Parameters Affecting the Back Flashover across the Overhead Transmission Line Insulator Caused by Lightning

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***Abstract*— This paper describes analysis study on some factors, which affecting the back flashover across the insulator in a transmission system. Parameters of this study include the modeling of transmission line tower, the modeling of tower footing ground system, magnitude of lightning stroke, front and tail times of lightning stroke impulse, and striking distance. All components of the system, which is under study, are simulated by using ATP program.**

***Index Terms*—ATP, Back Flashover, Induced Voltage, Overhead Transmission Line.**

I. Introduction

In this paper, the lightning overvoltage in 500 kV transmission line is described. The lightning overvoltage is one of an important factors causing flashover and damage the insulators in the transmission line. A lightning flash generally consists of several strokes which are charges, negative or positive from the cloud to the ground. The first stroke is most often more severe than the subsequent stroke [1]. In stroked location a current impulse is injected into the transmission line. Voltage and current waves propagate from this stroked location to both sides of line, which reflect in every place where there is a change in surge impedance. Probability of direct lightning strike to phase conductor is decreased by using of ground wires. If ground wire is stroked by lightning, reflections appear in places of connection with tower or on earthing of tower. As the lightning current propagates on ground wire to both sides from stroked place, the value of overvoltage in this place can be determined as voltage drop caused by lightning current flow through parallel combination of line surge impedance and tower where steel tower bears as surge impedance approximately of hundreds ohm depended on tower configuration and dimensions. When lightning strikes a tower, a traveling voltage is generated which travels back and forth along the tower, being reflected at the tower footing and at the tower top, thus raising the voltage at the cross-arms and stressing the insulators. The insulator will flashover if their transient voltage exceed its withstand level (backflash).

II. Modeling of the System Under Study

A. Single-Circuit 500 kV Transmission Line

The 500 kV transmission line has three sub-conductors per phase and two ground wires. The span length is equal to 400 m. The tower is of flat configuration as shown in Fig. 1, and the distance between two adjacent phases is equal to 13.2 m. Modeling of transmission line tower is an essential part of the travelling-wave analysis of lightning surges in overhead transmission lines. Tower equivalent circuit is shown in Fig. 2, and Fig. 3 shows the transmission line tower model, which is simulated by ATP program. The model consists of main legs and cross-arms. The surge impedance of each part is expressed by the functions of their dimensions and geometry [2]. The surge impedance in ohm, propagation velocity in mega meter per second and length in meter of each tower's part are indicated in Fig. 2.

