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Corona discharges and their effect on lightning attachment revisited: Upward leader initiation and downward leader interception

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ABSTRACT

Previous studies have suggested the possibility of using glow corona discharges to control the frequency of lightning flashes to grounded objects. In order to revisit the theoretical basis of this proposal, the self-consistent leader inception and propagation model – SLIM – is used together with a two-dimensional glow corona drift model. The analysis is performed to quantify the effect of glow corona generated at the tip of ground-based objects on the initiation and propagation of upward positive connecting leaders under the influence of downward lightning leaders. It is found that the presence of glow corona does not influence the performance of Franklin lightning rods shorter than 15 m, while it slightly reduces the lateral distance of rods up to 60 m tall by a maximum of 10%. Furthermore, the results indicate that it is not possible to suppress the initiation of upward connecting leaders by means of glow corona. It is found instead that unconventional lightning protection systems based on the generation of glow corona attract downward lightning flashes in a similar way as a standard lightning rod with the same height.

1. Introduction

During a thunderstorm, the presence of space charge produced by glow corona at the tip of tall objects can hinder the production of subsequent streamer and leader discharges prior to a lightning strike (e.g. Aleksandrov et al., 2006, 2005a,b,c, 2002, 2001a,b). While the effect of the glow corona on the initiation of streamers has been revisited quantitatively by Becerra (2013), the analysis of its influence on the subsequent inception and propagation of upward connecting positive leaders is presented here.

As a follow-up to Becerra (2013), this paper also intends to independently revisit and discuss some of the estimates and conclusions previously published in the literature (Aleksandrov et al., 2006, 2005a,b,c, 2002, 2001a,b; Bazelyan and Drabkin, 2003; Bazelyan et al., 2008). These previous studies are based on simple models of both glow corona and leader discharges. In the first place, a one-dimensional model of the glow corona generation was used based on the solution of the continuity equations for small and larger ions and Poisson's equation. It assumed that the space charge produced at the object's tip expands holding a hemispherical shape, even for objects such as slender masts or lightning rods. However, this basic assumption leads to considerable errors on the estimation of the generated space charge and the conditions for streamer initiation. As shown in Becerra (2013), where the glow corona model of Aleksandrov et al. (2006, 2005a,b,c, 2002, 2001a,b) was extended to two-dimensions, the consideration of the actual shape of the space charge cloud significantly influences the estimation of the glow corona shielding effect in the entire air gap (in the area close to the rod tip as well as far from it). Secondly, a semiempirical model (Bazelyan and Raizer, 2000) was used to evaluate whether an upward connecting leader could be initiated through the corona space charge cloud. This

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model used a set of empirical equations obtained for leaders in the laboratory under space charge free conditions. Nevertheless, it has been recently shown that the conditions for the initiation of upward connecting leaders under the influence of downward stepped lightning leaders are not similar to those of laboratory leaders (Becerra and Cooray, 2008). Therefore, there are doubts of the validity of such a simple model to properly estimate the conditions for inception and propagation of upward connecting leaders in the presence of space charge.

Based on the estimations made with these models, it was suggested that the presence of glow corona at the tip of tall objects can lead to the reduction of their efficiency to intercept lightning flashes. Moreover, it was proposed that such an effect can also be used to control downward lightning discharges, through a multi-point corona configuration (better known as a dissipation array system) (Bazelyan and Drabkin, 2003). According to Bazelyan et al. (2008), the presence of glow corona hinders the interception process from tall objects through three different conditions:

a. the delay of the inception of streamers.
b. the suppression of the unstable leader inception.
c. the inhibition of the propagation of the successful upward leader.

Condition *a* is caused by the corona space charge accumulated in the close proximity of the object surface, which strongly shields the electric field. Due to this, the streamer inception is delayed until a considerably fast change in the background electric field occurs, as caused by the approach of a downward stepped leader in the close proximity. However, it has been recently shown by Becerra (2013) that even though the delay of the streamer inception is indeed significant, this effect is not as severe as previously reported.

