

A NEW MODELLING FOR THE SIMULATION OF THE POSITIVE SPARK DEVELOPMENT IN LONG AIR GAPS

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Abstract : This paper presents a new modelling of the positive discharge development, based on new simplifying assumptions. The main hypothesis is that the E-field within the corona region keeps a constant value. The simulations are compared and discussed with experimental results performed in a rod-plane gap.

1. INTRODUCTION

All the studies of positive discharge modelling have shown that the most critical point of the model description are the coupling processes between the advancement of the corona front and the leader tip progression head.

This paper presents a model based on a new description of the leader-corona coupling, which allows simple practical computations. In this approach, the charge produced at each time step in the corona region is derived through a macroscopic electrostatic analysis. The main assumption is that the axial electric field in the corona region remains constant during the discharge propagation.

The first part of this paper presents the hypothesis and the principles of the simplified model. The second part presents the numerical simulations which results are discussed and compared with the experimental data.

2. PRINCIPLES OF MODEL

The major simplifying assumptions of the present model are based on electrostatic representations of the physical characteristics of the successive discharge phases : space charge, potential distribution, electric field. In the following parts these assumptions are shortly described.

(i) Corona inception and development.

The axial potential distribution in the rod-plane gap at corona inception is represented in figure 1.

$U_1(x)$ represents the geometric potential due to the electrode. The corona space charge extends from the electrode tip to the streamer front at coordinate x_s ; it has been shown that this region is characterised by an almost constant field E_{stab} [1] : according to this hypothesis, the potential distribution after corona formation is given by the linear curve $U_2(x)$ on figure 1.

The final characteristics of the first corona (extension x_s and the space charge Q) can be derived from the simple electrostatic formulation of figure 1. If the average field E_{stab} is fixed, the corona extension x_s is directly given by geometric construction. Under reasonable simplifying assumptions, the total space charge Q can be determined from the dashed area in figure 1 and distributed in the corona volume.

$$Q = \int_0^{x_s} q(x')dx' = K4\pi\epsilon_0 \int_0^{x_s} (U_2(x') - U_1(x'))dx' \quad (1)$$

where K is a geometric factor which takes into account all the streamers characteristics (length and number of streamers in the corona)

(ii) Leader propagation.

During the leader propagation from $x_L(t)$ to $x_L(t+\Delta)$, the corona front progresses from $x_s(t)$ to $x_s(t+\Delta)$ with an associated constant field equal to E_{stab} (fig. 2). Then, The resulting potential distribution varies from $U_2(t,x)$ to $U_2(t+\Delta,x)$. The potential distribution due to electrode and leader channel is given by curve $U_1(t+\Delta,x)$.

At each time step, the model calculates the net positive charge associated with the leader-streamer advancement. ΔQ can be evaluated by using a similar method as for the first corona.

$$\Delta Q = K \cdot 4\pi\epsilon_0 \cdot \int_0^{x_s(t+\Delta t)} [U_2(t+\Delta t, x') - U_2(t, x')] dx' \quad (2)$$

ΔQ is then proportional to the dashed surface on figure 2.

The created net positive charge ΔQ , during the time interval Δt , is associated with a current I_L flowing into the leader tip :

$$I_L = \frac{\Delta Q}{\Delta t} \quad (3)$$

It has been shown [1][2] that this current is related linearly to the leader tip velocity :

$$V_L = \frac{I_L}{q_L} \quad (4)$$

where q_L represents the charge per unit length necessary to realise the thermal transition from the diffuse glow to the leader channel.

The general electrostatic treatment described above can be easily adapted to the case of an applied potential which varies with time.

In the proposed model, a « rigid » electrostatic coupling between the leader tip and corona front advancement is therefore assumed : this leads to important simplifications, avoiding the complete calculation of potential distributions, which needs a full description of space charge geometry, the calculation of induced charge effect and the detailed simulation of the physical processes of streamer and leader advancement.

3. RESULTS

This model computes the time evolution of the main parameters of the positive discharge such as: the first and second coronas inception time; their geometrical and electrical characteristics, the leader tip and corona front position, their advancement speed, the injected current in the leader head, the space charge distribution and finally the potential gradient along the leader channel.

For a rod-plane configuration, the potential distribution (due to electrode and leader channel) can be approximated by a linear combination of the two contributions, the electrode and the leader being considered as hyperbolic pseudo electrodes respectively with a tip potential equal to $U_0(t)$ and $U_L(t)$ [2]. Where $U_L(t)-U_0(t)$ is then the potential decrease along the leader channel.

