Electric Field Calculation of High Voltage Transmission Line – Analysis and Modelling

Major Project Report

Submitted in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING
(Electrical Power Systems)

By

K SUJEET KUMAR REDDY
13MEEE05

DEPARTMENT OF ELECTRICAL ENGINEERING
INSTITUTE OF TECHNOLOGY
NIRMA UNIVERSITY
AHMEDABAD-382481

MAY 2015

Electric Field Calculation of High Voltage Transmission Line – Analysis and Modelling

Major Project Report

Submitted in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING

(Electrical Power Systems)

By

K SUJEET KUMAR REDDY

13MEEE05

DEPARTMENT OF ELECTRICAL ENGINEERING

INSTITUTE OF TECHNOLOGY

NIRMA UNIVERSITY

AHMEDABAD-382481

MAY 2015

Undertaking For Originality of the Work

I, **K Sujeet Kumar Reddy (Roll No:**13**MEEE**05**)**, give undertaking that the Major Project entitled " **Electric Field Calculation of High Voltage Transmission Line – Analysis and Modelling**" submitted by me, towards the partial fulfillment of the requirement for the degree of Master of Technology in Electrical Power Systems, Electrical Engineering, under Institute of Technology, Nirma University, Ahmedabad is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in event of any similarity found subsequently with any published work or any Dissertation work elsewhere; it will result in severe disciplinary action.

....

Signature of Student

Date:

Place: Ahmedabad

Endorsed By:

....

Project Guide

Dr. S.C. Vora

Department of Electrical Engineering

Institute of Technology

Nirma University

Ahmedabad

Certificate

This is to certify that the Major Project Report entitled **"Electric Field Calculation of High Voltage Transmission Line – Analysis and Modelling"** submitted by **Mr.K Sujeet Kumar Reddy (13MEEE05)**, towards the partial fulfillment of the requirements for the award of degree in Master of Technology (Electrical Engineering) in the field of Electrical Power System of Nirma University is the record of work carried out by him under our supervision and guidance. The work submitted has reached a level required for being accepted for examination. The results embodied in this major project, to the best of my knowledge, have not been submitted to any other University or Institution for award of any degree.

Date:

....

Project Guide

Dr. S.C. Vora

Department of Electrical Engineering

Institute of Technology

Nirma University

Ahmedabad

Head of Department

Department of Electrical Engineering

Institute of Technology

Nirma University

Ahmedabad

Director

Institute of Technology

Nirma University

Ahmedabad

Acknowledgement

With immense pleasure, I would like to present this report on the dissertation work related to **"Electric Field Calculation of High Voltage Transmission Line − Analysis and Modelling"**. I am very thankful to all those who helped me for the successful completion of the dissertation and for providing valuable guidance throughout the project work. It is a pleasant aspect that I have now the opportunity to express my gratitude towards them. It gives me immense pleasure to express my deepest sense of gratitude and sincere thanks to our highly respected and esteemed guide Dr.S.C. Vora (Professor,Electrical Engineering Department, IT, NU) for his valuable guidance and encouragement. I am very thankful to the university for providing the great facilities for the work. I am also thankful to all the staff members and all the lab technicians of Electrical Engineering Department who have directly or indirectly helped me during the project. Further, I am thankful to my classmates for making a good work environment without which the thesis work would not been completed.

- K Sujeet Kumar Reddy
13MEEE05

Abstract

An electric field exist in a region or space if a charge, at rest in that space, encounters an force of electrical origin. The electric field created by high voltage transmission line stretches out from the energized conductors to other conducting objects for example the ground, towers, vegetation, building, vehicles and individuals. Electrical field is theoretically affected by the transmission line voltage, load current, sag above the ground and environment condition.

In this project a three-phase overhead transmission line model in different configuration as analyzed for electric field radiating to atmosphere around the transmission line. The electric field line calculated, at different voltage levels in various configuration as helps deciding in the height and ROW for towers.

Abbreviations

FDM .... Finite difference method

FEM .... Finite element method

CSM .... Charge simulation method

BEM .... Boundary element method

ROW .... Right of Way

E_p .... Peak Value of Electric Field

List of Tables

List of Figures

Contents

Chapter 1

Introduction

Electric field in the region of space is defined, if a charge at rest experiences a force of electrical origin in that space. High voltage transmission line creates Electric field which extend to other conducting objects such as the ground, tower, vegetation, building, vehicles and people. In order to meet the increasing electric demand there is a need for increasing transmission voltage levels, at the same time there is a need for reducing size and weight of electrical equipment. Design for higher voltage level transmission tower is possible only through proper understanding of the insulating materials and knowledge of electric field.

The electric field around the line is directly proportional line voltage, as we go for higher transmission voltage the electric field around the overhead transmission line is also increased. High electric field leads to health problem, affects the vegetation, corrosion of other cable near the transmission line,etc. It is necessary to calculate the electric field around the transmission line taking sag into consideration specially in case when the transmission line are to be designed for long span or uneven surfaces, to find the height of the tower, the insulation material to be used.

1.1 Literature Survey

For the better understanding of project literature survey plays a very important role. Literature Survey consists of papers referred which gives fundamental knowledge of

Electric field.

- **Yong Lu** [1] This paper entitled "Electric Field Calculation of High Voltage Transmission Line" presented about the electric field generated by the overhead transmission line is studied and to achieve this the desired calculation surface charges method is used.

- **S.Tupsie, A.Isaramongkolrak, and P.Pao-la-or** [2] This paper entitled "Analysis of Electromagnetic Field Effects Using FEM for Transmission Lines Transposition " proposed the six type of 500kV high voltage double circuit transmission line, the mathematical modeling of the field generated by the transmission line is done and for analysis finite element method is applied, developed using MATLAB® program.

- **Shizuo Li, Huajun Lu** [3] The paper entitled "Electric Field Calculation of Double Circuit Compact Overhead Transmission Line on Same 550kV Towers" discusses the electric field around the 550 kV double circuit high voltage transmission line, Surface charge method is used for calculation.

1.2 Objective

This project propose to calculate the electric field intensity around the transmission line in different configurations, to decide the minimum height of transmission line for a given voltage level, developing a three phase transmission line model and analyzing the electrostatic field radiating to atmosphere around the transmission line and also find the safe distance away from the transmission line. To achieve this objective, the scope of the project is outlined as:

- Developing mathematical modeling and calculation the value of electric field around the DC transmission line.(as an initial test only)

- comparing the results obtained from the mathematical calculations and from the simulation done in ANSYS to validate the design for DC transmission line.

- Developing the mathematical model of 3 phase transmission line, assigning 3 phase sinusoidal AC voltage to all 3 phases and finding the electric field around this at different time instinct and coordinates.

- Develop same model in the ANSYS for which mathematical calculation was done to validate results and to analyze the results to get the safe distance and have electric field as per standard or below.

- Model different 3 phase transmission line with the help of standards to reach the electric field level below standard limit.

1.3 Methodology

In order to achieve the objective of developing a model of three phase transmission line in different configurations and to get the most optimum design, the FEM based software is used.

1.4 Organization of Thesis

The work carried out during the dissertation work is divided into four chapter chapters. the present chapter consist of introduction, literature survey, objective, methodology. The other three chapters are as follows.

- **Chapter 2** Define electric field, equipotential and formulation of mathematical equation to find the electric field around two parallel conductors(DC case for initial test), then carrying the same for different configuration of three phase AC transmission line.

- **Chapter 3** It include calculation, validation and simulation result. Here the mathematical calculation and it is used for validation of simulation results and electric field around different model of overhead transmission line is analyzed.

- **Chapter 4** It comprises of conclusion and future work.

