

Modeling of Ion Flow Field under HVDC Transmission Lines Considering Sand Storm

Jianhui Wang¹, Yaotong Yang¹, Yong Ju², Tiebing Lu¹

¹ North China Electric Power University, Beijing, 102206 China, wangjh226@foxmail.com

² Department of High Voltage, China Electric Power Research Institute, Beijing, China, ju710@sina.com

In order to analyze impact of sandstorms on the ion flow field around HVDC transmission lines, a modeling and calculation method for the ion flow field in the sandstorm environment is proposed in this paper. The forces, motion, and the charge effects of sand particles are incorporated into the ion flow field calculations with the upstream finite element method. After the model is validated against the experiment results, the charging characteristics of the sand particles and the ion flow field in the sandstorm environment are analyzed. This study is helpful to the design of HVDC lines in sandstorm-prone areas.

Index Terms— HVDC transmission lines, ion flow field modeling, sand storm, charge effect.

I. INTRODUCTION

With the rapid development of HVDC engineering in desert area of western China, ion flow fields problem around HVDC transmission in sandstorm environments deserves more attention. Previous studies have shown that wind [1] and charged particles [2] significantly affect the distribution of ground-level electric fields. Research has also been conducted on modeling and calculating of the ion flow fields under the influence of fine suspended particles like haze [3]. In these models, the fine particles are assumed to be stationary in the air, so they have enough time to reach saturation charging.

During the sandstorms, the sand particles move rapidly under the wind drag, which results in much shorter charging times. Therefore, the charging process before saturation must be considered. Moreover, since the sand particles in storm can be larger and heavier, their velocity relaxation time cannot be ignored, and the forces and motion acting on the sand particles must be taken into account.

The objective of this study is to develop an ion flow field model that incorporates the forces, motion, and unsaturated charging of sand particles in sandstorm environments. The model's results are compared with experimental data to verify its effectiveness. Finally, the model is used to analyze the charging behavior of sand particles and the distribution of ground-level electric fields as sandstorms pass over HVDC transmission lines.

II. MODEL AND METHODOLOGY

A. Physical Model

Corona discharge on HVDC transmission lines generates space charges that affect the ion flow electric field nearby. Fig. 1 shows that when the sand particles pass through the ion flow electric field, they become charged by the ions, which forms sand current coupled with the ion flow field.

To simplify the model, the following basic assumptions are introduced:

- 1) Sand and ion flows are consistently stable and laminar.
- 2) The charge transfer between sand particles caused by the collisions are ignored.

- 3) The influence of the sand on the dielectric constant of the air is not considered.

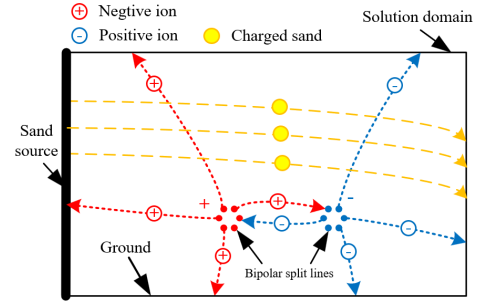


Fig. 1 Ion flow electric field in sand storm.

Sand particles near the corona lines are charged through collisions with ions. Collisions driven by the electric field are referred to as the *field charging* process, while those driven by the thermal motion of ions are termed the *diffusion charging* process [4], [5]. Near bipolar transmission lines, the sand particles are charged by both positive and negative ions. Reference [6] indicates that the charging processes by positive and negative ions are independent. Therefore, the charging process of sand particles can be described as follows:

$$\begin{cases} \frac{\partial q_{E+}}{\partial t} = \frac{K_+ q_{E\infty}}{4\varepsilon_0} \rho_+ \left(1 - \frac{q_{E+} - q_{E-}}{q_{E\infty}}\right)^2 \\ \frac{\partial q_{E-}}{\partial t} = \frac{K_- q_{E\infty}}{4\varepsilon_0} \rho_- \left(1 - \frac{q_{E-} - q_{E+}}{q_{E\infty}}\right)^2 \\ \frac{\partial q_{D+}}{\partial t} = \frac{\pi d^2 v}{4} \rho_+ \exp\left(-\frac{e|q_{D+} - q_{D-}|}{2\pi\varepsilon_0 d K_B T}\right) \\ \frac{\partial q_{D-}}{\partial t} = \frac{\pi d^2 v}{4} \rho_- \exp\left(-\frac{e|q_{D-} - q_{D+}|}{2\pi\varepsilon_0 d K_B T}\right) \end{cases} \quad (1)$$

where q_E and q_D represent the charges on the sand particles due to the field charging and diffusion charging processes, respectively, $q_{E\infty}$ is the saturation field charge, ε_1 and ε_0 are the dielectric constant of sand particles and air, v is the thermal velocity of the ion, K_B is the Boltzmann constant (eV/K), T is the temperature (K). v is the average velocity of thermal motion of space charges in ion flow field (m/s).