In figures 3 and 4, the computed evolution of the discharge and the total injected charge are compared with experimental measurements for a conic (curvature radius $R_e=1$ cm) 10 m rod-plane gap long, subjected to switching positive impulse voltages [3]. figures 3a and 4a correspond to a positive switching impulse with a 22 μs time to crest while figures 3b and 4b to 500 μs time to crest. In the both configuration, the computed charge and time to breakdown values are slightly larger than the measured ones.

This model has been also tested over a wide range of experimental configuration (different gap lengths, voltage levels and waveforms) and the results are consistent with the experimental measurements [4].

4. CONCLUSION

The presented model enables the numerical simulation of the positive discharge development in long air gaps, based essentially on simplified electrostatic considerations. Compared with existing models, the present one treats the corona region by use of new assumptions on charge and field distributions. These assumptions have been validated in the reference configuration of rod-plane gap subjected to positive impulse voltages.

REFERENCES

- [1] Gallimberti I 1972 The inception mechanism of the first corona in non uniform gaps *J. Phys. D: Appl. Phys* **5** 2179-89
- [2] Bondiou A and Gallimberti I 1994 Theoretical modelling of the development of the positive spark in long gaps *J. Phys. D: Appl. Phys.* **27** 1252-1266
- [3] Les Renardières Group 1977 *Electra* **53**
- [4] N. Goelian, P. Lalande, A. Bondiou-Clergerie, G.L. Bacchiega, A. Gazzani, I. Gallimberti « Simplified model for the simulation of the positive spark development in long air gaps » submitted to *J. Phys. D.*

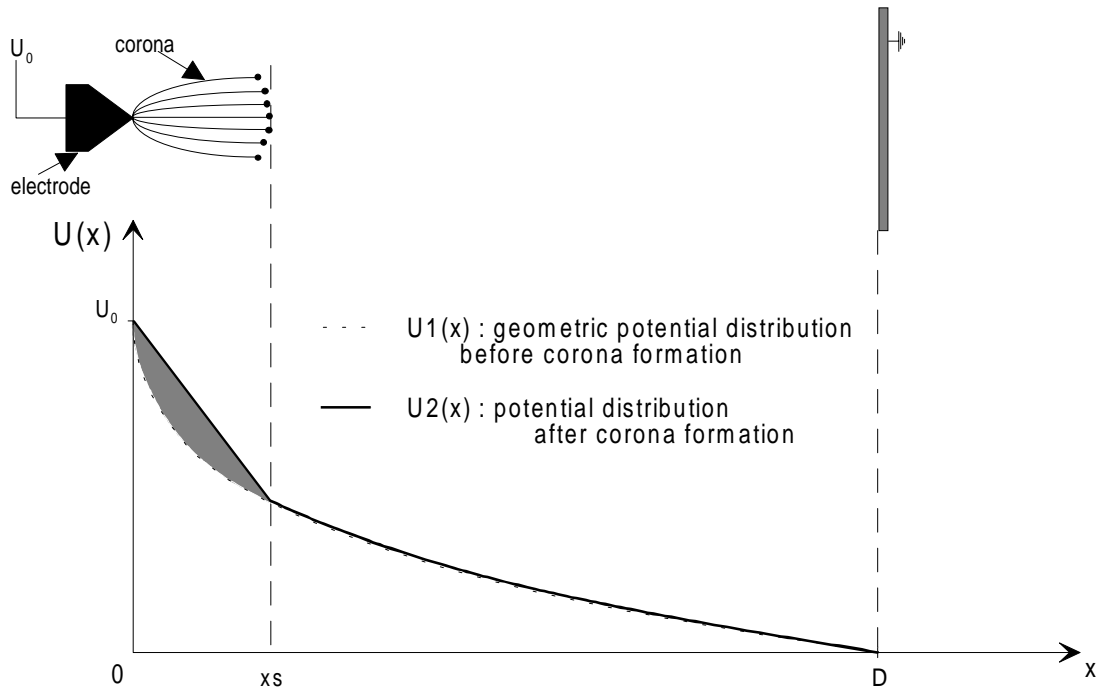


Figure 1 : Potential distributions in the rod-plan gap at corona inception.