Chapter 2

Calculation of Electrostatic Field of AC Lines

2.1 Electric field

Electric field is a vector of electric field quality characterized by its space component along three orthogonal axes. For steady state sinusoidal field, each space segment is a phasor that may be indicated by a rms value (V/m), due to increasing electric demand there is a requirement for raising the transmission limit and to achieve that we need to try for higher transmission voltage. With the increasing voltage the issue identified with electric field is increased as the electric field around a conductor is straightforwardly relative to the transmission voltage.

2.2 Equipotential

Equipotential is a region in space with each point in that region is at same potential. Electrostatic equipotentials are two dimensional surface at which electric field lines are perpendicularly intersecting it at each point of surface.

2.3 Electric field Around Two Parallel Conductor

The two parallel conductors of same magnitude potential (with respect to ground) and far away from other parallel conductors is discussed. generally, bundle conductors are used for high voltage transmission line, but for simplicity equivalent conductors are used for modelling and simulation. Here, two cylindrical conductors are charged with inverse extremities. The two line charges $\pm Q/l = \pm\rho_l$ running in parallel and symmetrically placed in the conductors. This arrangement is shown in fig 2.1, in which separation between the line charges $\pm\rho_l$ is b. At any point P the potential Φ_p can be found by using principle of superposition. If r is the separation of the point from the line charge then the electrical field at that point is given by $E(r) = \frac{\rho}{2\Pi\epsilon r}$. By applying the superposition ,the following equation is obtained.

$$\Phi_p = \frac{\rho l}{2\Pi\varepsilon} ln(\frac{r"}{r'}) + k \tag{2.1}$$

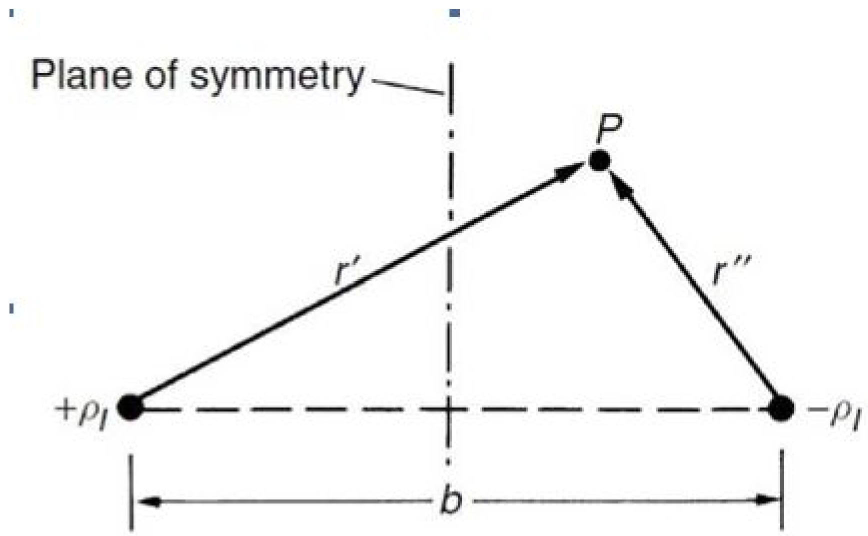

Figure 2.1: Two charges $\pm\rho_l$ in parallel

The two conductors shown in fig 2.2, with separation c between the line charges and both conductors having same equivalent radius $r_1 = r_2 = r$. As r << (a/2) we can take separation c = (a - b)/2 and all of the field lines are coming out from one conductor and terminating on other conductor. Here the potential $\Phi(y)$ along the

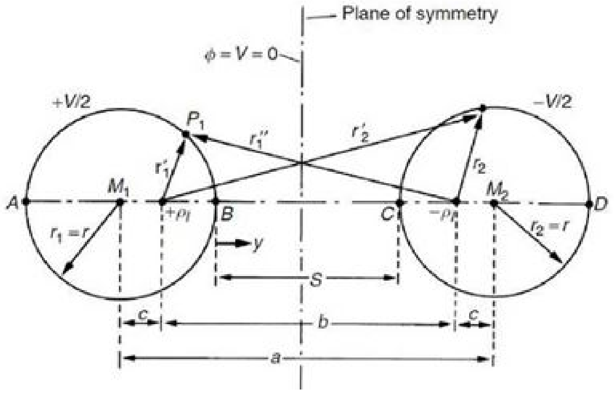

Figure 2.2: Two equal cylindrical conductors in parallel, symmetrically charged

line joining two line charges beginning at B (y =0)

$$\Phi(y) = Aln(\frac{r''}{r'}) \tag{2.2}$$

Here A is constant define by the boundary conditions, y is the distance from the positive conductor to the point at which the potential is to be calculated, Assuming the potential $\Phi(y) = +V/2$ at the surface of the conductor (at y =0).

$$A = \frac{V/2}{ln(\frac{b+S}{b-S})} \tag{2.3}$$

using the constant value of A in 2.3 and applying superposition on 2.2 and $E(y) = \frac{d\Phi(y)}{dy}$ to get electric field.

$$E(y) = \frac{V}{2}\frac{b}{[(\frac{b}{2})^2 - (\frac{2y-S}{2})^2]ln(\frac{b+S}{b-S})} \tag{2.4}$$

As equal and opposite potential is given to both the lines, with zero potential at mid point (y = S/2) and simplifying the above equation we get final equation

$$E(y) = \frac{V}{S}\frac{((\frac{S}{2r})^2 + \frac{S}{r})^{1/2}}{[1 + \frac{y}{r} - \frac{y^2}{rS}]ln(1 + \frac{s}{2r} + ((\frac{S}{2r})^2 + \frac{S}{r})^{1/2})} \tag{2.5}$$

From 2.5 the electric potential at the different points on the line joining the center of two conductor.

$$\Phi_p = \frac{\rho l}{2\Pi\epsilon} ln\frac{r''}{r'} + K \tag{2.6}$$

For all ratios r″/r′ = const, also K is constant and may lead to any positive or negative potentials. However, all constant ratios of r″/r′ generate cylindrical surfaces. These surfaces may be assumed to be cylindrical conductors of different diameters. Interested in two conductors of equal diameters, the two line charges will be eccentrically but symmetrically placed within

these two conductors as shown in fig 2.2. The eccentric position, indicated by the distance c between the line charges and the centers M of the conductors.

$$\Phi(y) = Aln[\frac{\frac{b+S}{2} - Y}{\frac{b-S}{2} + Y}] \tag{2.7}$$

$$E(y) = \frac{d\Phi(y)}{dy} = A[\frac{1}{\frac{b+S}{2} - Y} + \frac{1}{\frac{b-S}{2} + Y}] \tag{2.8}$$

$$E(y) = \frac{V}{2}\frac{b}{[(\frac{b}{2})^2 - (Y - \frac{S}{2})^2]ln\frac{b+S}{b-S}} \tag{2.9}$$

2.4 Calculation of Electrostatic Field of AC Lines

$$\frac{1}{2\pi\epsilon}[Q] = [P]^{-1}[V] = [M][V] \tag{2.10}$$

where [Q]= Total charge

$[V]$= Line to ground voltage

$[P]$= n× n matrix of maxwell's potential coeffcients

here $P_{ii} = ln(\frac{2H}{r}) and P_{ij} = ln(\frac{I_{ij}}{A_{ij}})$

H_i=distance between the ground and the conductor i

I_{ij}=distance between the conductor i and the image of j conductor in ground

A_{ij}=aerial distance between conductor i and j

r=radius of conductor

Taking 3 phase line with 3 conductors placed at a height 13.5 m above the ground level with voltages

