International Conference on Lightning Protection
33rd International Conference on Lightning Protection
25 - 30 September 2016
Estoril, Portugal

Effects of Aerosol Particles on Corona Discharge upon Lightning Rod under Thundercloud

Xiufeng Guo
Collaborative Innovation Center on Forecast and Evaluation of Meteorological Disasters, Nanjing University of Information Science and Technology
Key Laboratory for Aerosol-Cloud-Precipitation of China Meteorological Administration, Nanjing University of Information Science and Technology
Nanjing, China
E-mail: xiufengguo@nuist.edu.cn

Qilin Zhang
Collaborative Innovation Center on Forecast and Evaluation of Meteorological Disasters, Nanjing University of Information Science and Technology
Key Laboratory for Aerosol-Cloud-Precipitation of China Meteorological Administration, Nanjing University of Information Science and Technology
Nanjing, China
E-mail: zhangqilin71@163.com

***Abstract*—Aerosol particles as a carrier of corona ion have a great effect on corona discharge. As the number concentration of aerosol differs significantly in different environment, a two dimensional corona particles diffusion/convection model in Cartesian coordinate system is conducted to investigate the effect of aerosol particle number concentration (NA) on corona discharge. By contrast the characters corona discharge electrical parameters variation and three corona particles movement in different environment with different NA, the results show that:1)NA has an effect on the attachment between aerosol particles and positive small ions released from lightning rod tip, and on the generation of positive large ions. More NA leads to larger ratio of positive large ions. The large ions move slower. The small ions move quicker. In addition, the charge structure of the large ions are relatively stable and gathered while that of the small ions are unstable and dispersive.2) Under the background condition that the electric field created by thunder cloud keeping changes, the waveform amplitude of corona current varying with time and the distribution of corona charge layer are different with different NA. The higher NA is, the lower corona current peak is and the faster rate of current fell is. Meanwhile, Corona space charge layer structures are gathered and relatively stable.**

Keywords- aerosol particle number concentration, corona particle, convection/diffusion, numerical simulation

I. INTRODUCTION

Corona discharges are common phenomena initiated from the tips of sharp objects on the ground under a thundercloud. And when the cloud was negatively charged, positive ions which are generated by these discharges move upwards under the influence of the background thundercloud electric field and then form a thick space charge layer around the object. This space charge layer is known to be shielding layer which has a great influence on the initiation and propagation of lightning upward leader and also on the measurement of the ground surface electric field used in artificially triggering lightning. Thus, the physics process of corona discharge and the temporal evolution of the space charge layer are both need to be studied. Extensive theoretical research on corona discharges from tall objects has been published in the literature in recent years[1,2]. However, in all of these studies the analysis has been based on very simple one dimension model of glow corona. A two dimensional model of the drift of the space charge generation was performed with COMSOL Multiphysics by Becerra[3]. But it was a axisymmetric model that is limited when objects is asymmetric or horizontal wind is existed in nature. What's more, aerosol particles floating in the air are indispensable to corona ions formation. Because they can attach the small ions generated from corona discharges and turn to be large ions. They are carriers of corona ions. Number concentrations of aerosol particles(*NA*) in different areas are greatly different between each other. Whether or not the different *NA* will take a great influence on corona discharge on lightning rod tip, it is still rarely known.

In order to contribute to the scientific discussion on this issue, a two-dimensional analysis of the effects of aerosol articles on corona space charge formation and drift is performed with Cartesian coordinate model. Thus, this paper introduces to the implementation of such model and the preliminary results obtained.

II. SIMULATION METHORDS

A. Governing Equations

In order to properly evaluate the effect of *NA* on the drift of corona ions from lightning rods, the two dimensional axisymmetric model proposed by Becerra is changed to two dimensional Cartesian coordinate model. The sketch of corona particles variation according to lightning rod are show as Fig.1. The continuity equations for small ions n_+, large aerosol ions N_+, and aerosol neutrals N_a are as follows:

$$\partial n_+ / \partial t = D \cdot \nabla^2 n_+ - \nabla \cdot \left(n_+ \cdot \mu_{n_+} \cdot E \right) - k_{nN} \cdot n_+ \cdot N_a \tag{1}$$

$$\partial N_+ / \partial t = D \cdot \nabla^2 N_+ - \nabla \cdot \left(N_+ \cdot \mu_{N_+} \cdot E \right) + k_{nN} \cdot n_+ \cdot N_a \tag{2}$$

$$\partial N_a / \partial t = D \cdot \nabla^2 N_a - k_{nN} \cdot n_+ \cdot N_a \tag{3}$$

together with the Poisson's equation for electric field E and potential φ:

This work was supported in part by the National Key Basic Research Program of China (2014CB441405), in part by the National Natural Science Foundation of China under Grant 41275009，40975002, and a project funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD) .

$$\nabla \cdot E = \nabla^2 \varphi = e \cdot (n_+ + N_+) / \varepsilon_0 \quad (4)$$

the where μ_{n+} and μ_{N+} are the ionic mobilities for small and aerosol ions which values are respectively $1.5 \cdot 10^{-4}$ $m^2s^{-1}V^{-1}$ and $1.5 \cdot 10^{-6}$ $m^2s^{-1}V^{-1}$. k_{nN} (assumed to be $2.9 \cdot 10^{-12}$ $m^{-3}s^{-1}$, while D is chosen as 1 m^2s^{-1}) is the small positive ion attachment coefficient to aerosol particles, D is the diffusion coefficient, e is the elementary charge and ε_0 is the dielectric permittivity. The values used for these quantities are taken from [3,4]. The initial number concentration of N_+ and n_+ are zero (LN respect for the number concentration of large ions while SN for small ions). The initial value of N_a is based on cases that we study in the following paper and used N_0 to express the initial value.

The boundary conditions used in the model are as follows. When solve (4), a time varying potential with voltage $V=E_b \cdot H$ is applied to the upper boundary, where E_b is the background electric field and H is the height of the boundary. E_b is the negative thundercloud electric field assumed to increase linearly up to 20 kV/m in 10s. The left and right boundaries are defined as electric insulation. The other boundaries are set as zero potential. When solve the continuity equations, the rod surface boundary is defined as a concentration boundary. The surface of the rod where the local electric field is equal to or larger than the onset corona field *E*cor is assumed to be satisfies the condition. And the corona ions are emitted from this boundary. The concentration of small ions at this boundary can be calculated based on Kaptzov's assumption. The ground surface boundary considered as a zero flux boundary while others are set as convection edge. The corona onset electric field *E*cor is estimated with the Peek equation.

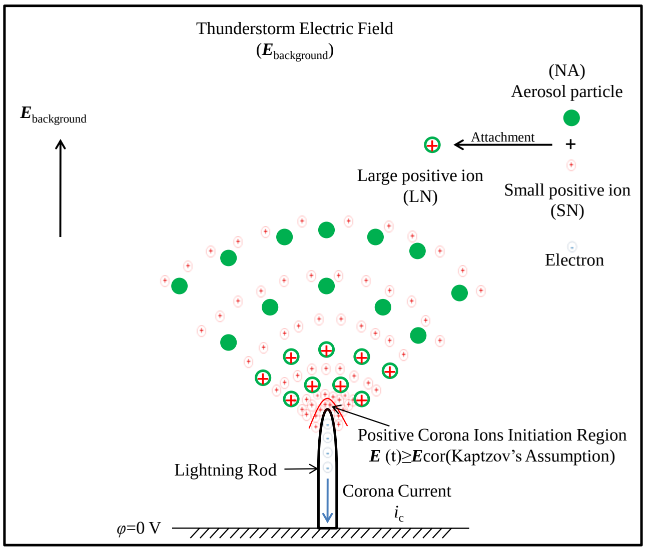

Figure 1 Sketch of corona particles variation according to lightning rod.

B. Calculation Methods

We use five point finite difference method to solve the Poisson's equation. And upwind difference scheme[5] is used to solve the continuity equations. The lightning rod considered in this paper is 40 m height with 0.5 m tip radius. In order to make ions drift within the boundaries, we get a simulation region with hundreds meters width and height. In order to calculate faster and make the area can be considered much larger, the appropriate spatial resolution and time resolution should be set and meanwhile should match with each other. Thus, spatial resolution and time resolution are respectively 1m and 0.01s. The solutions of the continuity equations is stable. Based on Peek equation, *E*cor has been calculated under 1m spatial resolution for the rod and its value is $1.08 \cdot 10^5$V/m. And when E_b small than 20kVm^{-1}, E_b=8600V/m+t*(20kVm^{-1}/10s). When t=5.7s, E_b equal to 20kVm^{-1}.

III. SIMULATION RESULTS

Two typical values of the number concentrations of aerosol particles assumed in this paper are $N_0=10^9$ m^{-3} as a value for clean air and $N_0=10^{11}$ m^{-3} as a value for a moderately polluted urban area, respectively.[6] Then, the effects of aerosol particles on corona discharge upon lightning rod under thundercloud are considered. The differences caused by N_0 on corona current varying with time, distribution of corona charge density, temporal evolution of three corona particles and the electric field in the space are discussed. And the results are all shown as the following figures.

