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Analyzing and Modeling the Lightning Transient Effects of 400 KV Single Circuit Transmission Lines

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Abstract- Nowadays over voltages caused by lightning in transmission line located in mountainous regions are very important in power system transient studies. This study aims to present and investigate modeling 400 KV single circuit transmission lines. Hence this study, the performed analysis for assessing single phase ignition and back flash over, three common models of the tower in transient studies including Multistory, simplified Multistory and simplified wide line models have been used. The paper illustrates the benefit of ATP / EMTP to finding the best type of line against the lightning. The paper has proven that for negative polarity of current wave, range of overvoltage caused by lightning is the lowest for the Multistory model, Moreover the paper considering the same negative polarity, range of voltages from arms to earth is the lowest for Multistory model. Also results of this study show that Multistory is better and more acceptable than the other two models for the studied line.

Keywords- *Over-voltages, lightning, Transient behavior, Multistory model, simplified Multistory, simplified wide line, ATP / EMTP.*

I. INTRODUCTION

Lightning is very important as it is the most important external source of transient overvoltage in the power network. Importance of transient voltages caused by lightning can be found in their destructive role in power networks. By developing power transmission lines and the importance of power supply to different regions, power transmission line outages caused by lightning have been considered by engineers and designers of power systems. Lightning causes destruction of conductors in the network and this issue mostly leads to the outage of transmission lines and finally, the subscribers' power outage [1].

On this basis, it is very important to identify phenomenon of lightning and calculate density of lightning in different regions in order to take necessary measures for protecting power network equipment. The modeling transient behavior of a tower is very important at time of lightning and for a transmission line which has been designed well, direct collision of lightning with conductors of phases seldom occurs. Lightning causes many outages due to back flash over. When lightning collides with shield wire or tower, the injected current on tower to earth and causes an increase of voltage and this issue cause's back flash over [2].

Ignition occurs in high heights, therefore, short and H-shaped towers seldom collide with ignition. Shorter length of spin and higher number of towers can cause a decrease of the number of collisions. Shield Wires installed on top of phases effectively prevent collision of the lightning with conductors. Figure 1 shows the effect of shield wires.

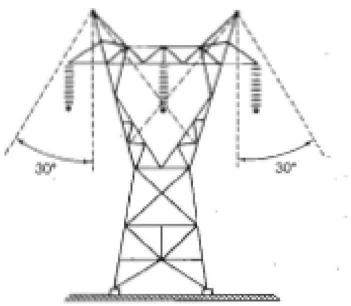


Figure 1. Effect of shield wires

It has been shown that probability of direct collision of lightning with the phase conductor which is inside arc of $\pm 30°$ shield wires decreases by 1000 times. When lightning collides with shield wire considering that shield wire is directly connected to the tower, the wave which enters into the tower is conducted to earth through it. However, if tower impedance or tower to earth impedance is very high, the created voltage causes insulation resistance failure of phase insulators. The number of insulators in each chain should be selected such that string of insulator is not subject to insulation failure. Tower impedance and resistances of the tower shall be as small as possible and in case tower structure naturally has no low resistance against earth, earth rods are used to decrease earth resistance. Field tests are effective tools for evaluation and access to the transient structure of a tower but since this method is difficult and expensive, it is better to use computer simulation for completion of results [3].

To design insulator of power systems, study of lightning behavior and overvoltage resulting from it is an important factor in protection of different tools of substations and power plants. Lightning seldom directly collides with a transmission line. Lightning almost collides on top of tower of transmission line or shield wires and lightning currents flow on top of tower downward. This major current increases its voltage considering impedance of the tower. With increase of tower voltage, ignition may be created between the arms of the tower and earth and between two arms of the tower [4]. For this reason, a combined model of a transmission line and tower has been applied for analyzing the effect of lightning on the power system and some studies have been conducted on it. Depending on the applied model for the tower, results are expected to be different from each other. One of the proposed suitable models of the tower is Multi story model which is parallel R-L and has been widely used in Japan for analysis of lightning [5].

In the present paper, the characteristics of the Multi story tower model on 400 kV transmission line have been presented based on lightning simulation with ATP / EMTP with negative polarity. The paper is organized as follows: in section 2, the system model is presented. Three different models of tower including Multistory, simplified Multistory and simplified wide line are evaluated in section 3. Result of three models included in the paper is mentioned in section 4 and finally the most important results are elaborated in section 5.

