Electric field and exposure time in a EHV substation near a bay-equipment: concerning ICNIRP guidelines

D Harimurugan,
NITK, Surathkal,
INDIA-575025
harimur@gmail.com

G S Punekar,
NITK, Surathkal,
INDIA-575025
gsp652000@yahoo.com

N K Kishore,
IIT Kharagpur,
INDIA-721032
kishor@ee.iitkgp.ernet.in

***Abstract*—The occupational exposure to electric field (E-field) is one of the major concern in high voltage environment present in EHV substations. In the vicinity of the bay equipment of an EHV substation, there are enhanced E-fields, where the occupational exposure limit of 10 kV/m as specified in the ICNIRP guidelinesmay be exceeded. If this guideline is to be strictly adhered, then it will result in a highly conservative design, when the entire substation area and occupational exposure time (8 h) is considered. With respect to the enhanced E-field in the vicinity of bay equipment, a reduced exposure time limit can be thought off. This suggestion would be such that the product of exposure time and E-field intensity (in h-kV/m) does not exceed the prescribed value (80 h-kV/m). In view of this, a relook at the E-fields near a bay equipment of a 765 kV substation is attempted through simulation. A single-bay with a single-bay-equipment is modeled using CSM. The bay-conductors (R, Y, and B phases) are modelled using finite line charges and the bay-equipment is modeled using ring charges (multi-dielectric CSM). The E-field computed at 2 m above the ground plane in the vicinity of the bay equipment is reported. The variation in the E-field distribution with and without the bay-equipment is compared. An analysis related to product of exposure time and E-field intensity (in h-kV/m) is made (perhaps for the first time) which may help refine ICNIRP guidelines. The effect of variation in the height of bay conductors and support structure on the E-field distribution is also analyzed.**

I. INTRODUCTION

With the ever-increasing power demand, the power transmission utilities are increasing the transmission voltage levels for efficient bulk power transmission. With the increase in voltage levels, the effect of non-ionizing radiation(NIR) is one of the major concerns. Over the last five decades, individual’s exposure to the NIR has increased significantly due to the usage of technological applications that utilize NIR, such as electrical appliances like microwave oven, televisions, and communication devices. Numerical techniques are generally used for computing electric field (E-field) distributions. Some of the commonly used numerical techniques are finite element method (FEM) [1], charge simulation method (CSM) [2], boundary element method (BEM) [3] and combination of BEM and CSM [4], BEM and Galerkin method [5]. CSM is a commonly preferred method for E-field computations in high voltage open boundary problems as it doesnot involve the discretization of the solution region [6,7].

CSM was used to calculate the E-field in a 400 kV substation (with two buses and transmission lines). The ring charges and linear charges were used to model the various components of the substation. The simulation results were compared with the measured E-field values [8]. The more accurate case-specific CSM model of a substation using finite line charge was developed [9]. It is used in modelling of a 500 kV substation, which consists of a single bus with incoming and outgoing feeders. The feeders may not always be a straight line; in such cases, finite slant line charges have also been used [10]. A computer program was developed using CSM along with BEM to calculate the E-field in a 400 kV substation consisting of three busbars and a bay arrangement [4].

For the reduction of E-field in transmission line system, shield wires are normally used [11-13]. Shielding net [14] and personnel protective equipment [15] have also been used for the reduction of E-field magnitude in transmission line system in view of public exposure. With the increase in the transmission voltage levels, occupational exposure in the extra high voltage (EHV) substation has become one of the major concern. In view of occupational exposure, International Commission on Non-Ionizing Radiation and Protection (ICNIRP) prescribes the reference value of 10 kV/m for E-field intensity (unperturbed rms value). An EHV substation may have bus, bay and flexible bus conductors at different heights. Along with these conductors, there are bay equipment and associated support structures which enhances the E-field intensity. Hence, in the vicinity of the bay equipment, the E-fields may exceed the occupational exposure limit of 10 kV/m as specified in the ICNIRP guidelines[16]. If this guideline is to be strictly adhered, then it will result in a highly conservative design, when the entire substation area and occupational exposure time (8 h) is considered. Hence the product of exposure time and E-field intensity (in h-kV/m) is also being thought of as an alternative guideline [17].

