On the Estimation of the Charge of Positive Streamers Propagating in Air

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ABSTRACT
Streamer discharges are an important breakdown mechanism in air-based electrical insulation systems. This paper introduces a method to estimate the spatial distribution of the charge density of positive streamers in air, based on the solution of a Poisson inverse problem by optimization. In contrast to other methods, it does not require tuning parameters and can also be used in configurations including dielectric interfaces or preexisting space charge. Three different experimental datasets reported in the literature are used to validate the method. Good agreement between the measurements and the predictions of the method is found.

Index Terms — Corona, Gas discharges, Gas insulation.

1 INTRODUCTION
Accurate estimation of the charge of positive streamer corona is important to assess the conditions of breakdown in electrical insulation systems under impulse voltages. In the same way, it is necessary to evaluate the properties of leader discharges in long air gaps and in lightning. Even though the physical properties of individual streamer filaments can be simulated in great detail [e.g. 1–4], the analysis of a complete streamer discharge event is far more complex due to a less understood process: branching [e.g. 4, 5]. Once a positive streamer corona is initiated, it splits into a large number of narrow channels, forming a branched and complex structure [6]. Since this branching process depends on many factors such as the gas type, pressure [7], the gap configuration [8] and the rate of voltage rise [9], the estimation of the total charge of the complete discharge is still challenging.

Two main approaches have been followed in the literature to estimate the total charge of positive streamers. The first approach is based on the estimation of the charge of individual streamer filaments [e.g. 9–11]. Then the total streamer charge is assumed proportional to the charge of a single filament. Assuming that the individual filaments are not influenced by each other, the proportionality constant is related to the total number of filaments in the streamer discharge. The second approach neglects the filamentary nature of streamer corona and considers it instead as a uniform, continuous discharge which propagates within a known volume [e.g. 12–17]. Then the total streamer charge is estimated by assuming that the electric field along the discharge is constant and equal to the stabilization electric field, which is the minimum field required to sustain the propagation of streamers [18].

Even though good agreement between measurements and estimations made with both approaches has been reported in the literature, there is need for further improvements since:
- The existing calculation methods have a limited predictive power. Since these estimations use at least one parameter which is unknown or difficult to estimate, they require additional “tuning” of the estimations with experimental data.
- The calculation of the streamer charge in configurations without rotational symmetry or involving dielectric barriers (i.e. streamers in air along dielectrics) is difficult with the existing methods.
- In some cases, it is also relevant to estimate the charge of streamers following the inception of a first streamer burst. However, the estimation of the charge of these subsequent streamers is not possible with most methods. Since the spatial distribution of the streamer charge is usually not calculated, the shielding effect of any previous discharge is generally neglected.
In order to improve the estimation of the charge of positive streamers, this paper introduces an alternative method which does not have tuning factors and that can be extended to any configuration. The method is based on the second approach, and uses an optimization technique to estimate the spatial distribution of the streamer charge density. It is introduced for geometries with axial symmetry in Section 2. The method is validated in Section 3 with three different experimental datasets reported in the literature, one of them including a dielectric barrier. The advantages and limitations of the approach are discussed in Section 4.

2 NUMERICAL METHOD.

2.1 DEFINITION OF THE PROBLEM

The estimation of the streamer charge assuming a uniform, continuous discharge is, from a mathematical stand point, an inverse Poisson problem. The solution to such a problem requires identifying the charge distribution source in the Poisson equation such that the electric field inside the streamer volume is equal to the stabilization field $E_{str}$. In order to introduce the proposed solution method, let us consider the rod-to-plane configuration in two dimensions with axial symmetry, as shown in Figure 1. In the analysis, the geometry is divided into two separate calculation domains: the bounded volume domain and the streamer-free region $\Omega_0$. Both domains form the bounded volume domain $\Omega = (\Omega_{str} \cup \Omega_0)$ where the calculations are performed. In order to estimate the streamer charge, it is necessary to find the unknown charge distribution function $\rho_{str}(r, z)$ which satisfy the Poisson equation:

$$\nabla^2 \phi(r, z) = -\frac{\rho_{str}(r, z)}{\varepsilon_0}, \quad (r, z) \in \Omega_{str}$$

(1)

$$\nabla^2 \phi(r, z) = 0, \quad (r, z) \in \Omega_0$$

(2)

when the solution of (1) is known and equal to the streamer potential $\phi_{str}$. The boundary conditions for the domain $\Omega$ are

$$\phi(r, z) = \phi_{app}, \quad (r, z) \in \Gamma_1$$

(3)

$$\phi(r, z) = 0, \quad (r, z) \in \Gamma_2$$

(4)

where $\Gamma_1$ is the boundary condition on the stressed electrode under an applied voltage $\phi_{app}$, and $\Gamma_2$ is the boundary condition on the other electrode in the configuration. Since the remaining boundaries limiting the domain $\Omega$ are open, they are positioned as far as possible from the streamer zone $\Omega_{str}$ and they are represented by the zero charge condition.

