pi D_i}, where\ D_i = \sqrt{(x-s)^2 + (y+h)^2} \ldots (12)$$

Horizontal components of the field are shown in equations (13)

$$H_i\cos\theta_i = \frac{I.(y+h)}{2\pi((x-s)^2+(y+h)^2)} \ldots (13)$$

Total horizontal components of the field are as shown in equations (14

$$H_h = H_i\cos\theta_i + H_c\cos\theta_c = \frac{I_c}{2\pi}\left[\frac{y+h}{(x-s)^2+(y-h)^2} - \frac{y-h}{(x-s)^2+(y+h)^2}\right] \ldots (14)$$

Corresponding flux densities are

$$B_h = \mu_o H_h \text{ and } B_v = \mu_o H_v, Tesla \ldots (15)$$

Following the above procedure, we can extend the equations to calculate the magnetic field at P(x, y) due to the combined effect of all 3 conductor-currents. Let the three currents be:

$$I_a = I\angle 0^o, I_b = I\angle -120^o, I_c = I\angle 120^o \text{ Amps}$$

Then:

$$H_{ht} = \frac{I_a}{2\pi}\left[\frac{y+h}{(x+s)^2+(y+h)^2} - \frac{y-h}{(x+s)^2+(y-h)^2}\right] + \frac{I_b}{2\pi}\left[\frac{y+h}{x^2+(y+h)^2} - \frac{y-h}{x^2+(y-h)^2}\right] + \frac{I_c}{2\pi}\left[\frac{y+h}{(x-s)^2+(y+h)^2} - \frac{y-h}{(x-s)^2+(y-h)^2}\right] Amp/meteres \ldots\ldots (16)$$

Since we have assumed the ground surface to be a flux line, the vertical component of H due to any phase-current is zero, and the magnetic field at the ground surface is entirely in the horizontal direction.

It is convenient to abbreviate the six geometric factors from equations (16), Horizontal components:

$$K_a = \frac{y+h}{(x+s)^2+(y+h)^2} - \frac{y-h}{(x+s)^2+(y-h)^2} \ldots (17)$$

$$K_b = \frac{y+h}{(x)^2+(y+h)^2} - \frac{y-h}{(x)^2+(y-h)^2} \ldots (18)$$

$$K_c = \frac{y+h}{(x-s)^2+(y+h)^2} - \frac{y-h}{(x-s)^2+(y-h)^2} \ldots (19)$$

Magnitudes of horizontal and vertical components can be obtained as

$$H_{ht} = \frac{I}{2\pi}.(K_a^2 + K_b^2 + K_c^2 - K_aK_b - K_bK_c - K_cK_a)^{\frac{1}{2}} Amp/meter \ldots (20)$$

Corresponding values of flux densities will be

$$B_{ht} = \mu_o H_{ht} \text{ and } B_{vt} = \mu_o H_{vt}, Tesla \ldots (21)$$

## V. EXAMPLE OF SINGLE CIRCUIT HORIZONTAL CONFIGURATION

### *A. Electrostatic Field*

Design Data: Voltage rating of line: 400 kV (420 kV max.)
Configuration: Simple horizontal
Height of conductor: 13 m
Phase spacing: 12 m

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Conductors: twin moose (2x3.18 cm Dia.)
Bundle radius: 45.72 cm
Plot the electrostatic field (1) on ground level and (2) 1 m above ground level by varying horizontal distance from 0 to half of ROW on each side from center of tower

Following figure (4) shows arrangement of the conductors as stated in the data

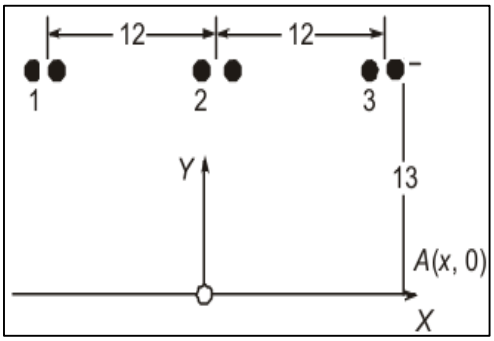


Fig. 4: Conductor arrangements for calculation of electrostatic field

Electrostatic filed at ground level has been computed using MATLAB programming and potted in subsequent figures (5) and (6) considering two different ROWs