II. SYSTEM MODEL

400 kV single –circuit transmission line has triplet bundle conductors. Tower resistance of this system is 10 ohms and range of lightning current is 50 kA with negative peak. Figure 2 shows the structure of the studied tower. Physical specifications of conductors are given in table 1 and geometrical parameters of the tower are given in table 2.

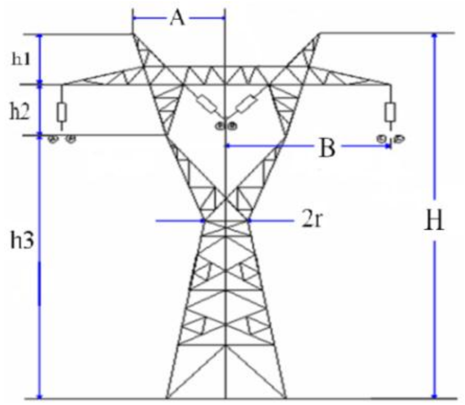


Figure 2. Structure of the studied tower

TABLE I. PHYSICAL SPECIFICATIONS OF CONDUCTOR

GMR (cm)	Resistance dc	AREA (MM2)	Stranding	Conductor
1.2161	0.0599	523.68	AL54/3.5 ST 7/3.52	CURLEW

TABLE II. GEOMETRICAL PARAMETERS OF TOWER SHOWN IN FIG 2

H	h_1	h_2	h_3	A	B	2r
44.6	4.6	5.6	34.4	7.9	10.4	4.0

All dimensions are in m.

III. EVALUATION OF THREE DIFFERENT MODELS OF TOWER

In order to model the tower as a transmission line, it is necessary to determine characteristic impedance and wave velocity and then to model it with help of uniform or non-uniform transmission line. Later, different types of models are studied for tower modeling and they have been obtained using laboratory theory approximations.

A. Multistory Model

Tower model and its multistory model are shown in Figure 3. In this model, transmission line tower is considered as a set of serial circuits with parallel R-L circuits. The above circuits indicate weaknesses of fluid wave across the tower [6,7]. Because R-L parameters are accessible for 500 kV transmission line, it is necessary to convert its geometrical dimensions in order to be used in 400 kV voltage level. For this reason, relations (1) - (4) have been used.

$$\mathrm{Ri} = \frac{-2\mathrm{Zt\,i}\,.\ln\sqrt{\gamma}}{\mathrm{h}_1 + \mathrm{h}_2} \qquad (i = 1, 2) \tag{1}$$

$$\mathrm{R3} = -2\,\mathrm{Zt3}\,.\ln\sqrt{\gamma} \tag{2}$$

$$Li = \alpha\,.Ri\,.\frac{2H}{V_t} \qquad (i = 1, 2, 3) \tag{3}$$

$$\mathrm{H} = \mathrm{h}_1 + \mathrm{h}_2 + \mathrm{h}_3 \tag{4}$$

In which, γ is d the diffusion coefficient equal to 0.8, α is damping coefficient equal to 1 and V_t is wave velocity equal to 300 $m/\mu s$. It should be noted that values corresponding to each tower are given in table 3.

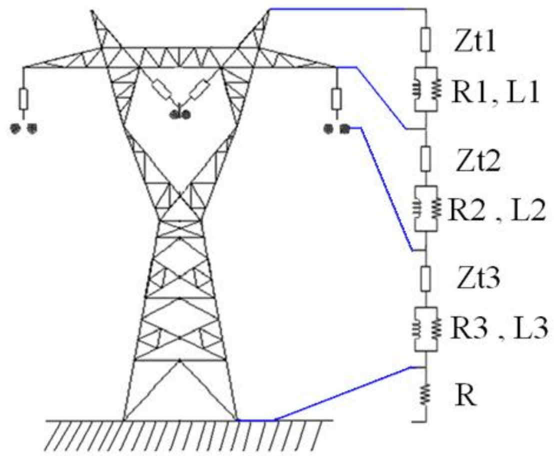


Figure 3. Tower model and its Multistory model

TABLE III. EQUIVALENT PARAMETERS OF MULTISTORY MODEL

R 1	22.1393	L 1	6.5827	Zt 1	220
R 2	26.9522	L 2	8.0138	Zt 2	220
R 3	33.472	L 3	9.9523	Zt 3	150
R	10.0				

R 1, R 2, R 3, R, Zt 1, Zt 2, and Zt 3 are all in Ω.
L 1, L 2, and L 3 are all in μh.

In Figure 4, simulated model in ATP / EMTP is shown for multistory tower.

