

# Original Article: Transient Simulation of Lightning in the Transmission Line and Consideration of Corona Impact and Frequency Dependence and Analogy between Them

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## ABSTRACT

The waveform and amplitude of overvoltage generated in the transmission line due to lightning strikes are of great importance in the insulation coordination of electrical equipment in the power grid and the choice of lightning protection. Corona impact and frequency dependence are among the factors that cause overhead line attenuation and distortion. One of the existing skin effects that cause the radial parameters of the line to be dependent on the frequencies of lightning and cause changes in other parameters is corona strokes. It is necessary to consider the optimal insulation design and lightning protection and economic aspects in the transient characteristics caused by lightning transmission lines by analyzing the two issues of corona impact and frequency dependence. In this paper, lightning-induced transient simulations in transmission lines are considered by considering the effects of frequency dependence and corona shocks. The model simulation was performed by ATP-EMTP.

## Introduction

**T**ransient voltages are generated in high voltage transmission lines when lightning strikes. Amplitudes and their waveform are very important

for coordinating the insulation of electrical equipment in the power grid and choosing lightning protection. Most of the factors cause overvoltage waves in reducing and distorting the overhead transmission line [1-5]. One of the most important is the presence of a skin

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effect that leads to the radial parameters of the lines depending on the frequency of lightning, and the other is the changes in the lateral parameters caused by the impact crown. Considering the insulation optimization plans, lightning shock protection, and economic aspects of high-pressure transmission lines, it is necessary to examine the lightning transient characteristics of strong pressure transmission lines from the above aspect to accurately measure the level of possible additional voltage in the transmission line. Research on the frequency-dependent properties of high-pressure transmission lines has become more mature with the continuous improvement of analytical methods and methods of line acceptance weight function method [6-9], transient wave function method [10-13], and the well-known Marti line model [14-17]. And other methods were proposed sequentially. There has been a lot of research on the crown for a long time. But due to the complexity of crown behavioral phenomena, an accurate and effective model is still needed to describe the impact of the crown. Voltage charge characteristics are obtained by physical work based on crown discharge at the conductor level in sources [18-21]. Due to the difficulties of the impact phenomenon of crown impact, it has been simplified to varying degrees in the sources. Considering the relationship between charge, strength, and voltage of the magnetic field, the volt-Coulomb characteristics of the crown were analyzed by some authors by linking the development process and the characteristics and effects of the crown [22-25]. On the one hand, according to the frequency-dependent parameters of the transmission line, the transient responses of the lightning corona must be carefully analyzed in the frequency domain. Impulse crowns, on the other hand, are generated when the overvoltage on the line is greater than the imagined voltage, and the development of the shockwave depends on the overvoltage amplitude. Therefore, the impact of the impact crown must be considered in the time domain. Also, in the literature [26-29], the electromagnetic transitions of high-pressure transmission lines were calculated using well-known methods with frequency-

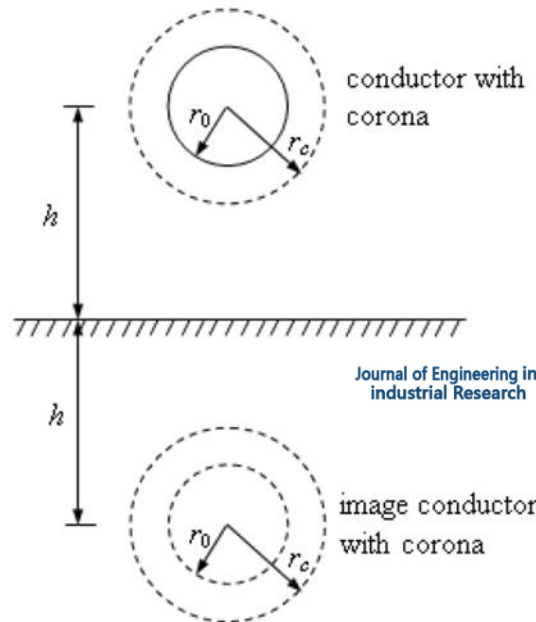
dependent parameters and corona effects with and without consideration. Further, a state-space method was proposed to analyze the impact of the crown impact and the parameters dependent on the frequency of transmission lines and the phenomenon of skin effects [30-35].

