Electric field distribution in an EHV substation: A Case study

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***Abstract*— As International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines suggest maximum limit for safer electric field shall be less than 10 kV/m, this paper investigates exclusively electric field strength below a bay in a 765 kV substation in INDIA. Substation has been modelled using freeware FEMM 4.2 and it includes overhead lines, buses, bays, and overhead ground wires as its primary component. Bays are at height of 14 m and are at the lowest height from ground compared to other components. Detailed study of substation has given the complete data of electric field at 2 m height from ground—this being the region of interest from the point of view of ICNIRP guidelines with E-field interaction and biological effects on human beings. The simulation results indicate that for this case study, maximum field values are ranging between 8 kV/m to 13 kV/m at a height of 2 m above the ground. Some more additional parameters influencing the electric field strength are studied through simulation and will be reported during the presentation.**

I. INTRODUCTION

Post-independence scenario, India had 1362 MW of installed capacity which is now increased to ~288 GW as on 29th February 2016 [1-2]. Increase in installed capacity demands improved power infrastructure for efficient and effective bulk power transmission. As a result of this country is reviewing and reforming its power infrastructure. As of today maximum transmission level in India is 1200 kV and it successfully transmit power at various level as 765 kV, 400 kV, 220 kV etc. With increase in transmission level voltage the electromagnetic field effect has become a concern for all biological elements, be it plants, animals or humans [3-5]. Standards and guidelines were issued by many government and international organizations to deal with these electromagnetic effects. International Commission on Non-Ionizing Radiation Protection (ICNIRP) is one of major organization which was established to deal with non-ionizing radiation, and the guidelines by ICNIRP suggest that maximum electric field should not be more than 10 kV/m for occupational and 5 kV/m for public exposure (occupational exposure is considered for 8 hours or less while public exposure is for 24 hours) [6-7].

There are many approaches to calculate electric and magnetic (E & H) field strength due to high voltages (HV) and currents in substations. Some of the most commonly used methods are Charge Simulation Method (CSM), Finite Element Method (FEM) and Boundary Element Method (BEM) [9-16]. Similarly, there are many technical papers which investigate electromagnetic fields in EHV and UHV substations and in the proximity of transmission lines. They also report the E & H fields measured at the site [17-24].

The E & H fields and their effect on biological elements are of great concern in EHV and UHV substations. Hence, this paper investigates electric field (E-field) stress in an EHV (765 kV) substation in INDIA for an actual layout plan which is under construction. E-field computation is done using FEMM, a freeware, finite element method based software [25-27]. The FEMM facilitates only the 2-D analysis. Using the two 2-D analyses carried out in two different planes and superposing them, the 3-D E-field results (with certain approximations) are obtained and reported.

II. Substation Details

The analyzed substation is a 765 kV generating substation of a 3×660 MW thermal power plant in INDIA. This substation basically has three main components: lines, buses and bays. This substation has four bays, out of these three are generating bays and one is reactor bay. All the bays are charged at 765 kV and at a height of 14 m above the ground. Lines are at a height of 39 m from ground. The lines and bays run in parallel and have a span (length) of 272 m. This is the span of these lines within the substation, although they extend beyond this length. The lines run above the bays and the 2-D layout of these is as shown in figure 1. As shown in figure 1, these lines run into the plane of the paper and this direction is assumed to be along the z-axis. For the sake of computations in FEMM this layout is used. As shown in figure 1, there are overhead ground wires running in parallel with bays and lines at 45 m above the ground plane. There are two buses in this substation main bus-1 and main bus-2 which are also at 765 kV, located at a height of 27 m above the ground plane. These buses run at right angles to the bay and line conductors and have span of 293 m. Hence they are shown in other 2-D figure (figure 2). As shown in figure 2, these buses conductors run into the plane of the paper and this direction is assumed to be along the x-axis. For the sake of computations in FEMM this layout is used. The height of these buses above the ground plane is 27 m. As overhead earth wires are along the z-axis (as shown in figure 1) their representation while computing the E-fields along with bus conductors is assumed as per the representation shown in figure 2. The bay conductors are at lowest height (distance from the ground plane).

