
Simulation of pre-breakdown discharges in air in a wide range of conditions

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Résumé

The physics of low-current discharges in high-pressure gases, such as corona, Townsend, and streamer discharges, has been understood reasonably well by now and a number of useful theoretical results, including analytical ones, have been obtained under various approximations. It is desirable to have also a unified method of numerical modelling, which would be fast, robust, and applicable to a wide range of conditions.

A method developed in this work employs, in the framework of a single code, stationary or time-dependent solvers, depending on the discharge being modelled being stationary (e.g., stable corona or Townsend discharge) or non-stationary (e.g., streamers). Note that stationary solvers offer important advantages in simulations of steady-state discharges compared to time-dependent solvers; in particular, they allow decoupling of physical and numerical stability and are not subject to the Courant–Friedrichs–Lewy criterion or analogous limitations on the mesh element size. The developed method allows investigating in a natural way steady-state discharges, their stability, and transition into other discharge forms, e.g., loss of stability of a glow corona and corona-to-streamer transitions.

The model comprises the conservation equations of species, transport equations of species, written in the drift-diffusion approximation, and the Poisson equation. Three negative ion species (O⁻, O₂⁻ and O₃⁻) are considered and the conventional set of reactions: ionization by electron impact, photoionization, two-body (dissociative) attachment, three-body attachment, collisional detachment, associative detachment, charge transfer, electron-ion recombination, and ion-ion recombination. The rate of photoionization is evaluated by means of the three-exponential Helmholtz approximation.

Two examples are treated. In the first example, the inception voltage of positive glow corona discharge between concentric cylinders in air in a wide pressure range was computed. It was found that the boundary condition for the rate of photoionization at the surface of the corona electrode (anode) affects the corona inception voltage for lower values of pr (here r is the radius of the corona electrode), while the account of detachment affects the corona inception voltage for higher values of pr . The modelling was validated by comparison with standard experimental data and a very good agreement was found.

*Intervenant

In the second example, a pre-breakdown discharge in weakly non-uniform electric field between concentric cylinders in air in a wide pressure range was computed. The effect of microscopic non-uniformities on the positive (inner) electrode was studied by means of straightforward (multidimensional) modelling. The effect of field emission from non-uniformities on the negative electrode was studied with the use of the field enhancement factor and the Murphy-Good formalism, which is supposed to be more accurate than the Fowler-Nordheim formula. It was found that both effects play no role for lower values of air pressure and come into play for higher values, however field emission comes into play for values of pressure lower than those for which the effect of comparable non-uniformities on the positive electrode comes into play. The dependence of the inception voltage on the air pressure, computed with the account of field emission, reveals saturation with increasing pressure and conforms to the measured dependence of the breakdown voltage on pressure.

The work at UMa was supported by FCT of Portugal (project Pest-OE/UID/FIS/50010/2013).