A Time-Efficient Method for the Simulation of Ion Flow Field of the AC-DC Hybrid Transmission lines

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Abstract — This paper presents a simulation method for the calculation of the field effects caused by the corona activities of hybrid AC-DC transmission lines. The present approach can simulate the convection and recombination of the space charge generated by AC or DC corona without improper simplification, and the conductor surface gradient is strictly kept on the onset value. The calculated ground level electric field and ion current density agree well with the measurement results of a hybrid line model.

I. INTRODUCTION

The AC and DC transmission lines sharing the same corridor or same tower (hybrid line) is a cost effective way for the transport of bulk power. However, due to the interaction between the AC and DC corona activities, it's difficult to accurately predicate the ground level electric field intensity and ion current density when the AC and DC transmission lines are in close proximity, which is a major obstacle for the design of an environmental-friendly hybrid line.

In the past three decades, several researches on the environmental effects of hybrid lines have been carried out. The first theoretical calculation was presented by Maruvada and Drogi in 1988 [1], but the voltage of AC line was assumed as 0 when the DC lines were analyzed. T. Zhao et al. proposed an improved method which assuming AC line is in several DC cases with instantaneous AC voltage during a cycle [2]. Recently, W. Li et al. reported the time dependent upwind difference method [3], which waives the Deustch's assumption. However, an explicit time scheme is used in [3], which makes it impossible to adopt a large time step. Another shortage of [3] is that the conductor surface gradient far exceeds the onset value, which contradicts with Kaptzov's assumption.

This paper proposes a time-efficient algorithm for the predication of the field effects of hybrid line corona performance. The finite element method (FEM) is applied to solve the Possion's equation, and the conductor surface gradient is kept on its onset value through an iterative scheme, which has not been reported by previous works. The convection and the recombination of the corona-generated space charge are simulated by the upwind finite volume method (FVM), but not just simple approximated by the solution of DC ion flow field. The combination of FEM and FVM is an extension to the donor cell approach proposed in [4-5]. Furthermore, an implicit scheme is utilized in this work, which can accelerate the computation. The validity of the proposed method is confirmed by the experimental results.

II. METHODOLOGY

Under some assumptions, the corona activities of hybrid lines can be described by following equations:

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

$$\begin{aligned} &\frac{\partial\rho^+}{\partial t} + \nabla\cdot\left(\rho^+ k^+ E\right) = -R\rho^+\rho^-/e \\ &\frac{\partial\rho^-}{\partial t} - \nabla\cdot\left(\rho^- k^- E\right) = -R\rho^+\rho^-/e \end{aligned} \tag{2}$$

where φ is the electric potential, ρ is the charge density, ε is the dielectric constant of air, k is the ion mobility, R is the ion recombination rate, e is the charge of the electron, and the superscript $+$ is for positive and $-$ for negative.

FEM is adopted to solve (1), which is formulated via Ritz method with linear elemental interpolation. The functional is:

$$\mathrm{I}(\varphi)=\int_\Omega\left[0.5\varepsilon\nabla\varphi\nabla\varphi - \rho\varphi\right]dV + \int_\Gamma \varepsilon\varphi E_n dS \tag{3}$$

where Ω is the computational domain, Γ is the Dirichlet boundary of Ω, E_n is the electric field intensity on Γ. E_n can be solved directly in (3), which greatly improved the accuracy for the calculation of the electric field intensity on surfaces of lines [6].

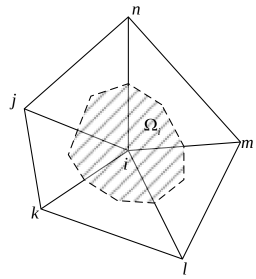


Fig. 1. Triangular mesh and its dual grid

Fig. 2. Field mills and Walson plates

Functional (3) is discretized in a triangular mesh, which is shown as solid lines in Fig. 1. Equation (2) is discretized in the dual grid of the triangular mesh, which is formed by connect the barycenters of two adjacent triangles, and the dual grid is illustrated as dashed lines in Fig. 1. After spatial and temporal discretization, equation (2) becomes:

$$\begin{aligned} &\rho^+_{i,n} + \Delta t\cdot R\rho^+_{i,n}\rho^-_{i,n-1}/e + \frac{\Delta t}{\Omega_i}\sum_{m=1}^{N_i}\rho^+_{i,m,n}k^+E_{i,m,n}l_{i,m} = \rho^+_{i,n-1} \\ &\rho^-_{i,n} + \Delta t\cdot R\rho^-_{i,n}\rho^+_{i,n-1}/e - \frac{\Delta t}{\Omega_i}\sum_{m=1}^{N_i}\rho^-_{i,m,n}k^-E_{i,m,n}l_{i,m} = \rho^-_{i,n-1} \end{aligned} \tag{4}$$

