Arrangement of conductors in 220 kV double circuit line to reduce E-fields in view of public exposure

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***Abstract*—With the increase in transmission line voltage level, the exposure to non-ionizing radiations has increased significantly. This has become one of the major concerns in high voltage transmission systems. International commission on non-ionizing radiation protection (ICNIRP) prescribes the reference value of electric field (E-field) intensity as 5 kV/m for public exposure. Generally, shield wires are used for the reduction of E-field in transmission systems which leads to additional construction cost. Alternatively, one can use the E-field cancellation effect in the transmission lines with more than one circuit. This would reduce the E-field magnitudes to a certain extent. In the present work, the effect of transposition of transmission line conductors in a double circuit 220 kV transmission line on E-field exposure is analyzed. Charge simulation method (CSM) using complex charges is used to simulate a double circuit line (with infinite conductor assumption) and to compute the E-fields. The E-field is computed (at 2 m above the ground level) for all combinations of transposed transmission line conductor arrangements and analyzed. The quantitative E-field results with different transposed system of conductor arrangements is reported. The conductor arrangement which results in minimum value for maximum rms E-field is identified. Cancellation effect could bring about a decrease of E-field greater than 50 %. The obtained results are compared with the ICNIRP guidelines and the E-field intensity are found to be within the allowable limit.**

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 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 does not involve the discretization of the solution region [6, 7].

For the reduction of E-fields due to transmission lines at ground level, the shielding wires are generally used. Their use on bipolar HVDC line with optimal arrangement for reduced E-field is obtained through time domain method[8]; The effect of using active and passive shield wires in a double circuit 500 kV transmission line on the spatial distribution of E-field is analyzed using CSM [9]. A shielding net under the 400 kV transmission lines and personal protective equipment [10] have also been used in mitigation of the E-fields.The E-field due to 500 kV transmission line on a nearby building is minimized by using the metal shielding eave on the edge of building roof [11]. The E-field analysis is carried out in the vicinity of power lines with two different species of trees beneath it and it is shown that the presence of trees results in reduction of E-field at ground level [12].The usage of shield wires and other protective equipment helps in reduction of E-field values; however, it also results into additional cost. Hence, an attempt to reduce the E-field without using any additional equipment (any additional cost) is made in the present work with the help of cancellation effect brought about by transposition of conductors.

In this paper, the E-field cancellation effect present in a 220 kV double circuit line is analyzed using CSM. The E-field analysis is carried out for all possible arrangements in a double circuit line at 2 m from the ground level. The best arrangement which results in the minimum value for the maximum of rms E-field is selected and reported. The effect of energizing a single line on E-field is also analyzed. The results obtained are compared with the International Commission on Non-Ionizing Radiation and Protection (ICNIRP) guidelines reference value.

II. ICNIRP GUIDELINES

ICNIRP was established to provide scientific advice on possible health effects of NIR[13]. Various international organizations reviewed the scientific literature on the effects of NIR[14,15]. IEEE and IEC standards related to EMF exposure can be found in the literature [16-18]. 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 transmission lines, for the 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. In the present work, the E-field magnitudes under a 220 kV double circuit is analyzed at 2 m height from the ground level and the results are compared with the ICNIRP reference value in the following sections.

III. DOUBLE CIRCUIT LINE AND ITS MODEL

A double circuit 220 kV transmission line system is modelled using charge simulation technique. The dimensions of the conductors and clearances are shown in Fig.1. The phase conductors of the transmission line (Line 1: C1, C2, and C3 & Line 2: C4, C5, and C6) are located at the heights of 16.2, 21.2, and 26.2 m from the ground plane. The horizontal clearance between the conductors is 4.315 m. The number of sub conductors per phase is two and sub conductors have a spacing of 0.3 m between them. The radius of the single conductor is 0.0135 m. All the dimensions are taken from an actual transmission line located in northern Karnataka, in South of India. This is a double circuit line with vertical arrangement of conductors.