Assuming that the streamers propagate radially from the electrode’s tip, it is convenient to describe the domain $\Omega_{str}$ in terms of an auxiliary polar coordinate system $(l, \theta)$ with origin at the center of the arc defining the electrode tip. In this way, the streamer filaments can be easily described along the radial coordinate $l$ while the lateral boundary $\Gamma_3$ of the streamer region is defined at the angular coordinate by the angle $\theta_{str}$. Since the electric field in the direction of the streamer propagation remains constant, the term $\phi_{str}$ corresponds to the potential distribution given by

$$\phi_{str}(l) = \phi_{app} - E_{str} \cdot (l - l_{tip})$$

(5)

where $l_{tip}$ is the distance between the stressed electrode boundary and the polar system origin.

Since the total charge of positive streamers is influenced by humidity $h$ and relative air density $\delta$, the stabilization field $E_{str}$ is defined as a function of these two parameters as [14]:

$$E_{str} = d \cdot \delta^{1.5} + (e + f \cdot \delta) \cdot h$$

(6)

with the constants $d=379053$ V/m, $e=4000$ V-m$^2$/g and $f=6000$ V-m$^2$/g obtained from the best fitting of the experimental data reported in [19].

It is important to observe that the angle $\theta_{str}$ depends on the branching of the streamer. Since branching depends on the vector field defined by the shape of the electrode and the streamer’s own space charge [6], a guess value for this angle is required. Nevertheless, the calculation of the total charge is relatively insensitive to the value chosen for $\theta_{str}$ granted that the domain $\Omega_{str}$ does not truncate any streamer branch, as it will be shown in the following section.

On the other hand, note that the extension of the streamers along the radial coordinate $l$ is defined by a free end boundary condition $\Gamma_4$. As the streamers propagate, this boundary moves forward towards the other electrode until the total electric field on it becomes equal to the stabilization field $E_{str}$ (Figure 2). At this condition, the streamers stops propagating and the maximum streamer length $l_{str}^{(max)}$ is reached. Since the electric field in the gap changes as the streamer propagate (as seen in Figure 2), it is not possible to know beforehand the final location of the boundary $\Gamma_4$. For this reason, the location of this boundary needs to be traced by following the propagation of the streamers until the total electric field in front of the domain $\Omega_{str}$ becomes equal to the stabilization field $E_{str}$.

Figure 1. Axi-symmetrical geometry considered for the streamer calculation in a rod-to-plane configuration, including the domains and boundaries.
Figure 2. Potential (top) and electric field (bottom) distributions for different streamer propagation steps. The laplacian potential $\phi_{\text{str}}$ and electric field $E_{\text{str}}$ distributions are shown as reference.

Once the domains and boundary conditions are defined, the inverse Poisson problem is treated as a least squares optimization problem. The squared residual function between the calculated voltage $\phi$ and the expected streamer voltage distribution $\phi_{\text{str}}$ along each streamer filament is given by:

$$
\varepsilon (\theta) = \int_{l_{\text{str}}}^{l_{\text{max}}} \left( \phi(l, \theta) - \phi_{\text{str}}(l) \right)^2 \cdot dl \quad (7)
$$

The solution to the problem is reached for the charge density $\rho_{\text{str}}(l, \theta)$ that minimizes the total residual function $\varepsilon$ in the streamer domain $\Omega_{\text{str}}$:

$$
\varepsilon = \int_{\Omega_{\text{str}}} \int_{l_{\text{str}}}^{l_{\text{max}}} \left( \phi(l, \theta) - \phi_{\text{str}}(l) \right)^2 \cdot dl \cdot d\theta \quad (8)
$$

Once the charge density distribution $\rho_{\text{str}}$ is estimated and the streamer has reached its maximum extension $l_{\text{max}},$ the total true charge $Q_{\text{str}}$ of the streamer is calculated as:

$$
Q_{\text{str}} = \int_{\Omega_{\text{str}}} \rho_{\text{str}} \cdot d\Omega_{\text{str}} \quad (9)
$$

Note that the described streamer calculation method can be easily modified to consider electrode configurations without axial symmetry. In those cases, (1–5, 7–9) can be expressed instead in a three-dimensional space ($x, y, z$) and in an auxiliary spherical coordinate system ($l, \theta, \phi$). In addition, observe that an additional term can be added at the right hand side of the Poisson’s equation (1) in order to consider existing distributed space charge from a previous streamer burst.

