"Electric field Analysis of the 1200kv AC Line"

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Abstract: We know that the UHV transmission lines are essential to transmit the bulk amount of power more efficiently.To tackle this situation 1200 KV UHV transmission line is India's forthcoming project. However, a line to line voltage level increase, the complexity of the transmission line increases. ROW is one of the major concerns with transmission lines. Many parameters need to take care in designing; electric and magnetic field are two parameters to define ROW. In this work, electric field of the two configurations of the 1200kv line is calculated with the help of Finite Element Method(FEM). FEM is used to solve partial differential equations. Results of FEM is compared with Method of images results. Plotted results are compared with ICNIRP standards and safety limits defined.

Keywords: UHV, Electric field, Finite Element Method (FEM),Method of images International commission on non-ionizing radiation protection (ICNIRP), Right Of Way.

1. Introduction

To limit the Right Of Way with bulk amount of power transfer over long distances, countries need to incite the ultra-high voltage transmission system. China has initiated the project of commissioning of 1000kv UHVAC transmission line [2].

Major power transmission systems operates in India are 220kv and 400kv voltage level. To meet increasing power demand we adopted 1200kv UHVAC transmission network which is under implementation. 1200kv test station is established at Bina, Madhya Pradesh. The first 1200kv test line is installed between Wardha to Aurangabad having length of 382km [1].

Many parameters need to be taken care with higher voltage level as its affects human beings. One of them is an electric field. ICNIRP is one of the standards which specify a limit of the electric field for occupational and general public, which helps to define ROW [3][4].

In this paper, electric field produced due to the 1200kv AC line is evaluated by Finite Element Method(FEM). An electric field is calculated at ground surface and above ground surface up to several meters of height. From these results right of way is defined for transmission line. Biological Effects of excess electric field on living beings, animals and plants also discussed [4][6].

2. Line Parameters

A design specification of 1200kv AC lines is given in table.1. In this paper, three configurations of a line have been discussed, which are single circuit horizontal configuration, and double circuit vertical configuration [5]. In table 1, R represents radius of bundle conductors. For evaluation of electric field bundle conductor can be represent as in single conductor with equivalent radius as given in (1).

$$r_{eq} = R\left(\frac{Nr}{R}\right)^{\frac{1}{N}} = 0.518 \text{ meter} \quad (1)$$

Table 1. Line Parameters

Description	Notation	Value	Units
Number of sub-conductors in a bundle	N	8	Nos.
Bundle Radius	R	0.60	M
Sub conductor spacing	B	0.46	M
Diameter of sub-conductor	D	4.63	Cm
Conductor height above ground at a tower	H	37	M
Conductor height above ground at midspan	Hm	24.3	M
Phase spacing	S	27	M
Bundle conductor type	Bersimis/moose		

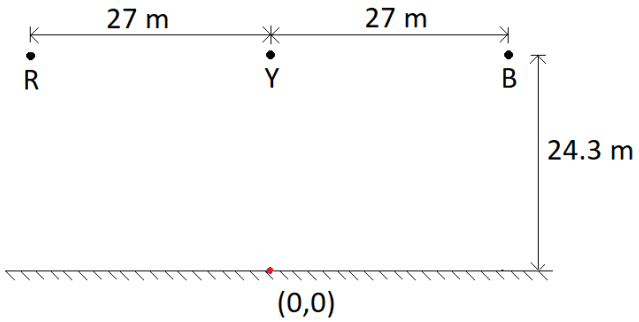

Figure 1. S/C Horizontal Configuration

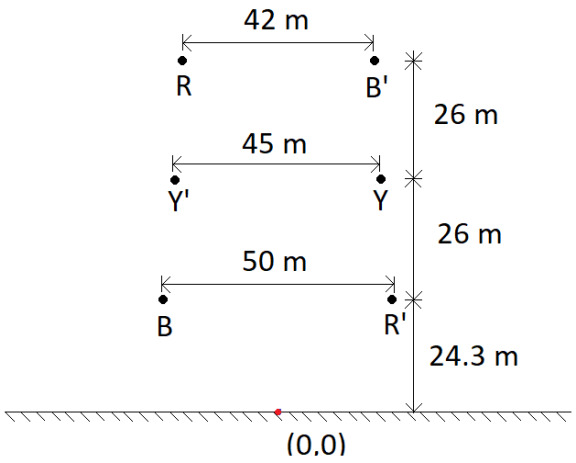

Figure 2. D/C Vertical Configuration

3. Electric Field Calculation

The Finite Element Method is used to calculate electric field distribution at the ground surface and above the ground surface up to 10-meter height. In this study, one assumption is made that ground surface is flat. As per Gauss law relation between electric field and voltage is given as in (2) [6]-[7].