where Δt is the time step, Ω_i is the area of the i th control volume, subscript i, m, n means the corresponding variable locates at the m th edge of the i th control volume, and the time step number is n . N_i is the total number of edges encircling the i th control volume. The charge density at the midpoint of the edge is obtained from the interpolation in the upwind control volume, which is:

$$\rho_{i,m} = \rho_{i,m,up} + (x_{i,m} - x_{c,up})\left(\frac{d\rho}{dx}\right)_{up} + (y_{i,m} - y_{c,up})\left(\frac{d\rho}{dy}\right)_{up} \qquad (5)$$

where $\rho_{i,m,up}$ is the average charge density of the upwind control volume of the m th edge of the i th control volume, $x_{c,up}$ is the coordinate x of the barycenter of the upwind control volume for the m th edge of the i th control volume.

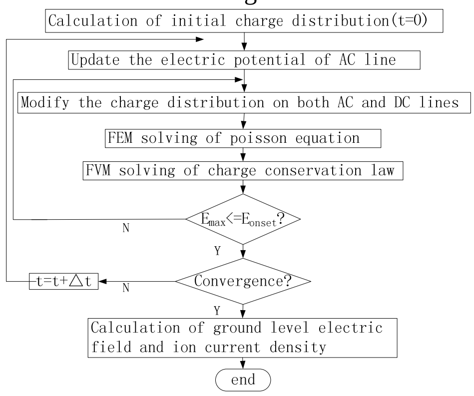


Fig. 3. Flow chart of the proposed algorithm

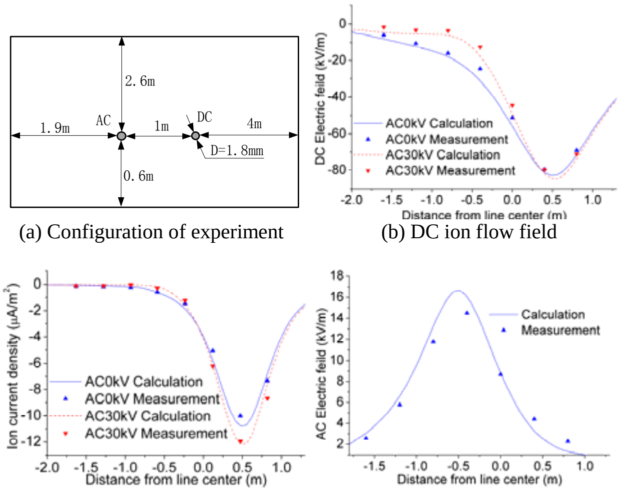
The calculation process of the proposed method is illustrated in Fig. 3. Two loops are incorporated. The inner loop is to found the appropriate charge distribution on both AC and DC lines, which makes the conductor surface gradient not higher than its onset value. The outer loop is for the time marching of the governing equations, which is repeated until the similar average charge density is obtained during the past two cycles. In each step, the linear equations derived from (4) are solved by the generalized minimum residual algorithm (GMRES).

III. Verification

In order to testify the validity of the proposed method, several different hybrid line models are set up. Parts of the electric mills and Walson plates for the measurement of electric field and ion current density are shown in Fig. 2. A hybrid line model with one AC line and one DC line is shown in Fig. 4(a). The DC line is charged to 60kV and the AC line is charged to 0V (without corona) or 30kVrms (with corona).

Both the calculated and the measured results of ground level DC ion flow field, DC ion current density and AC ion flow field are shown in Fig. 4(c)-(d). The calculated results agree well with experimental data, which validated the proposed algorithm. Fig. 4(b)-(c) show that the magnitude of ion current density right under the DC line increased by 11.2%, when AC line is in corona. On the contrary, the magnitude of ground level DC ion flow field right under AC line reduced by 48.6%, owning to an intensified AC line shielding effect results from the AC corona.

The mesh used in calculation consists of 2848 control volumes, and the radius of the smallest control volume is 0.204mm. According to Courant-Friedrichs-Lewy (CFL) condition, the time step of an explicit scheme should be smaller than 0.223 μs , which takes nearly 670,000 to reach a converged result. On the contrary, the time step adopted for the implicit scheme in this paper is 0.5ms, which only takes 300 steps to get a steady result.



(a) Configuration of experiment (b) DC ion flow field

(c) Ion current density (d) AC ion flow field

Fig. 4. Experiment configuration and measurement results

IV. Conclusion

A time-efficient method based on FEM and FVM is proposed to predict the field effects caused by hybrid line corona activities. The method is then verified by the experimental data. The calculation results with or without the presence of the AC corona are compared in this paper, which shows that AC corona has significant effect on the ground level electromagnetic environment.

V. Acknowledgement

This project is partly supported by Key Program of National Nature Science Foundation of China under grant No. 51037001.

VI. References

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