$[V] = V_m[sin(wt), sin(wt - 120), sin(wt + 120)]$

Here, V_m is the peak phase to ground voltage taking the point just below the mid conductor at the ground as origin and the coordinates of line conductor (x_i, y_i) and taking any random point (x,y) at which we have to calculate the total electrical field.

$$E_{ti} = \frac{Q_i}{2\pi\epsilon D_i} \tag{2.11}$$

where D_i is the distance of conductor i from the point A at which electrical field is to be calculated. dividing the electrical component to horizontal and vertical component

$E_{hi} = \frac{Q_i}{2\pi\epsilon}\frac{x-x_i}{D_i^2}$

$E_{vi} = \frac{Q_i}{2\pi\epsilon}\frac{y-y_i}{D_i^2}$

$E_{hi'} = \frac{Q_i}{2\pi\epsilon}\frac{x-x_i}{(D_i')^2}$

$E_{vi'} = \frac{Q_i}{2\pi\epsilon}\frac{y+y_i}{(D_i')^2}$

From the above 2.10 and 2.11 we get

$$E_{h1} = V_m S_1[M_{11}sin(wt) + M_{12}sin(wt - 120) + M_{13}sin(wt + 120)] \tag{2.12}$$

Similarly, for other two conductors the calculate of total horizontal component at point A due to all three conductors and for vertical component E_{v1}

$$E_{v1} = V_m R_1[M_{11}sin(wt) + M_{12}sin(wt - 120) + M_{13}sin(wt + 120)] \tag{2.13}$$

'where,

$S_i = (x - x_i)[\frac{1}{D_i^2} - \frac{1}{(D_{i'})^2}]$

$R_i = \frac{(y-y_i)}{D_i^2} - \frac{(y+y_i)}{(D_i')^2}$

After having the total horizontal and vertical component the total electrical field at that point is

$$E_t = \sqrt{E_h^2 + E_v^2} \tag{2.14}$$

2.5 Method to Solve Electric Field Equation

a. Finite difference method (FDM)

b. Finite element method (FEM)

c. Charge simulation method (CSM)

d. Boundary element method(BEM)

2.6 Finite Element Method (FEM)

The FEM standouts amongst the well known numerical systems utilized for machine simulation. The focal point of the FEM over other numerical methods in engineering applications is the capacity to handle nonlinear, time-dependent and circular geometry issues. Subsequently, this technique is suitable for taking care of the issue including electric and magnetic field effects around the transmission line created by circular cross section of high voltage conductors. In the finite element method, the differential equations that describe the transmission line are not tackled directly. Instead, this method takes advantage of the equivalent physical principle that the voltage distribution along the line will always adjust itself as to minimize power loss. When coupled with familiar idea of piecewise approximation. Here, in the finite element approach for the transmission line to find out the electric field around it, there is a need for boundary condition.

2.6.1 Boundary Conditions

Boundary condition is the condition or the value given to any node ,edge,all or part of the boundary in which the set of differential equation to be solved. Let's take an example of a two line in parallel design to carry signal, the receiving end is taken to be very lightly loaded, practically an open circuit. The equivalent circuit of a short length dx of the line. The final differential equation are formed depending on the system with some unknown constants. In the above case the equation require two boundary condition to be applied, One will be the sending end voltage and the other will be the receiving end current which vanishes. Similarly in case to find the electric field around the transmission line through finite element approach there is need of assign the boundary condition. In this case cylinder surrounding the three transmission line will be taken as the balloon boundary and with that we will be giving the respective voltage to the three transmission lines .

2.7 Summary

In this chapter electric field, equipotential is defined and formulation of mathematical equation to find the electric field around two parallel conductors(DC case for initial test), then carrying the same for different configuration of three phase AC transmission line.

Chapter 3

Calculation and Simulation Results

3.1 Calculation and validation

3.1.1 Electrostatic Field of Two Parallel Conductor

In this 2 D model, each circle represents a conductor of diameter 20 mm, each circle is of aluminium material, the gap distance between the consecutive circle is 7 m. The extreme left circle is given ground potential and the other two circle are given opposite potential of magnitude 190 kV(peak line to ground potential) each. The boundary condition is given by a arc enclosed structure give ground potential to it's edges, the arc of 60m radius, its center at the origin enclosed by a line y = -13.5 m and assigned vacuum as material to it. Here, the calculated electric field at different distance (given to the electric field magnitude scale) and similarly the electric field generated around the conductor from the simulation is compared. The below equation 3.1 is used for calculation of electric field on the line joining the two conductors.

$$E(y) = \frac{V}{S}\frac{((\frac{S}{2r})^2 + \frac{S}{r})^{1/2}}{[1 + \frac{y}{r} - \frac{y^2}{rS}]ln(1 + \frac{s}{2r} + ((\frac{S}{2r})^2 + \frac{S}{r})^{1/2})} \tag{3.1}$$

Known value

$$V = 380kV$$

$$S = 6.980m$$

$$r = .01m$$

Calculation

At Y=1 m

$$E(1) = 2908.6/86.67 = 33.559kV/m$$

At Y=2 m

$$E(2) = 2908.6/143.68 = 20.243kV/m$$

At Y=3m

$$E(3) = 2908.6/172 = 16.910Kv/m$$

At Y=4 m

$$E(4) = 2908.6/172 = 16.910kV/m$$

At Y=5 m

$$E(5) = 2908.6/143.68 = 20.243kV/m$$

At Y=6 m

$$E(6) = 2908.6/86.67 = 33.559kV/m$$

putting this value of electric field in the scale we get,

33.559 kV/m at Y=1 m

20.243 kV/m at Y=2 m

16.910 kV/m at Y = 2.9 m

16.910 kV/m at Y = 4.1 m

20.243 kV/m at Y = 5 m and

33.559 kV/m at Y = 6 m .

As the result of the electric field magnitude obtained from the calculation and the simulation are nearly same

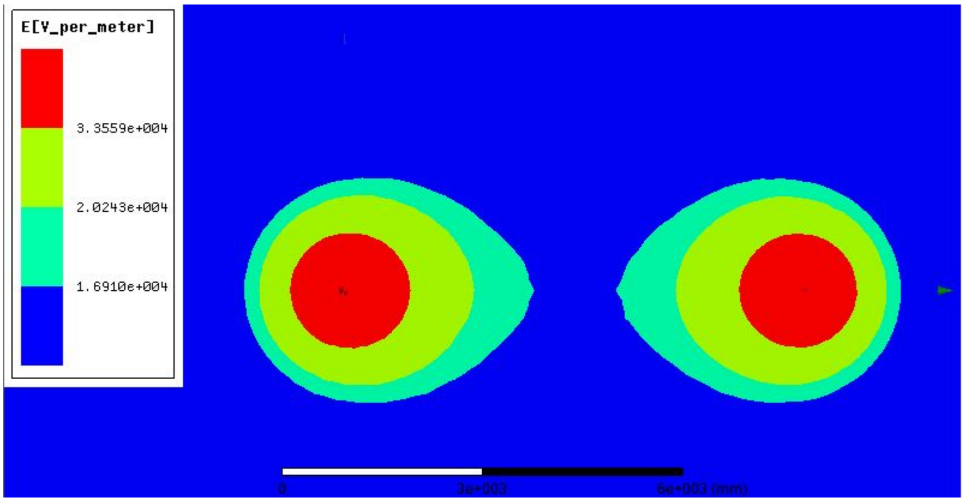

Figure 3.1: 2D model of 3phase line showing the electric field magnitude

3.1.2 Electrostatic Field of an AC Conductor

In this 2 D model each circle represent the conductor of diameter 20 mm, each circle is of aluminium material, the gap distance between the consecutive circle is 7 m. The mid circle is give 188 kV(peak line to ground voltage) and the other two circle are given negative potential of magnitude 94kV each. The boundary condition is given by an arc enclosed structure of radius 60 m and assigned balloon boundary to it, the straight line y = -10 m closing the arc and given ground potential(representing ground) to it.

