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Effect of relative humidity on current–voltage characteristics of monopolar DC wire-to-plane system

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ABSTRACT

This paper deals with the DC monopolar corona discharge in wire-to-plane geometry under variable humid air conditions. The classical formulas of Townsend commonly used for the current–voltage characteristics were used to determine the various corona parameters for the both polarities of the corona discharge. A circular biased probe has been adapted to the plane and is used to measure the ground plane current density and electric field during the monopolar corona discharge. A new approach to the problem of corona discharge in transmission system has been described in this paper. The effect of varying the humidity and wires diameter is also investigated. The values of the electric field and the current density are maximum beneath the corona wire and decrease when moving away from them and the current–voltage characteristics follow the quadratic Townsend's law. The experimental results show that the monopolar corona discharge is strongly affected by the air humidity. The current density and the electric field are measured and compared with the computed values. The agreement between the calculated values and those obtained experimentally is satisfactory. The per unit electric field and current density are also represented by a unique function.

1. Introduction

The stable corona discharge is used in various ways in an increasing number of engineering applications. Corona discharges are partially ionized gas discharges that occur between a sharp electrode (called a corona source), typically a needle or a wire, and a blunt electrode (called a collecting electrode or counter electrode) such as a plate or a cylinder. Corona discharges have been a field of study since early in the 20th century as a detrimental mode of breakdown in high voltage conductors. But because of the wide variety of possible configurations and operating conditions, corona discharges have also been developed for applications as varied as electrostatic precipitation and separators [1–3], painting and spraying powders [4,5], ozone generation [6] and flow generation and control [7] to chemical analysis [8].

However, the corona effect produced by overhead HVDC transmission lines forms space-charges in the surrounding air which may, for example, cause radio interference, audible noise and electrification of objects, in addition to generating power losses. Also, the space-charges will affect the natural balance of ions in the air, which might have some unknown biological and environmental effects. Therefore, it is of interest to study the fields associated with HVDC power transmission lines in the presence of corona, both theoretically and experimentally.

Monopolar DC corona discharge consists of high-field active electrode surrounded by ionization region where free charges are produced, a low-field drift region where charged particles drift and a low-field electrode acting as a charge collector [9–11]. Fig. 1 shows a simple monopolar DC wire-to-plane system. It consists of one wire, with a radius R, located at a height H above the ground plane. Assuming the wire to be infinitely long, the problem is considered two-dimensional in Cartesian coordinates.

The corona drift region is governed by the Poisson and current continuity equations. A complete solution of these equations is not straightforward. For practical applications, therefore, many authors have made some simplifying assumptions for the basic equations and empirical and semi empirical formulas have a useful function [26,27]. Actually, the ions created in the ionization region drift to

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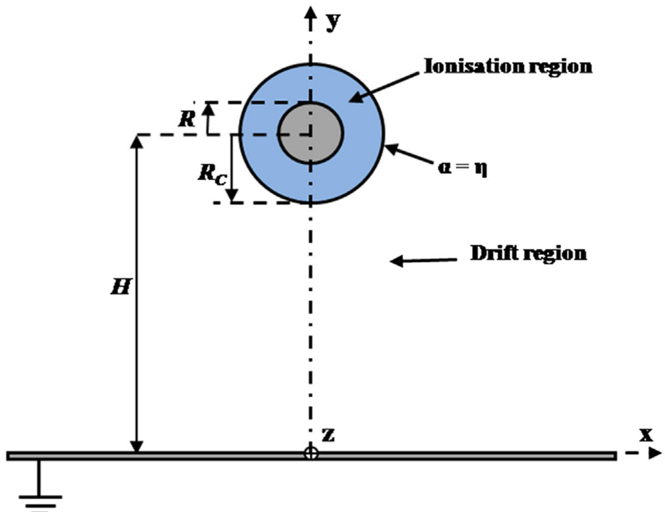

Fig. 1. Monopolar wire-to-plane configuration.

the passive electrode and the space charge modifies the original Laplacian applied field. Many theoretical and experimental works have been devoted to the study of the discharge behavior with various electrode systems. However, measurements of the modified electric field over the collector electrode are not easy in the presence of space charge.

