Experimental Study on Influence of Gas Flow on Trichel Pulse Discharge

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Abstract. Negative corona discharge is the basis of electrostatic precipitator (ESP) which has been widely used in various production fields due to its significant advantages. The characteristics of negative corona discharge have an important impact on dust removal efficiency of ESP. In this paper, the influence of airflow on negative corona discharge has been studied experimentally based on needle-net discharge model which is simplified of ESP discharge electrodes. Using statistical method, the influence of airflow on the parameters of Trichel pulse was analyzed. According to the simulation results of the negative ion density distribution in the discharge zone by COMSOL software, the reasonable explanation for the experimental results is given.

1. Introduction

With the rapid development of social economy, air pollution has become one of the main factors that restrict the development of social economy. Electrostatic precipitator (ESP) is a device for collecting dust by negative corona discharge effectively [1, 2]. With lots of advantages, such as high dust removal efficiency, small resistance loss, large amount of treatment flue gas, and so on, it is widely used in various industry fields [3, 4]. With the increasingly strict regulations on dust emission standards, how to improve the efficiency of ESP and reduce energy consumption within limited conditions has become one of the primary problems for researchers.

Negative corona discharge is the basis of ESP, of which the intensity and characteristics affect the dust removal efficiency. There are many factors that affect the negative corona discharge in ESP. Most of research work about ESP is carried out around these factors. The influence of temperature on negative corona discharge has been studied by PEIYAN [5]. The influence of humidity on negative corona discharge has been studied by Deng Chunfeng and H. Nouri [6-7]. However, the research work on the effects of airflow direction and airflow velocity on negative corona discharge is rare.

In this paper, the influence of airflow on negative corona discharge has been studied experimentally based on needle-net discharge model. Using statistical method, the influence of airflow on the parameters of Trichel pulse was analyzed. With COMSOL, the negative ion density distribution in the discharge zone is simulated. According to the simulation results, the explanation for the influence is given from the microscopic angle and the ion force angle.
2. Experimental setup

The experimental device includes three parts: a negative high voltage DC power supply, discharge system and measurement system as shown in Fig.1. The high-voltage power can supply the voltage with -30kV and 0.3A. In order to make sure the airflow pass smoothly, the needle-net is used as the discharge system. The needle tip radius is 0.1mm. The net size is 50×100mm². The area of the net-hole is 2×2mm². The distance between needle and net is 10mm. The needle and net are stainless steel. The measurement system includes a oscilloscope, a high-voltage probe, a common probe, and a sampling non-inductive resistance. The oscilloscope is Tek Tronix DOP2024, of which the sampling frequency is 1G/s. The high voltage probe is connected to the discharge needle for measuring the discharge voltage. The ground plate is connected to the ground through the sampling resistor. The current wave can be obtained by measuring the voltage of the non-inductive resistance.

During the experiment, the airflow is provided by an air compressor and the velocity was measured by a pitot tube up to 80m/s. The airflow direction is supplied from three directions as shown in Figure 1: direction 1 is perpendicular to the direction of the electric field; direction 2 is opposite to the direction of the electric field, which is from the needle to the net; the direction 3 is the same as the direction of the electric field, which is from the net to the needle. In order to facilitate the subsequent description, the directions 1, 2, and 3 are used instead of the specific direction of the airflow in the paper.

3. Experimental results

The influence of the airflow direction and airflow velocity on negative corona discharge is studied respectively in this paper. Figure 2 shows the VI characteristic curves of negative corona discharge under the different directions and the different velocity of airflow.
It can be seen that airflow from different directions has different effects on negative corona discharge. Meanwhile, this kind of effect is amplified by the increase of the airflow velocity. When there is no airflow, the discharge current is about 4.9 μA at the voltage of -5kV. When voltage rises to -10kV, the discharge current is about 54 μA. When the airflow is from direction 1 and the velocity is 80m/s, the discharge current is about 3 μA at the voltage of -5kV and 52 μA at the voltage of -10kV. It can be seen that the discharge current is almost unchanging. Therefore, the airflow from direction 1 has little effect on the negative corona discharge intensity. When the airflow direction is direction 2 and the velocity is 80m/s, the discharge current is about 8.9 μA at the voltage of -5kV and 78 μA at the voltage of -10kV. It can be seen that the discharge current increases with the increasing of the velocity of airflow. Therefore, the airflow from direction 2 promotes the intensity of negative corona discharge. When the airflow direction is from direction 3 and the velocity is 80m/s, the discharge current is about 0.1 μA at the voltage of -5kV and 27.4 μA at the voltage of -10kV. It can be seen that the discharge current decreases with the increasing of the velocity of airflow. The airflow from direction 3 weakens the intensity of negative corona discharge.

The current waveform of negative corona discharge is Trichel pulse. The typical pulse waveform is shown in Figure 3. Using statistical methods, the influence of airflow on parameters of Trichel pulse is statistically analysed in this paper. The parameters mainly include the rising time $t_r$, the half-wave falling time $t_f$, the amplitude of pulse $A$, and the time of adjacent pulse interval $t_i$. In the follow-up study, it is found that the trend of influence does not change with the change of the load voltage. Due to the space problem, the analysis results at the voltage of -8kV is given in this paper.