2.2 IMPLEMENTATION

Inverse problems are inherently difficult to solve. They are usually ill-posed problems since there is not a unique solution. In addition, the solutions are strongly sensitive to small perturbations in the reference data used in the objective function [20]. Fortunately, the inverse Poisson problem defined in the previous subsection is mildly ill-posed since the charge density to be estimated in continuous and smooth, and the streamer potential $\phi_{\text{str}}$ is well defined.

In order to solve the optimization problem efficiently, the residual function (8) is rewritten in the base coordinate system $(r, z).$ In this way, the objective function $\varepsilon$ to be minimized is defined by:

$$
\varepsilon = \int_{\Omega_{\text{str}}} \left( \phi(r, z) - \phi_{\text{str}}(l) \right)^2 \cdot dr \cdot dz \quad (10)
\text{with} \quad l = \sqrt{(r-r_c)^2 + (z-z_c)^2}
$$

where $r_c$ and $z_c$ define the coordinates of the electrode’s tip center. In addition, an auxiliary optimization variable $p$ defined as:

$$
p(r, z) = \log_{10}(\rho_{\text{str}}(r, z)) \quad (11)
$$

is used to improve the convergence of the solution and to guarantee the positivity of the estimated charge density [10] without adding an extra constraint.

Thus, the optimization problem defined by

$$
\min_p (\varepsilon) \quad (12)
$$

is coupled to the solution of the Poisson equation ((1) and (2)) by using a commercial software [21]. While Poisson’s equation is solved with the finite element method, the objective function is solved by using a gradient-based optimization algorithm called SNOPT [22]. For the discretization of the domains, different mesh methods are used. A mapped mesh distributed exponentially along the streamer propagation direction is set for the zone $\Omega_{\text{str}}.$ The mesh element size increases from $10^{-5}$ m close to the rod’s tip, with an element growth rate of 1.2. A free meshing of normal predefined size is used for the domain $\Omega_{\text{str}}.$ A discontinuous Lagrange shape function with constant element order is used since it reduces the demands on core memory [23] and it reduced the calculation time.

On the other hand, a proper initial guess for the charge distribution function can help to improve the convergence of the solution significantly. In order to obtain a suitable guess distribution for the optimization variable $\rho_{\text{str}}^{\text{guess}},$ the charge distribution proposed in [13]:

$$
\rho_{\text{str}}^{\text{guess}}(l) = \frac{a_s}{(l + c^s)^3}, \quad \text{for } l \leq l_s \quad (13)
$$

is used as first approximation to the real charge distribution $\rho_{\text{str}}.$ The parameters $a_s, b_s, c_s,$ and $l_s$ are obtained as an early optimization step such that the residual function (7) along the streamer axis is minimized when $\rho_{\text{str}}^{\text{guess}}$ is used.

Furthermore, it has been found that the convergence of the solver is significantly faster when a proper weight function is
added to the optimization function \( \varepsilon \). Since the streamer charge is maximum close to the stressed electrode and decays rapidly [15], the optimization solver is more efficient when a suitable function increase the weight of the residual function close to the electrode. For this reason, an exponential weight function \( W(\varepsilon) \)

\[
W(\varepsilon) = a \cdot \exp\left(-b \cdot (\varepsilon - l_{\text{trip}})\right) + c
\]

with constants \( a=10^{-1} \), \( b=100 \, \text{l/m} \) and \( c=10^{-2} \) is used.

