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Minimization of Electric Fields Underneath High Voltage Direct Current Transmission Lines Based on Shielding Technique

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A R T I C L E I N F O

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A B S T R A C T

This paper is aimed at mitigation the electric fields underneath extra high voltage transmission lines using active and passive shield wires. Two extra high voltage alternating current transmission lines are modeled and analyzed. One line is operating at 400 kV homopolar and the other is at 600 kV bipolar. The electric field calculated at the ground level for the two transmission lines with and without active and passive shield wires. The charge simulation method is used for calculating electric fields underneath the lines with and without active and passive shield wires. The percentage reduction of electric field is 67.77% for passive shield wires against for active shield wires for 220 kV transmission line at shield wires height of 15m. The corresponding values of the reduction percentage of electric field of 500 kV transmission line are respectively for active and passive shield wires at height of 15m.

1. Introduction:

Nowadays extra high voltage direct current (EHVDC) transmission lines became widely used for transmission of electrical energy. Consequently, the possible effects of electric fields underneath EHVDC lines received an increasing interest in research studies, e.g., electric field induction and short circuit currents through conducting objects (e.g., parallel metallic fences and large vehicles), the electric field environmental impact on people and electric field interaction with human beings near power lines [1].

Consequently, a precise calculation of the electric field underneath overhead transmission lines became a very important task in transmission line design. Quantitative description of the electrostatic field around EHVDC overhead transmission line has been presented in many papers [2-4]. The electric field effect of operating transmission lines is an important issue that the electric utility engineer is most often required to respond to regarding the potential hazards due to the public exposure to these fields. The effect of long term or chronic exposure to electric fields is currently under study in several countries.

Several studies have reported that children living near high voltage transmission and distribution lines had a higher cancer and leukemia incidence than other children [5] did. However, limited studies have been reported regarding adults who live near high voltage transmission and distribution lines. Higher cancer incidence was observed than other adults. In addition, various lines of research have suggested that exposure to electromagnetic fields could lead to DNA damages in cells under certain conditions [6-8]. Effects depend on factors such as the mode exposure, the type of cell and intensity and duration of exposure.

Overhead transmission lines require strips of land to be designed as right of way (ROW). These ROWs can also support other uses besides the transmission line. Increasing the amount of power transmitted requires higher voltages, therefore the transmission corridors are increased, and in turn, the competition for land and ROW increased.

The analysis and reduction of the electric field at ground level is the most direct objective of efforts to minimize the field effects of EHVDC transmission lines. In fact, most electric field effects occur close to ground level and are function of the magnitude of the unperturbed electric field at one meter above ground.

For these above reasons, electric field must be reduced to overcome its harmful effects on the people living or work nearby the transmission lines. One of the approaches is to use active and passive shield wires underneath the line conductors [9-16]. This is the main objective of the present paper.

For a simple physical system, it is usually possible to find an analytical solution. However, in many problems the physical systems are so complex that it is extremely difficult, if not impossible, to find analytical solutions. Hence, in such cases numerical methods employed for electric field calculations. The existing numerical methods include the Finite Difference Method, the Finite Element Method, the charge simulation Method, the Surface Charge Simulation Method. The Surface Charge Simulation Method often called the Integral Equation Method. CSM has many advantages when compared with the other numerical methods for calculating electric fields

Therefore, the charge simulation method is used in this paper for calculating electric fields underneath EHVDC transmission lines with and without active and passive wires.

