E-FIELDS INSIDE 765 kV SUBSTATION: INFLUENCE OF CONDUCTOR & BAY ARRANGEMENTS

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***Abstract*—Increasing voltage level in generation and transmission system have become inevitable. The threats of non-ionizing radiation and their biological effects at substations have increased. As per International Commission for Non-Ionizing Radiation and Protection (ICNIRP) guidelines suggest maximum limits for electric and magnetic field exposure is 10 kV/m and 1 mT for occupational and 5 kV/m and 250 µT for public exposure.**

Keeping this in view results of a case study of electric field distribution in an upcoming 765 kV substation in INDIA are computed and discussed in this paper. Using the existing layout of this substation, the E-fields at 2 m height above the ground plane are computed using FEMM (a free ware). Results show that Bays which are at a height of 14 m from ground are dominant and contributing more to the E-fields. The paper further computes and compares E-field strength due to (i) a single conductor (a phase of bay alone), (ii) single bay (iii) and with all the bays of substation with buses, overhead headlines and ground wires. The effect of bay height (around 14 m) on the E-field is also reported. The average E-field in substation arena is well within the ICNIPR suggested limit of 10 kV/m, whereas E-field at some places exceeds this value.

Keywords*— *Bay, Bus, E-field; FEMM, Exposure, Ground conductors, ICNIRP guidelines; Lines, 765 kV substation.

I. INTRODUCTION

Extra High Voltage (EHV) AC transmission lines were first installed in 1952 [1]. Since then, industrialized countries of all over world have adopted EHV and other higher voltage system to meet their demand. Soon the world came to know about the adverse environmental impact of these high voltage transmission systems. The effect of E-field stress on biological elements, particularly on humans became a concern for all the scientific community [2-3]. The World Health Organization (WHO) (along with several other international organizations) has particularly studied the impact of these extremely low frequency fields on human body [4]. To monitor all type of Non-Ionizing Radiation (NIR) the International Commission of Non-Ionizing Radiation and protection (ICNIRP) has issued guidelines for safe-exposure-limit for electromagnetic fields. The ICNIRP guidelines suggest that the 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) [5-6]. There are several methods like Finite Element Method (FEM), Charge Simulation Method (CSM) and Boundary Element Method (BEM) by which E and H field distribution can be studied in heavily stressed high voltage (and/or current) regions [7-14].

This paper reports the E-field study of a 765 kV substation associated with a generating plant located in INDIA. Although this substation has bays, buses, lines and overhead ground wires, the study focuses on bay(s) and its height; bays are at 14 m and are nearest to the ground plane. The E-fields computed at 2 m height above the ground plane are reported and discussed in the view of ICNIRP guidelines. The computational tool FEMM (a freeware) [15-17] is used. Although, not included in this paper, the actual E- field data is being measured at some places in the site using ELF meter HI3604 will also be part of oral presentation. In this report a detailed 3-D study of E-fields of a 765 kV switch yard is attempted using a 2-D computational tool (freeware). This includes E-field stress due to various components such as Bay, Bus and line with their cumulative E-field effect in the switch yard. Further, simulation studies are made to explain the effect of various physical parameters such as conductor height and number of conductors on the E-fields in a substation by systematically varying them near-around the actual dimensions opted in the 765 kV substation under study. All this is directed towards the reduction of the E-field levels, keeping in view the ICNIRP guidelines.

II. SUBSTATION DISCRIPTION

The substation is of 765 kV belonging to a thermal power plant in INDIA of a 3×660 MW. The substation mainly has three energized components: lines, buses and bays. It has four bays, all the bays are at a height of 14 m above the ground and are charged at 765 kV. There are four lines at a height of 39 m. The bays and lines span (length) over a length of 293 m. They run in parallel, lines being above the bay. The 272 m (width of the substation) is the span of the buses within the substation. The substation 2-D layout showing its breadth is given in figure 1. In this figure these lines and bays run into the plane of the paper. This is the z-direction, as per the convention adopted. The overhead ground wires run in parallel with bays and lines at 45 m above the ground plane (see figure 1). In 2D computation using FEMM this layout is used neglecting two buses. Substation has two main buses (main bus-1 and main bus-2) charged to 765 kV. The buses are at a height of 27 m. The buses are also showing in figure 1. Buses run along the length of the substation (at right angles to the bay and line conductors) and have span of 293 m. The length of substation by convention is assumed to be along the x-axis. The bay conductors are at lowest height (distance from the ground plane) and have large influece on the E-field prevailing in the area at 2 m.