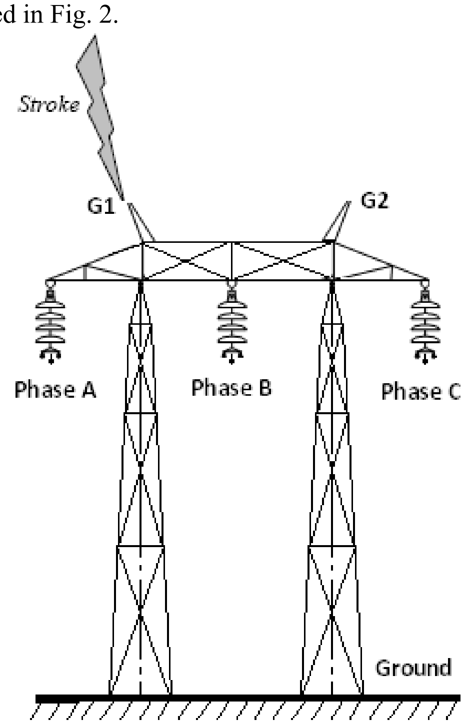

Fig. 1 500 kV transmission line tower

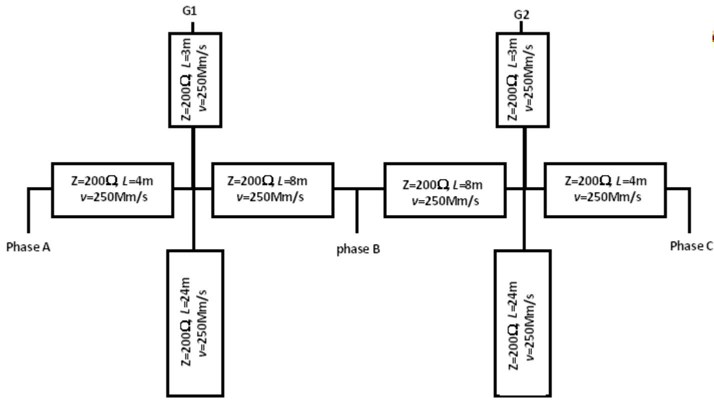

Fig.2 Simplified representation of 500 kV tower

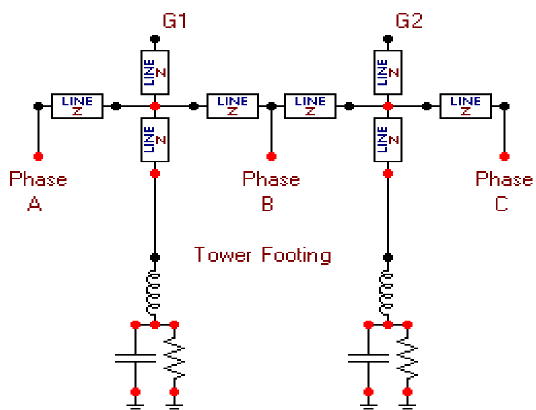

Fig. 3 ATP Model of 500kV transmission line tower

B. *Tower Footing Ground System*

In order to simulate behavior of different tower footing ground system during lightning transient, a vertical or horizontal electrode is used at each leg of the transmission line tower and simulated by ATP program as shown in Fig. 3. A simple lumped circuit high frequency mode suggested by Rudenberg [3-4] is illustrated in Fig. 4. For the vertical electrode, according to Dwight [4-5], the resistance (in Ohms) is calculated as:

$$R = \frac{\rho}{2\pi l}\left[\ln\left(\frac{4l}{a}\right) - 1\right] \quad (1)$$

and for the horizontal electrode, according to Sunde [6], the resistance is calculated as:

$$R = \frac{\rho}{\pi l}\left[\ln\left(\frac{2l}{\sqrt{2ad}}\right) - 1\right] \quad (2)$$

where ρ is resistivity of the earth in ohm. meter, l is ground electrode length in meter, a is its radius in meter, and d is depth of burial of horizontal electrode in meter.

and the grounding capacitance C (in Farad) for both vertical and horizontal electrode is computed based on the relationship [4-5]

$$C = \frac{\rho\varepsilon}{R} \quad (3)$$

where ε is permittivity of the soil in farad per meter.

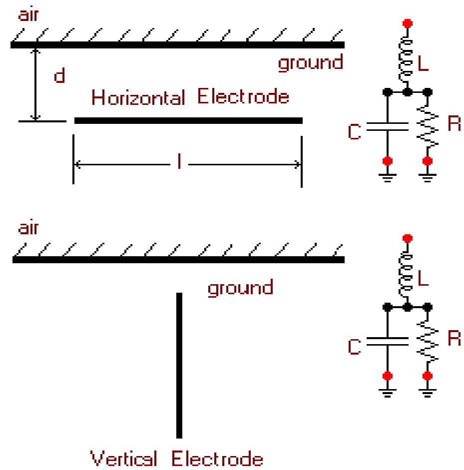

Fig. 4 High Frequency lumped *RLC* circuit simulates the grounding electrode.

Finally, the inductance L (in Henries) for both vertical and horizontal electrode is given by:

$$L = \frac{\mu l}{2\pi}\left[\ln\left(\frac{2l}{a}\right) - 1\right] \quad (4)$$

where μ is permeability of the soil in henries per meter.

C. *Lightning strike*

The lightning stroke is modeled by a current source and a parallel resistance, which represents the lightning-path impedance. Lightning-path impedance is selected as 400 Ω according to [7]. Figure 5 shows the lightning stroke model that simulated by ATP program. Typical stroke impulse current waveform is shown in Fig. 6.

