Research on the Influence of the Ground Wire on Ionized Field of Double-circuit HVDC Transmission Lines

Guodong Huang, Jiangjun Ruan, Zhiye Du, Changwei Zhao
School of Electrical Engineering, Wuhan University
No.8, South Road of Eastern Lake, 430072, China
dexter_whu@163.com

Abstract — Deutsch's assumption has been widely used in the research of the ionized field of high voltage direct current (HVDC) transmission line, and validity of the method based on Deutsch's assumption has been testified. Analysis of the influence of the inter-spacing, the line height, etc. on the ionized field has been conducted by many researchers, while, the influence of the ground wire get little concern. In this paper, for the case of vertical bipolar configuration, the lateral distribution of the electrical field at the ground level was calculated and compared with the measured data; it was also calculated for double-circuit HVDC transmission line which has four different pole conductor arrangements with the ground wire protection. The influence of the ground wire has been analyzed considering the lightning-protection theory in the study of the ionized field of double-circuit HVDC transmission line, and we find the ground wire has little effect on the ground level electrical field and current density, thus can be ignored in the calculation of the ionized field in engineering design.

I. INTRODUCTION

In recent decades, China has been developing the HVDC transmission project vigorously for its efficiency and stability in the long-distance power transmission over conventional HVAC transmission. But space charge which flows from the conductor as a consequence of corona discharge can cause environmental concerns inherently. Moreover in recent years, the concept of double-circuit HVDC transmission line which has more severe electromagnetic environment was put forward in order to save corridor source. Hence, the electric field and the ion current density on the ground level under HVDC transmission line have to be analyzed.

There is an ongoing interest in the analysis of the ionized field under HVDC transmission line, and the Deutsch's assumption has been widely used by researchers for its effect on the simplification of the nonlinear PDE equations. Some researchers made efforts on analyzing the error introduced by the Deutsch's assumption and studying the applicability of it [1], [2], and most others applied the assumption to the engineering design, calculating the ground level electrical field and current density for different line arrangements [3]-[5], studying the influence of the inter-spacing, the line height, etc. [6] and even the nearby building [7] on the ionized field of the real HVDC transmission line, while little attention has been given to the influence of the ground wire on the ionized field in spite of its absolute existence.

In this paper, calculation of the electrical field underneath vertical bipolar HVDC test line was conducted and the result was compared with the experimental data. The same thing was calculated in a double-circuit HVDC transmission line with four different pole conductor arrangements to get an environment-friendly configuration. More emphasis was put on the ground wire to study the influence on the ionized field of double-circuit HVDC transmission line.

II. THEORY

The main system of equations describing the ionized field of a bipolar corona is:

$$\nabla \cdot \overrightarrow{E_s} = (\rho_+ - \rho_-) / \varepsilon_0 \tag{1}$$

$$\vec{j}_\pm = k_\pm \rho_\pm \overrightarrow{E_s} \tag{2}$$

$$\nabla \cdot \vec{j}_\pm = \mp \delta \rho_+ \rho_- / e \tag{3}$$

During the solving process, numerical methods are used; assumptions are as follows [3]:

1. Deutsch's assumption: ions only affect the magnitude of the field without changing the direction of the field line;
2. Kaptsov's assumption: the magnitude of the electric field at the surface of the positive and negative conductors keeps unchanged on the onset value.
3. The thickness of the ionization layer around the conductors is small enough to be neglected.

Via the upper equations and the assumptions, we can get the following equations for calculating the field intensity and the ion current density.

$$\overrightarrow{E_s} = A\vec{E} \tag{4}$$

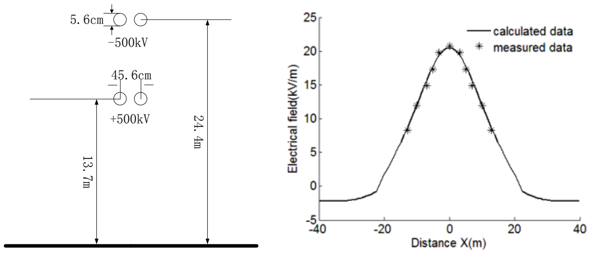
$$A^2 = A_e^2 + \frac{2\rho_e A_e}{\varepsilon_0} \int_\varphi^U \frac{d\varphi}{E^2} \tag{5}$$

The equations can be solved by numerical integration along bipolar field lines as described in the following steps:

1. Space-charge-free field line which goes through a given point P over the ground surface is traced, thus the electrostatic field along the line can be obtained.
2. Using a initial guess value of the ion density on the surface of the sub-conductor, the average value of the ion density along the field line is calculated, compared with the real value, the true surface ion density can be determined.
3. Refer to "(5)", field enhancement factor A is obtained, so are the field intensity and the current density.

III. ALGORITHM VERIFICATION

The electrical field underneath vertical bipolar HVDC test line was calculated and compared with the experimental data. The vertical configuration and the calculated result were illustrated in Fig. 1, and the result of the electric field fit well with the measured value.