Finally, the estimation of the total streamer charge (9) is performed by solving the optimization problem (given by (12)) two times. First, the calculation is performed for an initial guess of the maximum streamer propagation length \( l_{\text{str}}^{(\text{max})} \). For this, the length \( l_i \) defined by the crossing point between the laplacian potential distribution \( \phi_{\text{ap}} \) and the line with slope \( E_{\text{str}} \) is used [e.g. 12, 16]. Since the electric field at this point \( l_i \) is significantly lower than \( E_{\text{str}} \) once the streamer has propagated (as seen in Figure 2), the effective length \( l_{\text{str}}^{(\text{max})} \) is always shorter than \( l_i \). Since the difference between \( l_{\text{str}}^{(\text{max})} \) and \( l_i \) can be significant (up to 35% for the case studies introduced in the next section), a second step is usually performed to obtain the electric field at the streamer front within the range \( E_{\text{str}} \pm 5\% \). Thus, based on the obtained first solution, an improved estimate of length \( l_{\text{str}}^{(\text{max})} \) is found from the calculated electric field along the axis, as the place where the field becomes lower than \( E_{\text{str}} \). Then the problem is solved a second time with the updated improved guess of the length \( l_{\text{str}}^{(\text{max})} \).

### 3 CASE STUDIES

In order to validate the method with experimental data, three different datasets reported in the literature are considered in this section. It is worth to mention that the apparent injected charge was measured in these experiments, which is always lower than the true net streamer charge [24]. For this reason, the apparent streamer charge \( Q_{\text{app}} \) is estimated as the difference between the true streamer charge \( Q_{\text{str}} \) and the charge induced at the electrodes \( Q_{\text{ind}} \) by the actual charge deposited in the gap \( Q_{\text{str}} \). Note that the induced charge \( Q_{\text{ind}} \) should be integrated over the surface of the electrode section connected to the current or charge probe.

#### 3.1 STREAMERS IN A 1 M AIR GAP

The first dataset corresponds to the charge-voltage characteristics of first streamer corona measured for a rod to plane configuration as reported in [12]. In this test, a 30° conical tipped electrode with 0.002 m tip radius, forming an air gap of 1 m, was exposed to voltages with a rate of rise ranging between 45–50 kV/\( \mu \)s. Considering this risetime, the voltage applied at the end of the streamer propagation (lasting between 300–400 ns [12]) is about 15–20 kV larger than the streamer inception voltage. The measurements were performed for humidity values \( h \) varying between 4–5 g/m\(^3\) and a relative density \( \delta \) of 0.96.

Figure 3 shows the comparison between the streamer apparent charge \( Q_{\text{app}} \) measured and estimated as a function of the inception voltage. Since the branching angle is the only unknown in the calculation, the estimated apparent charge is also plotted for different values of \( \theta_{\text{str}} \). As it can be seen, the estimations converge towards the measurements as the branching angle increases. Moreover, the estimations become nearly angle-independent for larger values of \( \theta_{\text{str}} \) (90 and 120 degrees in Figure 3).

It is worth to point out that when the angle \( \theta_{\text{str}} \) is large enough, the optimization method can also predict the effective streamer shape, as shown in Figure 4 (left side). For a given streamer calculation domain \( \Omega_{\text{str}} \) (limited by the dashed lines in the left figure), observe that two different regions separated by a sudden change in the charge density are found. The first region corresponds to the volume with significant charge density, which defines the effective shape of the streamer. The second region corresponds to the zone where the estimated charge density is negligible (more than two orders of magnitude lower than in the first region). These two regions are obtained as the areas where the solution of Poisson’s equation allows (or blocks) the propagation of a streamer with electric field \( E_{\text{str}} \), such that the objective function (10) is minimized.

Even though it has been suggested that the angle \( \theta_{\text{str}} \) in this configuration can be assumed equal to 60 degrees [12], a still image reported in that experiment (although for a slightly shorter air gap of 0.5 m) also show streamer filaments propagating at larger angles (right image in Figure 4).

Interestingly, the effective branching angle \( \theta_{\text{str}}^{(\text{real})} \) in the photograph (about 100 degrees in Figure 4) agrees rather well with the minimum angle \( \theta_{\text{str}} \) from which the calculations become independent of angle. This indicates that the estimated charge \( Q_{\text{str}} \) is almost independent of the chosen \( \theta_{\text{str}} \), as far as all streamer filaments are included in the calculation domain \( \Omega_{\text{str}} \).

In this case, the predicted streamer branching shape is in reasonable agreement with the effective extension of the streamer observed in the experiment (Figure 4).