Three types of conductors are used in this substation. In lines and buses Quad Bull AAC type of conductors (20 mm diameter) are used. Equipment interconnections are from the bay conductors and they are of 4.5” (11.25 cm) diameter Al tube. The overhead earth wires are of 7/3.66 mm G.S shield wires. These dimensions are considered for representing these conductors and E-fields are computed. As per technical specification minimum clearance between two phase conductors is 7.6 m for 765 kV. In the case of present substation, the layout diagram specifies the clearance to be of 15 m between phase to phase for lines, bays and buses. The bay to bay (and also line to line) clearances are 24

m. These details showing the relative placements of all the conductors are given in figure 1 and 2.

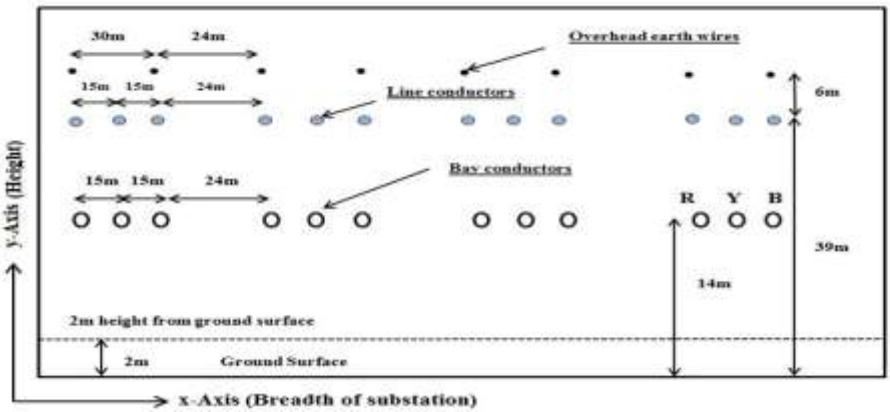

Fig.1. The 2-dimensional representation of Bay, line and overhead earth conductors used in FEMM simulation. The conductors running into the plane of the paper is assumed to be the z-axis.

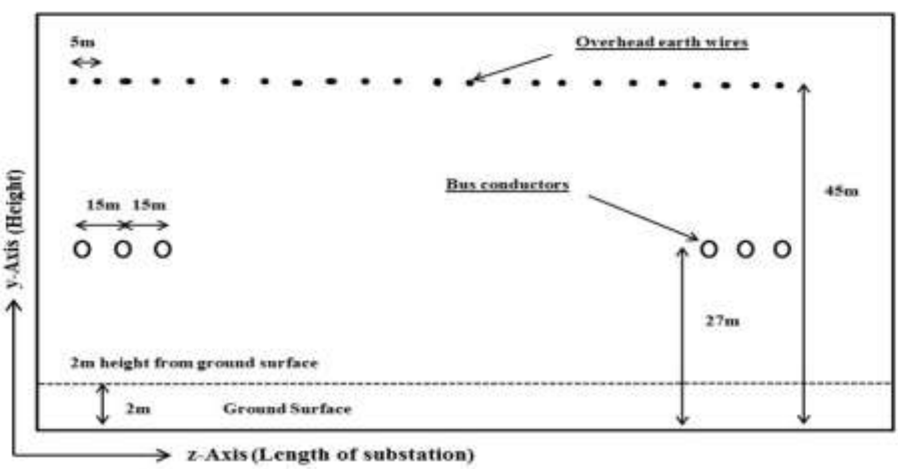

Fig.2. The 2-dimensional representation of Bus conductors used in FEMM simulation. These conductors running into the plane of the paper is assumed to be the x-axis. (earth wires are also assumed to be running in parallel to the bus conductors).

