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Impact of fine particles on the direct current electric field of the conductor due to corona discharge

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ABSTRACT

Corona-generated ionized field is an essential electromagnetic parameter of high voltage direct current transmission lines. In order to investigate the impact of atmospheric fine particles on the DC ionized field, distributions of the ground-level ionized field and ion current density were measured under various air contamination extents in a wire-to-ground platform. The fine particles were generated from burning incense. Measurement results show that the magnitude of ground-level ionized field may increase approximately by 20% when particles in the order of 10^2 μg m^{-3} exist in air. Restriction effect on the ionized field by using grounded shielding lines was also examined.

1. Introduction

Corona discharge occurs when the electric field strength on the surface of the conductor exceeds the corona inception value. Air molecules near the high-voltage (HV) conductor are ionized when corona discharge takes place, giving rise to positive and negative ions. Ions in direct current (DC) corona discharge may have severe effects on the distribution of electric field, contributing to the field known as the ionized field [1], or the ion-flow field [2]. Ions move to the ground and then the ion current is generated.

When designing HVDC transmission lines, it is an important and fundamental task to predict the corona-generated electric field, which may endanger human exposure [2] because the ions increase the electric field magnitude on the ground. However, it is difficult to calculate the electric field of HVDC lines due to the complicated mechanisms of corona discharge. In addition, when haze pollution episodes occur, atmospheric aerosols or fine particles will be charged by the ions and make the characteristics of the ionized field more complex [3]. Thus, it is necessary to investigate the impact of fine particles on the ionized field of HVDC transmission lines.

The impact of atmospheric charged particles on the electromagnetic environment of HVDC transmission lines may be investigated firstly in 1980. Dr. Hoppel [4] utilized three particle number densities (10^4, 3×10^4, 10^5 cm^{-3}) to denote clean, moderately, and severely polluted air. The charge transfer due to the ions captured by the particles was analysed. In 1988 Dr. Johnson et al. [5] measured the densities of ions and charged particles under the 500 kV unipolar test line by using a Faraday cage. Dr. Bailey et al. [6] reported the measurement results of charged aerosols near 500 kV HVDC transmission lines in 2012. However, the ionized field strength under the HVDC lines was not measured with the presence of atmospheric particles.

In this paper, the ionized field distribution on the ground level is measured with the presence of fine particles. The ionized field is generated between a HV cylindrical conductor and the ground. Fine particles are generated from burning incense. Moreover, the restriction of the ionized field with the presence of fine particles is also performed by utilizing parallel grounded shielding lines, which are supported between the HV conductor and the ground.

2. Analysis of the fine particles

Fine particles were generated from burning incense, which was mounted on the ground plate of the measurement platform. The mass concentration of the incense particles was measured by a laser particle meter (LD-5C) based on the light scattering theory [7]. The magnitude order of the diameter of incense particles was in the range of micrometer (μm) [8], which was measured by an optical

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particle sizer (TSI 3330) and shown in Fig. 1.

The scanning electron microscope (SEM) image of the incense particles was obtained by FEI Quanta 200 F, as indicated in Fig. 2. The incense particles were collected by a glass fiber filter paper mounted in the laser particle meter. Incense particles adhered to the fibers of the filter paper. The particles have ellipsoidal shape with a size in the order of μm.

The elementary composition of the incense is shown in Table 1. In Table 1, the terms of "*wt*" and "*at*" denote the weight proportion and atom number proportion, respectively. The feature element of the incense particles is carbon. The quality of oxygen and silicon was also significant because the glass fiber paper was made from SiO_2.

3. Measurement of the DC ionized field with the presence of fine particles

3.1. Measurement platform

The configuration of the measurement platform for the ionized field is shown in Fig. 3. The measurement platform was located in an indoor closed laboratory. A stainless steel wire with the diameter 4.0 mm was used as the high-voltage conductor, which was supported by two insulation rods on the grounded plate. The conductor was connected to a HV source (Matsusada AU-120) via a HV cable. The output voltage of the HV source was stable within 0.1% [9]. Two shielding spheres were interlinked into the conductor at both ends to reduce point discharge. The length and the height H of the conductor were equal to 4.5 m and 0.54 m, respectively. The burning incense was mounted under the HV conductor and was moved away when the experiments began.