$$E = -\nabla V \tag{1}$$

Electric flux density correlates with charge density and electric flux density correlate with the electric field as given in (2) and (3) respectively.

$$\nabla \cdot D = Q \tag{2}$$

$$D = \varepsilon E \tag{3}$$

By substituting (1) and (2) in (3) final relation between voltage and charge density given as (4).

$$-\frac{\partial}{\partial x}\left(\varepsilon \frac{\partial V}{\partial x}\right) - \frac{\partial}{\partial y}\left(\varepsilon \frac{\partial V}{\partial y}\right) = Q \tag{4}$$

Here, E stands for Electric field intensity V/m

V stands for voltage Volt

D stands for electric flux density C/m^2

ε stands for permittivity of medium F/m

Q stands for volume charge density C/m^3

Overall procedure of Finite Element Analysis can be explained in four steps.

3.1 Domain Discretization:

The first step of FEA is to divide the domain into a number of two-dimensional elements. In this problem, domain is divided into triangular elements with a quadratic shape we can also divided into rectangular elements but here the surface is irregular so we divided into triangular elements. So each element has six nodes. A triangular element is shown in the fig.3 [6]-[7].

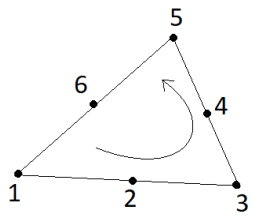

Figure 3. Quadratic Type Triangular Element

Each node is associated with two label numbers, one local number which represents its location within that element and second number is called the global number to represent the location of a node in a domain. Voltage equation at a node can be given as in (5).

$$A_{(x_1,y_1)} = a + bx_1 + cy_1 + dx_1^2 + ex_1y_1 + fy_1^2 \tag{5}$$

In (5) a, b, c, d, e and f are unknown constants. Voltage at all six nodes can represent in same manner. One common equation in matrix form can represent as given in (6). By simple matrix inversion, six constants can be representing in form of voltage and location point of node terms. Final equation for voltage at any (x, y) point in a particular element can be formed as (7).

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{bmatrix} = \begin{bmatrix} 1 & x_1 & y_1 & x_1^2 & x_1y_1 & y_1^2 \\ 1 & x_2 & y_2 & x_2^2 & x_2y_2 & y_2^2 \\ 1 & x_3 & y_3 & x_3^2 & x_3y_3 & y_3^2 \\ 1 & x_4 & y_4 & x_4^2 & x_4y_4 & y_4^2 \\ 1 & x_5 & y_5 & x_5^2 & x_5y_5 & y_5^2 \\ 1 & x_6 & y_6 & x_6^2 & x_6y_6 & y_6^2 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \\ d \\ e \\ f \end{bmatrix} \tag{6}$$

$$V = \sum_{i=1}^{6} N_{i(x,y)} V_i \tag{7}$$

3.2 Formulation of a system of equations:

Ritz method is used to formulate functional equations. Functional equations for eth element can be written as (8). It is a simple surface integration within the area of an element. V stands for voltage at nodes in an eth element. Q represents charge density in an eth element. Here, omega sign represents two dimensional0 problem [6]-[7].

$$\mathrm{F}^{\mathrm{e}}(V^e) = \frac{1}{2}\iint \left[\varepsilon \left(\frac{\partial V^e}{\partial x} \right)^2 + \varepsilon \left(\frac{\partial V^e}{\partial y} \right)^2 - 2QV^e \right] d\Omega \tag{8}$$

In (8) voltage is differentiating w.r.t. x and y. substituting (7) into (8), functional equation for eth element can be transformed into matrix form where the voltage at six nodes are used and it represented as in (9).