III. E-FIELD COMPUTATION

The field computation is carried out using a 2-D FEMM version 4.2 software, which is freeware. FEMM analyses the fields based on Finite Element Method (FEM). Inherently, FEMM freeware does not have the capabilities of 3-D computations. In order to compute and understand the 3-D E-field distribution in the 765 kV substation the FEMM based analysis is carried out in two different planes (namely x-y and z-y planes as depicted in figures 1 and 2) and results are superimposed. The superposition of the results has been obtained using MATLAB. The superimpositions of E-fields need vector addition. The final results given in the plots and tables in the paper are the absolute values of the E-field thus computed. Primary aim of this investigation is to know the E-field magnitudes to address the threat posed to working personal and public due to non-ionizing radiations. Hence all the field computations are performed at a height of 2 m above the ground plane (which is an approximation of human height). As the FEMM version used could analyze fields in 2-D only, the present analysis goes with following assumptions:

- All bay and bus conductors are assumed to be of infinite length, although they are of finite length. This would lead to deviations in the E-fields computed at the edges.
- All the bays are assumed as continuous, although there are many equipment connected to it.
- The jumpers and curved sections have been neglected.
- All the power equipments such as transformers are not considered for modelling.
- Computation is done in two 2-D planes, namely, x-y plane and z-y plane; the y correspond to height, z and x being length and breadth of the substation.
- As the earth wires run along the length (z-axis) of the substation, in the other plane they are included by having a large number of them at an equal interval of 5 m.

IV. RESULTS

The potential and E–field distribution in the 765 kV substation will be quasi static. At any given instant of time, the field distribution depends on the instantaneous value of the potential of all the conductors on 50 Hz cycle (power frequency). In the present study the potential of phase conductors (R, Y, B) are assigned a values as stated in equations 1 to 3. The assigned conductor potentials are such that potential of R phase conductors are at its peak of the voltage wave with phase sequence being R-B-Y.

$$V_{R\text{-}Phase} = \sqrt{2} \times \frac{765}{\sqrt{3}} \times \cos 0^0 \qquad (1)$$

$$V_{Y\text{-}Phase} = \sqrt{2} \times \frac{765}{\sqrt{3}} \times \cos 120^0 \qquad (2)$$

$$V_{B\text{-}Phase} = \sqrt{2} \times \frac{765}{\sqrt{3}} \times \cos 240^0 \qquad (3)$$

The potential and E-field distribution results for this instant on the 50 Hz cycle are computed and reported here.

A. Potential and E- field distribution along the breadth of the substation (x-y plane)

The 2-D potential distribution of the substation due to combined effect of line and bay conductors is as given in figure 3. This distribution is due to combined effect of four bays and four lines, as depicted in figure 1. In figure 3 the conductors with the maximum potential correspond to that of R-phase.

The E-field distribution along the breadth of this 765 kV substation is as given in figure 4. This x-y plane E-field distribution is because of combined effect of line and bay conductors. As seen from the results given in figure 4, even with lines and bays of the substations only considered for the analysis (leaving out the transversely disposed bays), the maximum E-field is slightly more than (10.7 kV/m) the ICNIRP limit of 10 kV/m. As expected this point of maximum stress (2 m above the ground) occurred near to the R-phase of the line-1.

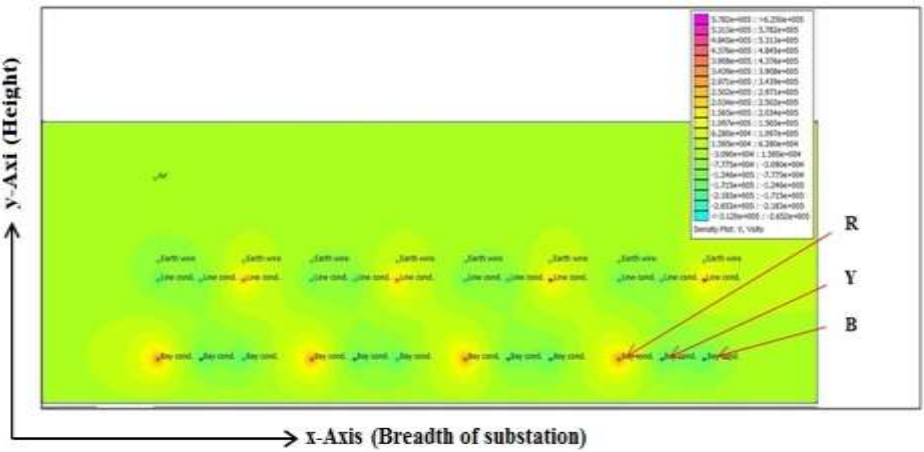

Fig.3. Density plot of potential distribution in x-y plane (breadth and height), corresponding to layout given in figure 1.