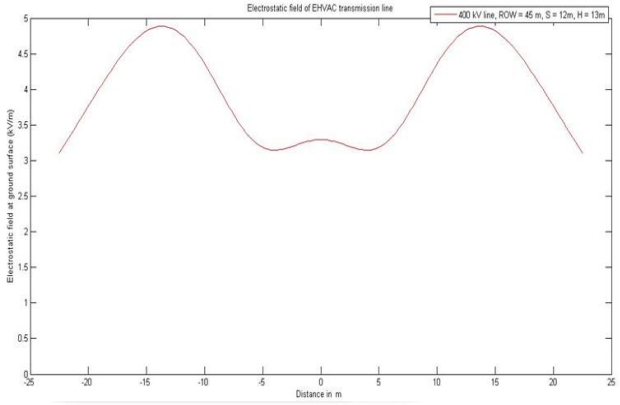


Fig. 5: Electrostatic field at ground level within ROW = 45 m

As observed from figure (5) ES filed at the edge of ROW (45 m) on ground level is 3.11 kV/m that is below accepted level of 5 kV/m.

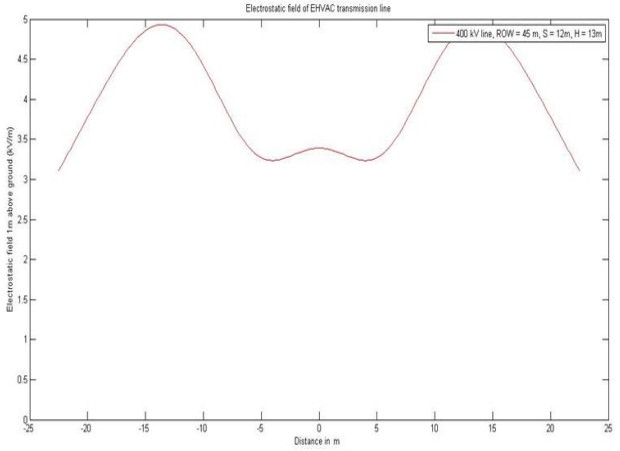


Fig.6. Electrostatic field 1 m above ground level within ROW = 45 m

As observed from figure (6) ES filed at the edge of ROW (45 m) 1m above ground level is 3.12 kV/m that is below accepted level of 5 kV/m.

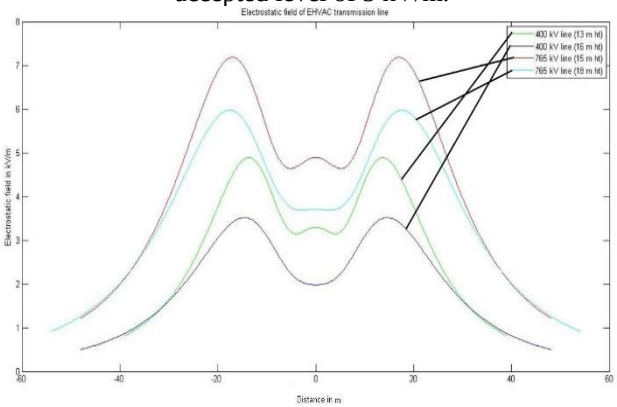


Fig. 7: Electrostatic field plots for 400 kV and 750 kV lines for different conductor heights

Finally figure (7) shows variation of electrostatic field with as horizontal and vertical distance from tower is varied. It is observed that as point of interest moving away from tower in x direction magnitude of field reduces. As point of interest moves above ground, ES field increases as point moves nearer to conductors

*B. Electromagnetic Field*

- Design Data: Voltage rating of line: 400 kV (420 kV max.)
- Configuration: Simple horizontal Load current: 1.46 kA Height of conductor: 13 m Phase spacing: 12 m
- Conductors: twin moose (2 x 3.18 cm Dia.)
- Bundle radius: 45.72 cm

Plot the electromagnetic field (1) on ground level and (2) 1 m above ground level by varying horizontal distance from 0 to half of ROW on each side from center of tower

Electromagnetic fields have been calculated using MATLAB as mathematical as well as programming platform. Following figures (8) and (9) show the electromagnetic field plots for two different ROWs 45 m as considered for ES field. Profile plot for both ground level field and that above 1 m from ground level are shown.