Once streamers are initiated, the transition to a leader discharge (referred to as the unstable leader inception) can also be hindered by the electrostatic shielding produced by the generated glow corona space charge (condition *b*). This shielding effect reduces the available electrostatic energy for the thermalization of the streamer stem, such that larger background electric fields are required to initiate an unstable leader in the presence of glow corona. On the other hand, glow corona also produces a similar hindering effect on the propagation of the newly created leader channel. Once created, a leader would steadily propagate only if the streamers at its tip supply enough energy to thermalize and elongate the leader channel. Considering this effect, it has been suggested that glow corona also inhibits the stable propagation of a newly created leader (Aleksandrov et al., 2005a; Bazelyan et al., 2008).

In order to revisit the existing arguments about the effect of glow corona on the lightning attachment process, the state-of-the-art, self-consistent leader inception and propagation model – SLIM – is used here (Becerra and Cooray, 2006a,b,c; Cooray and Becerra, 2009). Furthermore, estimations obtained with the two dimensional, glow corona model introduced by Becerra (2013) are used as input for the calculations. In this way, the effect of glow corona on the complete attachment process of ground-based objects is properly estimated without the several restricting assumptions considered in previous publications. The analysis is performed to evaluate the effect of glow corona on lightning rods and a dissipation array system up to 60 m tall (on flat ground).

2. The self-consistent leader inception and propagation model — SLIM

To overcome the limitations of the previous studies, the leader inception and propagation model recently introduced by Becerra and Cooray (2006a,b,c) is used in this paper. In contrast to the model of Bazelyan and Raizer (2000), SLIM self-consistently computes the physical parameters of the upward connecting leader, based on the leader model of Gallimberti (1972) and Bondiou and Gallimberti (1994) and the simplified representation of the corona streamer zone of Goelian et al. (1997). One important feature of SLIM is that it can predict the presence of precursor streamers and aborted leaders observed before the stable inception of upward positive leaders as observed in rocket triggered lightning experiments (Willet et al., 1999; Lalande et al., 1998; Jiang et al., 2013). The predictions of SLIM have been compared with the results of an altitude rocket triggered lightning experiment reported by Lalande et al. (1998). A good agreement between the predictions of SLIM and the measured upward leader current, the upward initiation time and the interception point between both leaders has been reported (Becerra and Cooray, 2006b,c).

The analysis is started at the height of the downward leader tip $z_{down}^{(str)}$ at which the surface streamer inception takes place in the presence of glow corona, as reported by Becerra (2013). Then the downward leader, represented as a non-uniform vertical line charge, is assumed to approach to ground with a constant average velocity of 2×10^5 m/s. The downward leader charge distribution proposed by Cooray et al. (2007) is used as a function of both the prospective return stroke peak current I_p (in kA) and the height of the downward leader tip above ground z_{down}:

$$\rho(z) = a_0 \cdot \left(1 - \frac{\xi}{H - z_{down}}\right) \cdot G(z_{down}) \cdot I_p + \frac{a + b \cdot \xi}{1 + c \cdot \xi + d \cdot \xi^2} \cdot W(z_{down}) \cdot I_p \ \ [\mathrm{C/m}] \tag{1}$$

with

$$G(z_{down}) = 1 - \left(\frac{z_{down}}{H}\right) \tag{2}$$

$$W(z_{down}) = 0.3 \cdot e^{-\frac{z_{down}}{50}} + 0.7 \cdot e^{-\frac{z_{down}}{2500}} \tag{3}$$

$$\xi = z - z_{down} \tag{4}$$

where H is the height of the cloud in meters (assumed to be equal to 4000 m) and constants $a_0 = 2.214 \cdot 10^{-5}$, $a = 7.3125 \cdot 10^{-5}$, $b = 5.8646 \cdot 10^{-6}$, $c = 0.522$ and $d = 3.73 \cdot 10^{-3}$.

In order to consider the possible lateral distance between the descending leader and the rod, three dimensional electrostatic calculations are performed with a commercial finite element method (COMSOL, 2007). In addition, the calculation includes the spatial distribution of the shielding potential of the generated glow corona space charge at the

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