I. INTRODUCTION

Direct current (DC) transmission technology has significant advantages in large-capacity and long-distance transmission, so it has important applications in many countries and regions. As the main electromagnetic environment problem, the space charge modified field under the DC transmission lines has attracted more and more attention. The electric field is called space charge modified field or ion flow field, which is determined by both wires and space charges. The calculation and measurement of the space charge modified field have always been important research directions. There is an increasing need to measure the electric field on the ground near the transmission line or on the building. The DC electric-field-strength meters are important devices for the measuring of electric field, especially the rotating shutter-type field mills, which is widely used in long-term measurement under the transmission lines. To ensure the accuracy and reliability, simulation analysis and calibration experiment are commonly used.

Aiming at problems of simulation and experiment about calibration, on the basis of the previous researches, we carried out a new method to solve space charge modified field based on time-domain FEM, considering the convection diffusion equation. The calibration device is used from [6]. Through the complete convection diffusion equation, the ion movement after corona was simulated. The experiment was carried out to prove the correctness of the simulation. Finally, as an extension of the calculation method, the calibration for field mills to measure the space charge modified field above the ground. It has been confirmed that the same time, simulation analysis was performed to explain the feasibility of the method and provide a reference for calibration.

II. METHODOLOGY

A. Basic Equations

The problem of space charge modified field after the corona of thin copper wires can be described by the following equations:

\[ \nabla \cdot \mathbf{J} = - \rho \]

\[ \mathbf{J} = \mathbf{q} \nabla \phi \]

Equation (1) and (2) are the Poisson’s equation, and Equation (3) and (4) current continuity equation. Where \( \phi \) is the potential value and \( \mathbf{q} \) is the basic electron charge. \( \rho_+ \) and \( \rho_- \) are the number densities of positive and negative ions, respectively. \( \mathbf{E} \) is the electric field intensity vector and \( s_i \) is the permittivity of free space. \( D_+ \) and \( D_- \) are the positive and negative ion diffusion coefficients respectively. \( \mathbf{u} \) is the positive and negative ion recombination coefficient. \( \mathbf{u}_+ \) and \( \mathbf{u}_- \) are the positive and negative ion drift velocities, respectively, which are defined as:

\[ \mathbf{u}_i = -z_i e \mathbf{E} \]

B. Convection-diffusion Equation of Space Charge Modified Field

In order to express the basic equations as a convection-diffusion form, we expanded (3) and (4) as:

\[ \frac{\partial \rho_+}{\partial t} + \mathbf{u}_+ \cdot \nabla \rho_+ = \nabla \cdot (D_+ \nabla \rho_+) \]

\[ \frac{\partial \rho_-}{\partial t} + \mathbf{u}_- \cdot \nabla \rho_- = \nabla \cdot (D_- \nabla \rho_-) \]

\[ q_+ = -D_+ \nabla \rho_+ \]

\[ q_- = -D_- \nabla \rho_- \]

C. Comparison of Simulation Result and Theoretical Solution

The applied voltage of middle plate (z=0) was 300~1800 V and -300~2000 V respectively. The saturation current value could be measured by the current collection element and the ion mobility could be calculated.

IV. SIMULATION OF THE CALIBRATION OF THE FLOATING PROBE

The probe is calibrated in the middle of the field. When calibrating, the insulating rod may be used to support the probe, and the calibration is only for the upper surface of the probe. The field probe is cylindrical and the radius on upper surface is 2.5 cm, with a height of 5 cm. The center of the probe is right in the middle of the calibration field. In this calibration device, ground is used as the bottom to provide enough space for the field mill (d=0.5 m).

V. CONCLUSION

A simulation method based on the convection-diffusion equation is presented for the space charged electric field. The simulation results are in good agreement with the theoretical results, which verifies the validity of the calculation method.

The research provides a calculation basis for the calibration of the space charge modified field above the ground plane. Although the probe’s potential will rise due to the presence of ions with the charge distribution changing, the electric field strength does not change significantly. The difference between the calibration coefficients with and without ions is small. It can be considered that the calibration of field mills used in space are almost the same in the space-charge-free field or space charge modified field.

This research can provide a basis for the experimental research on the calibration of field mills to be implemented. Furthermore, the space charge modified field above the ground and near the building can be measured accurately in the future.

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**Table: Parameters and Values**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Positive ion mobility ( \mu_+ )</td>
<td>( 1.6 \times 10^{-7} \text{ m}^2 \text{v}^{-1} \text{s}^{-1} )</td>
</tr>
<tr>
<td>Negative ion mobility ( \mu_- )</td>
<td>( 1.7 \times 10^{-7} \text{ m}^2 \text{v}^{-1} \text{s}^{-1} )</td>
</tr>
<tr>
<td>Positive ion diffusion coefficient ( D_+ )</td>
<td>( 3.8 \times 10^{-6} \text{ m}^2 \text{v}^{-2} \text{s}^{-1} )</td>
</tr>
<tr>
<td>Negative ion diffusion coefficient ( D_- )</td>
<td>( 4.2 \times 10^{-6} \text{ m}^2 \text{v}^{-2} \text{s}^{-1} )</td>
</tr>
<tr>
<td>Ion recombination rate ( \Gamma )</td>
<td>( 2\times10^9 \text{m}^{-3} \text{v}^{-1} \text{s}^{-1} )</td>
</tr>
<tr>
<td>Vacuum electric constant</td>
<td>( 8.85 \times 10^{-12} \text{C}^2 \text{N}^{-1} \text{m}^{-2} )</td>
</tr>
<tr>
<td>Elementary charge ( e )</td>
<td>( 1.602 \times 10^{-19} \text{C} )</td>
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