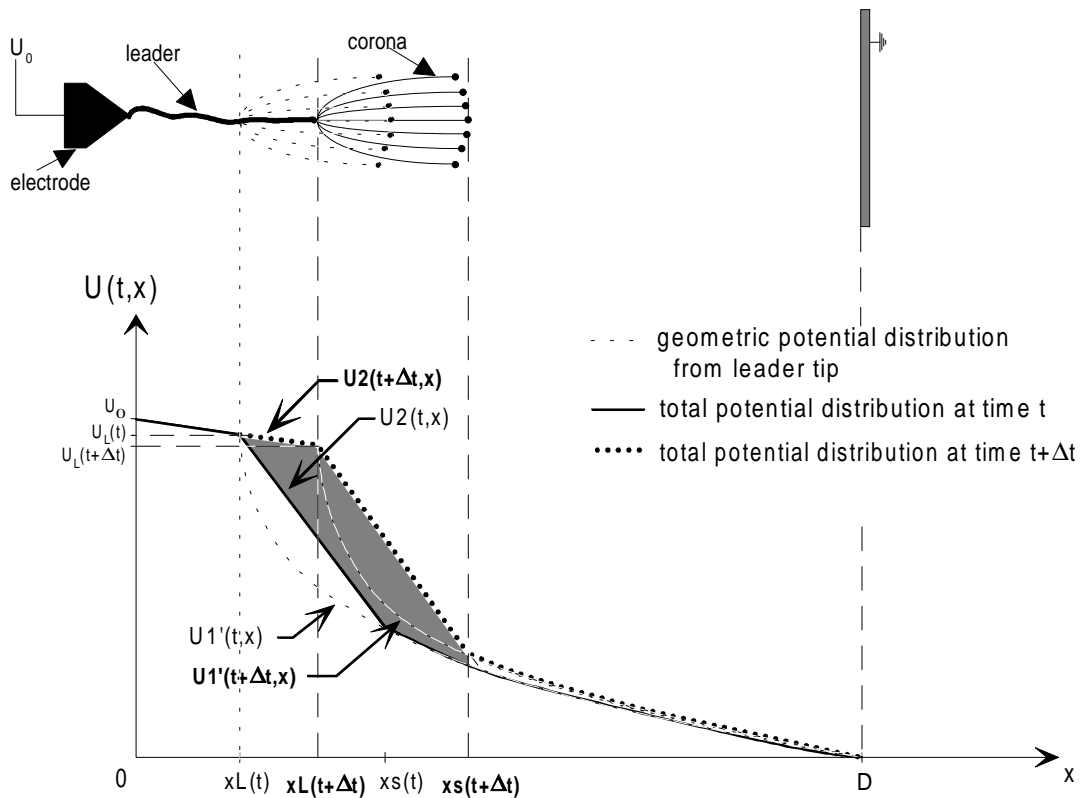


Figure 2 : Potential distributions in the rod-plan gap at different times during leader propagation, with the electrode potential U_0 assumed to be constant.