Here, the electric field is calculated at point where it attains maximum value at 6 m above the ground with the conductor just above that point is at maximum potential of 188 kV (peak line to ground voltage). The horizontal and vertical component of electric field at point A due to each point is calculated and vector addition is performed to get the total electric field at point A (0,6).

Known Quantities

$$V_1 = -94kV$$

$$V_2 = 188kV$$

$$V_3 = -94kV$$

$$H = 10m$$

$$(x_1, y_1) = (-7, 10)$$

$$(x_2, y_2) = (0, 10)$$

$$(x_3, y_3) = (-7, 10)$$

Calculation

$$S_i = (x - x_i)[\frac{1}{D_i^2} - \frac{1}{(D_{i'})^2}] \tag{3.2}$$

$$S_1 = 7[\frac{1}{65} - \frac{1}{305}] = 0.085$$

$$S_2 = 0$$

$$S_3 = -7[\frac{1}{65} - \frac{1}{305} = -0.085$$

$$R_i = \frac{(y - y_i)}{D_i^2} - \frac{(y + y_i)}{(D_i')^2} \tag{3.3}$$

$$R_1 = \frac{-4}{65} - \frac{-16}{305} = -0.114$$

$$R_2 = \frac{-4}{16} - \frac{-16}{269} = -0.3125$$

$$R_3 = \frac{-4}{65} - \frac{-16}{305} = -0.114$$

$$P_{ii} = ln(\frac{2H}{r}) \tag{3.4}$$

$$P_{ii} = ln(\frac{20}{0.01}) = 7.6$$

$$P_{ij} = ln(\frac{I_{ij}}{A_{ij}})$$

$$P_{12} = P_{21} = ln(\frac{21.2}{7}) = 1.11$$

$$P_{13} = P_{31} = ln(\frac{24.4}{14}) = 0.556$$

$$P_{23} = P_{32} = ln(\frac{21.2}{7}) = 1.11$$

$$E_{h1} = V_m S_1[M_{11}sin(wt) + M_{12}sin(wt - 120) + M_{13}sin(wt + 120)] \tag{3.5}$$

$$E_{h1} = 188 \times (0.085)[0.135(-0.5) - 0.0186 + 0.0036] = -1.318kV/m$$

$$E_{h2} = 0$$

$$E_{h3} = 188 \times (-0.085)[0.0036 - 0.0186 - 0.135(-0.5)] = 1.318kV/m$$

Similarly

$$E_{v1} = V_m R_1[M_{11}sin(wt) + M_{12}sin(wt - 120) + M_{13}sin(wt + 120)]$$

$$E_{v1} = -1.768kV/m$$

$$E_{v2} = 9.1415kV/m$$

$$E_{v3} = -1.768kV/m$$

$$E_v = 5.5kV/m$$

$$E_h = 0$$

From equation (2.5)

$$E_t = \sqrt{E_h^2 + E_v^2} \tag{3.6}$$

$$E_t = 5.5kV/m$$

Validation

In this 2 D model each circle representing the conductor of diameter 20 mm, each circle is of aluminium material, the gap distance between the consecutive circle is 7 m. The mid circle is give 188 kV(peak line to ground voltage) and the other two circle are given negative potential of magnitude 94kV each. The boundary condition is give by a arc enclosed structure assigned balloon boundary to it and the straight line closing

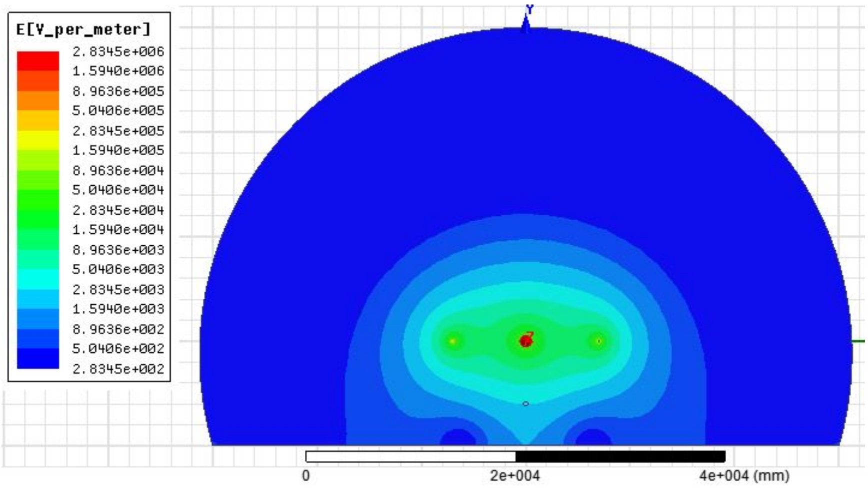

Figure 3.2: 2D model of 220 kV 3-phase line showing the electric field magnitude

the arc in given ground potential, the arc with its center at origin and radius of 60 m enclosed by a line y = -10 m. As the result of the electric field magnitude obtained from the calculation and the simulation are nearly same and are near the limit of 5 kV/m at the worse case taking sag as 3.5 m for the tower of 220 kV nominal voltage .

3.2 Result and Analysis

3D Model of 3-Phase Line

In this 3D simulation, small model is taken in which each line of length 40 m and radius 10 mm. Give respective voltage of -110, 220, -110 kV here the mid wire carries the 220 kV. The space difference between the two consecutive lines is 7 m, the center of the mid wire is taken as origin. The boundary condition is given by a hollow cylinder having its center at the origin and radius 13.5 m and the ground potential is applied to it. This simulation result show the electric field line and its intensity, electric field line are coming out perpendicular from the 220 kV line and getting terminated at the -110 kV lines ,and the electric field intensity shows that as move away from the line the intensity of the electric field decreases it in maximum near the highest potential line.

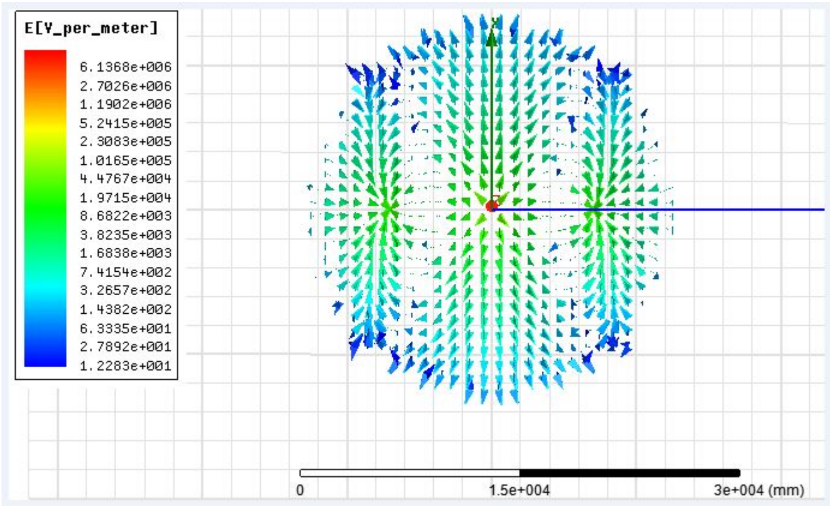

Figure 3.3: 3D model of 3-phase line showing the electric field lines

2D Model of 3-phase Line Showing Equipotentials

In this 2D simulation, three circle of 10 mm each representing the transmission line, each consecutive circle is 7 m apart from each other having voltage 220,-110,-110 kV respectively assign to them from left to right circles and mid circle center is taken as origin. The boundary condition in given by a arc with a center at origin, the radius of 30 m and enclosed by a line which is 13.5 m below the origin in the y axis, the edge of this boundary is given zero potential. This simulation result shows the equipotentials in different colour with zero potential existing in between the 220 kV line and the mid line of -110 kV, ideally it also exist at infinite distance from the transmission line. The equipotentials has its own importance at equipotentials the electric field line are perpendicularly cutting the equipotential layer and it is also important to find the safe distance from the ground if the voltage above the ground is high means the person and object will feel a high field and current will flow through the body which is above the desired level.

