Numerical investigation of stability of low-current point-to-plane negative corona in air

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Negative corona discharges occur when the electric field is enhanced in the cathode, e.g. due to its sharpened form. Although a stationary glow corona discharge with very low-current is mentioned in the literature, the most commonly referred discharge in negative corona is the Trichel pulse regime, where periodic pulses in current of high amplitude appear. It is usually believed that this regime follows immediately the corona inception. In some works experiments were performed to reveal the mechanism of formation of such pulses, e.g. [1], and in other works simple and detailed numerical models were used, e.g. [2]. In principle, the stationary glow corona can evolve into the Trichel pulse regime by applying a certain perturbation (e.g., by increasing the voltage).

This paper reports modelling of low-current negative corona, in a point-to-plane discharge configuration at atmospheric-pressure air. In a previous work [3], results of simulations have shown that immediately after ignition the stationary negative corona discharge is stable, but as the voltage increased, it lost stability and pulses appeared. As the voltage was increased further, at higher currents, the discharge regained stability. This work focuses on the study of the discharge regimes occuring before and after the limit of stability, and on the effect that certain perturbation characteristics have on those regimes. For this purpose, a numerical model of low-current discharges in high-pressure air will be used, comprising equations of conservation and transport of charged species and the Poisson equation. A 'minimal' kinetic model of plasmachemical processes in low-current discharges in high-pressure air is used, which takes into account electrons, an effective species of positive ions, and three species of negative ions (O_2^-, O^-, and O_3^-). This model was validated in previous works with different purposes: a) comparison of the computed inception voltage of corona discharges with several sets of experimental data on positive and negative glow coronas between concentric cylinders, with good agreement in a wide range of pressures and diameters of the cylinders; b) investigation of the saturation of the breakdown voltage with increasing pressure in weakly non-uniform electric fields in compressed air, with qualitative agreement with the experiment in all the studied cases being achieved for protrusion heights of the order of 50 μm; and c) investigation of time-averaged characteristics of DC corona discharges in ambient air, in both concentric cylinders and point-to-plane, with good agreement between modelling and experimental data [4].

The simulated point-to-plane geometry has a 10 mm gap with a needle tip radius of 20 μm in atmospheric air. This configuration yields an inception voltage of 2314 V, which corresponds to the discharge voltage that is just sufficient for the electron impact ionization to compensate losses of the charged particles, initiating of a self-sustaining gas discharge. Stability of the negative corona discharge was studied against finite perturbations: perturbations in the form of small increments of the applied voltage (1V or above) were imposed and the evolution of the discharge over time was followed by means of a time-dependent solver. The limit of stability was in this case 2338 V, corresponding to a current of approximmately 32 nA.

Results of simulations have shown the following general trend: when the applied voltage is below the limit of stability, a single Trichel pulse appears (one single pulse rather than a periodic sequence, with amplitude of the same order of magnitude as classic Trichel pulses), followed by small damped oscillations. The amplitude of these oscillations is significantly lower than that of the Trichel pulse. This can be seen in Fig. 1(a) by the dotted red line. When the applied voltage exceeds slighly the limit of stability, a single Trichel pulse appears followed by weak periodic oscillations (rather than damped). These periodic oscillations are still not classic Trichel pulses. This scenario can be seen in Fig. 1(a) by the solid blue line. Finally, when the applied voltage clearly exceeds the limit of stability, classic Trichel pulses appear, as seen in Fig. 1(b).

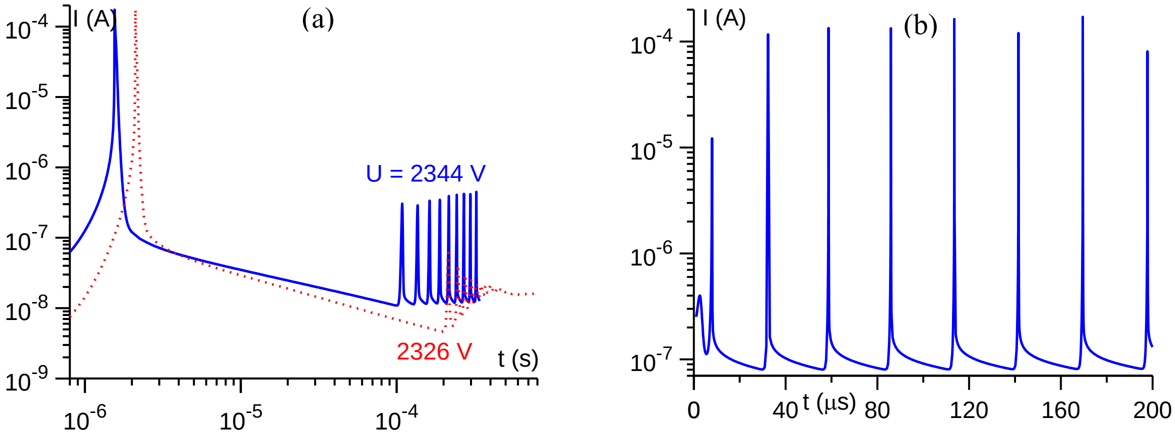

Fig. 1: Time evolution of current for an applied voltage below and slightly above the limit of stability (a), and significantly exceeding that limit (b).

In comparison with an instantaneous perturbation (constant applied voltage from t = 0), a step voltage perturbation (with finite growth rate) produces a peak of current (due only to displacement current) before the single Trichel pulse, and the single Trichel pulse appears slightly later when compared to the one produced by an instantaneous perturbation. For a perturbation amplitude of 2V, the single Trichel pulse is not present (there is a local maximum in current but the amplitude is much smaller than a typical Trichel pulse), whereas for perturbation amplitudes of 5V or higher the single Trichel pulse is present and has the same magnitude; the lower the perturbation amplitude the later the single Trichel pulse appears. When comparing different rise times of the step voltage perturbation, it can be seen that smaller rise times (0.2 μs – 1 μs) cause the sooner appearance of the single Trichel; if the rise time is big enough (e.g., 100 us) the single Trichel pulse is not present.

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