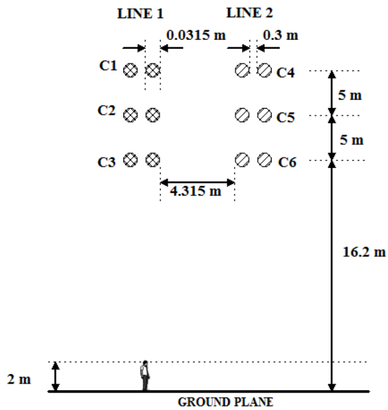

Fig. 1. Two-dimensional schematic showing dimensions and clearances of 220 kV double circuit transmission line system.

In the CSM based model, infinite line charges are used for the modelling of the transmission lines. For modelling each phase conductor, a single infinite line charge is kept at the center of the conductor and contour points are considered at the surface of the conductor. The number of infinite line charges used per phase is two (one for each sub-conductor) and hence, the total number of infinite line charge used for all six phase conductors is 12. The number of contour points and simulating charges are considered equal in the present work. The complex fictitious charges are used which helps in obtaining the maximum value of the time varying E-field. Image charges are used to simulate the effect of ground plane. With the appropriate potential assigned to contour points on the surface of the transmission line conductors, the magnitude of the simulating infinite line charges is computed using (1)

$$[V]=[P][Q] \tag{1}$$

Where, [V] is the matrix of conductor potentials assigned to the contour points, [P] is the potential coefficient matrix whose elements are function of distance between simulating charges and contour points and [Q] is the matrix of unknown charge magnitudes. The accuracy of the model developed is measured by selecting the test points on the surface of the conductor. The maximum potential error and rms potential error on the surface of the conductors is less than 0.01%. With the developed model, the electric field [E] at 2 m height form the ground level is computed using (2).

$$[E]=[F][Q] \tag{2}$$

Where, [F] is the field coefficient matrix and [Q] is the vector of simulating charge magnitudes. The effect of transposing the conductor is obtained with the CSM based model by changing the voltage assigned to the conductors. The E-field results obtained in the different combinations of conductor transpositions are discussed in the next section.

IV. Results and Discussions

The E-field cancellation effect present in the 220 kV double circuit transmission line is analyzed. It is effectively utilized to reduce the E-field exposure by conductors' arrangements. In the double circuit line arrangement, there are three phase conductors per line which results in $(^3P_3)*(^3P_3)=36$ number of possible arrangements (probability) of conductors. Due to symmetry existing between two circuits, there are arrangements which yield same result. Neglecting the similar ones, the total number of arrangements is reduced to 22. The E-fields are computed for all these combinations and the arrangement of conductors which gives minimum value for the maximum rms E-field is obtained.

Using the CSM model developed, the E-field is computed for different conductor arrangement at a height of 2 m from the ground level. The effect of using different phases with same arrangement for both the lines (e.g. RYB-RYB arrangement and YRB-YRB arrangement) does not have effect on the maximum value of rms E-field. These arrangements yield same results for maximum value of rms E-field. As a result of this, the 22 probable conductor arrangements yield only five different E-field results. They are grouped as

(i) Same conductor arrangement in both line (case-1): RYB-RYB (Note: there are another five arrangements of this kind),

(ii) Completely transposed with respect to one another (case-2): RYB-BRY (Note: there are another six arrangements of this kind),

(iii)Top and bottom conductors are interchanged (case-3): RYB-BYR (Note: there are another two arrangements of this kind)

(iv) Top two conductors are altered (case-4): RYB-YRB (Note: there are another two arrangements of this kind), and

(v) Bottom two conductors are inter-changed (case-5): RYB-RBY (Note: there are another two arrangements of this kind).

