2D/3D Hybrid Calculation of Ion Flow Field near House under HVDC Bipolar Transmission Line

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Abstract —In this paper, a hybrid 2D/3D numerical method is introduced to solve the ion flow field near house under bipolar high voltage direct current (HVDC) transmission lines. At first, a 2D upwind finite element method (FEM) for the computation of the ion flow field near bipolar line structure is set up. Then a 3D method is used to analyze the ion flow field in the vicinity of a house under the HVDC lines. The 2D results serve as boundary conditions of the 3D calculation.

I. INTRODUCTION

The HVDC transmission lines affect the electromagnetic environment significantly. Especially, the corona effect produced by HVDC lines enhances the electrical field and forms a space charge distribution in a large range, which causes actual harm to the devices and human in the vicinity [1]. This ion flow field can be simulated by various numerical techniques, such as the finite difference method, the charge simulation method, boundary element method, and FEM [1-5]. Because the electric field and the space charge density are interacted, the ion flow field problem is none linear, iterative methods are usually introduced. However, all of these methods are based on the 2D assumption. They can not calculate the ion flow field in the vicinity of a house near HVDC bipolar lines. In this paper, a 2D/3D hybrid method is introduced to solve the problem.

II. COMPUTATIONAL METHOD

The equations which rule the bipolar ion field are [1]:

$$\nabla \cdot \boldsymbol{E} = (\rho^- - \rho^+)/\varepsilon_0 \quad (1)$$

$$\boldsymbol{J}^+ = \rho^+(k^+\boldsymbol{E} + \boldsymbol{W}), \quad \boldsymbol{J}^- = \rho^-(k^-\boldsymbol{E} - \boldsymbol{W}), \quad (2)$$

$$\nabla \cdot \boldsymbol{J}^+ = -R\rho^+\rho^- / e, \quad \nabla \cdot \boldsymbol{J}^- = R\rho^+\rho^- / e, \quad (3)$$

where $\boldsymbol{J}$, ρ, k, R, e, and $\boldsymbol{W}$ are ion current density, ion density, ion mobility, ion recombination coefficient, electron charge, and wind velocity respectively. Superscripts "+" and "-" indicate that corresponding variables are for positive or negative ion. Because the electric fields and the ions affect each other naturally, iterative method is used.

Paper [2] proposed a 2D upwind FEM to solve the equations. In our previous work, the upwind FEM method is improved on initial value selection and boundary processing to get better computing performance [5]. This FEM method includes two iterative parts. One part is to calculate the electric field distribution from the already known space charge distribution based on (1). The other part is to calculate the space charge distribution from the already known electric field distribution based on (2) and (3). With upwind FEM, space charge density is computed from nodes lying on the surface of positively or negatively energized conductors gradually to outward nodes with the distance from the conductors [2, 5].

Above process can be extended from 2D to 3D without more physics formulas. At the same time, the 3D electric field distribution can also be calculated by using 3D FEM. Thus, a 3D approach is set up. However, for the ion flow field in the vicinity of a house near HVDC bipolar lines, dividing the whole region and calculating the ion flow field in 3D will cause huge computational amount because the characteristic dimensions of the structure vary in a wide range with an order of three to four or even more.

Fortunately, the structure is unchanged along the lines on axial direction most of time. Using 2D method near the conductors will not draw large inaccuracy. However, in the vicinity of a house, 3D model has to be solved. So, effort is made to combine the 2D and the 3D methods as Fig.1 shows. First, the field is solved with 2D method neglecting the house. Then, in the vicinity region of the house, 3D method is applied to get a fine solution. The boundary conditions of 3D problem are controlled by the 2D results neglecting the house. What's more, 2D calculation result indicates that only one kind of polarity ions plays a dominant role while the other kind of polarity ions can be neglected outside of the right of way as Fig. 2 shows. Thus, the 3D method can be simplified due to the reality that the house must be built outside of the right of way.