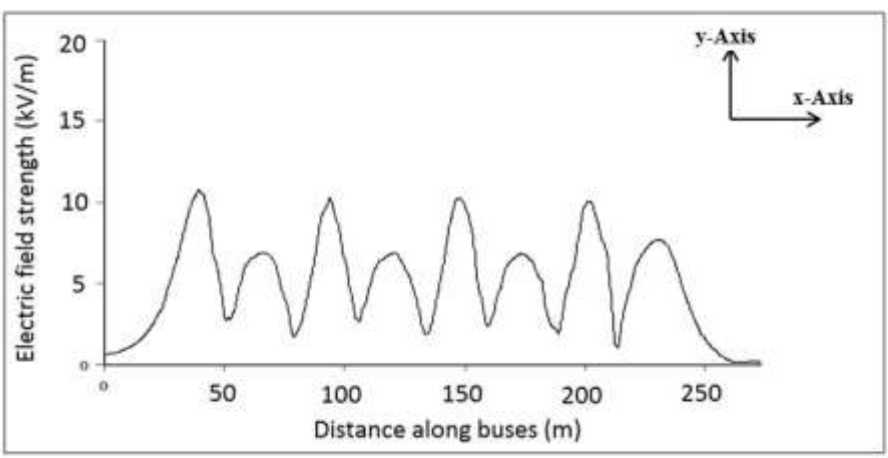

Fig.4. E-field distribution at a height of 2 m above the ground plane along the breadth of the substation due to four lines and four bays (corresponding to the layout given in figure 1).

B. E- field distribution along the length of the substation (z-y plane)

The E-field distribution at 2 m above the ground plane in the substation due to combined effect of bus conductors charged to 765 kV is as given in figure 5. This distribution is due to combined effect of 2 buses as depicted in figure 2. The E-field distribution is along the length of the substation (z-y plane) and is due to main bus-1 and main bus-2 only. These bus conductors are at a height of 27 m above the ground plane and run at right angles to the bay and line conductors shown in figure 1. The height of these bus conductors is nearly twice that of the bay conductors (14 m) from the ground plane. In this 2-D analysis the effect of HV buses only is considered, the net E-fields at 2 m above the ground plane are much lower than ICNIRP specifications (10 kV/m). The maximum E-field at 2 m above the ground plane is of order of 2.68 kV/m as seen from figure 5. This maximum strength occurs in vicinity of R-phase of the buses.

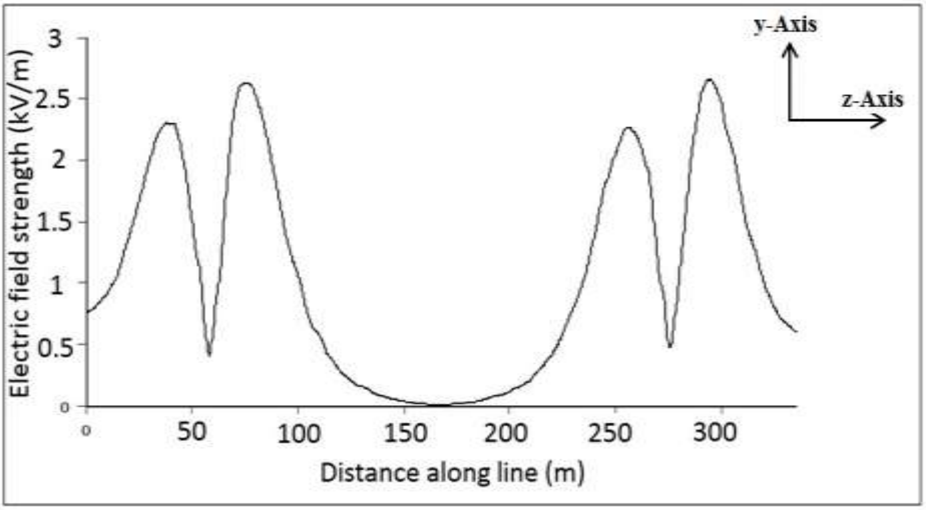

Fig.5. E-field distribution at a height of 2 m above the ground plane along the length of the substation due to main bus-1&2 (corresponding to the layout given in figure 2).