Figure 2 shows that when E_b reach to the maximum, the corona current (*I*c) reach to peak value, but while E_b do not increase, the *I*c begin to decrease. N_0 is larger, the peak of Ic is smaller, and its decrease tendency is larger.

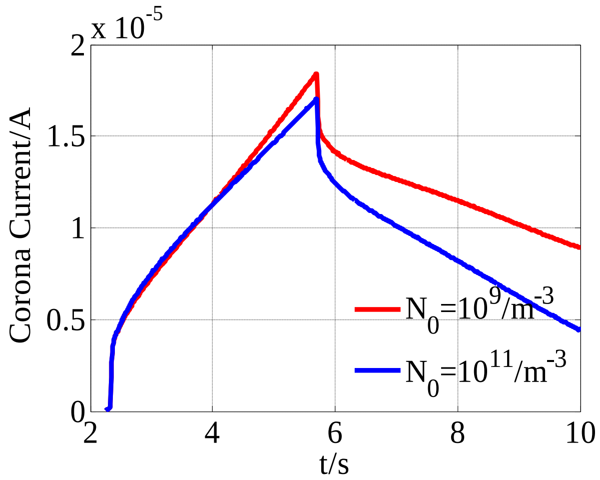

Figure 2 Computed time variation of the corona current computed with different N_0 under the background thundercloud electric field shown

The distribution of space corona charge densities (Q) are also shown different at the moment of E_b reach at 20kV$m^{-1}$for different N_0. As shown in Figure 3, when N_0 is large, the charges are mainly gathered near the lightning rod tip, the Q at this area is large than when N_0 is small. But it also shown that, the space corona charge can drift farther with small N_0. It means that the higher the concentration of neutral particles, for example, 10^{11} m^{-3}, the thinner the space charge layer but the charge density in this layer is larger.

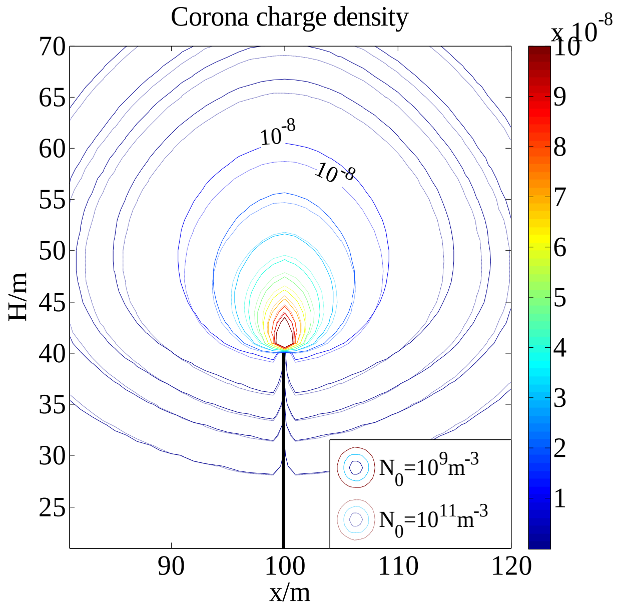

Figure 3 Contour plots of the numerical concentration of the generated space charge produced by the glow corona from from lightning rod. The figure correspond to the results when the $\boldsymbol{E}_{\mathrm{b}}$=20 kV/m. Solid lines are used for $N_0=10^9$ per cubic metre and dashed lines are used for $N_0=10^{11}$ per cubic metre.

Aerosol particles attach the small positive ions and charge to large positive ions. Thus, the more aerosol particles in the air, the more large positive ions will be generated. Because of the different mobility, the distributions of large ions and small ions will be different. As figure 4 shows, at the same height level, *SN* is smaller in larger N_0 while *LN* is larger in larger N_0. After E_{b} never change, the *SN* begin to reduce more significant in larger N_0. The variations of *LN* generation and *NA* disappearance with time are the same in the corresponding N_0.

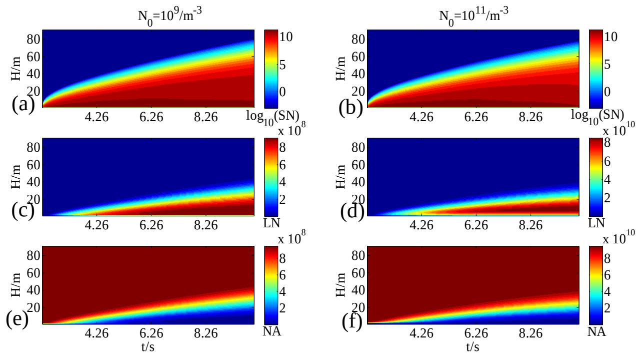

Figure 4 Time variation of numerical concentration of three corona particles computed with the 2D model upon the lightning rod tip with $N_0=10^9$ m^{-3} shown in the left column and with $N_0=10^{11}$ m^{-3} shown in the right column. The numerical concentration in (a)(b) is positive small ions; (c)(d) is positive large ions and (e)(f) is neutral aerosol particles. The vertical coordinates *H*=0 m shows the height of lightning rod tip.