Therefore, an important model has been developed for the analysis of lightning strike crowns in high voltage AC transmission lines and a simulation has been made in ATP-EMTP software. Simulations with mature Marti line models have been used in the application. Simulation of the electromagnetic transient response of high-pressure transmission lines with frequency-dependent parameters and lightning strike crown is also presented in this paper [36-39].

#### *Corona model structures and charging radius*

Due to the skin effect of the conductors and the alternating magnetic field of the lightning, the resistance and inductance of the transmission line will change with the current frequency. At this time, the transmission line tries to have a direct effect on the magnetic transient state process by presenting a series of specifications at different frequencies [40-42]. The frequency dependence parameters of the transmission line have been calculated and the Marti orbital model, which is a complete, simple, and accurate example, has been adopted in this paper. The frequency impedance profile is matched by the approximate impedance function in the line, and the equivalent line of the transmission line can represent the use of the line impedance function [43-46]. When lightning strikes the transmission line, the amplitude of the overvoltage wave generated on the line is greater than the starting voltage and bioelectric discharge occurs on the conductor surface [47-49]. When there is no corona, the geometric capacitance is on the line  $C_g$ , and when corona occurs, the capacitance on the conductor begins to change, in which case we have the dynamic capacitance, or  $C_d$ , on the line. The structure of the transmission line and its image are shown in Figure (1). And the corona geometry is shown as a uniform

cylinder around the conductor. And the electric field of the conductor surface is assumed to be constant [50].



**Figure 1.** Corona model conductor structure and charging radius

*Corona model calculations*

Corona will occur when the electric field of the conductor surface reaches the amount and size of the critical electric field.  $Q_c$  is the electric charge of the conductor in the critical electric field and  $r_0$  is the radius of the conductor. The electric field at distance  $r$  from the surface of the conductor is as follows:

$$E = \frac{Q}{2\pi\epsilon_0 r_c} + \frac{Q}{2\pi\epsilon_0(2h - r)} \tag{1}$$

In the above equation,  $\epsilon$  is the vacuum permeability coefficient. The critical field  $E_i$  at  $r = r_0$  is as follows:

$$E_i = \frac{Q \cdot 2h}{2\pi\epsilon_0 r_0(2h - r_0)} \tag{2}$$

And the initial voltage of the conductor surface is expressed as follows:

$$V_c = \int_{r_0}^h \frac{Q_c}{2\pi\epsilon_0 r} dr \int_{2h-r_0}^h \frac{Q_c}{2\pi\epsilon_0 r} dr$$

$$= \frac{Q_c}{2\pi\epsilon_0} \ln\left(\frac{2h - r_0}{r_0}\right) \tag{3}$$

$$V_c = E_i r_0 \left(\frac{2h - r_0}{2h}\right) \ln\left(\frac{2h - r_0}{2h}\right) \tag{4}$$

And geometric capacitance is calculated as follows:

$$C_g = \frac{Q_c}{V_c} = \frac{2\pi\epsilon_0}{\ln\left(\frac{2h - r_0}{r_0}\right)} \tag{5}$$

The dynamic capacitance of the transmission line with the corona is calculated as follows: A and B are two constants that are  $A = 0$  and  $B = 1.02$  in the positive polarity and  $A = 0.15$  and  $B = 0.85$  in the negative polarity. M is also a constant that is 1.36 and 1.13 in positive and negative polarity, respectively.

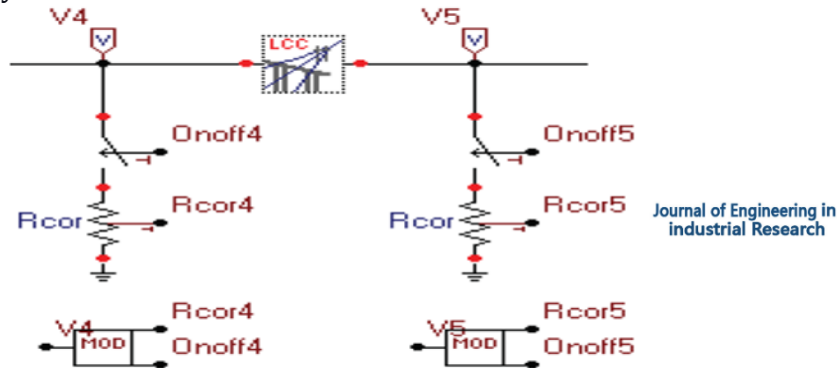
$$\frac{Q}{Q_c} = A + B \left(\frac{V}{V_c}\right)^{4/3}$$

