Adaptive Numerical Simulation of Streamer Propagation in Atmospheric Air

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Abstract

In many practical cases, an electrical breakdown of gaseous high-voltage insulation is caused by so-called streamer discharges. Streamers are self-sustained ionization waves propagating though a neutral gas in an applied electric field and their development is strongly dominated by created space charges. Visual appearance of such discharges varies depending upon conditions, in particular, gas density, pressure, applied voltage, etc. At atmospheric pressure in air, they are usually observed as thin plasma channels propagating between electrodes to which a voltage is applied. Information on properties and behavior of streamer discharges under various circumstances is highly desirable for proper design and optimization of high-voltage electric insulation systems.

Experimental investigations of internal processes in streamers are problematic due to several reasons and, therefore, numerical simulations are extensively used. The most popular model of a streamer discharge utilizes so-called drift-diffusion (or hydrodynamic) approach within which a collective motion of electric charge carriers (electrons and ions) is described in terms of their densities and fluxes and different physical processes (ionization, recombination, electron attachment, photo-ionization, etc.) are considered as sources and sinks of charges. A simplest set of PDEs typically consists of convection-diffusion equations (CDE) expressing conservation of mass for each type of carriers coupled with Poisson's equation for the electric potential, see e.g. [1]. Resolving the streamer problem numerically is challenging due to its strongly non-linear nature, high space resolution (~10 µm) and small time steps (~10 ps) required, strong gradients of carrier densities at the wave front (can be >10 orders of magnitude), etc. These make the solution process computationally expensive and extremely time consuming. One of the ways to improve the situation is to implement an effective numerical algorithm together with a smart meshing procedure.

Use of COMSOL Multiphysics®
In this paper, an implementation of an efficient adaptive implicit advection scheme for simulations of streamer propagation in atmospheric air is presented. In the model used, evolution of densities of electrons and ions (positive and negative) is described by generalized CDEs coupled to Poisson's equation. The rate of photo-ionization is calculated using three Helmholtz equations as

proposed in [2]. The problem is solved using the general mathematical interfaces of COMSOL Multiphysics® that provides a possibility to implement a logarithmic representation of the CDEs and to define their weak formulation. These impose the physical constraint of non-negative charge carriers' densities without a necessity of introducing corrections for the source term or any artificial diffusion. The problem is solved with an iterative multi-grid scheme with over-relaxation to obtain the solution in the presence of a highly nonlinear source term. To reduce solution time, the transport domain and Poisson domain are separated and time adaptive mesh refinement along the direction of streamer propagation is implemented. For validation, a nanosecond pulse streamer discharge in air was simulated and the results are compared with experimental data [3].

Reference

References
[1] R Morrow and J J Lowke 1997 J. Phys. D: Appl. Phys. 30 614
[2] A Bourdon et al 2007 Plasma Sources Sci. Technol. 16 656
[3] A Starikovskiy et al 2011 IEEE transactions on Plasma Science 39 2606