**Figure 2.** The influence of airflow on the current of negative corona discharge

**Figure 3.** The typical Trichel pulse waveform
Figure 4 shows the probability distribution of each parameter of Trichel pulse at different directions and different velocity of airflow when the voltage is -8kV. It can be seen that $t_r$ and $t_f$ are almost unaffected by the airflow. $t_r$ is always maintained at about 90ns, and $t_f$ is kept at about 200ns. Regardless of the direction of the airflow, $a$ increases with the increase of the airflow velocity, but the increase rate is not the same at the different directions of airflow. When there is no airflow, $A$ is mainly maintained at about 0.36mA. When the airflow is from the direction 1 and 80m/s, $a$ rises to about 0.7mA. When the airflow is from the direction 2 and 80m/s, $a$ rises to about 0.6mA. When the airflow is from the direction 3 and 80m/s, $a$ rises to about 0.86mA. It can be seen that, when the airflow is from direction 3, the amplitude of the pulses increases the most, and when the airflow is in the direction 2, the amplitude of the pulse increases the least. When the airflow is in direction 1 and direction 3, $t_i$ becomes larger, that is the pulse frequency decreases. When there is no airflow, $t_i$ is about 11.3 $\mu$s, and when the airflow is from direction 1 and 80m/s, $t_i$ increases to about 17$\mu$s, and when the airflow is from the direction 3 and 80m/s, $t_i$ increases to about 20$\mu$s. It can be seen from the comparison that when the airflow comes from direction 3, $t_i$ changes the most. When the airflow is from the direction 2 and 80 m/s, $t_i$ is shortened to about 7 $\mu$s.

Figure 4. The influence of airflow on the Trichel pulse parameters at the voltage of -8kV

4. Simulation results
Using COMSOL, the negative ion density in the discharge region of needle-net negative corona discharge is simulated. The modeling data was consistent with the experimental setup, and the loading voltage was -8kV. Figure 5 shows the negative ion density distribution at the pulse start time and the pulse peak time.
It can be seen from Figure 5 that the distribution of negative ion clouds changes as the direction of the airflow changes. In the presence of airflow from direction 1, the distribution of negative ion density deviates from the symmetry line and coincides with the direction of the airflow, whether at the start time or peak time of the pulse. The spatial distribution of the negative ion density remains symmetric when the longitudinal airflow exists. However, longitudinal airflow in different directions also has different effects on negative ion density distribution. The distribution of negative ion density changes correspondingly with the direction of the airflow. At the same time, in the presence of airflow, the negative ion density increases, which is consistent with the experimental result of the increase in the pulse discharge amplitude.

5. Discussion
According to the basic principle of gas discharge, when the discharge medium is air, there are electrons and oxygen anions in the discharge region, and the oxygen anions are mainly involved in the discharge. In this paper, further analysis is carried out from the angle of plasma stress. When there are airflows passing through the discharge region, the force of oxygen anions is shown in Figure 6. It can be seen that when there is airflow, when there is airflow, the combined force of the oxygen negative ions is the superposition of the electric field force and the inertial force of the airflow (ignoring gravity). So its moving speed and motion trajectory are changed compared with no airflow. Therefore, in the simulation results, when there is airflow, the distribution of negative ion density changes as the direction of the airflow changes. The dissipation time of the negative ion cloud determines the interval time between pulses. When there is airflow from the direction 2, the direction of inertial force is the same as the electric field force, which accelerates the movement speed of the negative ion cloud to the ground plate. Therefore, dissipation time of the negative ion cloud is shortened and the pulse interval time is shortened. When there is airflow from the direction 3, the direction of inertial force is the opposite of the electric field force, which slows down the movement speed of the negative ion cloud to the ground plate. Therefore, dissipation time of the negative ion cloud is longer and the pulse interval time is longer. When there is a flow in the direction 1, the trajectory of the negative ion cloud becomes longer, and therefore, the negative ion dissipation time increases, and the pulse interval time becomes larger.
6. Conclusion
In this paper, the influence of airflow on negative corona discharge is studied experimentally. Using statistical method, the influence of airflow on the parameters of Trichel pulse is analyzed. Based on COMSOL, the distribution of negative ion density in the discharge zone was simulated. The main conclusions are as follows:

1. The airflow from different directions has different effects on negative corona discharge. Meanwhile, this kind of effect is amplified by the increase of the airflow velocity. The airflow perpendicular to the direction of the electric field has little effect on the discharge intensity. The airflow opposite the direction of the electric field enhances the discharge intensity. Airflow in the same direction as the direction of the electric field weakens the discharge intensity.

2. The airflow has little effect on the rising time and the half-wave falling time of Trichel pulses. The presence of airflow increases the amplitude of the pulse. Pulse amplitude increases when there is airflow. Airflow in different directions has the different effect on the pulse interval time.

3. The distribution of negative ion density in the discharge region changes correspondingly as the direction of the gas flow changes. Negative ion density increases when there is airflow.

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