2. Method of calculating electric field

The idea of CSM [17-19] is very simple. For the calculation of electric fields, the distributed charges on the surface of the electrode are replaced by N number of fictitious charges placed inside the electrode at a radius R_f as shown in Fig.1. In order to determine the magnitudes of the fictitious charges, some boundary points are selected on the surface of electrode. The number of boundary points is selected equal to the number of fictitious charges. Then it is required that at any one of these boundary points the potential resulting from superposition of effects all the fictitious charges is equal to the known electrode potential. Let, $\boldsymbol{Q_j}$ is the jth fictitious charge and $\boldsymbol{V}$ is the known potential of the electrode. Then according to the superposition principle,

$$V = \sum_{j=1}^{n} P_{ij}\, Q_j \tag{1}$$

Where P_{ij} is the potential coefficient, which can be evaluated analytically for different types of fictitious charges. When Eq. (1) is applied to N boundary points, it leads to the following system of N linear equations for N unknown fictitious charges, then

$$[P]_{NxN}\,[Q]_N = [V]_N \tag{2}$$

Where [P] = potential coefficient matrix, [Q] = column vector of known potential of contour points.

Equation (2) solved for the unknown fictitious charges. As soon as the required charge system is determined, the potential and the field intensity at any point, outside the electrodes can be calculated. While the potential is found by Eq. (1), the electric stress components are calculated by superposition of all the stress vector components.

For a Cartesian coordinate system, the x, y coordinate E_x and E_y would then be for a number of N charges.

$$E_x = \sum_{j=1}^{N} \frac{\partial p_{ij}}{\partial x} Q_j = \sum_{j=1}^{N} \left(f_x\right)_{ij} Q_j \tag{3}$$

$$E_y = \sum_{j=1}^{N} \frac{\partial p_{ij}}{\partial y} Q_j = \sum_{j=1}^{N} \left(f_y\right)_{ij} Q_j \tag{4}$$

Where $(f_x)_{ij}$, $(f_y)_{ij}$ are "field intensity coefficients" in the x and y direction.

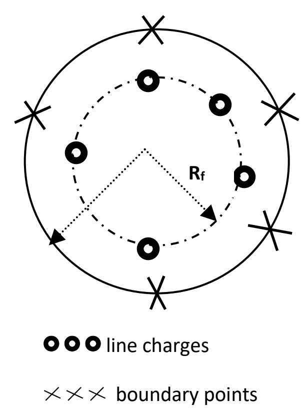

Figure 1. Charge representation for the line conductor and shield wires.

3. Results and discussions

A. Case study 1: A 400 kV transmission line with and without active and passive shield wires:

1) Without active and passive shield wires

The charge simulation method is applied to the 220kV transmission line shown in Fig. 2. The radius of pole conductors Rc is 0.0383m, the clearance d between poles is 22m and the height H is a variable parameter. The number of simulation line charges per conductor equals six. The simulation charges are arranged around a cylinder of radius equal to 0.05Rc. The potential error at selected contour points does not exceed 0.001%.

Fig.3 shows the electric field at 1m height above the ground level for the configuration shown in Fig.2. The maximum field strength at 400kV applied voltage is found to be about 14.2kVm-1 and corresponds to minimum ground clearance H=10m. Increasing the line height is the most effective parameter in line design, which reduces the maximum field stress at ground.

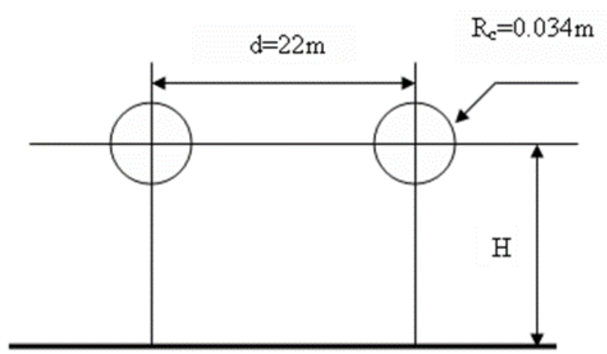

Figure 2. A 400kV, homopolar HVDC Transmission Line.