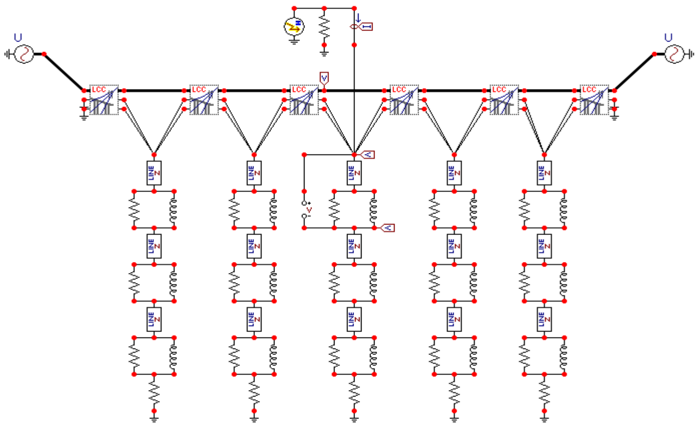


Figure 4. Equivalent Multistory circuit

B. Simplifiet Multistory Model

In this model, parallel R-L circuits available in multistory model are deleted. One of the reasons for creation of ignition in multistory model is the presence of parallel R-L circuits. For this reason, analyze has been done using simplified Multistory model i.e. model without parallel R-L circuits [7,8]. Characteristic impedance and other simplified parameters are the same values of multistory model. The equivalent circuit used in ATP / EMTP software is shown in Figure 5.

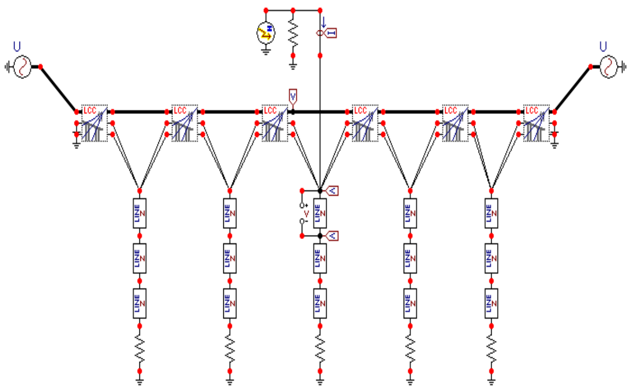


Figure 5. Simplified Multistory equivalent model

C. Wide line simplified model

Because multistory model has been designed for 500 kV line and height of the 500 kV tower is more than that of 400 kV tower, therefore, it is necessary to evaluate characteristic impedance of the tower. In order to calculate characteristic impedance of the tower in papers and references, different relations have been presented. The presented relation for tower as relation 5 is in agreement with results obtained from measurement of characteristic impedance of the tower in addition that it is simple and easy. The desired formula is generally obtained as the following relation and from Figure 6 [9].

The tower model used in ATP / EMTP is shown in Figures 7 and 8. In all simulations, wave velocity was considered equal to the speed of light and 300 m/µs.

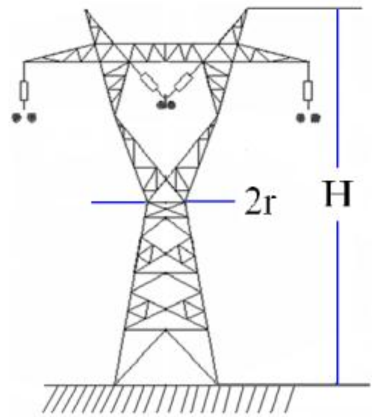


Figure 6. Tower equivalent structure

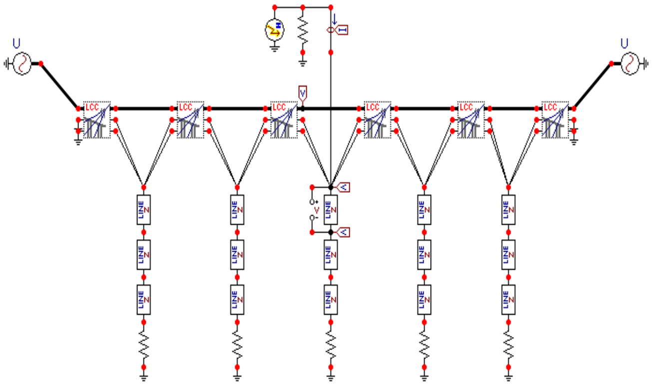
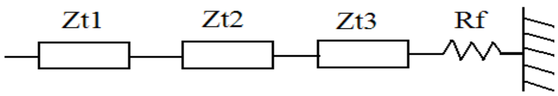


