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EPSR-5153; No. of Pages 9

ARTICLE IN PRESS

Electric Power Systems Research xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Merging of current generation and current dissipation lightning return stroke models

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ARTICLE INFO

Article history:
Received 19 May 2016
Received in revised form 28 March 2017
Accepted 9 May 2017
Available online xxx

Keywords:
Retrun stroke
Corona
Engineering return stroke models
Current generation type models
Current dissipation type models

ABSTRACT

Current generation and current dissipation return stroke models are engineering models based on the theory associated with the propagation of current pulses along transmission lines undergoing corona. However, neither of these models incorporates the complete theory associated with the phenomenon. One can make the physical scenario complete by combining the current generation concept with the current dissipation concept. In this paper how this can be done is demonstrated by creating a return stroke model which is a combination of these two model types. The new model encompasses the full theory associated with the pulse propagation along transmission lines under corona. The paper provides a full description of the model together with a description of the spatial and temporal variation of the return stroke current and the electric and magnetic fields generated at different distances as predicted by the model.

1. Introduction

Consider the injection of a current pulse into an ideal and uniform transmission line in air. If the amplitude of the current pulse is less than the critical current necessary for corona generation from the line, the current pulse propagates along the line without attenuation and dispersion and with a speed equal to the speed of light in free space. This basic idea, with several modifications either in the speed of propagation or the amount of current attenuation, is used as a basis in creating current propagation models [1]. In all the current propagation models the return stroke speed is assumed to be less than the speed of light and in several models the return stroke current amplitude is assumed to attenuate as it propagates along the return stroke channel [2–4]. On the other hand when the injected current amplitude is larger than the threshold current necessary for corona generation from the transmission line, each element of the transmission line acts as a corona current source. Half of the corona current generated by the sources travels downward and the other half travels upward. The speed of propagation of the pulses is equal to the speed of light in free space. The upward moving corona currents interact with the front of the injected current pulse in such a way that the speed of the net upward moving current (i.e. sum of the two upward moving current pulses) is reduced, and for a transmission line in air, to a value less than the speed of light in free space [5]. Thus in principle one would find three separate current waveforms along the return stroke channel. The first one is the upward moving injected current (Current Pulse 1). The second one is the current generated by the sum of upward moving corona currents (Current Pulse 2). The third one is the current generated by sum of downward moving corona currents (Current Pulse 3). The injected current transports positive charge upward, the current pulse due to upward moving corona current transports negative charge upward and the current pulse formed by the downward moving corona currents transports negative charge toward the ground. All the three current pulses propagate with speed of light along the return stroke channel. The net upward moving current is produced by the sum of Current Pulse 1 and Current Pulse 2. This concept with several modifications is used in constructing current generation [6–11] and current dissipation models [12–14]. In two recent publications [15,16] an attempt had been made to generalize the current generation type model introduced in reference [6].

First let us consider the basic assumptions of current generation models. In current generation models the leader channel is treated as a charged transmission line and the return stroke current is generated by a wave of ground potential that travels along it from ground to cloud. The arrival of the wave front (i.e. return stroke front) at a given point on the leader channel changes its poten-

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http://dx.doi.org/10.1016/j.epsr.2017.05.010
0378-7796/

Please cite this article in press as: V. Cooray, G. Diendorfer, Merging of current generation and current dissipation lightning return stroke models, Electr. Power Syst. Res. (2017), http://dx.doi.org/10.1016/j.epsr.2017.05.010

tial from cloud potential to ground potential causing the release of bound charge on the central core and the corona sheath giving rise to a corona current. Accordingly, each point on the leader channel can be treated as a current source which is turned on by the arrival of the return stroke front at that point. The corona current injected by these sources into the highly conducting return stroke channel core is assumed to travel downward to ground with the speed of light. One can see directly that these models utilize the Current Pulse 3 described previously to represent the return stroke current. In these models the speed of propagation of the return stroke front is selected to be less than the speed of light. The basic concept of current generation models is depicted in Fig. 1a. In a recent publication Cooray [12,13] showed that a combination of Current Pulse 1 and Current Pulse 2 described earlier can also be used to create return stroke models. He coined the term 'Current Dissipation Models' for the same. The basic concept of current dissipation models is depicted in Fig. 1b.

As one can see from the above introduction both current generation and current dissipation models neglect the existence of one current waveform predicted by the complete theory of current pulse propagation along transmission lines undergoing corona. In the current generation models it is the upward moving corona current and in the current dissipation models it is the downward moving corona current that was neglected. One can show that current propagation models are a special case of the current dissipation models [12,13]. Thus, the basic concepts utilized in all engineering models that are available today can be categorized either as current generation or current dissipation models. The goal of this paper is to take into consideration both the above mentioned corona current components so that the theory underlying the model is in agreement with the current propagation along transmission lines under corona generation.