Figure 3 plots the field strength for different line heights of 10, 14, 18, 22 and 27m. The maximum field stress values corresponding to these line heights are 14.2, 10.45, 8.54, 7.32 and 6.11kVm-1 respectively. It is clear that as the line height increases, the maximum field decreases with a significant amount within the transmission line corridor. Outside the line corridor, it is influenced by a completely different way. Table 1 lists the ROW widths for the transmission line configuration shown in Fig.2 for different line heights and the corresponding electric field stress at the border of ROW.

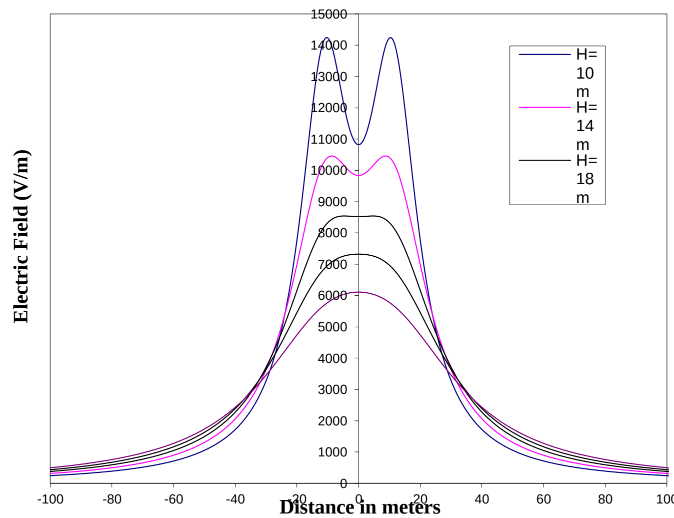

Figure 3. Electric field distribution at 1m height above ground surface for

400kV TL of Fig.2 with the line height H as a parameter

1) With passive shield wires

The charge simulation method is applied to the transmission line shown in Fig. 4. The radius of pole conductors R_c is 0.0383m, the clearance d between poles is 22m, the height H is 27m from conductor to ground. The radius of shield wires r_{sh} is 0.0039m, the spacing between grounded shield wires is S and the height from shield conductor to ground H_s.

Table 1: ROW widths for the homopolar transmission line.

Line height H (m)	Electric field (kV/m)	Required ROW (m)
	0.5	71
10	1	51
	1.5	42.5
	0.5	80
14	1	57
	1.5	46.5
	0.5	87
18	1	61.5
	1.5	50
	0.5	93
22	1	65
	1.5	52.25
	0.5	99.5
27	1	69
	1.5	54.5

The number of simulation line charges for both pole conductors and shield wires is equal to six. The simulation charges are arranged around a cylinder of radius equal to $0.05R_c$ for pole conductors and $0.05r_{sh}$ for shield wires. The potential error at selected contour points on the line conductors and grounded shield wires did not exceed 0.001%.

Different number of grounded shield wires, different spacings S between grounded shield wires and different heights H_s from ground to grounded shield wires are studied.

Figures 5 and 6 show plots of the electric field at 1m height above the ground level for the configuration shown in Fig.4 at H_s=15m with different number n_s of grounded shield wires and spacings S=1m, 6m between shield wires.