Five field mills were employed to measure the electric field distribution on the grounded plate. The No. 3 one was at the centre and directly under the conductor. The field mill has a sensing electrode that is periodically exposed and shielded from the external dc electric field by a grounded rotating shutter [1, 9–10]. The induced current in the field mill probe is obtained to indicate the polarity and the magnitude of the external electric field. The distance between two adjacent field mills equalled 0.25 m. The accuracy of the field mills to measure DC ionized field strength is 3% when space charge density is less than 0.5 μC m^{-3} [9, 11].

Ion current density directly under the HV conductor was measured by an ion current plate [12–14] located near the No. 3 field mill. The configuration of the ion current plate is shown in

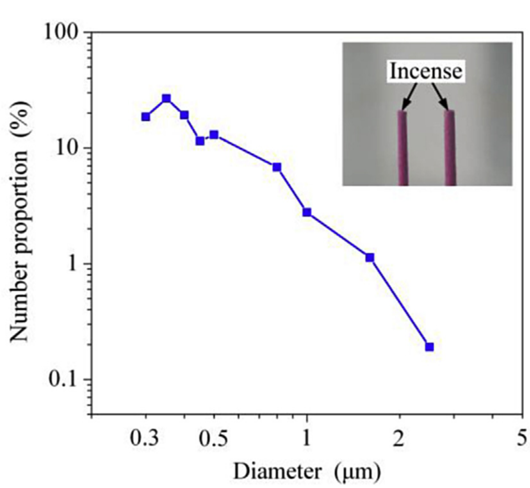

Fig. 1. Diameter distributon of the incense fine particles.

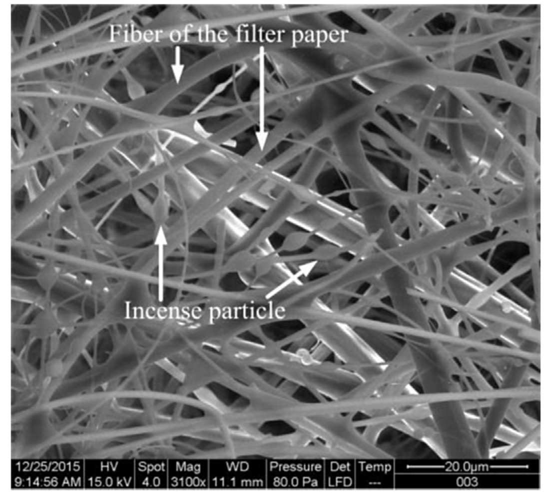

Fig. 2. SEM image of the incense particles collected on the glass fiber filter paper.

Table 1
Diameter distributon of the incense fine particles.

Element	*wt* (%)	*at* (%)
C	38.05	49.90
O	38.04	37.45
Na	3.88	2.66
Mg	0.58	0.38
Al	1.45	0.85
Si	12.69	7.11
S	0.45	0.22
K	1.33	0.54
Ca	1.79	0.71
Ba	1.73	0.20

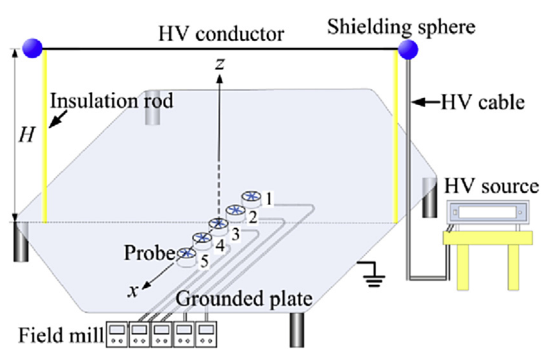

Fig. 3. Schematic view of the measurement platform for electric field.

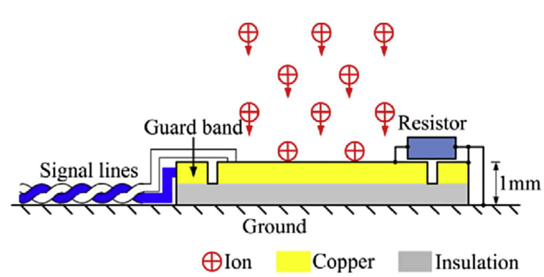

Fig. 4. Configuration of the ion current plate.

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