

A FEM Approach for Analyzing the Corona Ionized Field of Bipolar Bundled Conductors

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Abstract— A finite element method is proposed for an investigation of the bipolar bundled conductor ionized field. A computation program for the corona ionized field analysis was developed in which Deutsch's assumption was waived. The subconductors were considered as separate parts where the mutual impact was included. Each electric field line was initiated from the subconductor surface. The electric field was calculated by adopting the third order interpolating method. Furthermore, a method of estimating the initial space charge density of flux-tubes was introduced and then calculated by using the fourth order Runge-Kutta method. Finally, the computation program was verified and the corona current and related field properties of a $\pm 800\text{kV}$ HVDC transmission line were investigated.

I. INTRODUCTION

Many numerical attempts have been made to evaluate the ionized field associated with single and bundled conductors for monopolar transmission lines [1]-[3].

Some attempts have also been made to solve the bipolar ionized field equations. Sarma developed a method of calculating the electric field for bipolar lines based on Deutsch's assumption first [4]. Later, though Deutsch's assumption is waived, the bipolar ionized field equations were only solved in single conductor-to-plane configurations [5]-[6]. In [7] an integral form of the current continuity equation was used (instead of Poisson's equation) to compute the space potential with a bipolar bundled conductor line in a double circuit.

Al-Hamouz has done much more on the ionized field analysis. The main idea was solving Poisson's equation by using the FEM and calculating the charge density along the flux-tubes divided by field lines in the ionized field. His investigating range varied from monopolar to bipolar, from single conductor to bundled conductor, and to extending the limited boundary to infinity [1, 3, 6, 8]. However, the bipolar and bundled configuration aspects have not been taken into account simultaneously.

In this paper, an iterative FEM based numerical method is developed to solve Poisson's equation for the bipolar bundled conductor. Firstly, the computation process is explained in detail and then it is verified. Finally, the program is used to analyze the corona ionized field of a $\pm 800\text{kV}$ transmission line.

II. DESCRIPTION OF THE BIPOLAR IONIZED FIELD

The bipolar ionized field can be described by a group of equations:

$$\nabla \cdot \vec{E} = (\rho_+ - \rho_-) / \epsilon_0 \quad (1)$$

$$\vec{J}_{\pm} = k_{\pm} \rho_{\pm} \vec{E} \quad (2)$$

$$\nabla \cdot \vec{J}_{\pm} = \mp R_i \rho_{\pm} \rho_{\pm} / e \quad (3)$$

$$\vec{J} = \vec{J}_+ + \vec{J}_- \quad (4)$$

$$\nabla \cdot \vec{J} = 0 \quad (5)$$

where (1) is Poisson's equation; (2) is the equation of the positive and negative current density vectors \vec{J}_{\pm} ; (3) is the equation for \vec{J}_{\pm} continuity; (4) is the equation of the total current density vector \vec{J} ; and (5) is the equation for \vec{J} continuity. \vec{E} is the electric field, k_+ and k_- are the mobilities of positive and negative ions, ρ_+ and ρ_- are the modulus of the positive and negative space charge density values, R_i is the ion recombination coefficient in air, and e is the electron charge.

Using the FEM based numerical approach, with associated boundary and constraint conditions, the above partial differential equations can be solved.

III. PROPOSED ANALYSIS METHOD OF A BIPOLAR BUNDLED CONDUCTOR IONIZED FIELD

A general configuration of a bipolar HVDC transmission line is illustrated in Figure 1. A $\pm 800\text{kV}$ HVDC transmission line is used as an example. The triangular finite element grid is generated from quadrangles produced by the intersection of field lines with equipotential contours. In either the bipolar or monopolar component, the FEM is applied to obtain an evaluation of the nodal potential. The third order interpolating method is then adopted to calculate the electric field.