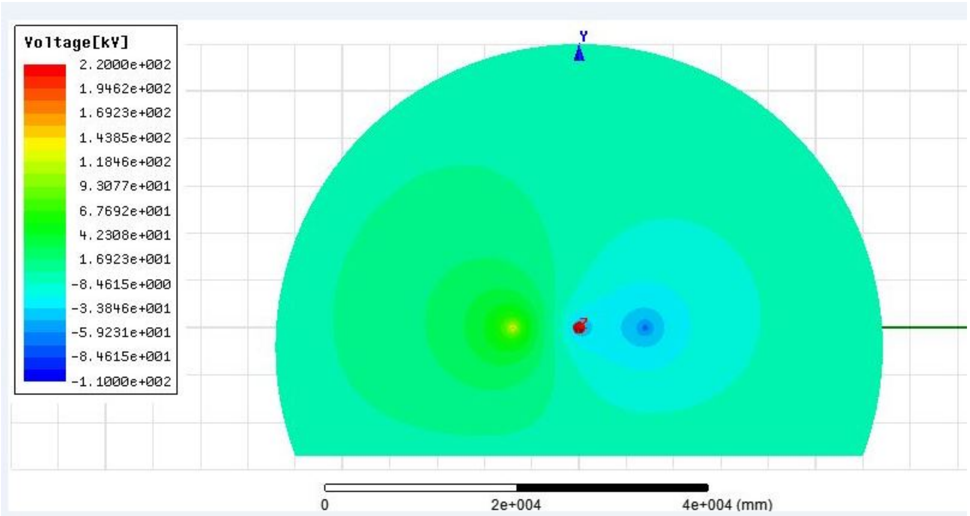

Figure 3.4: 2D model of 3-phase line showing the equipotential

Considering Different Cases for 765 kV Transmission Line Tower

Case 1: Three conductors are placed horizontally with two overhead earth wires(Single Circuit)

- Case 1.1: Showing electric field magnitude around the conductors.
- Case 1.2: Showing the equipotentials around the conductors.

Case 1.1: In this 2D simulation, four circles in each phase of 10 mm is taken, each representing the four sub conductor in each phase and are spaced 100 mm apart from each other and are excited with same voltage, each consecutive phase is 15.25 m apart from each other, sinusoidal voltages assigned to each phase with the phase displacement of 120 deg from each other and having peak magnitude of 653.2 kV (Peak line to ground voltage).

The boundary condition is given by an arc with a center at origin, the radius of 100 m with balloon boundary assigned to it and enclosed by a line which is 27.3 m below the origin in the y axis and zero potential is given to this line (representing ground). Two overhead earth wires are placed at a vertical distance of 13.8 m above the conductor and 21.5 m apart from each other, symmetrically placed .

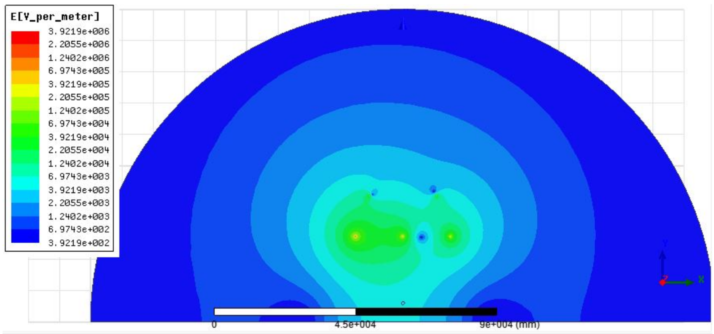

Figure 3.5: 2D model of 765 kV 3-phase line with conductors horizontally placed showing electric field magnitude around it

In this a non model point and line in constructed at point 6 meter above ground below the mid conductor, in this model we get 5.83 kV/m at that point, which is above the specified value of 5 kV/m and three low electric field point and formed two on earth wire which are stationary and a moving zero which is along the line joining three conductor. Using this model to get the value of peak value of electric field at different degrees and position of peak electric field at point 6 m above the ground.

Table 3.1: Peak Electric Field at Different Angles and Positions

Angle(degree)	E_p(kV/m)	Coordinates(m)
-30	4	(-8,6)
-20	4.55	(-7,6)
-10	5.05	(-6,6)
0	5.36	(-5,6)
10	5.6	(-3.5,6)
20	5.78	(-1.5,6)
30	5.83	(0,6)
40	5.78	(1.5,6)
50	5.6	(3.5,6)
60	5.36	(5,6)
70	5.05	(6,6)
80	4.55	(7,6)
90	4	(8,6)

Here 0 angle refer to instinct when phase A is at positive peak and similarly other angle refer to current angular position of phase A at that instinct from its peak.
E_p is the peak electric field noticed at a point vertically 6 m above the ground.
For coordinates the point below the center conductor on the ground is taken as reference.
From the table it is observed as A phase is at 30 deg from its peak the electric field attain its peak with phase B at zero potential and phase C has equal magnitude as phase A but opposite polarity.

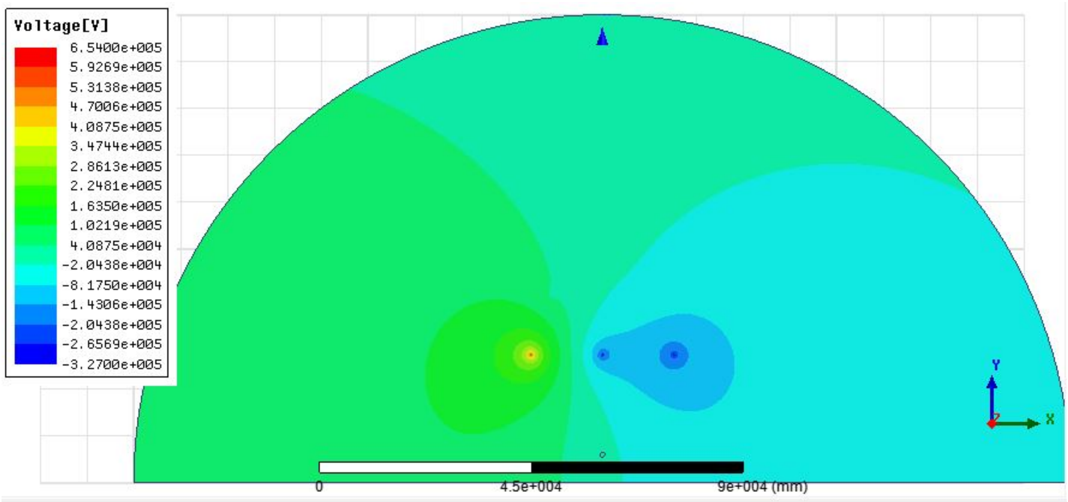

Figure 3.6: 2D model of 765 kV 3-phase line with conductors horizontally placed showing the equipotentials

Case 1.2: This simulation result shows the equipotentials in different colour with zero potential existing in between the 653.2 kV line and the mid line of -326.6 kV, ideally it also exist at infinite distance from the transmission line.

The equipotentials has its own importance, at equipotentials the electric field line are perpendicularly cutting the equipotential layer and it is also important to find the safe distance from the ground if the voltage above the ground is high, means the person and object will feel a high field and current will flow through the body which is above the desired level.