Figure 7. Simplified wide line equivalent circuit



Zt 1= Zt 2= Zt 3 = 188.6585 Ω

Figure 8. Simplified wide line equivalent impedance

IV. RESULTS OF STUDY

In this section, results of study are based on ATP / EMTP software. Impulse wave has a range of -50 kilo amperes, front of the impulse is 1 microsecond and tail of impulse is 70 microseconds. Lightning current at time of collision reaches its peak value within 1 and 10 microseconds (front of impulse) and then is reduced to half of this value within 20 and 100 microseconds (back on impulse). Distribution of this current is shown in Figure 9. 50% of all lightnings have a peak voltage of above 50 kilo amperes. Rarely, peak voltage can exceed 200 kilo amperes. Laboratory results show that almost 90% of all lightnings are negative [10]. Therefore, negative peak of lightning is tested in this paper.

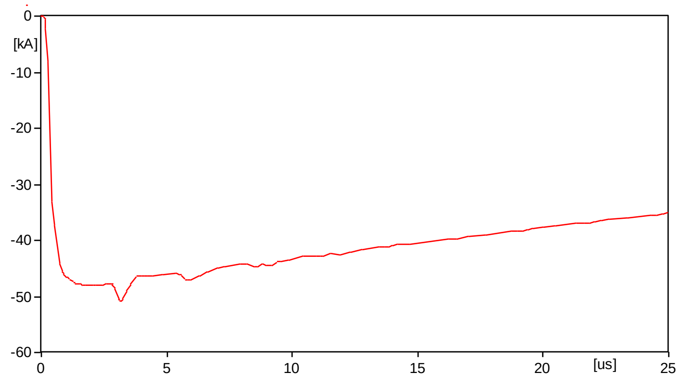


Figure 9. Impulse wave with negative peak

Figures 10-12 show range of overvoltage created on top of the tower (collision of lightning). As the above Figures show, the highest range of overvoltage created on top of tower relates to simplified wide line model and the lowest one relates to Multistory model of the tower and simplified Multistory model is between these two ranges.

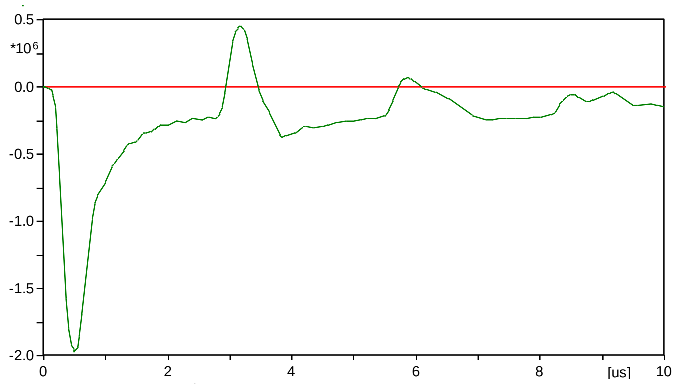


Figure 10. Range of voltage in lightning collision place in Multistory model

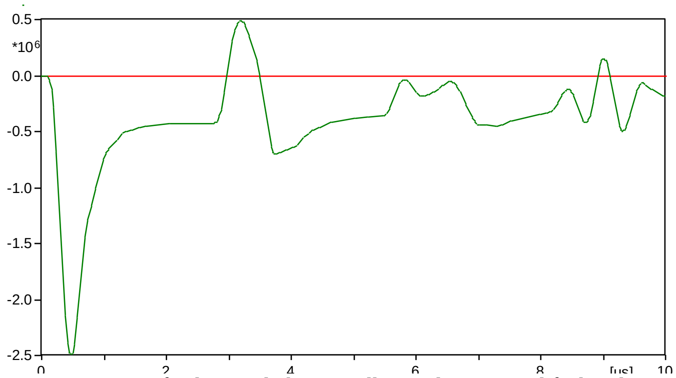


Figure 11. Range of voltage in lightning collision place in simplified Multistory model

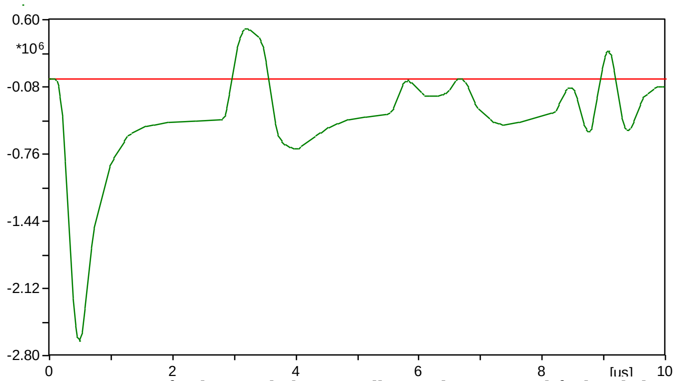


Figure 12. Range of voltage in lightning collision place in simplified wide line model of tower

Figures 13-15 show overvoltage of the tower arm relative to the earth. As it is evident, difference between arms relative to the earth is low in multistory model and possibility of ignition of the phase is lower in this model. In two other models, there is a high difference between the voltages of arms.