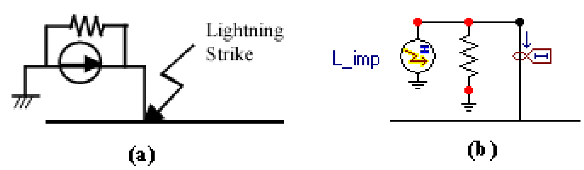

Fig. 5 Simulation of lightning stroke model

D. *Back flashover Model*

The transient-voltage withstands level of a power apparatus is not a unique number. An apparatus may withstand a high transient voltage which has a short duration even it has failed to withstand a lower transient voltage with longer duration. This characteristic of the insulator is known as the volt-time characteristic of the insulation. However, a simplified expression for the insulator voltage withstands capability can be calculated as [8]

$$V_{fo} = K_1 + \frac{K_2}{t^{0.75}} \qquad (5)$$

where

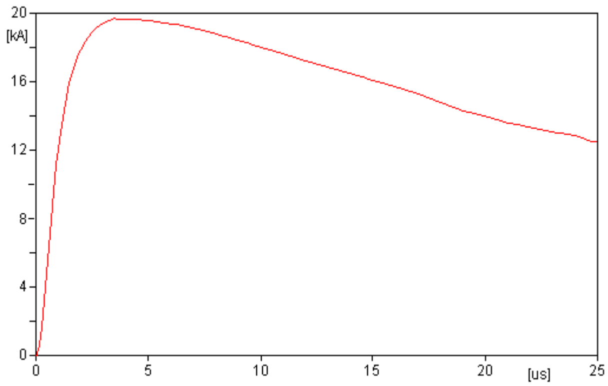

Fig. 6. Lightning current waveform

V_{fo} is a flashover voltage (kV),
K_1 is 400*L,
K_2 is 710*L,
L is insulator length, (meter),
t is elapsed time after lightning stroke, µs.

The back flashover mechanism of the insulators can be represented by volt-time curves. When a back flashover might occur, a parallel switch is applied. If the voltage across the insulator exceeds the insulator voltage withstand capability, the back flashover occurs. The back flashover is simulated by closing the parallel switch. Once the back flashover occurs, the voltage across insulator goes down to zero.

III. Simulation Results

In this section, the 500 kV overhead transmission line has been modeled using ATP program as shown in Fig. 7. In order to take into account the effect of the AC steady-state voltage of the line on a lightning surge, the transmission line is connected to AC voltage source via multiphase matching impedance (surge impedance matrix). As the transmission line is terminated with multiphase matching impedance, there is no reflected traveling wave from the far end of the transmission line, and thus, the transmission line is regarded as an infinite line. The parameters of the transmission line used in this study are shown in Table I.

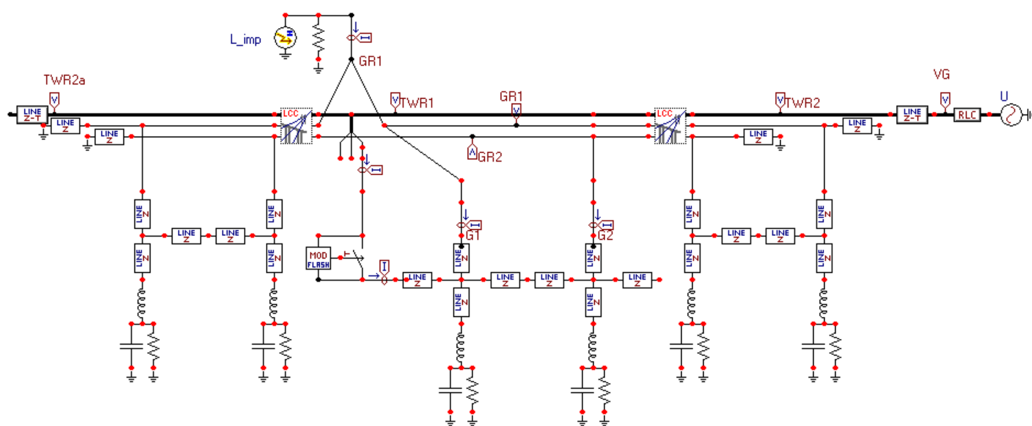

Fig. 7 ATP simulation of the system under study.