Case 2: Triangular spacing of two conductors with two overhead earth wires(Single Circuit). In this simulation model, each phase has six subconductor with minimum distance between them as 100 mm with two phases placed horizontally, 22 m apart from each other and the third phase is horizontally place symmetrically in between and vertically 11 m above the other two phases.

Two overhead ground wire is represented by a circle of 10 mm radius and placed vertically 10 m above the third phase and horizontally distance between the two ground wire is 10.73 m.

All the six subconductor in one phase are give same voltage of magnitude 654 kV(peak line to ground value) and voltage of each phase are 120 apart from each other, the two circle representing ground wire are give zero potential. Boundary condition is given by an arc of 60 m radius enclosed by a line vertically 26 m below the two horizontally placed conductor, along the x axis.

In this model height of tower is 47 m and ROW is 22 m and the peak value of electric field at point 6 m above the ground is 4.9 kV/m which is below the desired level of 5 kV/m.

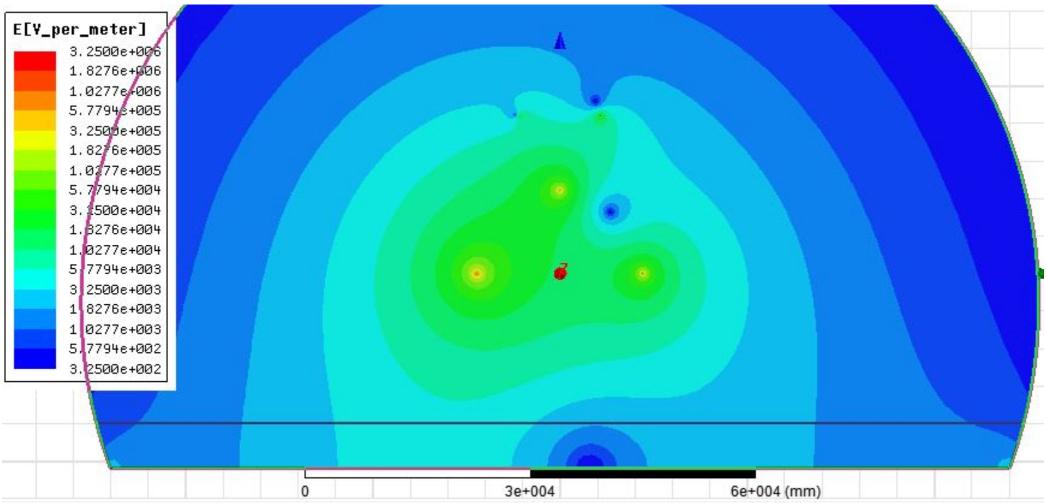

Figure 3.7: 2D model of 765 kV 3 phase line with cross arm length 22 m showing electric field magnitude around it

Case 3: Considering a 3 phase line with tower height 64.5 m, length of largest cross arm 37.5 m and phase sequence is CBA-A'C'B' (Double Circuit) In this tower

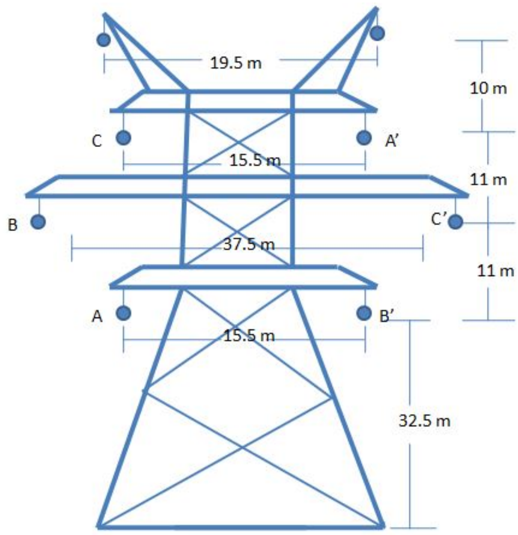

Figure 3.8: Tower design of 765 kV double circuit 3 phase line with height of 64.5 m

design the conductor are given assigned sinusoidal voltages as given in figure with phase A given 654 kV and phase B conductor is given 654 kV and phase displace of 120 degree from phase A and similarly phase C conductors are assigned voltages 120 degree apart from the phase B and A conductors and voltage 654 kV. The height of tower in this case is 64.5 m and the length of the largest cross arm is 37.5 meters.

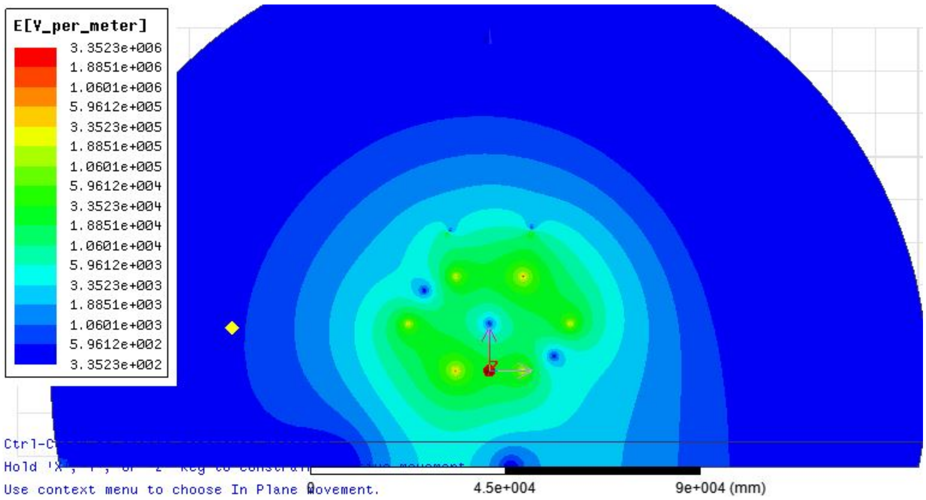

Figure 3.9: 2 D model of 765 kV double circuit 3 phase line with sag of 10m and height of 64.5 m

This 2D model of double circuit 765 kV transmission line with each phase consisting of 6 subconductors each of 10 mm radius and spacing between two consecutive subconductors is 100 mm. Here bottom conductors with horizontal distance between A and B' of 15.5 m and vertically placed 22.5 m above ground, the conductors B and C' are placed 32.5 m above the ground level and are place horizontally 18.75 m distance away from the center line of the tower and similarly conductors of phase C and A' place vertically above phase A and B' conductors and vertically 22 m above the phase A conductors.

Two overhead earth wires are placed symmetrically 19.5 m away from the center of tower and vertically 10 m above the phase C conductors. The total height of tower is 64.5 m with a sag of 10 m , ROW from the simulation result is 65 m and from the result of continuous variation in sinusoidal voltages in all three phases the maximum magnitude of electric field at point 6 m above the ground is 5 kV/m which is the standard limit of given by IEEE.