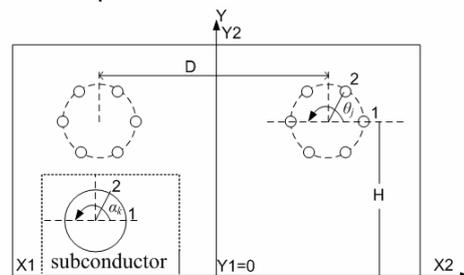


Fig. 1. Configuration of a $\pm 800\text{kV}$ HVDC transmission line

For the monopolar component, the initial estimation of the space charge density of each field line is:

$$\rho d_{j,k} = \rho_{ej} \cos((\pi - \alpha_k)/2), k = 1, 2, \dots, nd_{sub} \quad (6)$$

$$\rho_{ej} = \rho_e \cos((\pi - \theta_j)/2), j = 1, 2, \dots, n$$

where $\rho d_{j,k}$ is the space charge density in the monopolar component, nd_{sub} is the number of electric field lines in the monopolar component, ρ_{ej} is the value of $\rho d_{j,k}$ at $\alpha_k = \pm\pi$, n is the number of conductor bundles, ρ_e is the value of ρ_{ej} at $\theta_j = \pm\pi$ and can be calculated from an existing formula, and α_k and θ_j are shown in Figure 1.

In addition, the initial space charge density values in the bipolar component are assumed as [8]

$$\rho s_{j,k} = 0.02(\rho d_{j,k}), k = 1, 2, \dots, ns_{sub} \quad (7)$$

where $\rho s_{j,k}$ is the space charge density in the bipolar component, and ns_{sub} is the number of electric field lines in the bipolar component.

The fourth order Runge-Kutta method is then used to evaluate the space charge density of all nodes. The process is repeated until the errors of potential and space charge density calculated in two successive iterations are satisfied with the required accuracy. The errors of potential and space charge density are δ_1 and δ_2 respectively.

Figure 2 shows a block diagram of the solution procedure, where the corona current can be obtained.

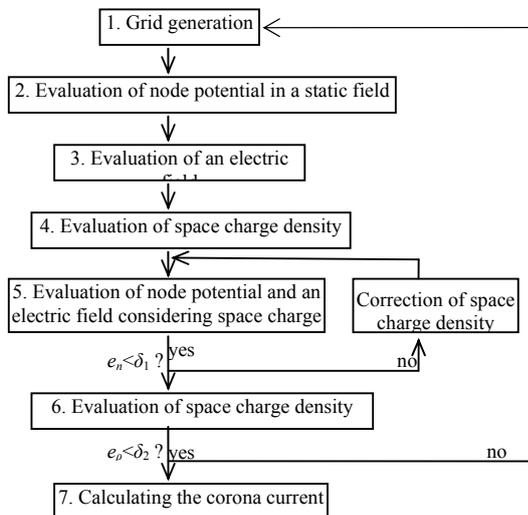


Fig. 2. The solution procedure

IV. VERIFICATION OF REAL ± 500 kV BIPOLAR LINES

In order to verify the proposed numerical program, a ± 500 kV transmission line model with experimental results was used to evaluate the corona ionized field as shown in Figure 3. The computation result (the solid line) was consistent with the experiment result (the star line). Thus, the computation program can be used to validate the ionized field of a bipolar bundled conductor.

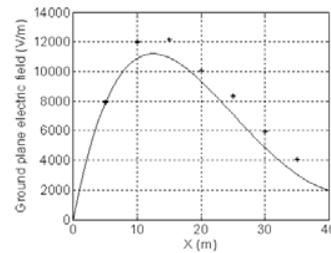


Fig. 3. ± 500 kV line ground-plane electric field, the solid line is the calculated result and the star line is the experimental result.

V. RESULTS AND DISCUSSION ON ± 800 kV HVDC TRANSMISSION LINE IONIZED FIELDS

The proposed program is adopted to analyze the corona ionized field of a ± 800 kV HVDC transmission line. The configuration is shown in Figure 1. The algorithm converges in three mesh generations, each with 13 iterations for the HVDC models. The errors of δ_1 and δ_2 are less than 0.5%. The corona current, ground electric field and ground current density are calculated for a ± 800 kV HVDC transmission line.

VI. CONCLUSION

(1) The proposed FEM based numerical method is effective for calculating the ionized field of a bipolar bundled conductor.

(2) An increase in the number of bundles decreases corona current, while an increase in bundle spacing increases corona current. If the monopolar component is not included, the corona current will be overestimated. The ground electric field and ground current density of the present ± 800 kV HVDC transmission line is less than 30kV/m and 100nA/m² respectively.

(3) The computation program can be used as an effective numerical tool for evaluating the electromagnetic environment around the HVDC transmission line.

VII. REFERENCES

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