

Statistical Analysis of Ion Flow Field under HVDC Lines with Influence of Suspended-Particles

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The charged suspended-particle around HVDC lines will affect the ion current density and ion flow field, which are important to the design. In this paper, the stochastic-distribution model of the suspended-particle charge is proposed to calculate the ion flow field based on upstream finite element method. After the validity of the proposed model is verified by experiment results, the ion flow field under $\pm 800\text{kV}$ HVDC lines in the polluted environment is analyzed. Finally, statistical results such as maximum, minimum, average and percentile level of electric field are obtained. The research is helpful to design and construct HVDC lines.

Index Terms—ion flow field, stochastic model, suspended-particle, upstream finite element method.

I. INTRODUCTION

CORONA DISCHARGE is accompanied with high voltage direct current (HVDC) lines in operation, and consequently the problem of ion flow field including ion current density and electric field is generated [1]. During polluted weather with aerosols, space charges due to corona discharge of HVDC lines are accumulated on suspended-particles, and the ground-level electric field is increased [2]. The charge density of particles is varied with the suspended-particle size and number density. Therefore, the influence of the suspended-particle on the ion flow field needs to be considered in detail.

During the past years, some test results were obtained along outdoor DC test sections or real HVDC transmission lines, but modeling and calculation of ion flow field were not enough discussed to present more accurate prediction. Y. Yi analyzed the effect of air aerosols on the ion flow field base on Fuchs theory and Stokes-Einstein relation [3]. Q. Yong analyzed and calculated the ground-level electric field of $\pm 500\text{kV}$ HVDC lines under sand and dust conditions [4]. But the fixed particle size or the average particle size without consideration of particle stochastic distribution is the prerequisite in the above models. In March 2022, the revised Chinese national standard about the designing code of $\pm 800\text{kV}$ overhead transmission line was implemented, where the effect of airborne particles on ion flow field is required during the design of HVDC lines [5]. Therefore, it is necessary to better understand the influence of the suspended-particles. But in reality, the suspended-particles exist stochastically, therefore it is important to improve the charging model and calculation method with stochastic distribution of suspended-particles in order further to obtain more statistical results of ion flow field.

II. MODELLING OF SUSPENDED-PARTICLES

Because the movement of suspended-particles is much slower than positive and negative ions, the contribution of suspended-particles on ion current density can be neglected. Generally, the governing equation of ion flow field under HVDC lines in suspended-particle environment are:

$$\begin{aligned}\nabla^2 \varphi &= -(\rho_{e+} + \rho_{a+} + \rho_{e-} + \rho_{a-}) / \varepsilon_0 \\ \nabla \cdot (\rho_{e+} k_{e+} \nabla \varphi) &= -R_i \rho_{e+} \rho_{e-} / e \\ \nabla \cdot (\rho_{e-} k_{e-} \nabla \varphi) &= -R_i \rho_{e+} \rho_{e-} / e\end{aligned}\quad (1)$$

where e is the electron charge, φ is electric potential, ε_0 is the permittivity of the air, ρ_e is ion space charge density generated from corona discharge, ρ_a is suspended-particle charge density, k_e is ion mobility, R_i is ion recombination coefficient, and subscripts $+$ and $-$ indicate positive and negative polarity, respectively. After the artificial boundary is set besides the potentials of the conductor and the ground, upstream finite element method (FEM) can be used to solve the coupling problem of potential and space charge by iteration process [6], but the suspended-particle charge density should be determined firstly.

Space charges can be accumulated on particles in the ion flow field through field charging and diffusion charging [7]. If particles are suspended in the ion flow field for longer than 16 minutes, the charge on the surface of one spherical particle due to the field charging can be looked as the saturation value. For diffusion charging, the charge is depended on ion density.

Generally, particle sizes and density can be obtained by measurement, but the position of the particle with defined size is stochastic. At the node j , the charge density of the suspended-particle with the random size r_j can be determined:

$$\rho_{a,j} = 4\pi\varepsilon_0 N_j (r_j^2 E \frac{3\varepsilon}{\varepsilon + 2\varepsilon_0} + \frac{r_j K_B T}{e} \ln(1 + \frac{e\rho_e r_j t}{\varepsilon_0 \sqrt{2m\pi K_B T}})) \quad (2)$$

where E is the electric field, ε is the permittivity of the particles, N_j is the number density of the particles, K_B is Boltzmann's constant, T is the temperature, m is the mass of the particle, t is the duration time of the particles, which can be determined by

$$t = \varepsilon_0 \sqrt{2m\pi K_B T} (X - 1) / (e\rho_e r_j) \quad (3)$$

where the parameter X can be obtained by solving (4).

$$\frac{\varepsilon_0}{e} \ln X = \frac{100\rho_e r_j}{\sqrt{2m\pi K_B T}} \frac{1}{X} \quad (4)$$

In order to calculate the ground-level electric field, upstream FEM is modified to consider the charge density of the stochastic suspended-particles until the space charges and the electric field in the whole calculation region satisfy the stable condition. The

iterative process of ion flow field is illustrated in Fig. 1.