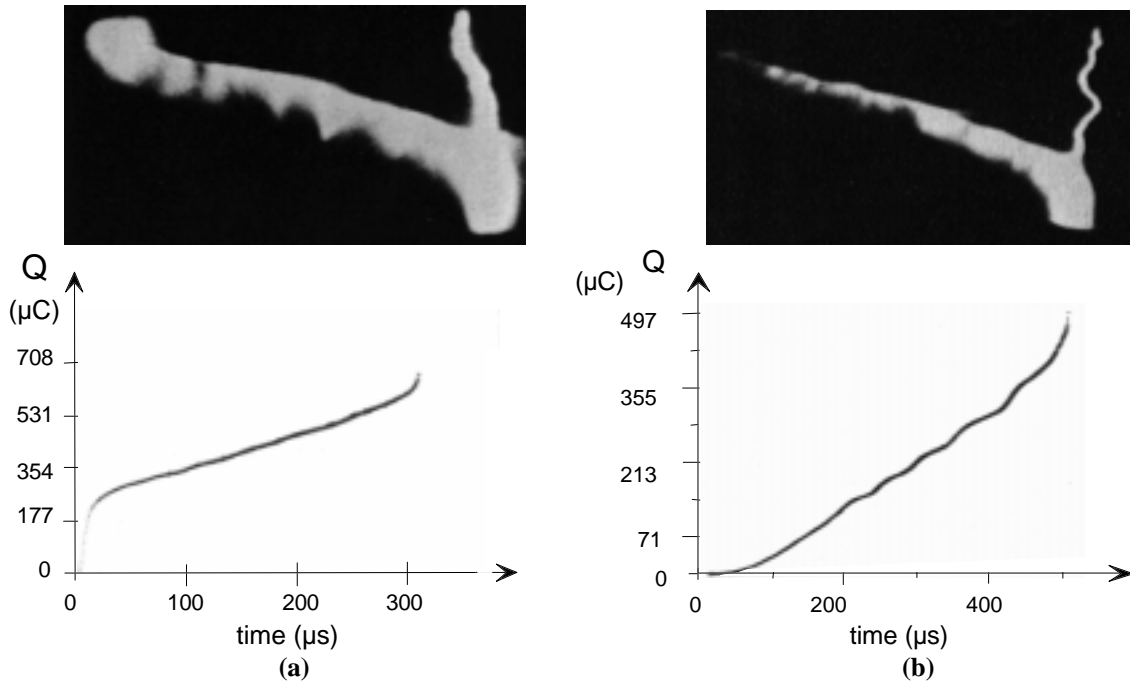


Figure 3 : Streak photograph and integral of current measured at the electrode (rod-plane configuration; 10 m gap long) (a): U_{50} switching impulse with 22 μs time to crest. (b): U_{50} crest voltage switching impulse with 500 μs time to crest.

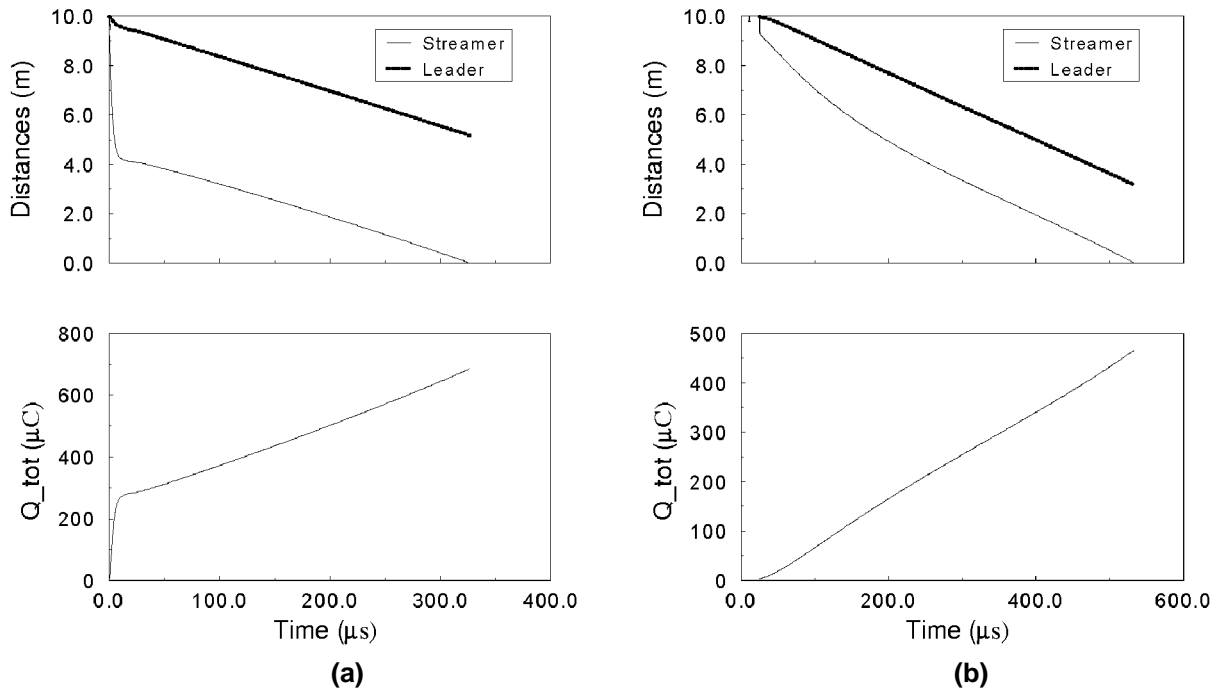


Figure 4 : Numerical simulation of the discharge development and the charge injected into the leader (gap : 10 m electrode; : conic tip). (a): U_{50} switching impulse with 22 μs time to crest. (b): U_{50} crest voltage switching impulse with 500 μs time to crest.