The Quad Bull AAC type of conductors of 20 mm diameter are used for lines and buses. The bay conductors are of 4.5” (11.25 cm) diameter alluminimum tube Al tube. The 7/3.66 mm G.S shield wires form the overhead earth wires. E-fields are computed are computed using these dimensions for conductors. The clearance between two phase conductors is 15 m between phases for lines, buses and bays. The line to line (and also bay to bay) clearances are 24 m. Figure 1 shows some of these details.

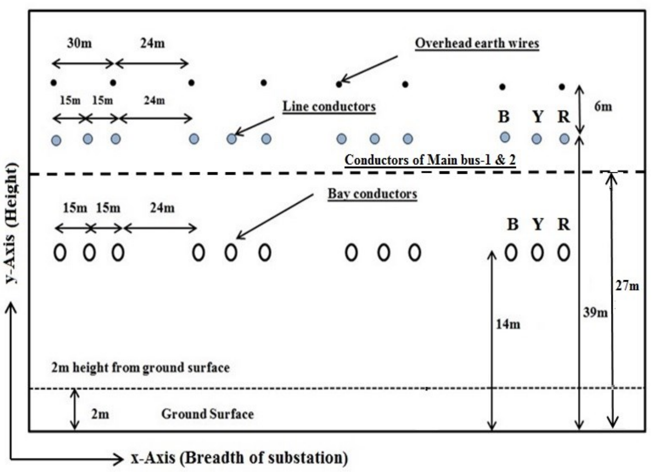


Fig.1 The view of the substation with bay, line and overhead ground conductors running into the plane of the paper (z-axis). The main bus 1 and 2 run parallel to the x-axis. Y-direction represents the height above the ground plane.

III. COMPUTATION OF E-FIELDS & ANALYSIS

The complete substation is modeled as per substation layout. The 3D E-field strength is computed over the 79696 m^2 arena of the substation using a 2D computational tool FEMM 4.2. The 3 D results are obtained by superposing the results obtained in orthogonal vertical planes (x-y and z-y planes). The E-field analysis of x-y plane includes bays, lines and earth wires (refer fig.1). The E-field analysis of z-y plane includes buses (the dotted lines of fig.1) and overhead ground wires. Plane x-y represents breadth-height of substation and plane z-y represents length-height of substation. One should note that the E field computation is done at a height of 2 m from ground surface (considering approximate height nearing that of humans).

There are certain assumptions made for the 3D field computation such as-

- The 2D modelling is done assuming all the conductors to be of as infinite length.
- The bays are assumed as continuous section.
- All the curved sections such as jumpers, clamps, mechanical sag of lines were ignored.
- All the power equipment’s such as transformer are not considered in E-field computation.

The E-field computations given in this paper are instantaneous value of potential corresponding to R-phase conductor voltage being at its peak (625 kV). The phase sequence is assumed to R B Y and corresponding instantaneous voltages are assigned to other phases.

IV. RESULTS AND DISCUSSION

A. E-field distribution of the substation

The typical density plot of voltage distribution due to lines and bays is given in figure 2