Figure 3 also shows that the estimated streamer charge \( Q_{\text{str}} \) is underestimated as the charge of some filaments is truncated.
in the calculation by choosing an angle \( \theta_{\text{str}} \) smaller than the actual branching angle \( \theta_{\text{true}} \). However, the estimations are not proportional to the chosen branching angle \( \theta_{\text{str}} \), in contrast to the other methods in the literature [12, 13]. Observe that the streamer charge estimated for small branching angles of 15 and 30 degrees is about 45\% and 65 \% of the total charge of all the branches (for an angle of 120 degrees) respectively. This shows that a major fraction of the total charge \( Q_{\text{str}} \) comes from the longer filaments close to the streamer axis. Instead, as the filaments branch radially at larger angles from the streamer axis, their contribution to the total charge (as well as their length) decreases.

3.2 STREAMERS IN A 10 M AIR GAP

The second experimental dataset used as reference is based on the streamer charge values measured in [15] as a function of the electric field at the electrode tip. In this case, switching voltages were applied to a rod to plane configuration with 10 m air gap. The rod was pencil-shaped with a tip radius of 0.01 m. The humidity was reported between 4–5 g/m\(^2\) and the relative air density is assumed equal to 1. The voltage risetime at streamer inception is estimated between 9 and 15 kV/\(\mu\)s based on the results published in [15].

Figure 5 shows the comparison between the measured apparent streamer charge and the estimations for different branching angles \( \theta_{\text{str}} \). As in the previous case study, there is very good agreement between the measurements and the calculations for sufficiently large branching angles (larger than about 60 degrees in this case).

An example of the calculated distribution of potential, electric field and charge density logarithm (variable \( p \)) along the discharge axis under an applied voltage of 395 kV is shown in Figure 6. Observe the significant distortion of the potential and electric field distributions as the streamer reaches its maximum length. The charge density logarithm required to produce that distortion has a “bathtub” shape, with a global maximum value close to the rod tip and an additional local maximum at the streamer front. The lowest streamer charge density lays few centimeters behind the streamer front, reaching values more than one order of magnitude lower than the global maximum. Even though the error in the optimization problem (12) can reach small values (less than 1\%), note that the solution of the charge density logarithm can include small local variations (artefacts). However, the errors caused by those artefacts cancel each other locally such that the electric field and the potential distributions are smooth functions, as shown in Figure 6. Since these local artefacts do not influence the total charge calculation either, no attempt is done in order to further minimize them.
3.3 STREAMERS ALONG A DIELECTRIC BARRIER

The last experimental dataset considered is based on the potential distribution profiles measured along streamers propagating on a dielectric crystal, as reported in [25]. In this experiment, a positive impulse voltage (with risetime of about 70 ns) was applied to a conical rod electrode whose tip stood perpendicular on the surface of a \(2.56 \times 10^{-3}\) m thick crystal plate, as shown in Figure 7. The electrode had a radius of \(1.5 \times 10^{-3}\) m. The crystal (with a relative permittivity of 16) was placed as a planar dielectric barrier between the rod and a transparent ground plane, and it was used as a Pockels sensor to measure the instantaneous, two-dimensional potential distribution on its surface. An example of the instantaneous voltage profile measured along a streamer, 48 ns after its inception, is shown in Figure 8a. At this time, the streamer reaches a length of about \(1.2 \times 10^{-2}\) m.

The instantaneous charge distribution for that case was also estimated in [25], as shown in Figure 8b. However, the distribution reported corresponds to a surface charge density since the streamer was assumed to have no thickness. In order to calculate the streamer charge density in this experiment, the stabilization field \(E_{str}\) is estimated as \(6.5 \times 10^5\) V/m from the measured potential distribution (Figure 8a). Note that \(E_{str}\) in this case is larger than the value estimated with (6) since the stabilization fields of streamers propagating along dielectric surfaces are larger than in pure air [26]. In addition, the calculated volumetric charge distribution (shown in Figure 6, left) is integrated along the \(z\) vertical axis for each radial distance to the electrode. In this way, an equivalent surface charge distribution is obtained which can be compared with the surface charge density reported in [25]. As it can be seen in Figure 8, there is a good agreement between charge density distributions reported in [25] and that computed with the optimization method.

