Highly Stable Upwind FEM for Solving Ionized Field of HVDC Transmission Line

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Abstract — The ionized field produced by corona discharge from high voltage direct current (HVDC) transmission line has a great influence on the electromagnetic environment. In this paper, a highly stable iterative algorithm based on upwind FEM is introduced to analyze the ionized field of HVDC transmission line in the presence of the wind. The Kaptzov's assumption is introduced on conductor surface as a boundary condition. In the iterative procedure presented by Takuma, a controlling method is added to guarantee the convergence of the iteration, which has been tested to be effective. The impact of the wind on the ground level electric field and ion current density of a bipolar HVDC transmission line is analyzed, and we find the wind has significant influence on the ionized field which has to be considered in the engineering design.

I. INTRODUCTION

HVDC transmission line has many advantages over conventional ac transmission line for long-distance power transmission, which has been utilized in China for many years. But space charge which flows from the conductor as a consequence of corona discharge can cause environmental concerns. Hence, the electric field and the ion current density on the ground level under HVDC transmission line must be analyzed.

In the presence of the space charge, ionized field is difficult to be analyzed for its inherent nonlinearity. Researchers have been making efforts in the last 80 years. In the 1960s, Sarma and Janischewskyj [1] developed a method based on Deutsch's assumption which is still a subject of study. After that, Janischewskyj and Gela [2] presented finite element method (FEM) to analyze the ionized field without Deutsch's assumption. Two separate partial differential equations were solved iteratively. Later, other numerical solution techniques, such as the finite difference method (FDM), the boundary element method (BEM), and the finite volume method (FVM) have been introduced to solve the dominating equations. In 1981, Takuma [3] presented an upwind FEM which can consider the effect of the wind to solve the current continuity equation. But the space charge density was set to be constant which was relevant to the experimental result on the surface of the conductors. As a consequence, upwind FEM was modified by researchers to fit the Kaptzov's assumption. As detailed by Brooks and Hughes [4], the application of the upwind method is desired for removing spurious node-to-node oscillations in numerical solutions. Some researchers found it uncomfortable with the upwind method for its sometimes unconvergence.

In the paper, a highly stable iterative algorithm based on upwind FEM is introduced to analyze the ionized field of HVDC transmission line in the presence of the wind. In the iterative procedure presented by Takuma, finite element method is used in solving Poisson's equation with a given charge distribution, and upwind method is applied for solving the current continuity equation in order to update the space charge density. To make the iteration efficiently convergent, a controlling method is implemented when solving Poisson's equation. A detailed introduction is as follows: the space charge density obtained in the previous iteration is mixed in proportion with the one obtained in the current iteration. The controlling method is effective to prevent the space charge density and the electric field to change violently which would cause wiggles in numerical solutions. The effect of the wind is also analyzed for the engineering design of HVDC transmission line.

II. THEORY

The ionized field of a HVDC transmission line is a 2D, time-independent field, the main system of equations describing the ionized field is as follows [3]:

$$\nabla^2\varphi = (\rho^- - \rho^+)/\varepsilon_0 \tag{1}$$

$$\vec{j}^+ = \rho^+(-k^+\nabla\varphi + \vec{w}) \tag{2}$$

$$\vec{j}^- = \rho^-(-k^-\nabla\varphi - \vec{w}) \tag{3}$$

$$\nabla\cdot\vec{j}^+ = -R\rho^+\rho^-/e \tag{4}$$

$$\nabla\cdot\vec{j}^- = R\rho^+\rho^-/e \tag{5}$$

In order to simplify the nonlinear solving problem, following assumptions are adopted [3]:

(1) The thickness of the ionization layer around the conductors is small enough to be neglected.

(2) The positive and negative ion mobility k^+, k^- are assumed to be constant, and they are also considered to be independent of the electric field.

(3) The magnitude of the electric field on the surface of the positive and negative conductors keeps unchanged on the onset value E_{on}.

Considering the controlling method in the iterative procedure, Poisson's equation should be substituted with

$$\nabla^2\varphi = -\frac{(1-\lambda)(\rho_p^+ - \rho_p^-) + \lambda(\rho_p^+ - \rho_p^-)}{\varepsilon_0} \tag{6}$$

where λ is mixing coefficient, ρ_p is the space charge density obtained in the previous iteration, and ρ_c is the space charge density obtained in the current iteration.

The detail of the upwind FEM theory and the iterative procedure can be found in [3], [5], and [6].