$$F^e(V^e) = \frac{1}{2}\iint \varepsilon \left[\mathrm{V}^{\mathrm{T}}\right] \left[\left(\frac{\partial [N^T]}{\partial x} \right) \left(\frac{\partial [N]}{\partial x} \right) + \left(\frac{\partial [N^T]}{\partial y} \right) \left(\frac{\partial [N]}{\partial y} \right) \right] [V] d\Omega$$

$$- \iint Q[N][V] d\Omega \tag{9}$$

Differentiation of functional equation w.r.t. a voltage at any node equals to zero. Expanding this differentiation with all node voltages. An expanded equation can be written as in (10). In (10) M is representing total numbers of nodes in domain of the system.

$$\frac{\partial F(V)}{\partial V_i} = \sum_{j=1}^{M} \iint \varepsilon \left(\left[\left(\frac{\partial N_i}{\partial x} \right) \left(\frac{\partial N_j}{\partial x} \right) + \left(\frac{\partial N_i}{\partial y} \right) \left(\frac{\partial N_j}{\partial y} \right) \right] V_j - Q N_i \right) d\Omega = 0 \quad (10)$$

In a simplified manner, these equations can be represented in matrix form as in (11).

$$[K]_{(M \times M)} [V]_{(M \times 1)} = [B]_{(M \times 1)} \quad (11)$$

Where K and B terms of matrices stand for,

$$K_{ij} = \iint \varepsilon \left[\left(\frac{\partial N_i}{\partial x} \right) \left(\frac{\partial N_j}{\partial x} \right) + \left(\frac{\partial N_i}{\partial y} \right) \left(\frac{\partial N_j}{\partial y} \right) \right] dxdy \quad (12)$$

$$B_i = \iint Q N_i dxdy \quad (13)$$

In (11) terms of matrix V are unknown which can be found by matrices K and B.

3.3 Incorporation of boundary condition:

Two types of boundary conditions have been used. One is Dirichlet condition and second is Neumann condition. At ground and conductor surfaces, Dirichlet condition is applied. Neumann condition is applied at an exterior boundary to bound air medium [6]-[7].

Dirichlet conditions:

$$V_g = 0V \quad (14)$$

$$V_r = 692.820323kV \quad (15)$$

$$V_y = 692.820323e^{-j\frac{2\pi}{3}} kV \quad (16)$$

$$V_b = 692.820323e^{j\frac{2\pi}{3}} kV \quad (17)$$

Neumann condition:

$$\left[\varepsilon \left(\frac{\partial V}{\partial x} \right) \hat{x} + \varepsilon \left(\frac{\partial V}{\partial y} \right) \hat{y} \right] \cdot \hat{n} = 0 \quad (18)$$

3.4 Continuity conditions:

In the domain of 1200kv power line conductors and air medium have different permittivity value, so at conductor surface two different types of material are interfaced which produces discontinuity. So at boundary interface some continuity conditions needs to be satisfied [6]-[7].

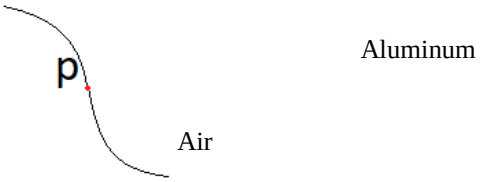

Figure 4. Two Boundary Interface

Fig.4 shows interface boundary interface of aluminum and air medium. So continuity conditions at interface given as in (19) and (20).

$$\left[\varepsilon_{air}\left(\frac{\partial V}{\partial x}\right)\hat{x}+\varepsilon_{air}\left(\frac{\partial V}{\partial y}\right)\hat{y}\right]\cdot\hat{n}=\left[\varepsilon_{con}\left(\frac{\partial V}{\partial x}\right)\hat{x}+\varepsilon_{con}\left(\frac{\partial V}{\partial y}\right)\hat{y}\right]\cdot\hat{n} \tag{19}$$

$$V_{+}^{p}=V_{-}^{p} \tag{20}$$

4. Implementation in COMSOL Multiphysics:

For Analysis COMSOL Multiphysics software is used. First rectangle is drawn with 300 meter height and 600 meter width to represent air medium. Reason behind take that much long dimensions are to generate more practical case as in real case air medium cannot be bound in any dimension. In air medium three circles are drawn with radius of 0.518 meter, each circle is distanced with 27 meters. Three circles are representing R, Y and B phase conductors respectively.