Case 4: Considering a 3 phase line with tower height 64.5 m, length of largest cross arm 37.5 m and phase sequence is CBA-A'B'C' (Double Circuit)

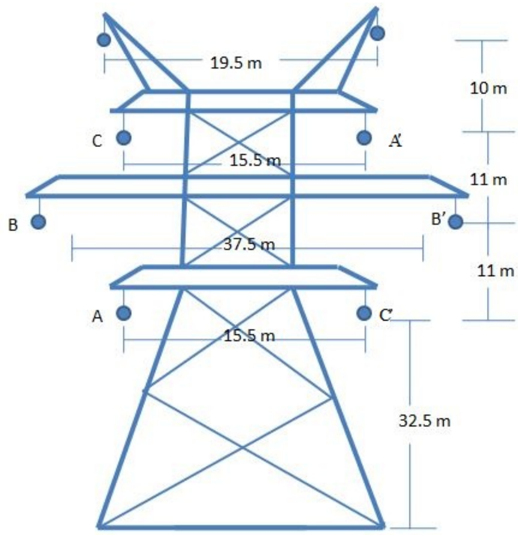

Figure 3.10: Tower design of 765 kV double circuit 3 phase line with height of 64.5 m

In this tower design the conductor are given assigned sinusoidal voltages as given in figure with phase A given 654 kV and phase B conductor is given 654 kV and phase displace of 120 degree from phase A and similarly phase C conductors are assigned voltages 120 degree apart from the phase B and A conductors and voltage 654 kV. The height of tower in this case is 64.5 m and the length of the largest cross arm is 37.5 meters.

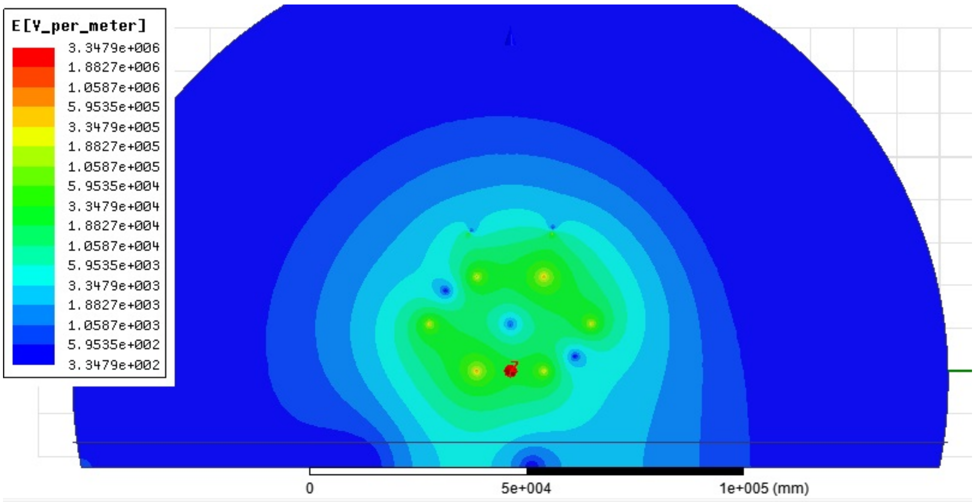

Figure 3.11: 2 D model of 765 kV double circuit 3 phase line with sag of 10m and height of 64.5 m

This 2D model of double circuit 765 kV transmission line with each phase consisting of 6 subconductors each of 10 mm radius and spacing between two consecutive subconductors is 100 mm. Here bottom conductors with horizontal distance between A and C' of 15.5 m and vertically placed 22.5 m above ground, the conductors B and B' are placed 32.5 m above the ground level and are place horizontally 18.75 m distance away from the center line of the tower and similarly conductors of phase C and A' place vertically above phase A and C' conductors and vertically 22 m above the phase A conductors.

Two overhead earth wires are placed symmetrically 19.5 m away from the center of tower and vertically 10 m above the phase C conductors. The total height of tower is 64.5 m with a sag of 10 m , ROW from the simulation result is 65 m and from the result of continuous variation in sinusoidal voltages in all three phases the maximum magnitude of electric field at point 6 m above the ground is 5 kV/m which is the standard limit of given by IEEE.

Case 5: Considering a 3 phase line with tower height 73.5 m, length of largest cross arm 31 m and phase sequence is CBA-A'C'B' (Double Circuit) In this tower

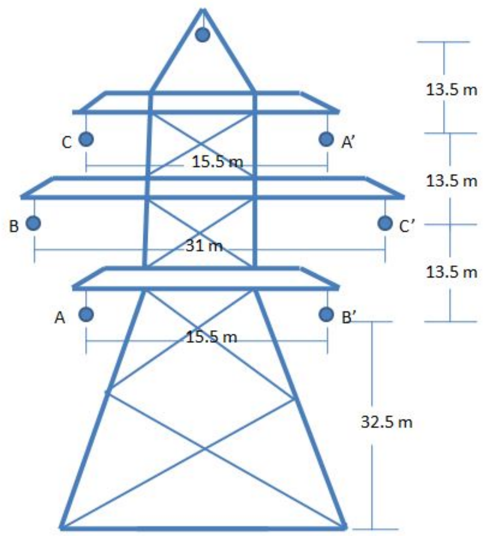

Figure 3.12: Tower design of 765 kV double circuit 3 phase line with height of 73.5 m

design the conductor are given assigned sinusoidal voltages as given in figure with phase A given 654 kV and phase B conductor is given 654 kV and phase displace of 120 degree from phase A and similarly phase C conductors are assigned voltages 120 degree apart from the phase B and A conductors and voltage 654 kV. The height of tower in this case is 73.5 m and the length of the largest cross arm is 31 m.

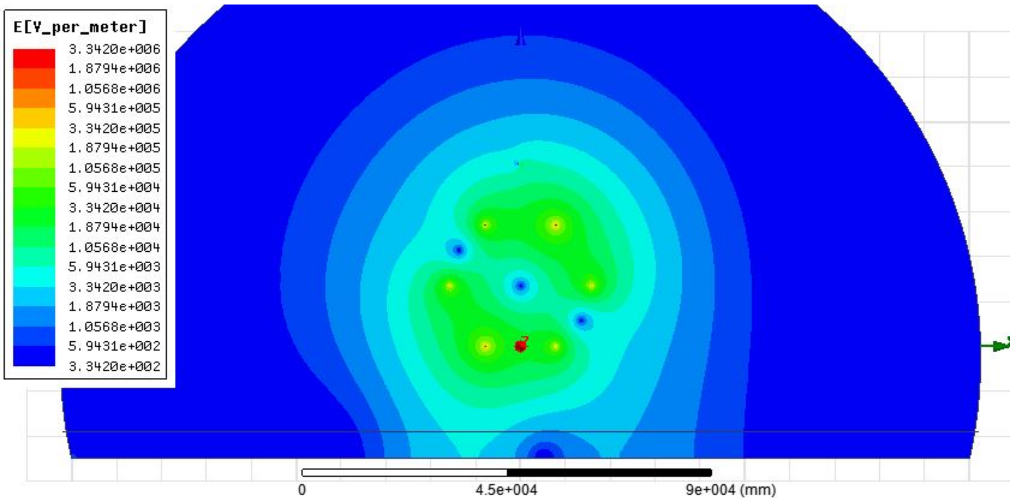

Figure 3.13: 2 D model of 765 kV double circuit 3 phase line with sag of 10 m and height of 73.5 m

This 2D model of double circuit 765 kV transmission line with each phase consisting of 6 subconductors each of 10 mm radius and spacing between two consecutive subconductors is 100 mm. Here bottom conductors are A and B$'$ with horizontal distance between them of 15.5 m and vertically placed 22.5 m above ground, the conductors B and C$'$ are placed 36 m above the ground level and are place horizontally 15.5 m distance away from the center line of the tower and similarly conductors of phase C and A$'$ place vertically above phase A and B$'$ conductors and vertically 27 m above the phase A conductors.

One overhead earth wires is placed horizontally at the center and 13.5 m above the phase C conductors. The total height of tower is 73.5 m with a sag of 10 m , ROW from the simulation result is 61 m and from the result of continuous variation in sinusoidal voltages in all three phases the maximum magnitude of electric field at point 6 m above the ground is 5 kV/m which is the standard limit of given by IEEE.