In the present work complex charges are used. The E-field variation (at 2 m from the ground level) for these five different cases is shown in Fig. 2. The maximum value of E-field intensity obtained is 2.021 kV/m which corresponds to the similar conductor arrangement on both the lines (Case-1). This value is reduced to 0.765 kV/m, when the top and bottom are interchanged with respect to the other line (Case-4). The percentage reduction in the maximum rms E-field (in Case-4 compared to Case-1) is 62.14%. With this transposed conductor arrangement (case-4), for the same E-field intensity at 2 m height (as of case-1), the ground clearance (tower height) can be reduced. This will result in saving of the material cost.

The cancellation effect will not exist when only one of the line is energized. To infer the effect of energizing one line, two cases (termed as case-6 and case-7; see Table 1) are considered. One line is energized and other line is considered to be at 0V. The maximum value of rms E-field is found to be 1.164 kV/m and percentage reduction in the E-field is 42.40% when compared to case-1. The percentage increase in E-field with reference to case-4 is 34.28%. The E-field variation corresponding to case-6, case-7 (single line energized), case-1 (existing conductor arrangement without transposition), and case-4 (conductor arrangement yielding lowest E-field on transposition) is shown in Fig.3.

The E-field results obtained are compared with the ICNIRP reference value of 5 kV/m for public exposure. In all the cases (case-1 to case-7), the E-field values are well below the prescribed limit of ICNIRP. These simulation results reported in the paper are without modelling the tower structures and sag of the conductors.

TABLE 1: E-FIELD RESULTS OF DIFFERENT CONDUCTOR ARRANGEMENT IN THE CONSIDERED 220 KV TRANSMISSION LINE SYSTEM

S.NO	Conductor arrangement						RMS E-field (kV/m)		Remarks
	C1	C2	C3	C4	C5	C6	Maximum value	Average value	
Case-1	R	Y	B	R	Y	B	**2.021**	0.499	Same conductor arrangement on both the lines (existing arrangement without transposition)
Case-2	R	Y	B	Y	B	R	1.027	0.396	Fully transposed with respect to each other
Case-3	R	Y	B	R	B	Y	1.974	0.103	Bottom two conductors are interchanged with respect to other line
Case-4	R	Y	B	B	Y	R	**0.765**	0.083	Top and bottom conductors are interchanged with respect to other line (Best case yielding minimum E-field on transposition of conductors)
Case-5	R	Y	B	Y	R	B	1.366	0.093	Top two conductors are interchanged with respect to other
Case-6	R	Y	B	0	0	0	1.164	0.077	Line 1 alone charged
Case-7	0	0	0	R	Y	B	1.164	0.077	Line 2 alone charged

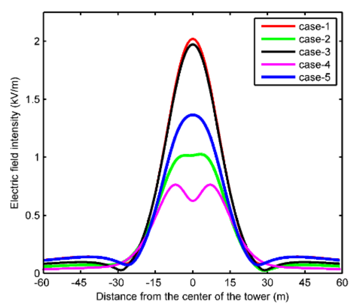

Fig. 2. E-field variation at 2 m height from the ground plane for different cases of conductor arrangements (case-1 to case-5; see Table 1) with energization of both lines.

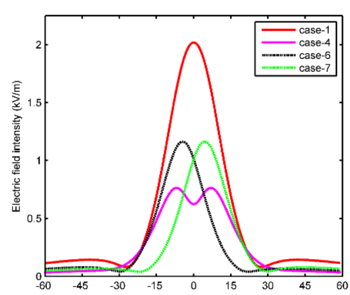

Fig. 3. E-fieldresults obtained through CSM model with energization of a single line (220 kV) and other line is considered to be at 0 V (case-6 & case-7).

V. Conclusions

The maximum value of rms E-field for the considered 220 kV double circuit transmission line is obtained through simulation using a semi-analytical method (CSM). The obtained E-field intensity values are well below the reference value of 5 kV/m (for public exposure) prescribed by ICNIRP. The conductor arrangement which results in reduced E-field is obtained through numerical experimentations. A reduction in E-field of 62.14% is obtained through transposition for an arrangement. The best arrangement of conductors which results in reduced E-fieldis applicable to the vertical arrangement of conductors in the double circuit line.

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