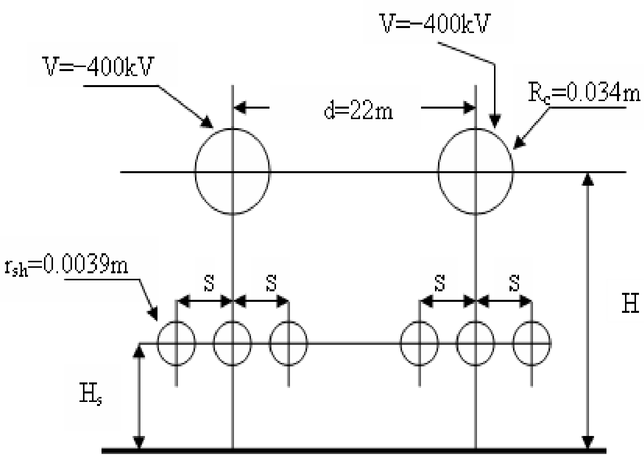

Figure 4. A 400kV- Homopolar HVDC Transmission Line with grounded shield wires

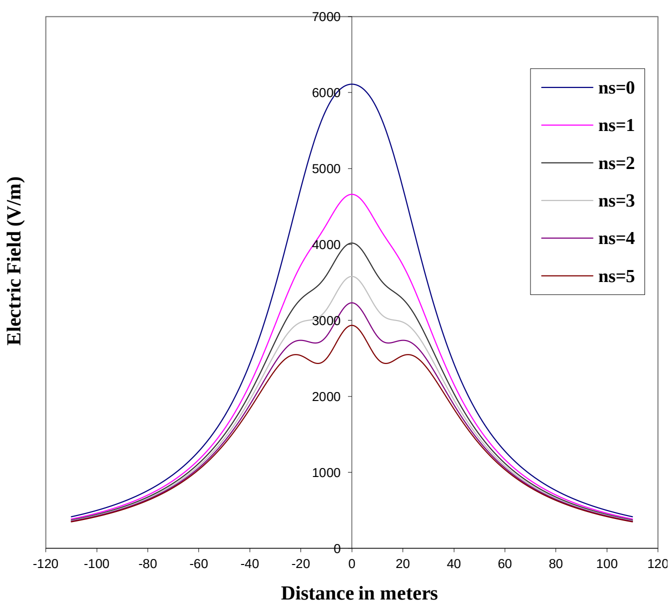

Figure 5. Electric field distribution at 1m height above ground surface of the homopolar line with S=1 and H_s=15m

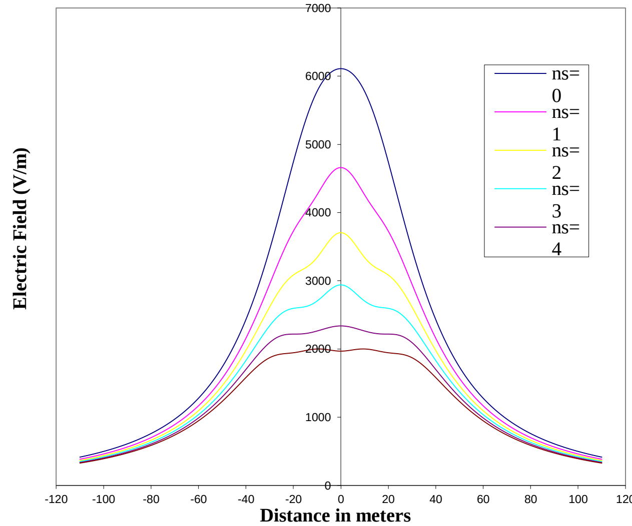

Figure 6. Electric field distribution at 1m height above ground surface of the homopolar line with S=6m and H_s=15m

From figures 5 and 6 it is clear that the maximum electric field decreases with the increase of the number ns of shield wires increase and the spacing S in between. Table 2 lists the ROW for the transmission line shown in Fig. 4 for S= 1, 6m and its percentage reduction due to the presence of shield wires.

Table 2: ROW widths for the homopolar transmission line with S of 1, and 6m and H_s=15m

Number of shield wires	Electric field (kV/m)	Required ROW (m) S=1m	Required ROW (m) S=6m	Percentage reduction of ROW S=1m	Percentage reduction of ROW S=6m
	0.5	99.5	99.5		
no	1	69	69		
	1.5	54.5	54.5		
	0.5	99	99	0.5%	0.5%
1	1	68.5	68.5	0.72%	0.72%
	1.5	54.25	54.25	0.45%	0.45%
	0.5	93.5	93	5.5%	6.5%
2	1	63.5	63.5	7.2%	8%
	1.5	49.5	49	8.25%	10.1%
	0.5	91.5	91	7%	8%
3	1	62	61.5	8.7%	10.8%
	1.5	47.5	49	10.55%	10.1%
	0.5	90	89	8%	10.55%
4	1	60.5	59.5	10.14%	13.76%
	1.5	46	44.75	12.38%	17.9%
	0.5	88.5	87.5	9%	12%
5	1	59	58	11.23%	15.9%
	1.5	44.75	42.25	13.76%	22.47%