Case 6: Considering a 3 phase line with tower height 73.5 m, length of largest cross arm 31 m and phase sequence is CBA-A'B'C' (Double Circuit) In this tower

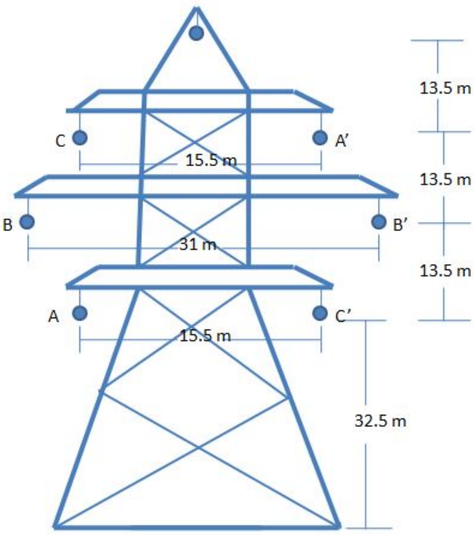

Figure 3.14: Tower design of 765 kV double circuit 3 phase line with height of 73.5 m

design the conductor are given assigned sinusoidal voltages as given in figure with phase A given 654 kV and phase B conductor is given 654 kV and phase displace of 120 degree from phase A and similarly phase C conductors are assigned voltages 120 degree apart from the phase B and A conductors and voltage 654 kV. The height of tower in this case is 73.5 m and the length of the largest cross arm is 31 m.

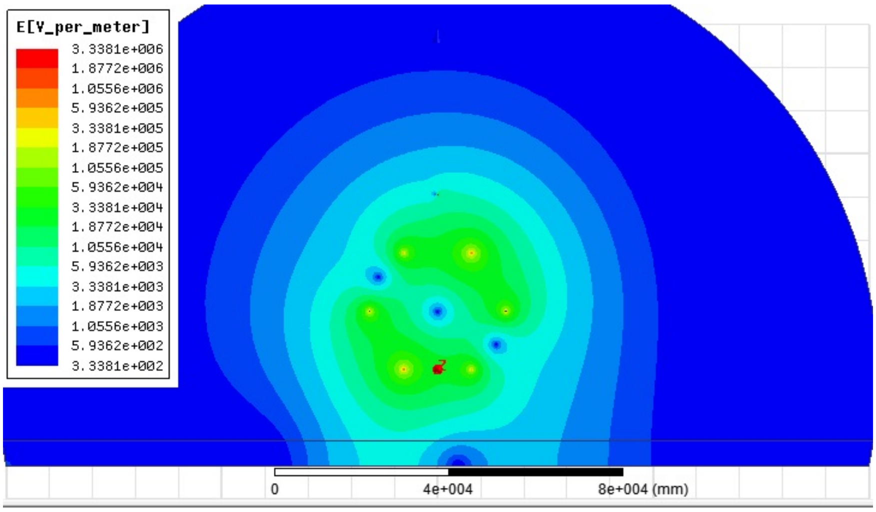

Figure 3.15: 2 D model of 765 kV double circuit 3 phase line with sag of 10 m and height of 73.5 m

This 2D model of double circuit 765 kV transmission line with each phase consisting of 6 subconductors each of 10 mm radius and spacing between two consecutive subconductors is 100 mm. Here bottom conductors are A and C$'$ with horizontal distance between them of 15.5 m and vertically placed 22.5 m above ground, the conductors B and B$'$ are placed 36 m above the ground level and are place horizontally 15.5 m distance away from the center line of the tower and similarly conductors of phase C and A$'$ place vertically above phase A and C$'$ conductors and vertically 27 m above the phase A conductors.

One overhead earth wires is placed horizontally at the center and 13.5 m above the phase C conductors. The total height of tower is 73 m with a sag of 10 m , ROW from the simulation result is 59 m and from the result of continuous variation in sinusoidal voltages in all three phases the maximum magnitude of electric field at point 6 m above the ground is 5 kV/m which is the standard limit given by IEEE.

3.3 Summary

It includes the calculation, validation and simulation result. Here, the mathematical calculation is shown and is used for validation of simulation results. Also, electric

Table 3.2: Summarising the results obtained considering above mentioned cases

case	Height(m)	Largest crossarm(m)	ROW(m)
1	41.1	31	56
2	47	22	53
3	64.5	37.5	65
4	64.5	37.5	62
5	73.5	31	61
6	73.5	31	59

field around different model of overhead transmission line is analyzed. The below table summarises the result obtained from the simulation of different model of 765 kV overhead transmission line.

Chapter 4

Conclusion and Future Work

4.1 Conclusion

The preliminary analysis is done on ANSYS/Maxwell with different condition. The simulation result is similar to calculation done by mathematical modeling, both the calculated value and the value from the simulation are just above the standard limit of 5 kV/m at a height 6 m above the ground level for 220 kV model.

For 765 kV, a standardize model and its results were not known in prior. So different models were developed, simulated and analyzed and the result of the same are presented for all models. In the first model, the length is of 30.5 m and the height is of 41.1 m from the simulation, the ROW for this model is 56 m, electric field is 5.83 kV/m at a point 6 m above the ground level. In the second model, ROW is 53 m and height is 47 m with electric field of 4.9 kV/m at height 6 m above the ground which is below the standard limit of 5 kV/m. The other four models consist of double circuit line, two models are of height 64.5 m, length of largest cross arm is 37.5, two overhead earth wire and ROW of 65 m and 62 m respectively whereas the other two models has the height of 73.5 m and length of largest cross arm is 31 m with single overhead earth wire for lighting protection. In both the models, the electric field is near the standard value of 5kV/m and ROW of 61 m and 59 m respectively as indicated in the simulation results and sag for both the models is 10 m.

4.2 Future Work

- Developing the model of three phase transmission line with more configuration.
- To analyze the result obtained by considering sub-conductors in a bundle conductors.

References

[1] E.Kuffel, W.S.Zaengl, J.Kuffel, *"High Voltage Engineering Fundamentals"*.

[2] S.Tupsie, A.Isaramongkolrak, and P.Pao-la-or, *"Analysis of Electromagnetic Field Effects Using FEM for Transmission Lines Transposition "*,World Academy of Science, Engineering and Technology 53 2009.

[3] Shizuo Li, Huajun Lu, *"Electric Field Calculation of Double Circuit Compact Overhead Transmission Line on Same 550kV Towers "*,Conference on High Voltage Engineering and Application,doi:10.1109/ICHVE.2008.4773917.

[4] Electrical power research institute, *"Transmission Line.Reference.Book.345kV"*

[5] M V Deshpande, *"Electrical power system design"*.

[6] Robert C. Degeneff, M. Harry Hesse *"Principle of power engineering analysis"*

[7] Rakosh Das Begamudre, *"Extra high voltage A.C. transmission engineering"*.

[8] R. Tukimin, W.N.L Mahadi, M.Y.M Ali, M.N.M Thari, *"Extremely Low Frequency Electromagnetic Field (ELF EMF) Survey of Residential Areas Around Transmission Lines"*,2007 Asia Pacific Conference on Applied Electromagnetic Proceedings,4 December 2007.

[9] I.O. Habiballah, T.K. Adble-Galil, M.M. Dawoud, C.A.Belhadj, M. Arif Abdul-Majeed and T.A.Al-Betairi *"ELF Electric and Magnetic Fields Exposure Assessment of Live-Line Workers for 132 kV Transmission Line of SEC"*,Transmission and Distribution Conference and Exposition: Latin America, 2006. TDC '06. IEEE/PES.

[10] IEEE Std C95.6-2002 *"IEEE Standard for Safety Levels with Respect of Human Exposure to Electromagnetic Fields, 0-3 kHz"*,IEEE Standards Coordination Committee 28 .