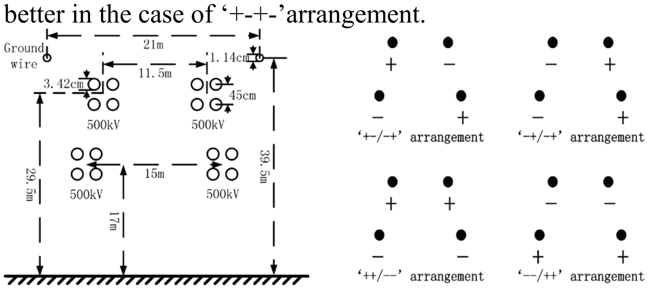


(a) (b)

Fig. 1. Vertical configuration (a) and the electrical field profile (b) at the ground level of bipolar HVDC test line

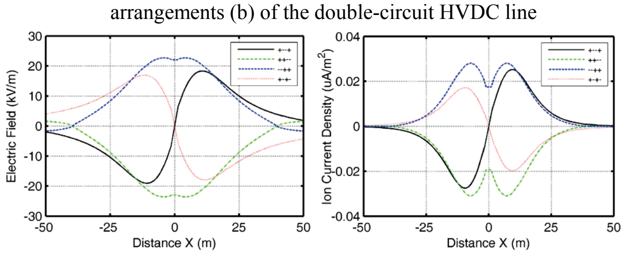
IV. APPLICATION

The electrical field and current density at the ground level of double-circuit HVDC transmission line were calculated to get an environment-friendly polar line arrangement considering the effect of the ground wire. Conductor configuration and four different polar line arrangements of the double-circuit HVDC line were illustrated in Fig. 2. Calculation results of the ground level electrical field and ion current density were plot in Fig. 3, and we found the electromagnetic environment is much better in the case of '+-+-'arrangement.



(a) (b)

Fig. 2. Conductor configuration (a) and four different polar line arrangements (b) of the double-circuit HVDC line



(a) (b)

Fig. 3. The distribution of ground level electrical field (a) and ion current density (b)

Taking the fourth arrangement as the research object, the maximal ground level electric field and ion current density under double-circuit HVDC transmission line were calculated with different ground wire radiuses (rg). From Fig. 5, we can see that the maximal ground level electric field and ion current density change little when the radius of the ground wire changes from 1cm to 2cm.

Considering the lightning protection requirement, shielding angle of the transmission line should be no more than 10° . The distance between the ground wires should not exceed five times of the vertical distance between ground wires and polar conductor, and the vertical distance should follow the inequality (6) at the center of span.

$$S \geq 0.012L + 1.5 \tag{6}$$

The ground level electrical field and ion current density of the double-circuit HVDC line were calculated with the ground wires varying in position on the tower. The maximal electrical field and ion current density which change with ground wire height and the distance between ground wires were shown in Fig.5 and 6, and we found the maximal value change little which can be ignored in the calculation of the ionized field in engineering design.

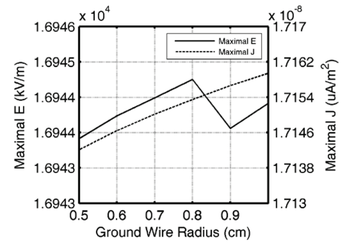


Fig. 4. The effect of the ground wire rdius on the ionized field

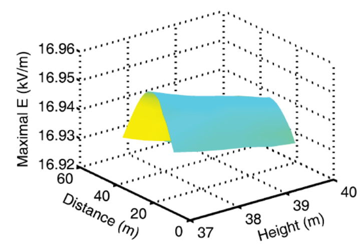


Fig. 5. Effect of ground wire position on the maximal electrical field

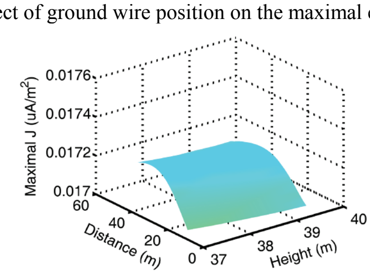


Fig. 6. Effect of ground wire position on the maximal ion current density

V. REFERENCES

[1] W. Li, B. Zhang, R. Zeng and J. He, "Discussion on the deutsch assumption in the calculation of ion-flow field under HVDC bipolar transmission lines". *IEEE Trans. on Power Delivery*, vol.25, no.4, pp. 2759-2767, 2010.

[2] A. Kasdi, H. Yala and Y. Zebboudj, "Finite element analysis of bipolar corona". *International Conference on Solid Dielectrics*, vol.2, pp. 538-541, 2004.

[3] M. P. Sarma and W. Janischewskyj, "Analysis of corona losses on DC transmission lines: I - unipolar lines", *IEEE Trans. on Power App. Syst.,* vol.PAS-88, no.5, pp. 718-731, 1969.

[4] M. P. Sarma and W. Janischewskyj, "Analysis of corona losses on DC transmission lines part II - bipolar lines", *IEEE Trans. on Power App. Syst.,* vol.PAS-88, no.10, pp. 1476-1492, 1969.

[5] S. Abdel-Sattar, "Corona current and field profile underneath vertical bipolar HVDC lines with bundle conductors". *IEEE Trans. on Electrical Insulation*, vol.EI-21, no.2, pp. 197-204, 1986.

[6] T. Lu, J. Zhao, X. Cui and H. Feng, "Analysis of ionized field under ±800kV HVDC transmission lines". *17th International Zurich Symposium on Electromagnetic Compatibility*, pp. 416-419, 2006.

[7] Z. Luo, X. Cui, et al., "Calculation method for the ionized field under HVDC transmission lines with building nearby". *Proceedings of the Chinese Society of Electrical Engineering*, vol.30, no.15, pp. 125-130, 2010.