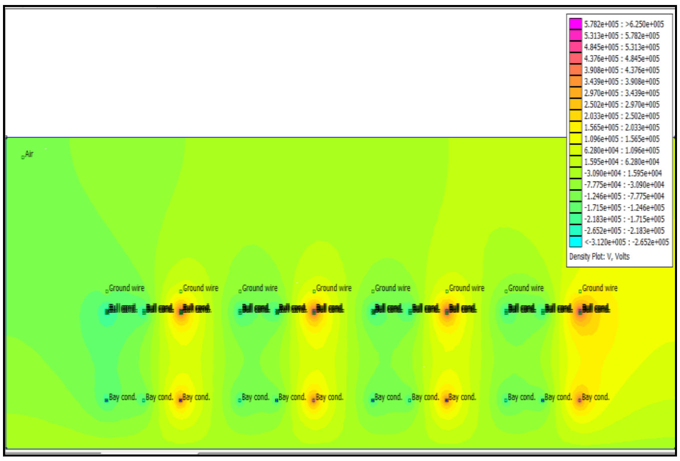
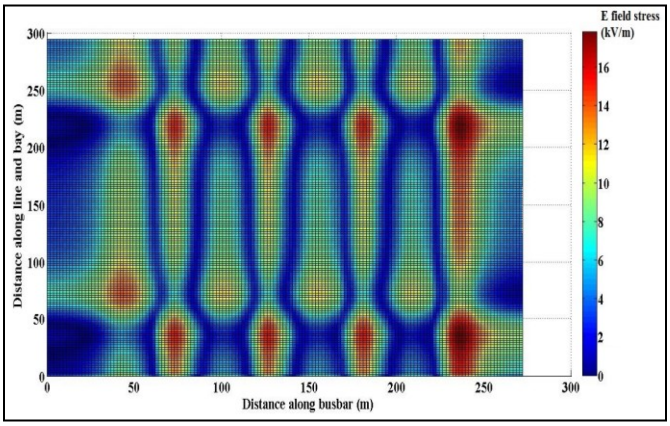


Fig.2 Density plot of voltage distribution due to lines, bays and overhead earth wires (breadth-height plane).

The superposed E-field results of breadth-height plane with those of length-height planes are used to draw the E-field density plot of the substation (shown in figure 3). Superposition is done at 150×150 points (length x breadth) in substation arena. From the 3-D distribution and E-field density plot it can be concluded that average E-field strength of the substation is 6.5 kV/m which is within occupational exposure limit specified by ICNIRP. The Maximum E field value in entire substation is 17.8 kV/m, measured at point x= 237.31 m (along breadth of the substation) and y= 37.42 m (along length of substation) at intersection point of near line-1 and main bus-1.



(b)

Fig.3 E-field density distribution in the 765 kV substation at 2 m height.

B. *Effect of changes in bay height, conductor & bay number on E-field distribution*

The bays in 765 kV substation being 14 m, nearest to the ground, their contribution to E-field is highest. Hence two set of numerical experiments were carried out: (i) to compare the E-field due to single conductors, single bay with the substation layout with all the bays (ii) To vary the height of the bay conductors around 14 m (the bay height used in the substation under study).

The comparison E-field at 2 m above the ground plane due to single bay conductor with a bay (all 3-phases included; 3 conductors) is given in the table I. It is to be noted that even with single conductor or single bay the maximum field observed at 2 m height above the ground plane exceeds 10 kV/m when they are at a height of 14 m. As the bay or conductor height is increased the maximum E-field will come down.

TABLE I. ELECTRIC FIELD DISTRIBUTION OF A SINGLE CONDUCTOR (R PHASE) AND SINGLE BAY (ALL THE THREE PHASES) AT DIFFERENT BAY LEVELS

Bay height(m)	Maximum E field at 2m height(kV/m)	
	For single conductor (R phase)	For single bay (all phases)
11.0	19.9	16.2
12.0	17.9	14.2
13.0	16.5	13.1
14.0	14.8	11.5
15.0	13.6	10.1
16.0	12.8	9.10
17.0	11.9	8.57

In actual substation there are four bays at 765 kV. The influence on E-field due to variation of height of these bays around 14 m (i) lines, buses and overhead earth wires of the substation not included (ii) lines and earth wires are included but buses not included, is computed and compared in figure 4. The bays and lines run in parallel being at a height of 14 m and 39 m above the ground plane, respectively. They are such that the R-phase of a bay is just below the R-phase of corresponding line. If this bay and line sequence is altered, then the E-field get altered. With such an altered line arrangement of line conductors with reference to bay conductors is used for computing the E-field the results are given figure 4 comparison. This arrangement with (interchanged bay and line phases) shows the lowest E-field compared to all other arrangements studied.