III. THE EFFECT OF MIXING COEFFICIENT

The ionized field of a ±660kV bipolar HVDC transmission line is computed. $6\times630mm^2$ bundle conductors are used. The spacing of split conductors is 45cm. The height of the conductors is 17.5m, and the distance between them is 19m. Two ground wires with diameter 15.75mm are placed 37.43m, the spacing between them is 21.4m. The effect of the mixing coefficient λ is shown in Fig. 1 and 2. When the mixing coefficient λ is employed (λ=1/4), the iterative procedure can be seen convergent when different initial ion densities are applied on the surface of conductors. Otherwise, convergence could not be achieved which can be seen in Fig. 2. Ec is the electric field on the surface of the positive conductor.

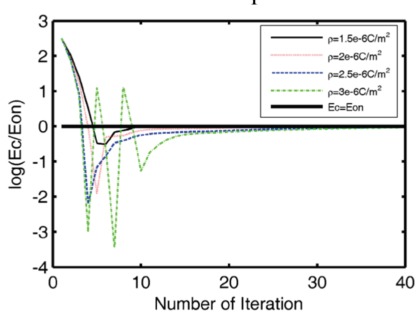

Fig. 1. Using mixing coefficient in the iterative procedure

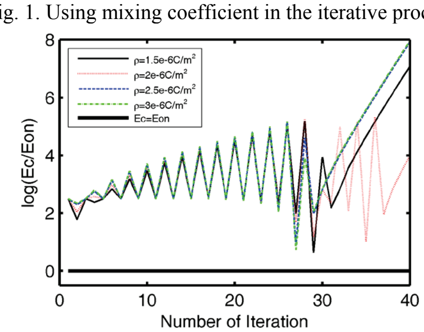

Fig. 2. Not using mixing coefficient in the iterative procedure

IV. THE EFFECT OF THE WIND

The ionized field of the bipolar line described above in the presence of the wind is computed. The electric field and the ion current density at the ground level for different wind velocities are calculated separately. Fig. 3 and 4 illustrate the ground level profiles of electric field and ion current density varying with the wind velocity.

The space charge density distribution of the transmission line described above with the wind velocity 5m/s is shown in Fig. 5 to analyze the influence on the ionized field. The charge density around the conductor is very strong. A small quantity of ions which are generated in the corona discharge flow to the ground wire, and the ions drift to the downwind side in the presence of the wind which can be seen clearly from Fig. 5. The phenomenon of the ions drifting lead accretion to the maximum of electric field and ion current density in the downwind side which can be seen in Fig. 3 and 4.

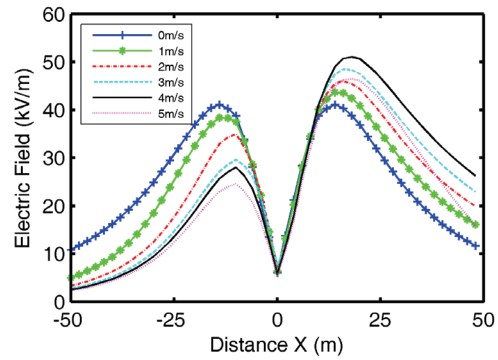

Fig. 3. Effect of the wind on the ground level electric field

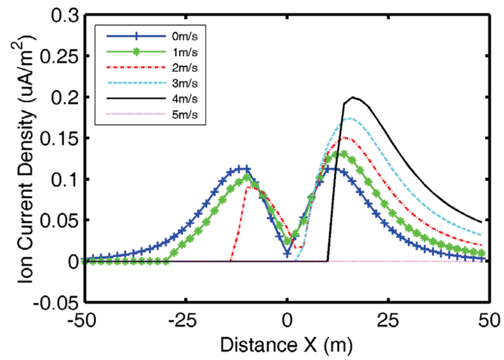

Fig. 4. Effect of the wind on the ground level ion current density

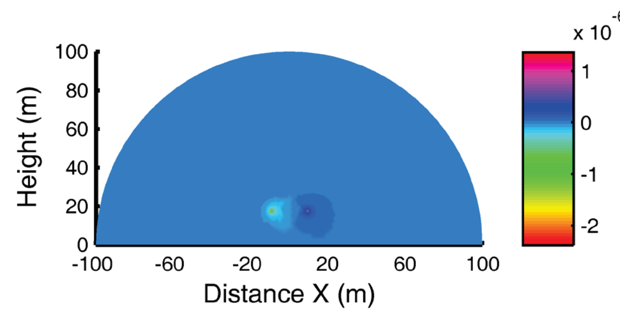

Fig. 5. The space charge density of the bipolar HVDC transmission line with the wind velocity 5m/s

V. REFERENCES

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