In this paper, the E-fields in the vicinity of a bay equipment in a 765 kV substation is analysed through simulation. A single-bay with a single-bay-equipmentis modeled using CSM. The dimensions of the bay-equipment and bay-conductor are taken from an actual layout of the 765 kV substation in India. The variation in the E-field distribution with and without the bay-equipment is compared. The E-fielddistribution at 2 m above the ground plane in the vicinity of the bay equipment is reported. In the proximity of the bay equipment, e-field may go beyond the reference value set by ICNIRP.In such regions, a reduced exposure time (in h) is calculated (and suggested) such that the product of exposure time and E-field intensity (in h-kV/m) does not exceed the prescribed value (80 h-kV/m). Using this criterion, the contour plot of the exposure time is obtained and reported. This will help in adhering the ICNIRP limit in the enhanced E-field regions near the bay-equipment.

II. BAY DETAILS AND MODELLING

A single bay with a single bay-equipment (current transformer) is modelled using CSM.The CSM based model is developed with bay-equipment modeled as a solid insulator along with its support structure. The dimensions of the bay-equipment and clearances between phase conductors of the bay are taken from the actual layout of a 765 kV substation in India [2]. The dimensions of the bay-equipment and bayclearances are shown in Fig.1.

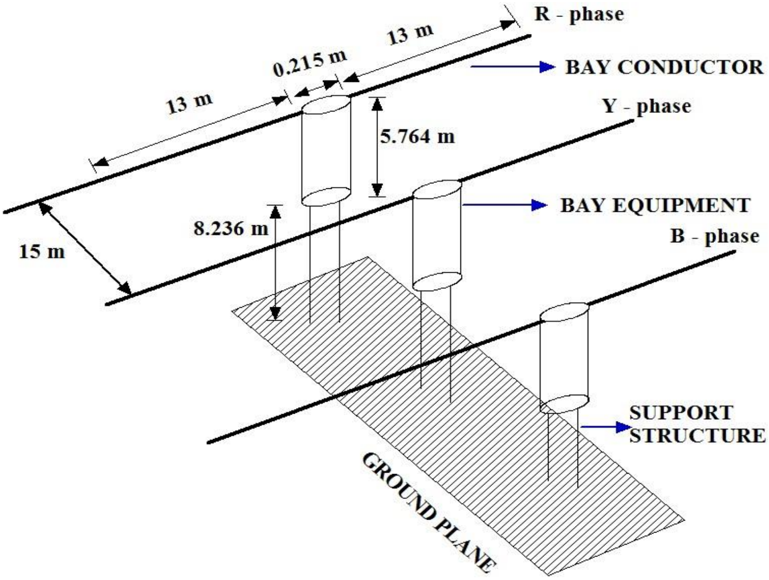


Fig. 1. Schematic showing the dimensions and clearances of a bay equipment modelled in CSM

In CSM based model, bay conductors are modelled using the finite line charges. The support structure of the bay equipment and the solid insulating structure are modelled using ring charges. The number of simulating charges used in different components of the CSM based model are given in the Table 1.

TABLE 1: NUMBER OF SIMULATING CHARGES USED IN THE CSM BASED MODEL

S. No	Equipment / Component	Type of simulating charge	Number of simulating charges
1	Single bay conductor	Finite line charge	153
2	Solid insulating structure in a bay equipment	Ring charges	14
3	Support structure of a bay equipment	Ring charges	7

The total number of simulating charges used in modelling of a single-phase conductor along with bay equipment and its support structure is 174. In the present study, all three phases of a bay conductor along with the bay equipment are simulated. Hence, the total number of simulating charges used are 522 charges (3 x 174). The number of contour points and simulating charges are considered equal in the present work. The complex fictitious charges are used which help in obtaining the maximum value of the time varying E-field. Image charges are used to simulate the effect of ground plane.

The system of equations is formulated by imposing following boundary conditions: (i) At the surface of the bay conductor, the potential must be equal to conductor potential, (ii) At the dielectric boundary in the insulation structure of the bay equipment, the potential and the normal component of the flux density must be same when viewed from either side of the boundary, (iii) At the surface of the support structures of the bay equipment, the potential is equal to the ground potential. The unknown magnitude of simulating charges is solved from the set of linear equations obtained. Once the simulating charge magnitudes are obtained, the e-field [E] at 2 m height form the ground level is computed using (2).[7]

$$[E]=[F][Q] \qquad (2)$$

Where, [F] is the field coefficient matrix and [Q] is the vector of simulating charge magnitudes.