TABLE I
Characteristics of 500 kV Line Conductors

Conductor number	Radius (mm)	X-Coordinate (m)	Y-Coordinate (m)	R_{dc} at 20°C (Ω/km)
A1	15.3	-13.425	22.13	0.0511
A2	15.3	-12.975	22.13	0.0511
A3	15.3	-13.2	21.74	0.0511
B1	15.3	-0.225	24.48	0.0511
B2	15.3	0.225	24.48	0.0511
B3	15.3	0	24.09	0.0511
C1	15.3	12.975	22.13	0.0511
C2	15.3	13.425	22.13	0.0511
C3	15.3	13.2	21.74	0.0511
G1	5.6	-8	30	0.564
G2	5.6	8	30	0.564

A. Striking Distance

In this section, a lightning stroke, of which a current is 20 kA, hits one of the two ground wires (G1). Figure 8 shows the induced voltage wave forms on phase A, which is the nearest phase to stroke point, at various striking distances; d=0, 400, 800, 1200, 1600 m (towers 1, 2, 3, 4 and 5). It is noticed that the induced voltage magnitude decreases with increasing striking distance, and they almost have the same wave form. Also it is noticed that there is a delay introduced in the induced voltage waveforms. The time delay seen in the induced voltage waveforms corresponds to the time taken for the electromagnetic field produced by the lightning current to travel to the respective observation points.

Figure 9 shows the induced voltage wave forms on the three phases A, B and C of tower 1. It is noticed that, due to asymmetry, the induced voltages are not the same in the three phases, but it is highest at phase A as it is nearest to the lightning strike point (G1), and it is smallest at phase C as it is farther to the lightning strike point.

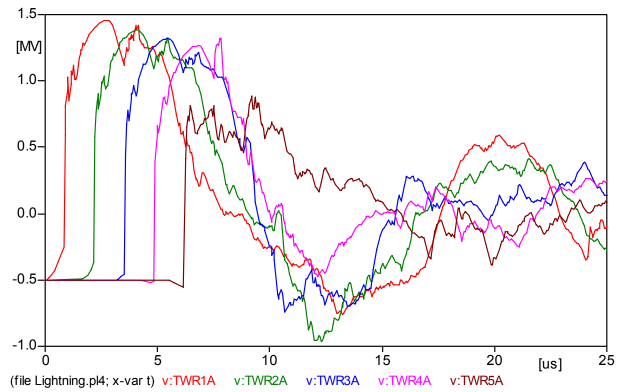

Fig. 8 Induced voltage at phase A for various striking distances

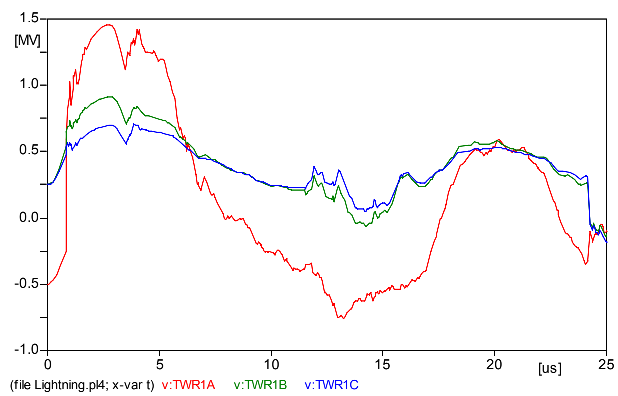

Fig. 9 Induced voltage at phase A for various striking distances

B. *Peak of the Lightning Current*

Figure 10 shows the induced voltage wave forms on the top of tower 1 with a various peaks of lightning current. It is noticed that the magnitude of the induced voltage increases with increasing the peak of the lightning current.

