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2-D corona field computation in configurations with ionising and non-ionising electrodes

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Abstract

An efficient method is proposed for the computation of the electric field strength and of the space-charge density in configurations of at least three ionising and non-ionising electrodes. The physical model is derived under the assumptions commonly accepted for the study of corona fields. The mathematical model makes use of a conformal mapping that converts the actual boundary-free field zone into a rectangular domain with well-defined boundary conditions. The finite-difference method is then used for solving the differential equations that describe the ionic space-charge and electric field distribution. The computational procedure was employed for studying the simple case of the drift zone of the corona discharge generated between a so-called dual electrode and a grounded plate. The dual electrode consisted of an ionising wire (diameter 0.22 mm) located at 20 mm from a tubular metallic support (diameter 25 mm). The computed current–voltage characteristic and current density distribution at the surface of the collector plate were in good agreement with the experimental data obtained for this combined corona–electrostatics electrode arrangement.

Keywords: Electric field computation; Corona discharge; Corona field; Conformal mapping; Finite difference method; Electric space charge

1. Introduction

Corona discharge in air is a physical mechanism frequently employed in electrostatic processes such as dust precipitation, electrostatic painting, powder coating, and separation of granular mixtures [1,2]. By associating one or several non-ionising electrodes with the corona (ionising) electrode, the efficiency of the above mentioned electrostatic processes can be significantly increased. Some authors refer to the electric field generated by any such electrode arrangement as corona–electrostatic [3].

Corona–electrostatic fields have been the object of several experimental studies [4,5], but these are very labour- and cost-intensive. At the same time and in response to this problem, attempts were made to derive a numerical model for simulating the specific phenomena associated with corona charging and particle motion in electric fields affected by the presence of space charge [6,7]. The main limitation of this model is related to the fact that the programs employed were not capable of simulating the distortion of the electric field due to the presence of the space charge. Any progress in this line is related to the solutions found to two types of problems: (1) formulation of physical models accurate enough for computer simulations to be able to effectively guide the experimentalist; (2) assuming that such a model is known, formulation of mathematical models fast and accurate enough for their results to be of practical interest and obtained at a lower cost than through experimental investigations.

The first problem does not appear to be a difficult one. The physical model of the corona field is rather well

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established and even though some authors still debate on which are the most appropriate boundary conditions at the ionising electrode, a consensus exists on the main assumptions to be used for simplifying the corresponding mathematical model. This issue will be briefly addressed in Section 2 of the paper, but the reader who wants to learn more about the different theoretical approaches to predict the electrical parameters in the presence of space-charge fields can use the excellent review given by Sigmond [8].

The second problem is relatively easy to solve for simple two-electrode configurations like wire-plane or point-plane. The various numerical models proposed for such situations are based on techniques such as finite-differences (FDM) [9], finite element (FEM) [10–13], the combined method of finite element and the method of characteristics (MOC) [14], and the charge simulation method (CSM) [15].

The formulation of the mathematical model is less easy to handle for those geometries where ionising electrodes are associated with non-ionising electrodes at the same or a different potential. Such configurations, designated sometimes as "dual electrodes" [5,7], are characterised by the existence of singular points where the electric field is zero, and this is a major difficulty for which very few of the existing algorithms are able to provide a solution. The most effective numerical scheme for addressing this problem seems to be the one proposed by Budd and Wheeler [16]. They successfully used the hodograph transformation to find, for instance, the solution of the space-charge problem for an array of cylindrical conductors all at the same potential situated midway between two parallel plates at lower potential, with the conductors having alternately zero and nonzero space charge specified on their surface. Caron and Dascalescu employed a different technique [17] for solving the space-charge problem in the case of a peculiar geometry: an ionising wire electrode parallel to both a non-ionising cylinder electrode at the same potential and a grounded plate electrode. Their method gives results that were in good agreement with experimental data regarding the corona current density distribution at the surface of the collecting electrode, but is less precise in evaluating the field and space charge near the ionising wire.

Therefore, the aim of the present work is to validate a numerical model capable of computing space charge and electric field distributions in "dual electrode" configurations. The basic idea was to use a conformal mapping to transform the geometrical domain into a simpler one more easily tractable by the classical numerical methods. The proposed mathematical and numerical models are presented in Sections 2–4, respectively. The results of the computed electric field and charge density are presented in Section 5 for a particular electrode configuration. In Section 6, the computed current–voltage characteristics are compared with measured ones carried out on a laboratory model of corona–electrostatic field. An important conclusion of this paper is that the proposed method could be employed for modelling other "dual electrode" configurations of practical interest.

2. The physical model of the corona–electrostatic field

2.1. Assumptions

The simplest combined corona–electrostatic field is the one generated by the three-electrode system consisting of a wire, a cylinder and a plate, as sketched in Fig. 1. The wire and the cylinder are parallel to each other and connected to the same high voltage potential. Their combination is known as a "wire-type dual electrode". The grounded plate electrode is normal to the plane defined by the axes of the other two electrodes. In this configuration, the small radius wire is the only ionising electrode. The plane collects the ions generated at the wire electrode of opposite polarity. The large radius cylinder is a non-ionising electrode, which repels the ionic charge. The physical model is presented here in relation to this electrode configuration, but it can be easily adapted to other situations of practical interest, such as that encountered in roll-type electrostatic

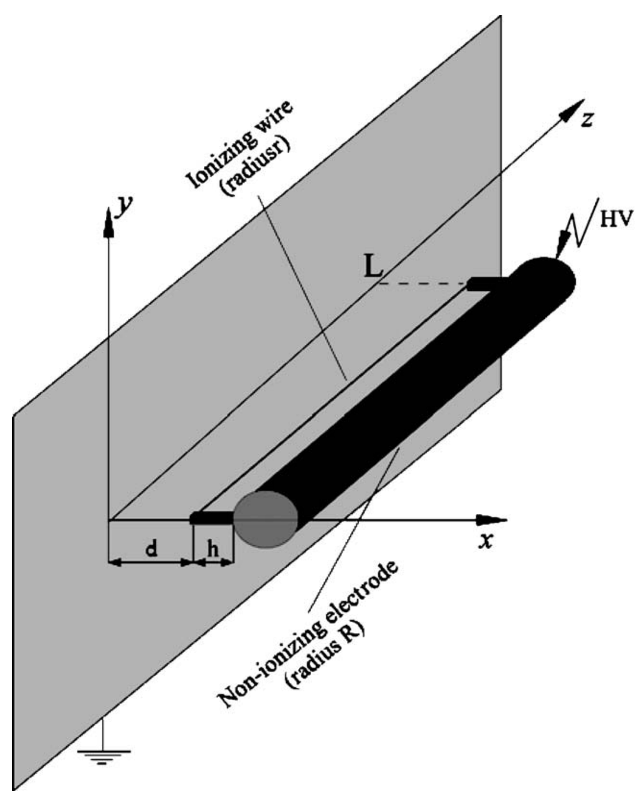

Fig. 1. "Dual electrode" configuration.