III. ICNIRP GUIDELINES OF INTEREST

ICNIRP was established to provide scientific advice on possible health effects of NIR [16]. Various international organizations reviewed the scientific literature on the effects of NIR [17-19]. IEEE and IEC standards related to EMF exposure can be found in the literature [20-22]. ICNIRP provides the protection guidelines against NIR in applications like Magnetic Resonance Imaging (MRI), power lines, mobile phones and base stations, wi-fi, and digital enhanced cordless telecommunications. In case of substations, at power frequency of 50 Hz, ICNIRP prescribes the reference value of E-field intensity (unperturbed rms value) as 5 kV/m for public exposure and 10 kV/m for occupational exposure. These values correspond to the exposure time of 8 h.

In the present work, the E-field analysis is carried out in the vicinity of bay equipment at a height of 2 m form the ground level. Because of the equipment insulation and support structures, the magnitude of E-fieldis expected to be more intense, and it may go beyond the prescribed value of 10 kV/m for occupational exposure. With respect to this, a reduced exposure time limit can be thought offin the high E-field regions. This suggestion would be such that the product of exposure time and E-field intensity (in h-V/m) does not exceed the ICNIRP prescribed value (80 h-kV/m).

IV. RESULTS AND DISCUSSION

With the CSM model developed, the E-field analysis is carried out at 2 m height from the ground plane in the vicinity of bay equipment. The E-fieldcomputations are carried out over the bay area at the node of square grids of 0.5 m^2. The contour plot of the E-field distribution obtained from CSM based model (at a height of 2 m from the ground level) is shown in Fig. 2. It is seen that, in the vicinity of structure of the bay equipment, theE-field intensity is higher (shown in red color in Fig.2). The patches of enhanced E-field in the proximity of R-phase and B-phase is higher compared to Y-phase. The reduction in the area of higher E-field intensity in the vicinity of Y-phase is attributed to the cancellation effect in the system.

To estimate the contribution of bay equipment and support structure to E-field, a CSM model has been developed without bay equipment and support structures (considering only with bay conductors). The results of E-field distribution obtained over the bay area without considering the effect of bay equipment and its support structure are shown in Fig. 3. The maximum value of rms E-field magnitude at 1 m left of R-phase is 8.230 kV/m (including contribution of bay equipment and its support structure). The corresponding maximum value of rms E-field magnitude without considering the contribution of bay equipment and its support structure is 6.840 kV/m. The percentage change in E-field (with and without bay equipment) at different radial distances form the center of the R-phase is shown in Table 2.

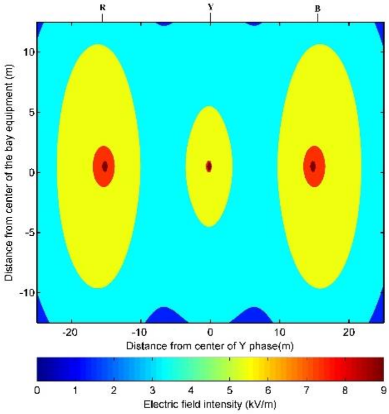


Fig. 2.E-fielddistribution obtained from the CSM based model involving bay equipment and support structure (bay conductor height =14 m)

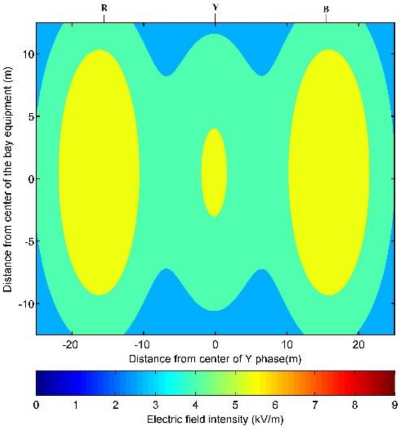


Fig. 3. E-fielddistribution obtained from the CSM based model without involving bay equipment and support structure (bay conductor height =14 m)

TABLE 2: PERCENTAGE DEVIATION IN MAXIMUM RMS E-FIELD (WITH AND WITHOUT CONSIDERING THE EFFECT OF BAY EQUIPMENT)

Breadth wise distance (left of R-phase of the bay conductor)	Maximum value of rms E-field (kV/m)		Percentage deviation in maximum E-field
	With bay equipment and support structure	Without bay equipment and support structure	
0.5	8.725	6.831	27.23
1	8.230	6.840	20.32
2	7.444	6.779	9.810
3	6.989	6.617	5.622