Electric field is to be calculated at ground surface and above ground surface with height 2m, 4m, 6m, 8m and 10m. For that 5 lines are drawn with 2 meter vertical distances. Final geometry in COMSOL Multiphysics is shown in fig.6. Aluminum material property is assign to three conductors and air medium property is assign to whole rectangular area except three conductors.

Ground surface representing as in red line in fig.6, has been applied Dirichlet condition as in (15). Conductor surfaces of R, Y and B phase also have been applied Dirichlet conditions as in (16), (17) and (18) respectively. At blue line boundaries representing in fig.6, Neumann condition is applied as in (19). Neumann condition represents that zero change in electric flux density in normal vector direction of boundary.

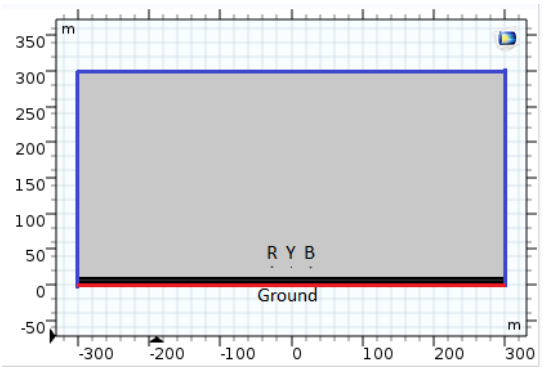

Fig.5 - Geometry of S/C horizontal configuration 1200kV transmission line

COMSOL provides feature to decide element size as your analysis area to get higher accuracy with lesser computation time and less RAM of device The results are need to be obtained at ground surface and some meters above from ground surface up to 10 meters. Here, results are evaluated at six equidistance lines from ground surface to height of 10 meters from ground surface, so small sized elements are constructed with 1 meter maximum element size as shown in fig.6, element size within conductors is 20 mm and in remaining area coarser type elements are formed.

Final geometry with construction of elements in whole domain is called as mesh domain. Mesh domain of S/C horizontal configuration of 1200kV line is shown in fig.7. Similarly model of D/C vertical configuration of 1200kV UHV transmission line can be implementing in COMSOL Multiphysics.

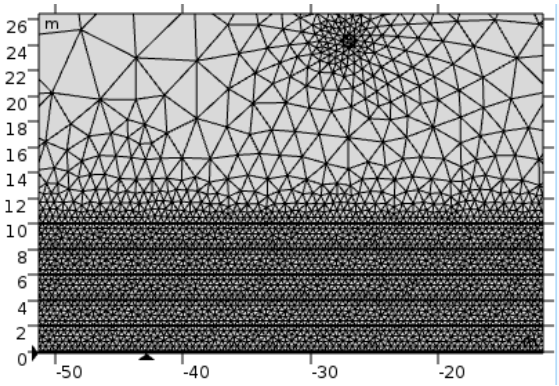

Figure 6. Discretization of domain with different element sizes

5. Results

An electric field is calculated and plotted for three configurations of a 1200kV transmission line; electric field plot is carried out for up to some distance from reference point on ground surface. It is repeated for various heights from the ground, ground surface and 2m, 4m, 6m, 8m and 10m above from the ground surface.

The Analysis is performed by considering the minimum height of conductors in a span.