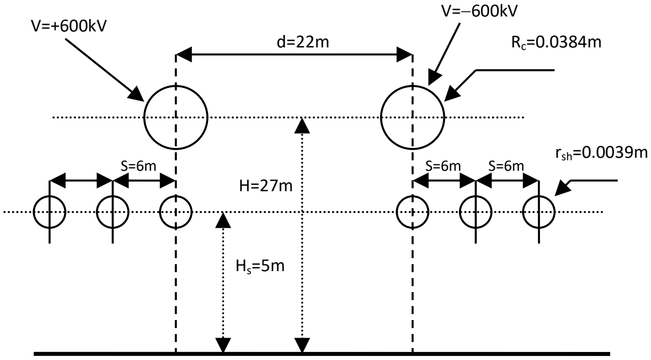

Figure 7. A ± 600kV- bipolar HVDC Transmission Line with grounded shield wires

The results are compared favorably with those reported in [7]. This confirms the accuracy of the proposed charge simulation method.

C. Case Study 2: A 600kV transmission line with and without active and passive shield wires

The grounded shield wires are centered underneath each pole as shown in Fig 8. The configuration of this transmission line is the same as that in Fig. 4.

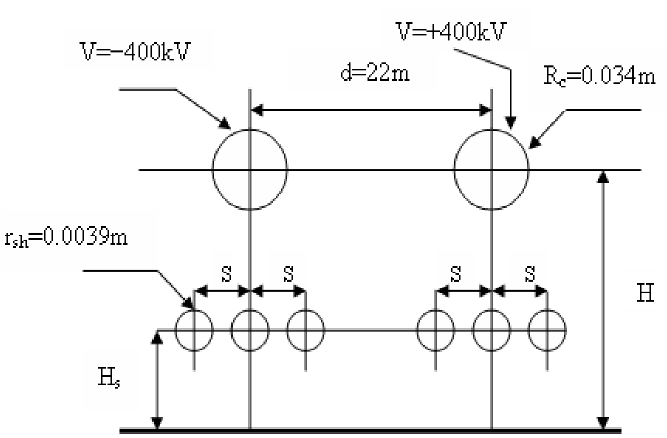

Figure 8. A ± 400kV- bipolar HVDC Transmission Line with grounded shield wires

Figures 9 and 10 show the electric field at 1m height above the ground level for the configuration shown in Fig. 9 at H_s=15m with different spacings S between shield wires and different numbers of n_s of grounded shield wires.

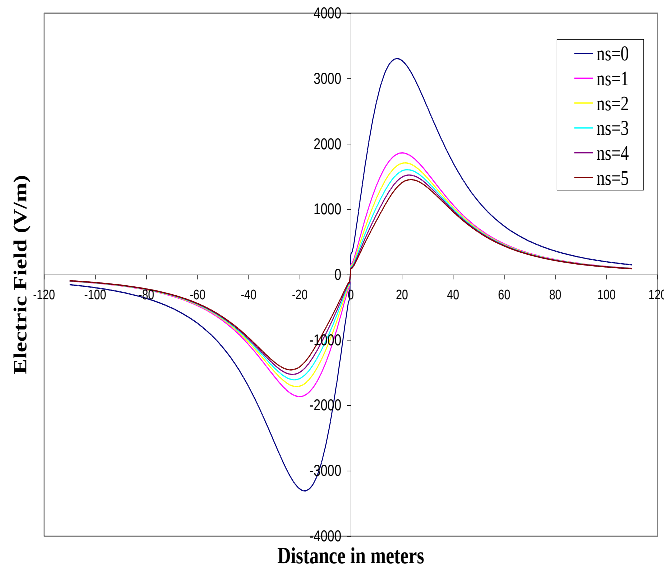

Figure 9. Electric field distribution at 1m height above ground surface of the bipolar line with S=1m