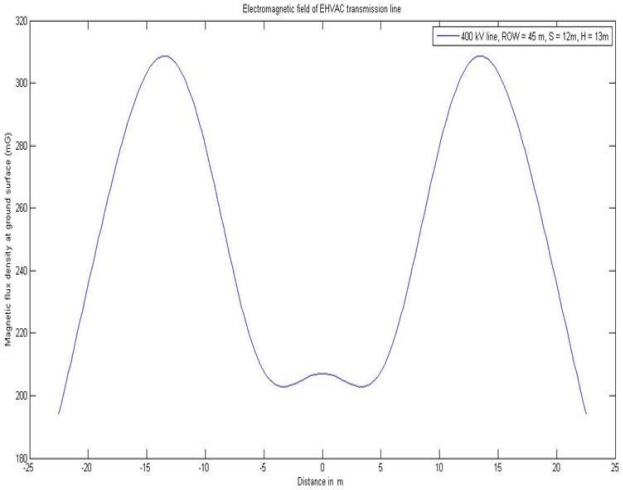


Fig. 8: Electromagnetic field at ground level within ROW = 45 m

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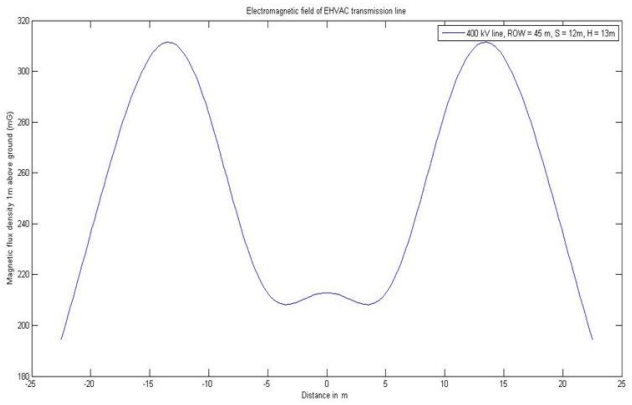


Fig. 9: Electromagnetic field 1 m above ground level within ROW = 45 m

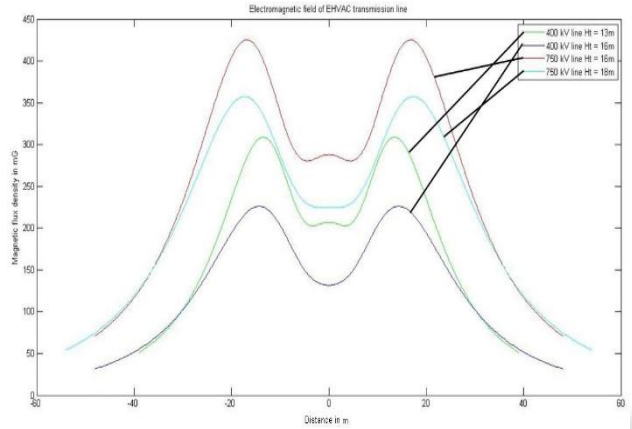


Fig. 10: Electromagnetic field plots for 400 kV and 750 kV lines for different conductor heights

As said earlier electrostatic field depends on voltage rating of the line. However electromagnetic field is decided based on load current. In case of 400 kV line load current given in the data is 1.46 kA. For the case of 750 kV line load current taken into account is 2.46 A. Figure (3.15) depicts that as load current increases the magnitude of the electromagnetic field is found to be increased. Again here with increase in height of conductors from ground level, intensity of magnetic field reduced.

## VI. Conclusion

With increasing extra high voltage transmission lines requirement, and increasing public pressure to minimize new right-of-ways, utilities are increasing the circuit density to maximize the use of existing right-of-ways. In recent years great public concern has arisen because of reports on adverse health effects due to Electric and Magnetic fields.

Electrostatic and magnetic fields calculate using above mathematical equations well below the values specified in the standards within ROW.

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