C. 3-D E-field distribution in substation at 2 m height above the ground plane (Superposition data)

Superposition adds up the vertical-component (E_y-component) of x-y and z-y E-field distribution data explained in sub sections A and B in this section. The entire area of substation (79696 m^2) is meshed in the form of 150×150 small rectangles (l= 1.97 m and b= 1.82 m) and result of superposition is obtained in the form of a 150×150 matrix at these nodes. The result of superposition giving the absolute value of the E-field is plotted in a 3-D plot and is shown in figure 6. These results are for the plane parallel to ground plane which is at 2 m above the ground plane.

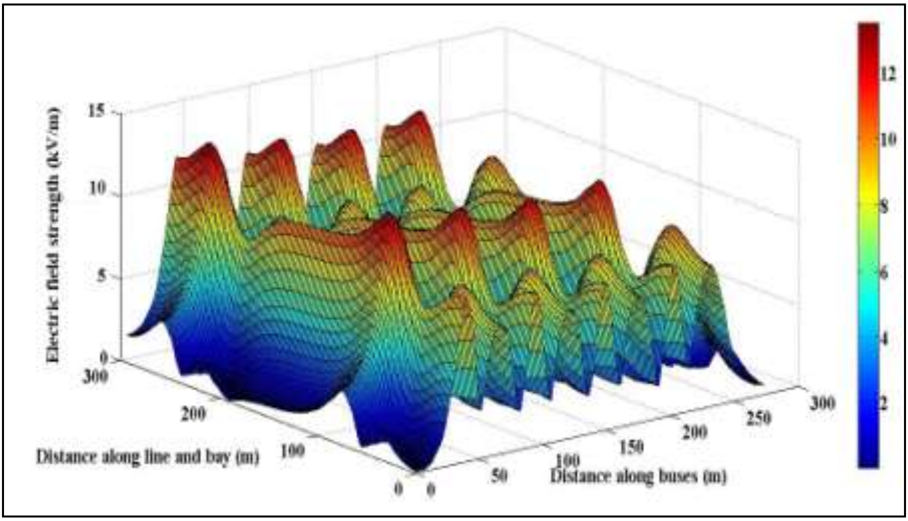

Fig.6. 3-D E-electric field distribution in 765kV substation arena at 2 m height above the ground plane.

Average E-field strength of the substation thus obtained is 5.21 kV/m, which is much lower than the occupational exposure limit specified by ICNIRP. But at certain location in the substations arena the maximum E-field value exceeds the ICNIRP limit of 10 kV/m. The field computation based analysis shows that the highest E-field strength for this EHV substation of 765 kV is 13.46 kV/m. From the 3-D plots few typical maximum E-field magnitudes exceeding 10 kV/m are tabulated and are given with their locations in Table-I. On the contrary the minimum value of the computed E-field in this substation arena at 2 m height above the ground plane is 36.46 V/m, and it occurs at x= 272 m and z= 171.36 m near B phase of line-4.

TABLE I. FEW TYPICAL MAXIMUM E-FIELD MAGNITUDE IN THE SUBSTATION ARENA AND THEIR LOCATIONS (TABULATED FROM THE DATA USED TO PLOT FIGURE 6) EXCEEDING THE ICNIRP RECOMMENDED LIMIT.

Maximum E-field values in the substation (exceeding limit of 10 kV/m)	Location of in the substation-(x,z) in m	In the vicinity of
13.46	(40.16, 273.78)	R phase of Bay 1
12.70	(96.75, 246.20)	R phase of Bay 2
12.29	(149.69,260.00)	R phase of Bay 3
12.50	(204.45, 260)	R phase of Bay 4

V. Conclusion

The quasi static E-field distribution in the 765 kV EHV substation at 2 m height above the ground plane is computed and reported using the FEMM freeware. The average value of E-field magnitude in the substation arena is 5.213 kV/m which much below the ICNIRP recommendations. The simulation results indicate that there are some areas at which computed E-field slightly exceed the maximum limit of 10 kV/m suggested in ICNIRP recommendations. The E-field prevailing in the substation arena in actuality can be got by measuring the same at few selected places. These values of E-field may further exceed those obtained and reported here by computations through simulation. This would be due to the assumptions made (e.g. conductors are regular and straight with no jumpers).

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