In the region where there is only single kind of polarity ions, the equations ruling the ion field can be simplified from (1) to (3) as

$$\nabla \cdot \boldsymbol{E} = \rho / \varepsilon_0 \quad (4)$$

$$\boldsymbol{J} = \rho(k\boldsymbol{E} + \boldsymbol{W}) \quad (5)$$

$$\nabla \cdot \boldsymbol{J} = 0 \quad (6)$$

By substituting (4) and (5) into (6), following equation can be obtained:

$$(\nabla\rho) \cdot (k\boldsymbol{E} + \boldsymbol{W}) = -k\rho^2 / \varepsilon_0 \quad (7)$$

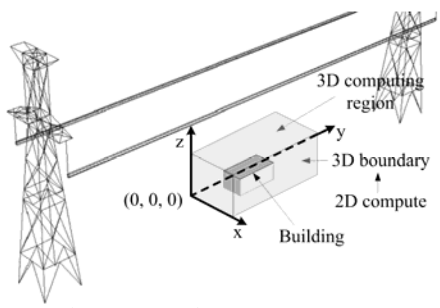

Fig.1. Method for calculating field around a house near HVDC lines

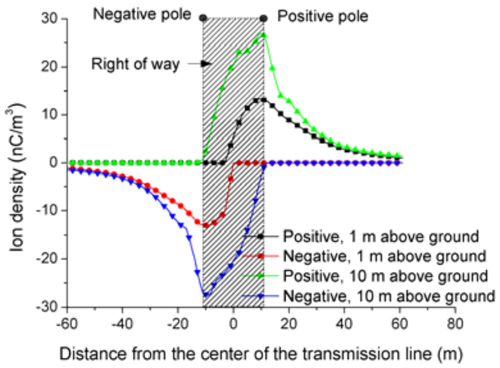

Fig.2. Ion density distribution under a ±800 kV bipolar HVDC line. Note that k^+ = 1.2 cm^2/V·s, k^- = 1.5 cm^2/V·s, R = 1.8×10^{-6} cm^3/s, $\boldsymbol{W}$ = 0 m/s, the lines are 18 m high. The two poles with 6 subconductors at each pole are 22 m away. The subconductor interval is 0.5 m and the radius is 17.2 mm.

Another equation is the Poisson's equation from (4):

$$\nabla^2 \varphi = -\rho / \varepsilon_0 \tag{8}$$

If the 3D computing region is subdivided into cuboids, and let the unknown variables φ and ρ be at the corners of the cuboids as Fig. 3 shows, (7) and (8) can be discretized into (9) and (10) by difference method [6]. Central-difference formula is used to get the electric field strength from the scalar potential φ in order to discretize (7) into (10).

$$\frac{\varphi_{i+1,j,k} + \varphi_{i-1,j,k} - 2\varphi_{i,j,k}}{\Delta x^2} + \frac{\varphi_{i,j+1,k} + \varphi_{i,j-1,k} - 2\varphi_{i,j,k}}{\Delta y^2} + \frac{\varphi_{i,j,k+1} + \varphi_{i,j,k-1} - 2\varphi_{i,j,k}}{\Delta z^2} = -\rho / \varepsilon_0 \tag{9}$$

$$\begin{aligned} &\frac{\rho_{i+1,j,k} - \rho_{i-1,j,k}}{2\Delta x}\left(k\frac{\varphi_{i-1,j,k} - \varphi_{i+1,j,k}}{2\Delta x} + W_x\right) \\ &+ \frac{\rho_{i,j+1,k} - \rho_{i,j-1,k}}{2\Delta y}\left(k\frac{\varphi_{i,j-1,k} - \varphi_{i,j+1,k}}{2\Delta y} + W_y\right) \\ &+ \frac{\rho_{i,j,k+1} - \rho_{i,j,k-1}}{2\Delta z}\left(k\frac{\varphi_{i,j,k-1} - \varphi_{i,j,k+1}}{2\Delta z} + W_z\right) \\ &= -k\rho_{i,j,k}^2 / \varepsilon_0 \end{aligned} \tag{10}$$