(6)

$$C_d = \frac{dQ}{dV} = C_g M \left(\frac{V}{V_c}\right)^{1/3} \tag{7}$$

Consideration of numerical calculations of lightning transient mode in the transmission line with frequency dependence parameters and corona impact with ATP-EMTP magnetic transient mode software has been performed in this paper. To calculate the frequency dependence profile, the Marti model is applied to the program for analysis. The TACS switch

is used for this corona model in the transmission line. When there is no corona, the switch can disconnect the corona model from the transmission line. The orbital model is shown in figure (2), and the time-varying resistance at any point on the line can calculate the dynamic capacitance when the corona occurs.

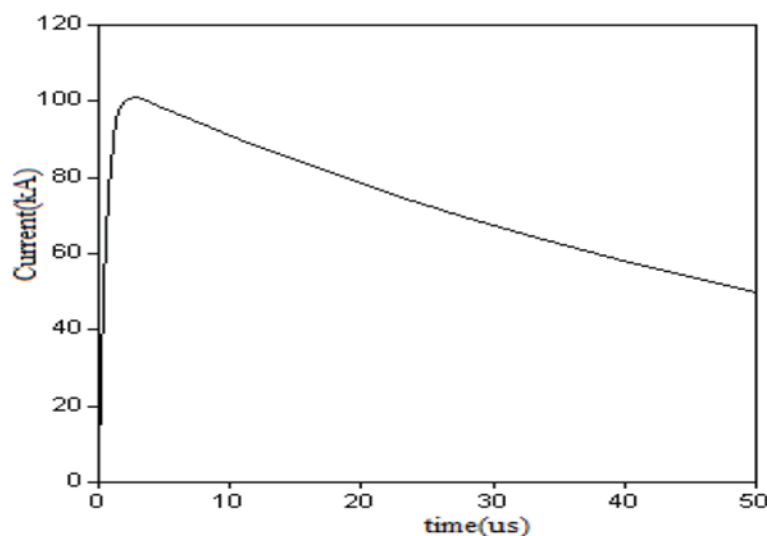


**Figure 2.** Simulated circuit model of corona

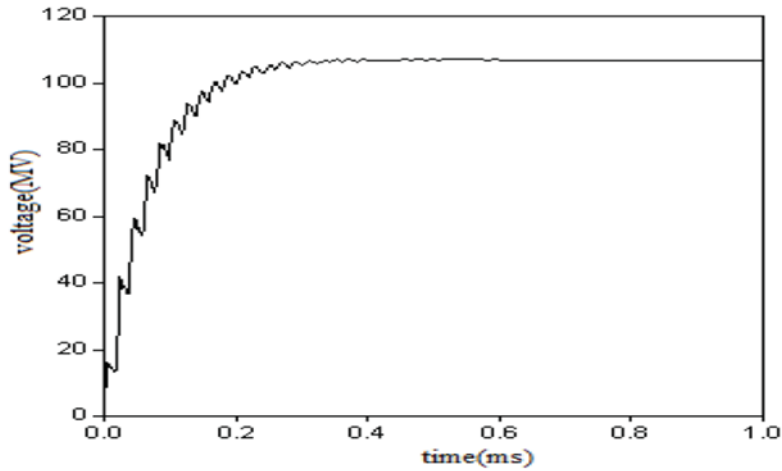
#### *Simulation results by ATP-EMTP software*

Transient responses caused by lightning in the single-phase transmission line were calculated and the transmission line with a length of one kilometer was divided into ten sections [54-57]. The lightning current injected at the starting point of the transmission line and the lightning waveform are shown in the form of a double exponential

pulse in figure (3). The injection shock voltage to the desired point calculated in figure (4) is shown [51-54]. Figure (5) shows the shock voltage by considering the frequency dependence. Based on the calculations, it can be seen that the effect of distortion and damping of transient waves due to corona shocks is more than the parameters of frequency dependence [58-62].