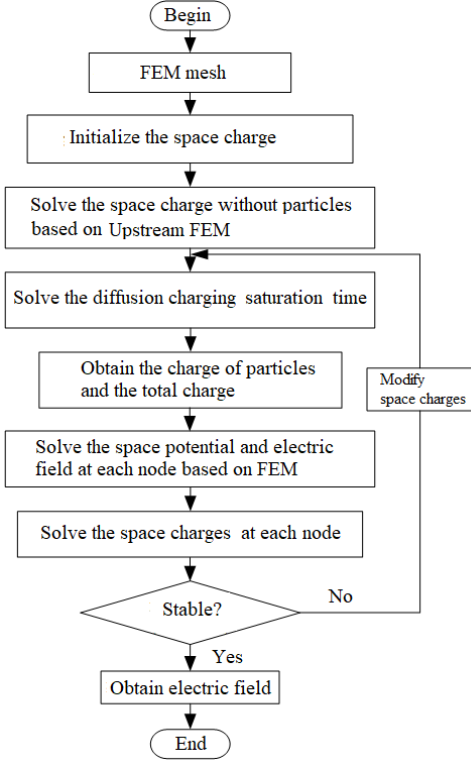


Fig. 1. The calculation process of ground-level electric field.

III. VALIDATION OF STOCHASTIC MODEL

In order to testify the validity of the stochastic model, the experiment is carried out in the artificial climate chamber filled with $2\text{mg}/\text{m}^3$ suspended-particles. The particle number density at different locations is the same. The temperature and relative humidity are regulated to 25°C and 40% , respectively. The electric field is measured by five field mills on the ground level. The particle size at different locations in the artificial climate chamber is measured separately, and the ground-level electric field is calculated based on the particle distribution. Statistic results of the ground-level electric field at the position 0.17m far from the projection of the test line are illustrated in Fig. 2. The average values of measurement results and calculation results at five positions are shown in Fig. 3 for the positive and negative line, respectively. The maximum error between measurement and calculation results is 8.11% . Calculation results agree very well with measurement results in the view of maximum, minimum, average and the probability distribution.

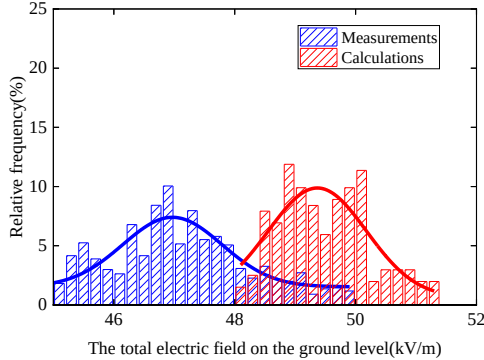


Fig. 2. Statistic results of calculation and measurement for positive line.

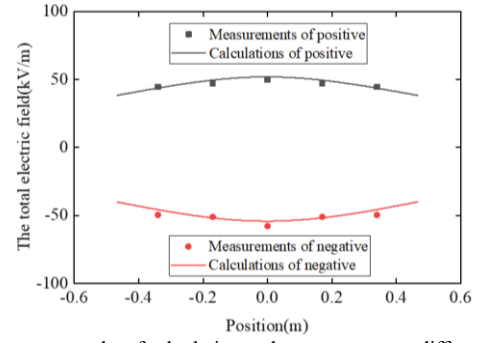


Fig. 3. Average results of calculation and measurement at different positions.

IV. APPLICATION

The ion flow field under $\pm 800\text{kV}$ DC lines in the polluted environment is statistically analyzed by using the proposed model. The ground-level electric fields at the lateral profile are illustrated in Fig. 4. Besides the results from the stochastic model, the results based on the average particle size is also calculated, which agree well with the average results based on stochastic model. But the maximum and minimum results cannot be determined if the average particle size is used. The electric field in clear weather also given in Fig. 4, which is lower than that in polluted weather. Therefore, when HVDC lines are designed, suspended-particles must be considered in order to predict the most serious situation. Other results will be analyzed in detail in the final paper.

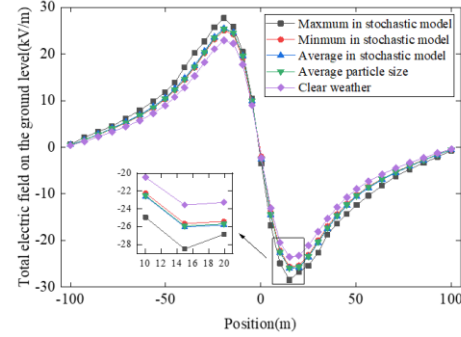


Fig. 4. The lateral results of ground-level electric fields under HVDC lines.

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