It is found that there are a number of physical phenomena of discharge without requiring interpretation and analysis as well as to find mathematical models that provide necessary and sufficient information on the evolution of the discharge in different configurations. These physical parameters may be: speed air flow, pressure, and humidity. The chemical composition of charged particles moving between the electrodes is another important parameter. The regrouping of these parameters is a bit difficult but it is very necessary to optimize the operation of the corona discharge.

In this paper, we have proposed a method to measure the current density and electric field at the grounded plane where the humidity of ambient air is associated. The method uses the biased-current probe, which was introduced by Tassicker [12] and further developed by many authors [13–16]. This type of probe can be miniaturized and is suitable for DC corona discharge investigations. A linear probe is used for current density and electric field measurements during the DC corona discharge in wire-to-plane [16,17]. The probe collector is of rectangular form and surrounded by two plates biased at a voltage V_b. For the first time, we use the circular biased probe in the presence of space charge during the monopolar corona discharge.

2. Experimental arrangement

2.1. Electrode system

The choice of the geometry is based on a wire-plane configuration because it is easy to implement and can work according to different physical parameters. The nature of the high voltage electrode may influence the threshold voltage of the corona. Stainless steel machined electrodes are used in this work, because this type of metals strongly supports the mechanical and electrical constraints with a considerable service lifetime.

The electrode system consists of a nickel wire (1), with a small radius of curvature R and a set of planes grounded Fig. 2. The active electrode is fixed by two insulating supports at a height $H = 50$ mm relative to the plane. The active electrode is raised to positive or negative potential.

The circular probe (P) is made of solid aluminum, is incorporated in the same surface level in a plane (E), provided with two guard planes whose role is to prevent the end-effects of current, and the assembly thus forming the collector electrode. The plane (E) and guard planes of respective dimension 180×800 mm^2 and 150×800 mm^2 are fixed with insulating props (2), and the leakage current between high voltage wire and the plane (E) of the measurement is evacuated to the earth by guard planes and reinforced with the stainless steel plane (3). The current collector (P) was fixed with two insulating plates (4) and connected to a picoammeter (8) via a coaxial cable for measuring the corona current.

2.2. Electrical measurements and air system supply

The positive or negative direct voltage, supplied by a 0 to ±140 kV source (5), was applied to the wire and the high voltage divider (7). A DC digital voltmeter (6) was used to measure the applied voltage. The polarization plane is connected to a low voltage DC supply (15) across which is connected a digital voltmeter for measuring the bias voltage V_b supplied. The electrode system and the measurement devices of temperature and humidity were placed into a plexiglas box of 200 L (9). The air inside this box came from the ambient atmosphere and was made to move in closed circulation by a pump (10). The humidity was controlled with a three-way circuit with taps. Air was hydrated (12) with the water vapor provided by heating a half full bottle of distilled water; ways (13) and (11) being closed. The drying of the air was made by the way (13) by using silicagel contained in a bottle, when the ways (11) and (12) were closed. The opening of way (11) and the closing of ways (12) and (13) of the circuit allow a constant humidity to be kept inside the box. Air was then filtered (14) before it was let in the box again. In order to eliminate the possible influence of the air flow on the corona discharge, the pump was stopped during the measurements.

3. Results and discussion

The present work is concerned with the measurements of current density, electric field distributions at the plane surface and the corona current–voltage characteristics with a biased probe during the monopolar DC corona discharge. The wire is positioned along the z-axis and the x-position of the probe collector on the passive electrode are achieved by displacing the wire (Fig. 1). The measurements are carried out for various parameters such as:

- The applied voltage V ($+V$ or $-V$);
- The x-position of the probe on the plane;
- The wire radius R;
- The relative humidity RH.

The gap between the wire and the collector is $H = 50$ mm. The tests are done within a large range of the corona voltage with varying humidity levels. The temperature and the pressure inside the box remain practically constant during the tests.

3.1. Current–voltage characteristics

The corona discharge is typically characterized by the current–voltage relationship. The current increases from the inception corona voltage up to the breakdown voltage. Townsend has introduced a law that bears his name, between the current and the voltage for corona discharge in a coaxial wire-cylinder [18]. Later, it was found that this law could also be applied to the wire-to-plane