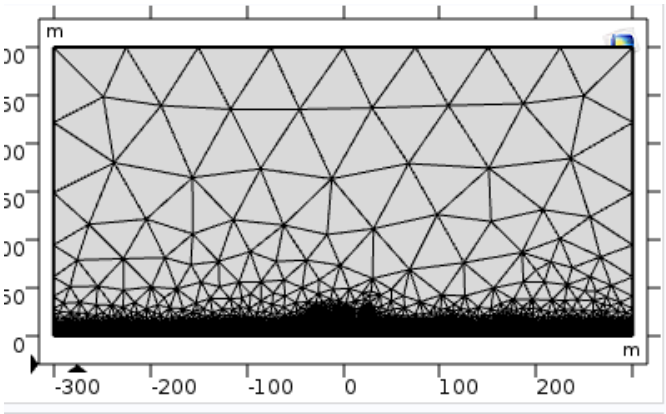

Figure 7. Mesh domain of S/C horizontal configuration

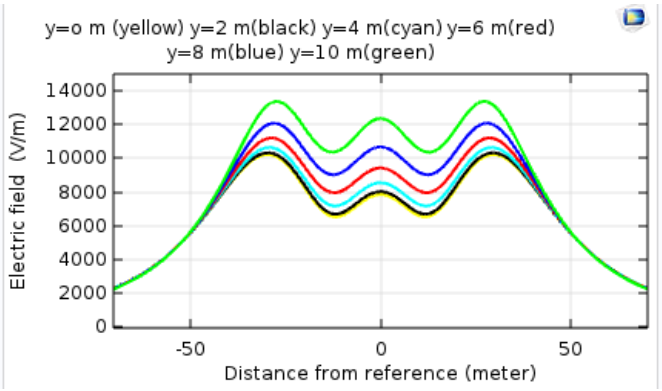

Figure 8. Electric Field Distribution for S/C Horizontal Configuration

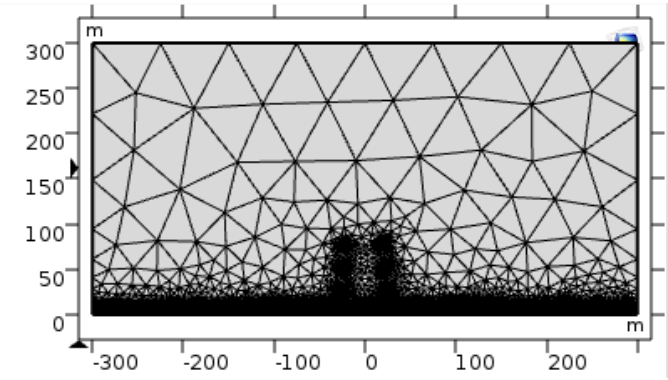

Figure 9. Mesh domain of D/C vertical configuration

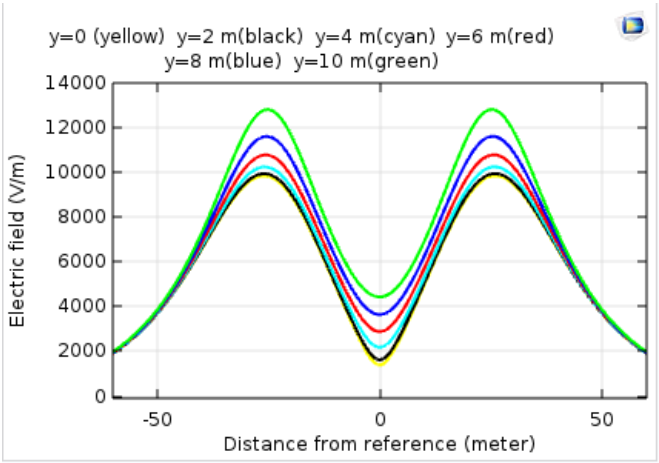

Figure 10. Electric field distribution for D/C vertical configuration

6. Importance with ICNIRP Guidelines

International Commission on non-ionizing radiation protection had approved the exposure limit of 50Hz based on electric field is shown as in table 2 [4].

Table 2 ICNIRP Guidelines

Exposure type	ICNIRP-2010
Occupational	10kV/m
General public	5kV/m

From the results of three configurations, a region can be defined where electric field is excessing the safety limits. By excessive electric field limit, right of way region can be defined for all configurations. For s/c horizontal configuration right of way is 104 meters. For s/c delta configuration right of way is 39 meters. For d/c vertical configuration right of way is 90 meters.

7. Conclusion

Application of Finite Element Method to evaluate an electric field of 1200kv AC line is explained. From electric field of 1200kv AC transmission line, Right of way of line is defined. Here three configurations have been taken for analysis; results of lines are compared with international standards for safe limits of electric field for public. Calculation is taken at ground surface and several meters of height from ground surface like 2m, 4m 6m, 8m, and 10m. For horizontal configuration ROW is 104 meters, for vertical configuration it is 90 meters.It is clear from the results that max electric field within a Row is around 13.4kV/m for S/C horizontal configuration, 12.9kV/m for D/C vertical configuration.

8. Acknowledgment

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