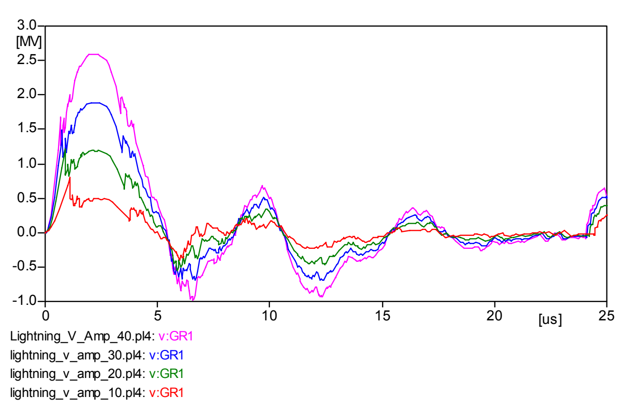

Fig. 10 Induced voltage at top of tower 1 with various peaks of lightning current

Backflash voltages are generated by multiple reflections along the struck tower and also along the ground. The backflash voltage across insulator for the struck tower is not a straightforward. The peak voltage will be directly proportional to the peak current as shown in Fig. 11. From Fig. 11 it is noticed that the transient-voltage withstands level of the insulator is not a unique number. The insulator withstands a high transient voltage for a short duration and it withstands a low transient voltage for relatively longer duration.

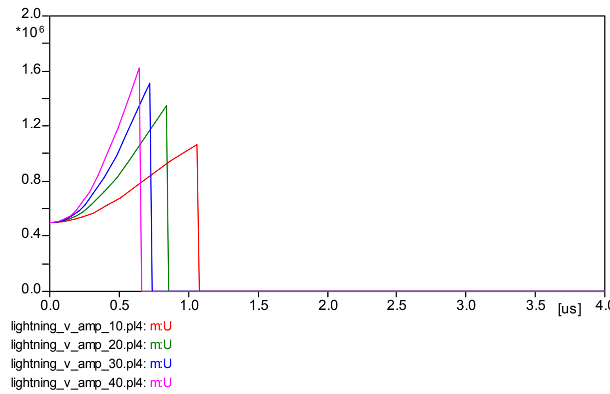

Fig. 11Backflash over clearance at insulator of phase A with various peaks of lightning current

C. *Front Time of Lightning Stroke*

Figure 13 compares induced voltage wave form on the top of tower 1 with various front time of lightning strokes; 1.2, 4, 6µs, with magnitude 40 kA, as shown in Fig. 12. It is noticed that the shorter front wave time increases the induced voltage. Figure 14 compares the time for clearing the overvoltage (backflash over) at insulator of tower1 with various front time of lightning strokes, also it is noticed that as the front wave time increases the induced overvoltage decreases and in turn the time to clear the overvoltage increases.

D. *Tail Time of Lightning Stroke*

Figure 16 compares induced voltage wave form on the top of tower 1 with various tail time of lightning strokes; 20, 30, 40 µs, with magnitude 40 kA, as shown in Fig. 15. It is noticed that the shorter tail wave time decreases the induced voltage. Figure 17 compares the time for clearing the overvoltage (backflash over) at insulator of tower1 with various tail time of lightning strokes, also it is noticed that as the tail wave time increases the induced overvoltage increases and in turn the time to clear the overvoltage decreases.