Figure 5 gives the maximum E-field observed at 2 m height above the ground plane for differing conductor and bay arrangements. These results are with 14 m conductor and bay and height. Comparing (a) with (b) it is observed that added two more conductors (with different potentials) brings down maximum E-field. Comparing (b) and (c), it can be inferred that the E-field magnitudes increase when bay numbers are increased. The bars (c), (d) and (e) can be compared to see the influence of adding number of additional high voltage components like lines and buses. Comparing (e) and (f) gives the possibility of reducing the E-field by changing the bay phase sequences with respect to those of lines.

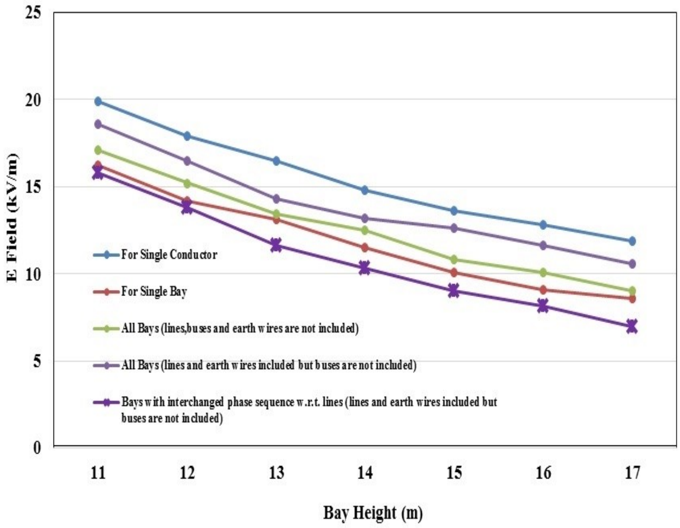


Fig.4 E-field distributions at 2 m height due to various bay conductors at different bay height.

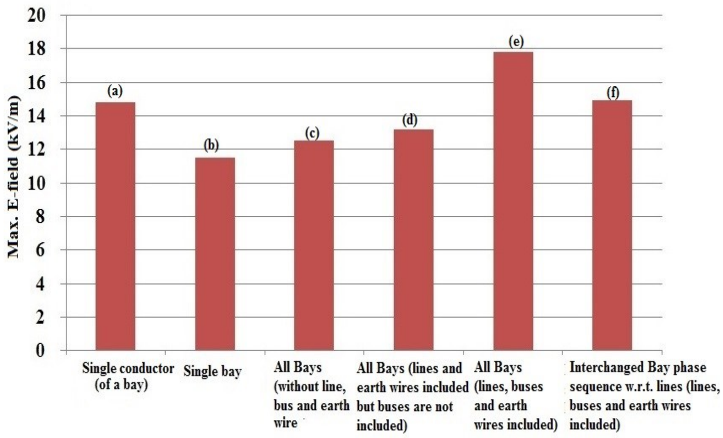


Fig.5 Maximum E-field observed for differing conductor and bay arrangements.

V. CONCLUSION

From the analyzed 765 kV generating substation the following conclusion can be drawn:

1. The normal and tangential components of each plane can be added to obtain the three dimensional E field of the substaion. The maximum field value obtained from this substaion is 17.8 kV/m near R phase of bay-1 which exceeds the ICNIRP guidelines. The average E field of substation is 6.507 kV/m which is within occupational exposure limits. Thus it can be concluded that the analysed substation is safe for working personals.

2. This paper presents an analysis on Effect of changes in bay height and change in bay conductor on E-field distribution of the substation. The maximumum E-field obtained in each case is plotted and shown in line chart (figure-4). A corrective experiment with altered bay phase sequence with respect to lines is done to bring down the E-field stress in entire substation region.

3. Bar plot is given for all these bay conductors at actual bay height (14 m) to observe the shift in maximum E field. E-field is gradually increasing with increse in bay and line conductors. Bar (e) and (f) gives the possibility of reducing the E-field by changing the bay phase sequences with respect to lines.

4. Maximum E field strength has been reduced to 14.925 kV/m as compared to actual figure of 17.8 kV/m. The phase reversal results 16.15% decrement in maximum E field stress. So this can be a viable solution and needs further study.