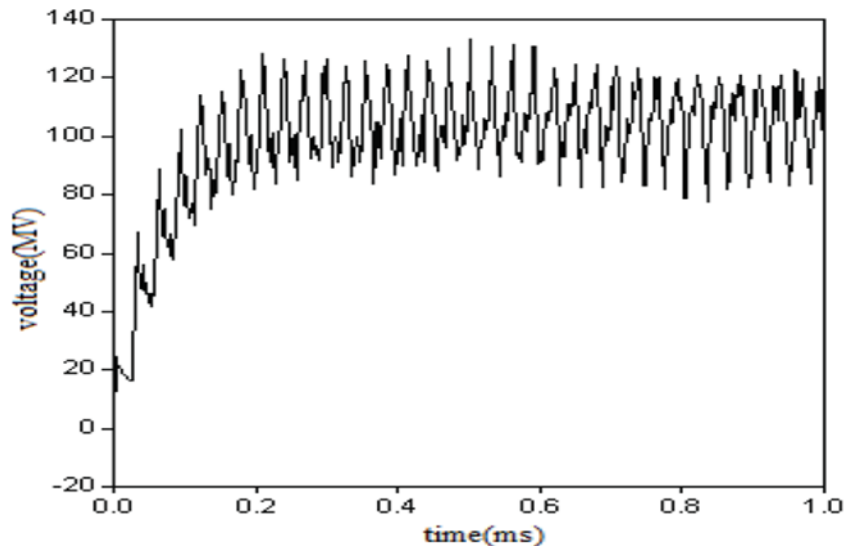


**Figure 3.** Lightning impulse current waveform



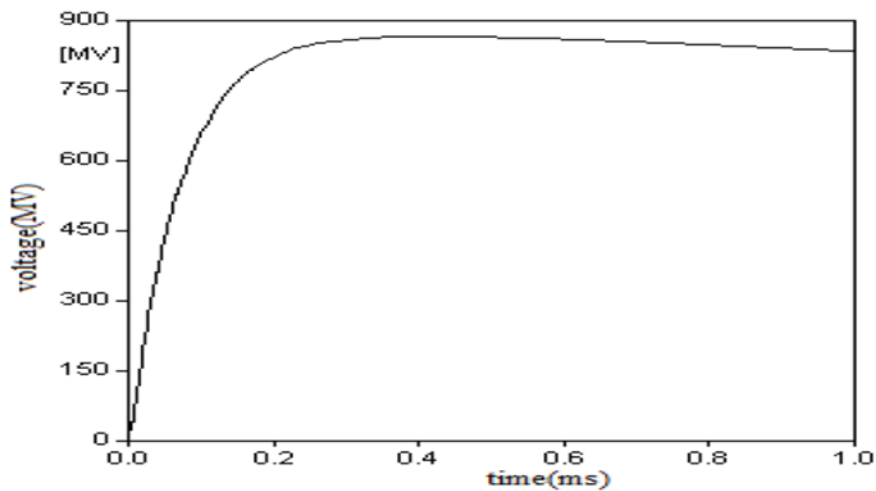
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**Figure 4.** Voltage waveform with frequency dependence and voltage shock parameters



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**Figure 5.** Voltage waveform only considering the corona impulse effect



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**Figure 6.** Voltage waveform only by considering frequency dependence parameters

## Conclusion

In this paper, a method using ATP-EMTP software to perform transient electromagnetic simulation of high voltage transmission line is presented and the frequency-dependent parameters and effects of lightning strike crown are applied with and without considering them. The sampling method is used to extract the geometric capacity of the high voltage transmission line, and the dynamic and static capacities are connected to the line by developing a crown accompanied by lightning. The Marty line model is a combination of the corona model presented at the same time as the lightning strike. In this software, the electromagnetic transient response of the transmission line hit by lightning has been used. The results can be accurate and reliable for the design of lightning protection insulation and equipment in the power grid in similar analyzes.

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