From (1), the charging rate of a sand particle depends on the saturation field charge, ion charge density, and the particle's existing charge. The charging process of sand particles thus acts as a charge source within the sand current. Consequently, the

physical problem can be described by the following set of equations:

$$\begin{cases} \nabla^2 \varphi = -(\rho_+ - \rho_- + \Sigma \rho_{si}) / \epsilon_0 \\ \mathbf{E} = -\nabla \varphi \\ \mathbf{J}_+ = \rho_+ \mathbf{V}_+ = \rho_+ (K_+ \mathbf{E} + \mathbf{v}_w) \\ \mathbf{J}_- = -\rho_- \mathbf{V}_- = \rho_- (K_- \mathbf{E} - \mathbf{v}_w) \\ \mathbf{J}_s = \Sigma \rho_{si} \mathbf{V}_s \\ \nabla \cdot \mathbf{J}_+ = -R_e \rho_+ \rho_- / e - \Sigma n_{si} \left(\frac{\partial q_{Ei+}}{\partial t} + \frac{\partial q_{Di+}}{\partial t} \right) \\ \nabla \cdot \mathbf{J}_- = R_e \rho_+ \rho_- / e + \Sigma n_{si} \left(\frac{\partial q_{Ei-}}{\partial t} + \frac{\partial q_{Di-}}{\partial t} \right) \\ \nabla \cdot \mathbf{J}_{si} = n_{si} \left(\frac{\partial q_{Ei+}}{\partial t} + \frac{\partial q_{Di+}}{\partial t} \right) - n_{si} \left(\frac{\partial q_{Ei-}}{\partial t} + \frac{\partial q_{Di-}}{\partial t} \right) \end{cases} \quad (2)$$

where φ is the potential (V), ρ_+ , ρ_- and ρ_{si} are the space charge density of positive ion, negative ion and charged sand particles respectively (C/m^3), $\mathbf{E}$ is the electric field intensity (V/m), K_+ and K_- are the positive and negative ion mobility (m^2/s), $\mathbf{v}_w$ is the wind speed, $\mathbf{V}_s$ is the speed of the sand particles, R_e is the ion recombination rate (m^3/s), e is the electron charge (C), $\mathbf{J}_+$, $\mathbf{J}_-$ and $\mathbf{J}_s$ are the current density of positive ion, negative ion and sand current respectively (A/m^2). The motion equations governing a sand particle are given by [5]

$$\begin{cases} \frac{d\mathbf{V}_s}{dt} = \frac{\mathbf{F}_E + \mathbf{G} + \mathbf{F}_d}{m} \\ \mathbf{V}_s|_{t=0} = \mathbf{v}_w \end{cases} \quad (3)$$

where $\mathbf{G}$, $\mathbf{F}_E$ and $\mathbf{F}_d$ are the gravity, electric field force and air drag force of a sand respectively, and m is the sand mass.

B. Solution Methodology

Extensive studies have been conducted on the modeling and calculation of ion flow fields, with the upstream finite element method (UFEM) being particularly well demonstrated and widely applied in previous works [7]. Like the ion current, the sand current can also be solved using the UFEM.

Fig. 2 illustrates the UFEM procedure considering the presence of a sandstorm, where δ_{ps} , δ_ρ and δ_E are the differences in sand space charge density, ion space charge density, and conductor surface electric field intensity between two iterations, respectively.

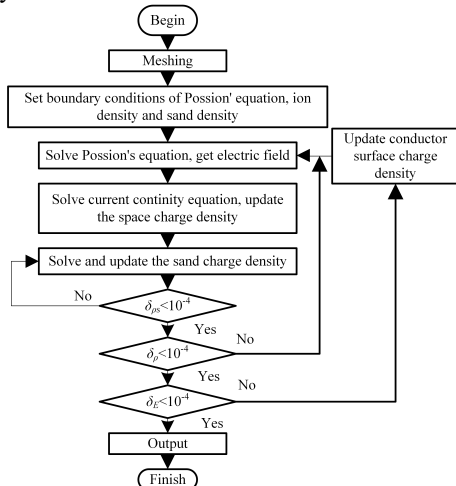
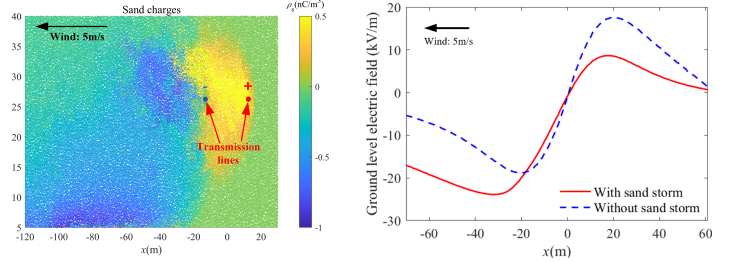


Fig. 2 UFEM considering the sand storm

III. PRELIMINARY RESULTS

A practical ± 800 kV HVDC transmission line model is analyzed, with the wind speed, sand particle diameter, and sand concentration set to 5 m/s, 0.1 mm, and 75 mg/m³.

Fig. 3 shows the calculation results for sand particle charges and ground-level electric fields. From Fig. 3 (a), sand particles become positively charged as they are blown near the positive line. However, as they approach the negative line, they quickly acquire negative charges, resulting in a significant accumulation of negatively charged sand particles beneath and beyond the negative line. From Fig. 3 (b), the ground-level electric field on the negative side is enhanced due to the presence of these negatively charged sand particles, while it is weakened on the positive side.



(a) Space charge density of sand.

(b) Ground level electric field.

Fig. 3 Calculation results.

IV. CONCLUSION

A modeling and calculation method for the ion flow field of HVDC transmission lines during sandstorms is proposed and the dynamics and charging behavior of sand particles are incorporated in the model. The charging characteristics of sand particles and the ground-level electric field distribution under sandstorm conditions have been preliminarily analyzed. Further calculation results and detailed analysis will be presented in the full paper.

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