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REFERENCES

[1] Rakosh Das Begamudre, “Extra High Voltage AC Transmission Engineering,” by New age international pvt. Ltd, New Delhi INDIA, 1-40, Oct.-1997.

[2] M. A. Stuchly and T. W. Dawson, “Interaction of low-frequency electric and magnetic fields with the human body,” *Proc. IEEE*, vol. 88, no. 5, pp. 643–664, May 2000.pp. 650-658.

[3] A. Ahlbom, E. Cardis, A. Green, M. Linet, D. Savitz, and A. Swerdlow, “Review of the Epidemiologic Literature on EMF and Health,” *Environ. Health Perspect.*, vol. 109, p. 911, Dec. 2001,pp. 916-929.

[4] International Labour organisation, International Commission on Non-Ionizing Radiation Protection and World Health organisation, Eds., *Extremely low frequency fields*. Geneva: World Health Organization, 2007,pp. 2-11.

[5] “Directive 2004/40/EC of the European Parliament and of the Council of 29 Apr. 2004 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields),” 18th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC.

[6] International Commission on Non-ionizing radiation Protection, “Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 Ghz)” , Health Physics, vol.74, pp. 494-522, April 1998.

[7] B. Y. Lee, J. K. Park, S. H. Myung, S. W. Min, and E. S. Kim, “An effective modelling method to analyze the electric field around transmission lines and substations using a generalized finite line charge,” *IEEE Trans. Power Deliv.*, vol. 12, no. 3, pp. 1143–1150, Jul. 1997., pp.- 1144-1146.

[8] W. Krajewski, “Numerical modelling of the electric field in HV substations,” *IEE Proc. - Sci. Meas. Technol.*, vol. 151, no. 4, pp. 267–272, Jul. 2004, pp. 267-269.

[9] A. Z. El Dein, “Calculation of the Electric Field Around the Tower of the Overhead Transmission Lines,” *IEEE Trans. Power Deliv.*, vol. 29, no. 2, pp. 899–907, Apr. 2014, pp. 899-903.

[10] A. Yializis, E. Kuffel, and P. H. Alexander, “An Optimized Charge Simulation Method for the Calculation of High Voltage Fields,” *IEEE Trans. Power Appar. Syst.*, vol. PAS-97, no. 6, pp. 2434–2440, Nov. 1978.

[11] C. P. Nicolaou, A. P. Papadakis, P. A. Razis, G. A. Kyriacou, and J. N. Sahalos, “Simplistic numerical methodology for magnetic field prediction in open air type substations,” *Electr. Power Syst. Res.*, vol. 81, no. 12, pp. 2120–2126, Dec. 2011.

[12] K. Sakai, K. Kato, H. Okubo, and A. Matusmoto, “ELF magnetic field measurement and calculation in 500 kV gas insulated substation,” 2002, vol. 2, pp. 1220–1225.

[13] H. Das, K. Gogoi, and S. Chatterjee, “Analysis of the effect of electric field due to High Voltage Transmission lines on humans,” 2015, pp. 1–4.

[14] N. Li, X. Yang, and Z. Peng, “Measurement of Electric Fields Around a 1000-kV UHV Substation,” *IEEE Trans. Power Deliv.*, vol. 28, no. 4, pp. 2356–2362, Oct. 2013.

[15] Meeker D (2010) Finite element method electrostatics user’s manual, Version 4.2, 25 jan, 2006.

[16] G. S. Punekar, D. Harimurugan, and G. H. Tantry, “Finite Element Method Magnetics Based Demonstration of Rotating Field in 4-Pole Induction Motor,” in *Recent Advancements in System Modelling Applications*, vol. 188, R. Malathi and J. Krishnan, Eds. India: Springer India, 2013, pp. 301–310.

[17] G. S. Punekar, T. Nafo, and N. K. Kishore, “On Electric Fields in Belted Cables and 3-Phase Gas Insulated Cables,” in International conference on power and energy systems, Dec 2011, pp. 1–4.

[18] I.S. Jha, Oommen Chandy, R.K. Sarkar and A.B. Singh, “Design Challenges in the 765 kV Air Insulated Substation,” CIGRE Proceedings, 2012, Paris.