It is noteworthy that the charge density distribution computed with the optimization method (as shown in Figure 7) predicts that most of the streamer charge forms a layer of about 100 \(\mu\)m thickness. Even though the streamer thickness along the dielectric crystal was not measured in [25], the estimated value agrees well with the typical radius of streamers in air at atmospheric pressure [27]. On the other hand, the actual streamer charge estimated for this experiment is 80 nC, which is of the same order of magnitude as the apparent charge (about 100 nC) estimated by integrating the current reported in [25]. On the other hand, observe that the equivalent surface charge density estimated for thin streamers propagating along a dielectric is particularly prone to small local artefacts (as seen in Figure 8b). These are caused by local errors in Poisson’s equation at the interface, where the charge deposited by the streamer on the surface and the charges induced in the dielectric are very close to each other. Since the mesh size at the interface is small but finite (less that 10 \(\mu\)m in this case), these oscillations are difficult to avoid. Nevertheless, they have a minimum effect on the total charge the potential distribution or the objective function (10) as already discussed in Section 3.2.

4 DISCUSSION

The case studies analyzed in the previous section have shown that the streamer charge estimated with the proposed method is in good agreement with measurements performed under different configurations. Even though the calculation effort required to solve the optimization problem is significantly larger compared with other methods, it has several advantages that compensate for it:

- It does not require any tuning parameter in order to
adjust the estimations to the experimental results.
- It is not strongly dependent on the branching angle $\theta_{br}$ as the other methods in the literature.
- It can provide a good approximation of the spatial charge distribution and it therefore gives information about the actual extension and maximum possible branching of the streamer.
- The method can be easily modified in order to estimate the streamer charge under different electrode configurations (even including dielectrics or preexisting space charge).

In addition, the optimization problem involved in the method can be interpreted in physical terms. An equivalent objective function can be obtained by rewriting (12):

$$\min_{\rho_{str}} \left( \int_{\Omega_{str}} (\nabla \phi(t) - E_{str}) \cdot d\Omega \right)$$

(15)

where the integral term can be related to the difference between the electrostatic energy within the domain $\Omega_{str}$ without and with the streamer. Thus, the optimization problem can be interpreted as the search of the charge distribution $\rho_{str}$ that minimizes the remaining electrostatic energy in the domain $\Omega_{str}$ after a streamer is incepted. In other words, the method finds the charge distribution $\rho_{str}$ such that the streamer dissipates the maximum available electrostatic energy in the gap, under the constraint of a constant streamer potential gradient $E_{str}$. For this reason, the calculation can provide suitable estimates of the charge distribution even when the domain $\Omega_{str}$ is larger than the predicted extension of the streamer (as in Figure 4).

It is relevant to keep in mind that the estimations performed with the optimization method are valid only in cases where two main conditions are fulfilled:

(a) The streamer branches into a significant number of filaments that propagate uniformly into the gap

(b) The streamer potential gradient can be assumed equal to the stabilization field $E_{str}$.

These conditions are normally valid for most experimental conditions with divergent electrode configurations under standard voltage risetimes (lower than about 100 kV/$\mu$s). However, caution is required when the streamer charge is estimated for configurations under very fast voltage risetimes (as in e.g. [7, 8]) where only few streamers propagate or “late” streamers appear (violating condition (a)). The same applies for estimations under voltage levels where streamers reach the opposite electrode (as in [11]) such that their electric field becomes different from $E_{str}$ (against condition (b)).

On the other hand, note that the optimization method as presented in Section II can be easily extended to other geometries without axial symmetry. Ultimately, it could be extended to three dimensional (3D) configurations with and without dielectrics. Although possible, it would require a careful balance between computational resources and accuracy of the solution, especially for complex geometries. The presence of preexisting space charge can easily be included in the method, by simply adding an extra source term in Poisson’s equation (1). This would allow the estimation of the charge of subsequent streamers or the study of dark periods between streamers. In addition observe that the method could also be applied to estimate the charge of negative streamers or of streamers in other gases. However, its use is restricted to cases where the conditions mentioned above are fulfilled and the corresponding stabilization field or the streamer potential distribution are known.

7 CONCLUSION

An alternative method to estimate the charge of positive streamers, based on the inverse solution of Poisson’s equation by numerical optimization, is presented. In contrast to existing methods, the proposed approach does not require “tuning factors” and can be easily applied for configurations with dielectrics. The method has been introduced for configurations with axial symmetry, with very good agreement with measured streamer charge values. The method has potential advantages to estimate the spatial distribution of the streamer charge density in configurations with preexisting background space charge or with interfaces with dielectric media along the streamer propagation path.

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