In figure 9, the maximum electric field stress is 3.3kVm^{-1} without shield wires. It decreases with the presence of shield wires and becomes 1.86, 1.7 and 1.6 kVm^{-1} for 1, 2 and 3 wires, respectively. With the increase of n_s above three, there is no noticeable reduction change in maximum electric field. With the increase of the number of grounded shield wires over three, there is no noticed change in maximum electric stress.

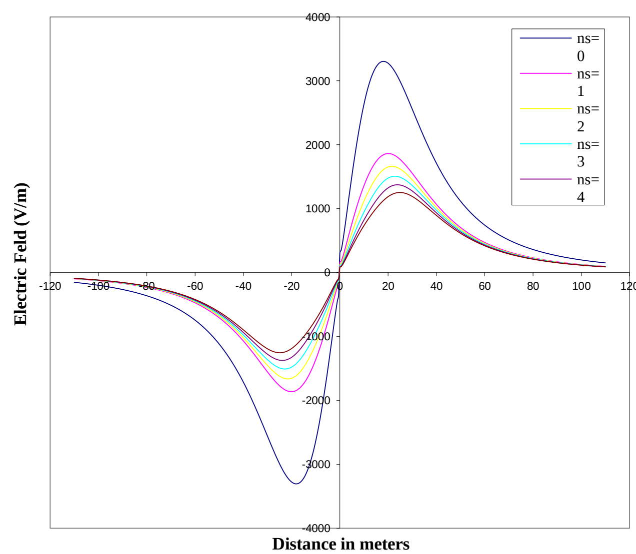

Figure 10. Electric field distribution at 1m height above ground surface of the bipolar line with S=3m

Table 3: ROW widths for the bipolar transmission line with S of 1 and 3m and H_s=15m

Number of shield wires	Electric field (kV/m)	Required ROW (m)		Percentage reduction of ROW	
		S=1m	S=3m	S=1m	S=3m
	0.5	70.5	70.5		
no	1	52.4	52.4		
	1.5	43	43		
	0.5	58.5	58.5	17%	17%
1	1	41.5	41.5	20.8%	20.8%
	1.5	31	31	24.8%	24.8%
	0.5	58	57.5	17.7%	18.4%
2	1	40.75	40.5	22.2%	22.7%
	1.5	29.5	28.75	31.39%	33.1%
	0.5	57.5	57	18.4%	19.1%
3	1	40	39.4	23.6%	24.8%
	1.5	27.75	24	35.4%	44.18%

In addition, figure 10 shows the electric field distribution at 1m above the ground level with 3m spacing between shield wires.

Table 3 lists the ROW for the transmission line shown in Fig. 9 for S=1, 3m and its percentage reduction due to presence of shield wires. It is noted from the table that the saving of ROW in case of bipolar transmission line with three shield wires equal three and spacing S of three meters reaches up to 44%.

4. Conclusions

1- The maximum electric field at the ground level (1m above ground surface) for homopolar and bipolar transmission lines decreases with the increase of the spacing S between shield wires irrespective of the height H_s and the number n_s of wires.
2- The maximum electric field at the ground level (1m above ground surface) for homopolar and bipolar transmission lines decreases with the increase of the number n_s of shield wires whatever the spacing S or the height H_s of the grounded wires.
3- The ROW of homopolar and bipolar transmission lines decreases with the increase of the number n_s of shield wires whatever the spacing S or the height H_s of the wires.
4- The ROW of homopolar and bipolar transmission lines decreases with the increase of the spacing S between shield wires irrespective of the height H_s and number n_s of grounded wires.

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