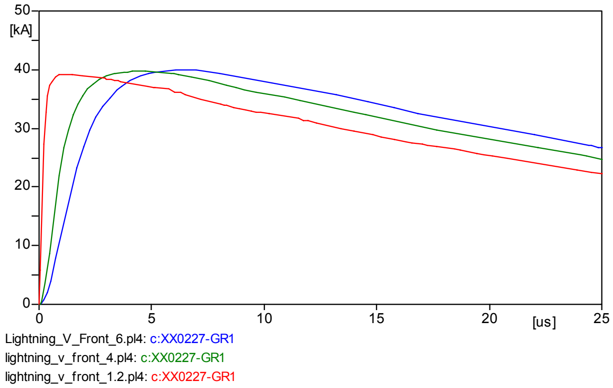

Fig. 12 Lightning source wave shape with various front time

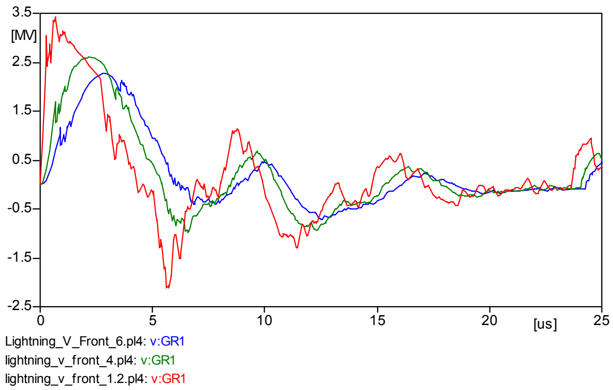

Fig. 13 Induced voltage at top of tower 1 with various front time of lightning current

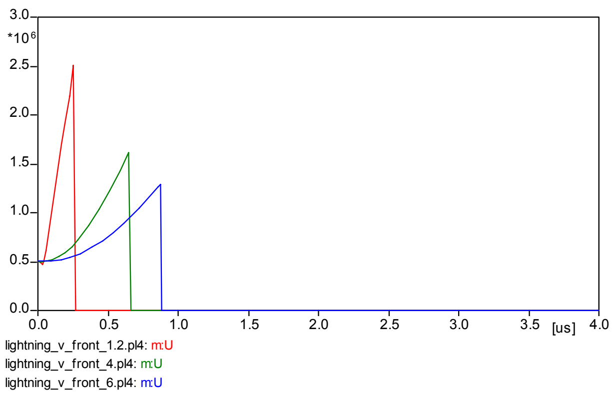

Fig. 14 Backflash over clearance at insulator of phase A with various front time of lightning current

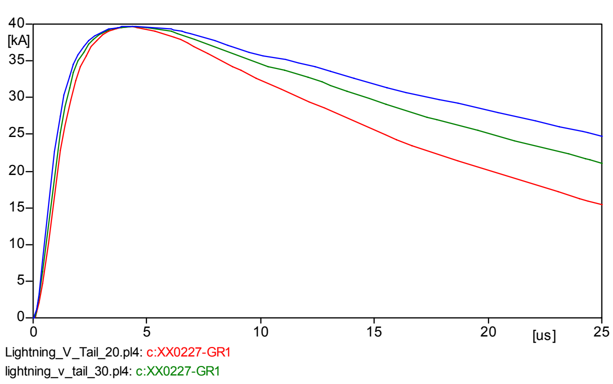

Fig. 15 Lightning source wave shape with various front time

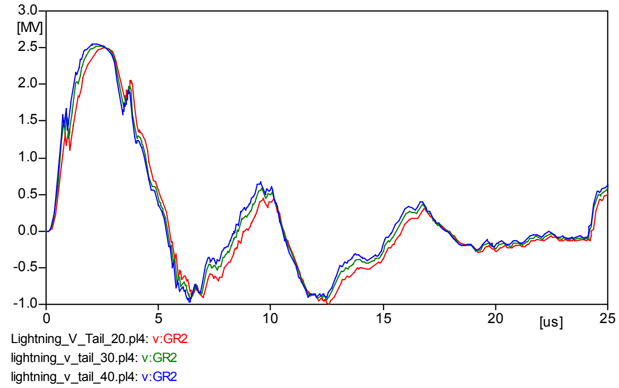

Fig. 16 Induced voltage at top of tower 1 with various front time of lightning current

