Modified Lightning Traveling Current Source Return Stroke Model

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***Abstract*— The classical lightning traveling current source (TCS) return stroke model without current reflections is considered. The TCS model is modified to take into account the current component caused by the transferred line charge density along the channel core below the return stroke wave-front. For the TCS model without current reflections this modification has yielded the final results similar to those of the Bruce-Golde model (BG). In the modified TCS model (MTCS) the distribution of the channel current is uniform i.e. there is no line charge along the core below the return stroke wave-front. Nevertheless, the physical picture of the discharge differs significantly from that of the BG model. For the TCS model with the current reflections from the ground and from the upper end of the lightning channel the modification is more complex. In this case the transferred line charge density along the channel core can be calculated from the equation of continuity.**

***Index Terms*—Atmospheric discharge, Lightning, Return stroke.**

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I. INTRODUCTION

Side view of the lightning channel containing channel core and the corona sheath during the return stroke stage is depicted in Fig.1. Transferred line charge density component $q'_{tr} = \partial q_{tr} / \partial z$ for the TCS model is [1]

$$q'_{tr} = -i_{0TCS}(t + z/c)/c\,, \qquad t \ge 0\,, \quad z \le vt\,. \tag{1}$$

The deposited line charge density component $Q'_{de} = dQ_{de}/dz$ above the return stroke wave-front for the TCS model is given in [3]

$$Q'_{de} = i_{0TCS}(z/v^*)/v^*\,, \qquad z \le vt\,. \tag{2}$$

where $i_{0TCS}(t)$ is the channel base current in the TCS model. The channel-base current can be expressed by the deposited charge density component if one substitutes $z = v^* t$ in (2). It follows

$$i_{0TCS}(t) = v^* Q'_{de}(v^* t)\,. \tag{3}$$

The current at some altitude in the TCS model [3] is given by

$$i_{TCS}(z,t) = i_{0TCS}(t + z/c)\,,\ z \le vt\,. \tag{4}$$

If one neglects the rotational electric field component generated by the axial time-variable current then the line charge density q'_{tr} below the return stroke wave-front (1) generates the negative electric field in the vicinity of the channel. This field is not observed in the measurements [2]. Besides, due to the perfectly conducting channel core and the absence of the rotational electric field, the voltage drop between point A and point B at the ground surface should be zero, Fig.1. It follows that the total radial electrostatic field

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component near the core should be zero i.e. the additional channel-base current component $i_{0tr}(t)$ should be generated. This component carries positive charge neutralizing the negative line charge q'_{tr} adding to the existing channel-base current. Moreover, due to the vicinity of the negative charge in the corona sheath above the return stroke wave-front and the finite conductivity of the channel core, an excess of positive charges along the core should be expected. However, for the purpose of this paper their presence is neglected although there is clear experimental proof of their existence [2].

First, we calculated the total negative transferred charge along the channel (seen from the channel base). It is placed along the entire activated part of the channel i.e. up to the height vt i.e.

$$q_{tr}\big|_{z=0} = -\int_0^{vt} i_{0TCS}(t+z/c)/c\,dz, \tag{5}$$

where $t \geq 0$, $z \leq vt$ and i_{0TCS} is the channel-base current in the TCS model. According to the aforestated assumption, the transition channel-base current component carrying the positive charge will be

$$i_{0tr} = \left|\frac{dq_{tr}}{dt}\right|_{z=0} = \frac{1}{c}\int_0^{vt} (di_{0TCS}(\xi)/dt)\,dz + \frac{v}{c} i_{0TCS}[t(1+\frac{v}{c})]\ , \tag{6}$$

where $\xi = t + z/c$, $t \geq z/v$. Since

$$di_{0TCS}(\xi)/dt = (di_{0TCS}(\xi)/dz)\,c, \tag{7}$$

the transition channel-base current component i_{0tr} reduces to

$$i_{0tr}(t) = \int_0^{vt} di_{0TCS}(t+\frac{z}{c}) + \frac{v}{c} i_{0TCS}(kt) = k\,i_{0TCS}(kt) - i_{0TCS}(t). \tag{8}$$

where $k = 1 + v/c$. The total channel-base current according to the MTCS model is the sum of the additional current component (8) and the current component $i_{0TCS}(t)$ in the classical TCS model

$$i_{0MTCS}(t) = i_{0tr} + i_{0TCS} = k\,i_{0TCS}(kt)\ . \tag{9}$$

If $v << c$ (9) reduces to the current expression in the classical TCS model. If $v \leq c$ the differences are more pronounced, the peak of the current multiplies by factor greater than one and it comes earlier. Using (3) one obtains

$$Q'_{de}(z) = i_{0MTCS}(z/v)/v. \tag{10}$$

The deposited charge component (10) is similar as in the BG model [4, 5].

II. CURRENT DISTRIBUTION ALONG THE CHANNEL ACCORDING TO THE MTCS MODEL

Similar as it is shown in (5) the negative line charge $q_{tr}\big|_z$ above altitude z is

$$(11)\ q_{tr}\big|_z = -\int_z^{vt} [i_{0TCS}(t+z/c)]/c\,dz,$$

where $t \geq 0$, $z \leq vt$. The additional channel current i_{ztr} carrying positive charge neutralizes the negative line charge above altitude z

$$i_{ztr} = \frac{d\left|q_{tr}\right|_z}{dt} = \frac{1}{c}\int_z^{vt} \frac{di_{0TCS}(\xi)}{dt}dz + \frac{v}{c} i_{0TCS}[t(1+\frac{v}{c})]\ . \tag{12}$$

Using (7), from (12) it follows

$$\begin{aligned} i_{ztr}(z,t) &= \int_z^{vt} di_{0TCS}(t+\frac{z}{c}) + \frac{v}{c} i_{0TCS}(kt) = \\ &= k\,i_{0TCS}(kt) - i_{0TCS}(t+\frac{z}{c}). \end{aligned} \tag{13}$$

The total channel current at some altitude according to the MTCS model is the sum of the additional current component (13) and the current component $i_{TCS}(z,t)$ in the classical TCS model, (9)

$$i_{MTCS}(z,t) = i_{ztr} + i_{TCS} = k\,i_{0TCS}(kt)\ . \tag{14}$$

Comparing (14) and (9) one obtains

$$i_{MTCS}(z,t) = i_{0MTCS}(t) = k\,i_{0TCS}(kt)\ . \tag{15}$$

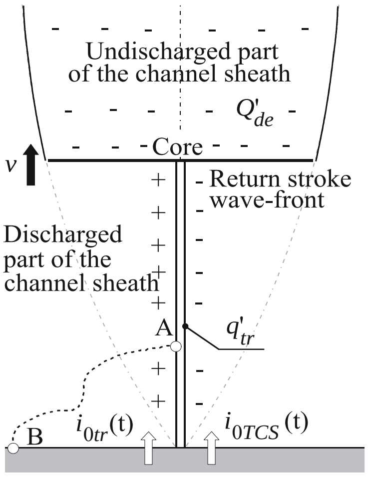

Fig. 1. Side view of the channel containing the core and the corona sheath during the return stroke stage.

III. CONCLUSION

The transferred line charge density is analysed in the TCS model without current reflections. The total (negative) transferred line charge along the channel as a function of time is calculated. The TCS model is modified to take into account the current component caused by the transferred line charge density along the channel core below the return stroke wave-front. For the TCS model without current reflections this modification has yielded the final result similar to that of the Bruce-Golde model. In the modified TCS model the distribution of the channel current is uniform i.e. there is no line charge along the core below the return stroke wave-front. Nevertheless, the physical picture of the discharge differs significantly from that of the BG model.

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