If the boundary conditions and the initial values are obtained, (9) and (10) can be solved by iterative steps:

1. The process is started by assigning initial values to ρ based on the 2D results. Let φ and ρ on the outside boundary which are determined by the 2D method be unchanged in each step. Let φ on the house be zero.
2. The scalar potentials are calculated by solving the group of equations of (9).
3. The ion densities are obtained by substituting φ into (10) and solving the corresponding equations. In order to get linear equations, ρ on the right side of the equations is regarded as known parameter which is the same as the one obtained in the previous step.
4. Step 2 and step 3 will be repeated until the scalar potential difference obtained in two consecutive iterations is small enough.

III. APPLICATION

In the formal paper, verification will be presented by comparing the calculated result with experimental one. As an application here, the ion flow fields around a house under a ±800 kV bipolar DC transmission line are analyzed. The transmission line and the coordinate system are the same with that in Fig.1. The origin of the coordinate is just under the positive pole of the line at the ground level. Then, the two diagonal points of the cuboid 3D computational domain are (0, 0, 0) m and (50, 60, 10) m. The two diagonal points of the cuboid house are (20, 20, 0) m and (30, 40, 5) m. Fig. 4 gives the scalar potential in the plane y=30 m which divides the house into two equal parts). It can be seen that the house can affect the electric field around it greatly.

IV. REFERENCES

[1] M.P.Sarma, *Corona performance of high-voltage transmission lines*, Research Studies Press LTD, New York, 2000.

[2] T. Takuma, T. Ikeda, and T. Kawamoto, "Calculation of Ion Flow Fields of HVDC Transmission Lines by the Finite Element Method," *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-100, No. 12, pp. 4802-4810, December 1981.

[3] Ming Yu, E. Kuffel, A new algorithm for evaluating the fields associated with HVDC power transmission lines in the presence of Corona and strong wind, *IEEE Transactions on Magnetics*, Vol. 29, No. 2, pp. 1985-1988, March 1993.

[4] Bo Zhang, Jinliang He, Rong Zeng, et al., "Calculation of ion flow field under HVdc bipolar transmission lines by integral equation method," *IEEE Transactions on Magnetics*, Vol. 43, No. 4, pp. 1237–1240, July 2007.

[5] Wei Li, Bo Zhang, Jinliang He, et al., "Calculation of the ion flow field of AC–DC hybrid transmission lines," *IET Gener. Transm. Distrib.*, Vol. 3, No.10, pp.911-918, October 2009.

[6] R. W. Hamming, *Numerical Methods for Scientists and Engineers*, Second Edition, McGraw-Hill Book Company, New York, 1973.

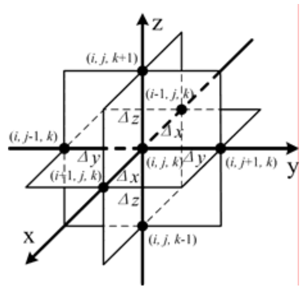

Fig.3. The coordinate system of the 3D method

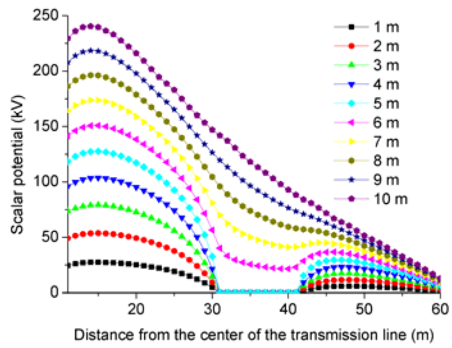

Fig. 4. Scalar potential at different height in the plane y=30 m. Note that the distance from the origin to the center of the transmission line is 11 m.