As the change of E_{b}, the space corona charge density and the ratio of the small ions and large ions in the space upon the lightning rod tip are all changed. And those change are different with different N_0. Thus, this will lead to differences of electric field temporal and spatial evolution. And this may further influence the initiation of upward leader from the rod. From figure 5, we can found that the differences between time variation of electric field with different N_0 are significant after E_{b} stay stable. With larger N_0, near the tip, space charges contain more large ions which drift slowly, the space charge layer are more gathering and stable, and the electric field created by those charges will change less obvious.

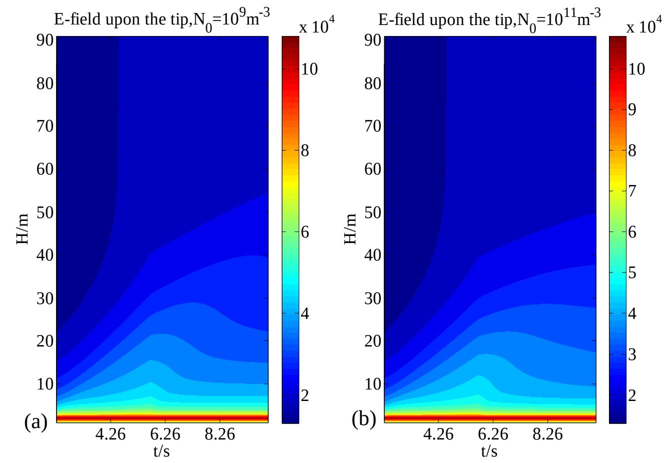

Figure 5 Time variation of electric field computed computed with the 2D model upon the lightning rod tip with (a) $N_0=10^9$ m^{-3} and (b) $N_0=10^{11}$ m^{-3}. The vertical coordinates *H*=0 m shows the height of lightning rod tip.

IV. Conclusions

A two dimensional Cartesian coordinate model of the drift of ions generated by glow corona at the tip of lightning rod under thundercloud has been introduced. The obtained results shows clear differences caused by different aerosol particles on corona discharge. Aerosol particles have an effect on the attachment between aerosol particles and positive small ions released from lightning rod tip, and on the generation of positive large ions. More aerosol particle leads to larger ratio of positive large ions. The large ions move slower. The small ions move quicker. In addition, the charge structure of the large ions are relatively stable and gathered while that of the small ions are unstable and dispersive. Under the background condition that the electric field created by thunder cloud keeping changes, the waveform amplitude of corona current varying with time and the distribution of corona charge layer are different with different aerosol particle number concentrations. The higher aerosol particle number concentrations is, the lower corona current peak is and the faster rate of current fell is. Meanwhile, Corona space charge layer structures are gathered and relatively stable.

References

[1] N. L. Aleksandrov, et al., The effect of coronae on leader initiation and development under thunderstorm conditions and in long air gaps. Journal of Physics D Applied Physics, 2001. **34**(22): p. 3256-3266.

[2] N. L. Aleksandrov, E. M. Bazelyan, M. M. Drabkin, R. B. Carpenter, and Yu. P. Raizer, 'Corona Discharge at the Tip of a Tall Object in the Electric Field of a Thundercloud', *Plasma Physics Reports*, 28 (2002), 953-64.

[3] M. Becerra, 'Glow Corona Generation and Streamer Inception at the Tip of Grounded Objects During Thunderstorms: Revisited', Journal of Physics D Applied Physics, 46 (2013), 135205-17(13).

[4] X. Qie, S. Soula, and S. Chauzy, 'Influence of Ion Attachment on the Vertical Distribution of the Electric Field and Charge Density Below a Thunderstorm', Annales Geophysicae, 12 (1994), 1218-28.

[5] Richard Courant, Eugene Isaacson, and Mina Rees, 'On the Solution of Nonlinear Hyperbolic Differential Equations by Finite Differences', Communications on Pure and Applied Mathematics, 5 (1952), 243-55.

[6] S. Twomey, Atmospheric AerosolsElsevier Scientific Pub. Co., 1977, pp. 275–78.