2. Description of the new model

In the new model the return stroke is simulated by a current pulse injected at the base of the leader channel. This current is denoted by $i_{ib}(t)$ in the model. The injected current pulse propagates upward with speed of light forcing the return stroke channel to go into corona. In the model it is assumed that the threshold current for corona generation is much smaller than the return stroke current and for this reason it could be made equal to zero without changing the model predictions. At any given point the corona current, which is a flow of electrons into the central core, gives rise to two identical current pulses one propagating upward and the other propagating downward. Both current pulses propagate with the speed of light. The upward moving corona current, which is negative, is denoted by $i_{cu}(t)$ in the model. This current component completely neutralizes the upward moving injected current (which is positive) above a certain level. In other words, at any given instant the current is completely zero above this level. This level, which indeed is the return stroke front, travels upwards with a speed less than the speed of light. The speed of propagation of this front is defined as the speed of the return stroke. This speed is denoted by v in the model. The creation of the corona currents in the return stroke channel takes place at the front of the return stroke. The downward moving corona current travels downward toward the ground with the speed of light. This current waveform is denoted by $i_{cd}(t)$ in the model. At any level below the return stroke front one can find three current components. The injected current (with positive polarity), the upward moving corona current (with negative polarity) and the downward moving corona current (with positive polarity). Above the return stroke front one can find two current waveforms, the injected current and the upward moving corona current. But, they cancel each other completely so that the net current above the return stroke front is zero. The removal of electrons in the form of a corona current from the leader channel can be treated as a deposition of positive charge along the leader channel by the return stroke. This deposited charge, per unit length, is denoted by ρ. In the model the temporal variation of the corona current is represented by an exponential function. The decay time constant of this exponential function is denoted by τ in the model.

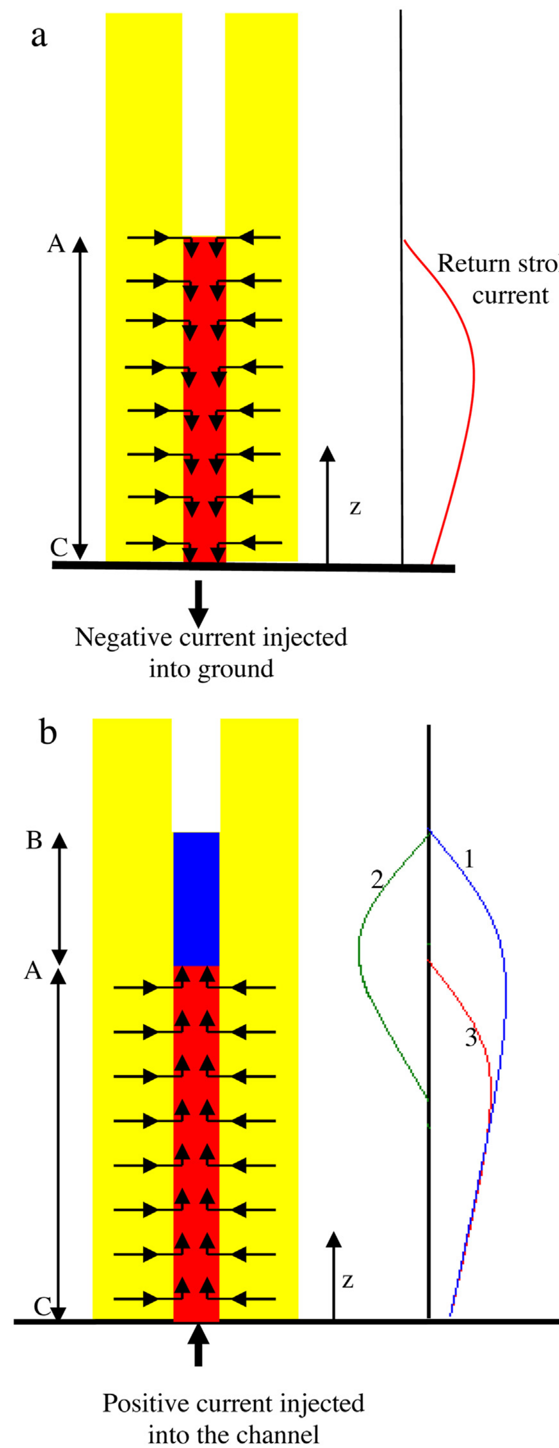

Fig. 1. (a) Pictorial description of the current generation (CG) concept. According to CG concept the downward moving corona currents generate the return stroke current. Adapted from Ref. [11]. (b) Pictorial description of the current dissipation concept. Waveforms to the right depict different current components along the channel. (1) Injected current. (2) Upward moving corona current. (3) Net current along the channel. (Adapted from Ref. [9]).