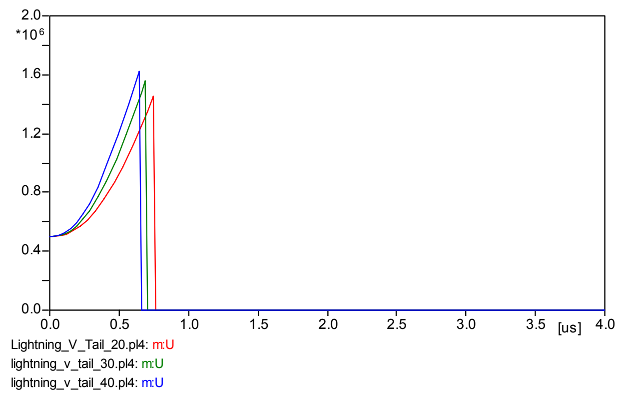

Fig. 17Backflash over clearance at insulator of phase A with various front time of lightning current

E. Parameters of the Ground System

Vertical and horizontal electrodes which are used at each leg of the transmission line tower as footing ground system during lightning transient, have many parameters such as:

resistivity of the earth in ohm. meter, ; permittivity of the soil in farad per meter, ε ; permeability of the soil in henries per meter, μ ; electrode length in meter, l ; electrode radius in meter, a ; depth of burial of horizontal electrode in meter, d .

Among these parameters, the length of the electrode has the major effect. Figures 18 and 19 show the induced voltage wave forms on the top of tower 1 with a various lengths of vertical and horizontal electrodes respectively. It is noticed that the magnitude of the induced voltage increases with increasing the length of vertical or horizontal electrode.

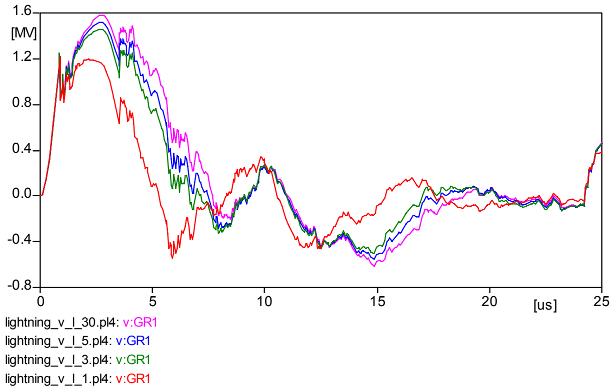

Fig.18 Induced voltage at top of tower 1 with various lengths vertical electrode

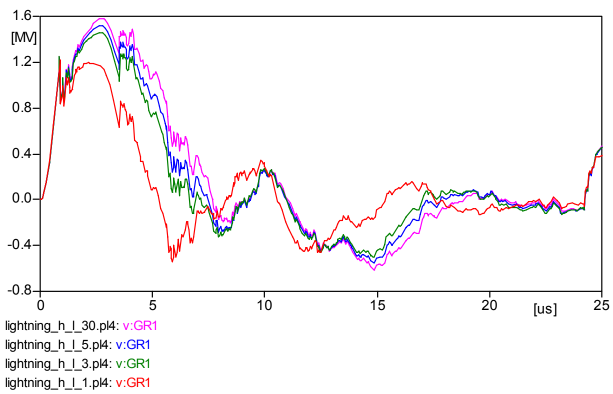

Fig.19 Induced voltage at top of tower 1 with various lengths horizontal electrode

IV. CONCLUSION

This paper has described an analysis of parameters effected the backflash voltage across insulator in a transmission system. Parameters of this study include the modeling of transmission line tower, the modeling of tower footing ground system, magnitude of lightning stroke, front and tail times of lightning stroke impulse and striking distance. All components of the system, under study, are simulated by using ATP program.

As seen from simulation results, the larger striking distance will decrease the induced voltage magnitude and will increase the time delay seen in the induced voltage waveforms.

Also, it is noticed that, all of the increase in the peak, the shorter front time and the longer tail time of lightning current will increase the induced voltage magnitude and in turn will reduce the clearance time of beckfash over.

Finally, among the parameters of the tower footing ground system, the length of the electrode has the major effect. Where the longer vertical or horizontal electrode will increase the induced voltage magnitude

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