For the existing clearances (bay height of 14 m), the e-field values are lower than reference value of 10 kV/m. However, in actual layout with additional conductors and equipment (additional bays, buses, transmission lines, etc.) total e-field intensity will be higher. To reduce the E-field magnitude, the ground clearance of the bay conductor can be increased. The effect of changing the bay conductor clearance on the E-field distribution at a height of 2 m from the ground plane is analyzed. This analysis is carried out in a CSM model involving bay equipment and its corresponding structures. With the increase in the bay height, the height of support structure is also increased such that the height of insulating structure remains same. The maximum value of rms E-field computed at different bay heights are given in Table 3. It is seen that the increase in bay height results in decrease in E-field. However, it will result in a highly conservative design, when the entire substation area and 8 h occupational exposure time is considered.

TABLE 3: VARIATION IN MAXIMUM RMS E-FIELDWITH CHANGE IN BAY CONDUCTOR HEIGHT

Bay height	Maximum value of rms E-field (kV/m) at 0.5 m left of R-phase
18	6.083
16	6.644
14	8.725
12	15.80
10	25.62

In such cases, a reduced exposure time limit in the vicinity of bay equipment can be thought off. This suggestion would be such that the product of exposure time and E-field intensity (in h-V/m) does not exceed the prescribed value (80 h-kV/m) [17]. In view of this, E-field distribution near the bay equipment is computed (bay height of 10 m) and the E-field distribution is shown in Fig.4. With the reduction in bay height, the area in which

E-field goes above the prescribed limit of 10 kV/m is increased considerably. In these high E-field regions, the allowable exposure time limit (in h) is calculated to adhere to the ICNIRP guidelines assuming a linear relation. The contour plot of exposure time over the bay area is shown in Fig. 5. Hence, by using this time-contour plot, one can adhere to the ICNIRP guidelines in regions of high E-fields.

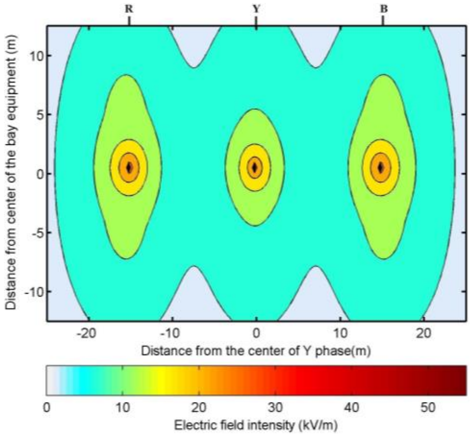
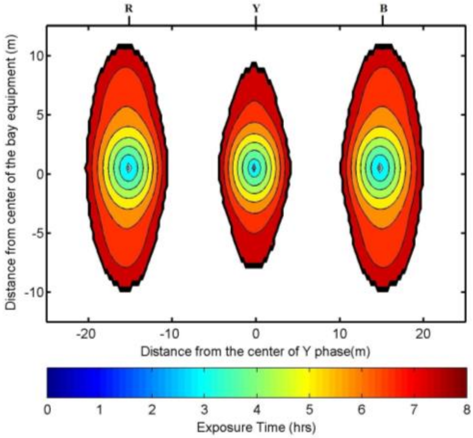


Fig.4. E-field distribution obtained from the CSM based model involving bay equipment and support structure (bay conductor height =10 m)



V. CONCLUSIONS

The contribution of bay equipment and support structures to the E-field distribution is analyzed by modelling a single bay whose dimensions are taken from the actual layout of a 765 kV substation in central India. The maximum value of rms E-field at 1 m left of R-phase (breadth wise) with and without considering bay equipment is estimated as 8.230 kV/m and 6.840 kV/m, respectively. In both the cases, for the considered single bay arrangement, the E-fields are well below the ICNIRP reference value of 10 kV/m. However, in the actual case, there are additional conductors and bay equipment which contribute to the E-field. Hence, in the proximity of the bay equipment, the E-field magnitude may go beyond the ICNIRP prescribed value of 10 kV/m for occupational exposure. This E-field can be reduced by increasing the bay height, however, it results in a highly conservative design. In such cases, reduced exposure time is obtained such that product of exposure time and E-field intensity (in h-V/m) does not exceed the ICNIRP prescribed value (80 h-kV/m). This criterion is used to obtain the contour plot of exposure time and it is reported, perhaps for the first time. This helps in adhering to the ICNIRP guidelines in the regions of high E-field.

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