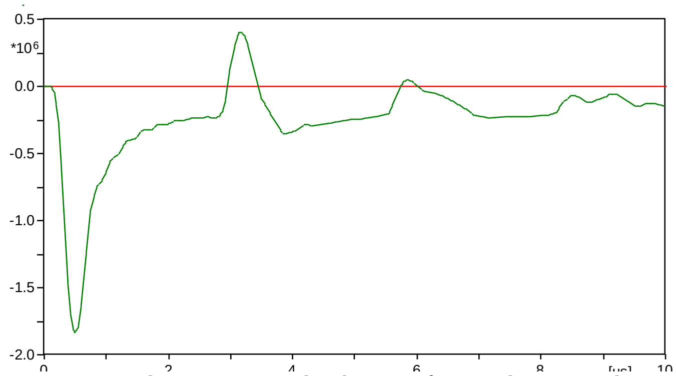


Figure 13. Voltage range created in the arms of tower relative to earth in Multistory model

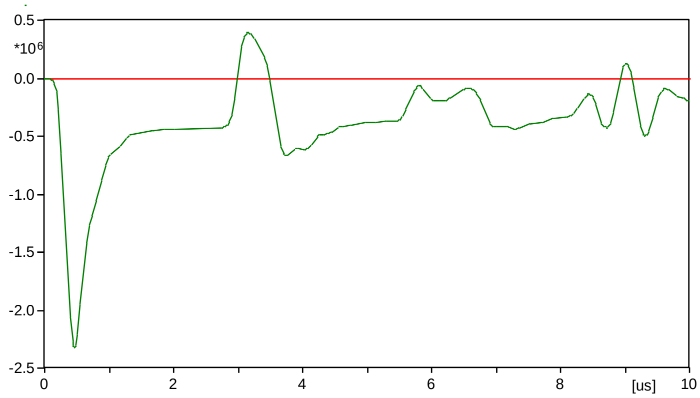


Figure 14. Voltage range created in the arms of tower relative to earth in the simplified Multistory model

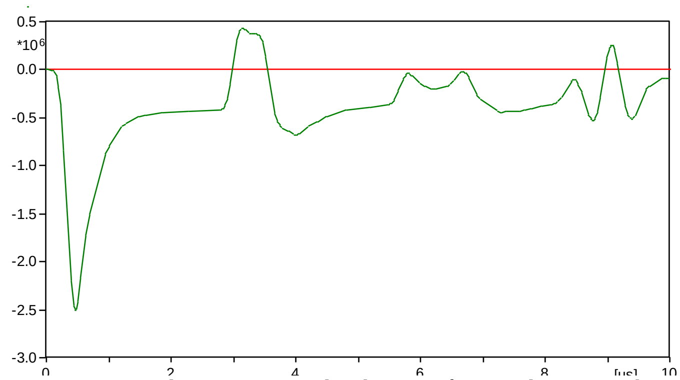


Figure 15. Voltage range created in the arms of tower relative to earth in a simplified wide line model of the tower

Figures 16-18 show range of voltages created on the insulator in different tower models.

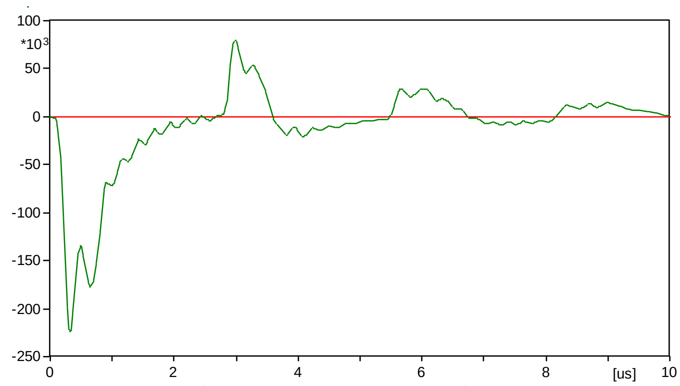


Figure 16. Range of voltages created on insulator from a tower in Multistory model

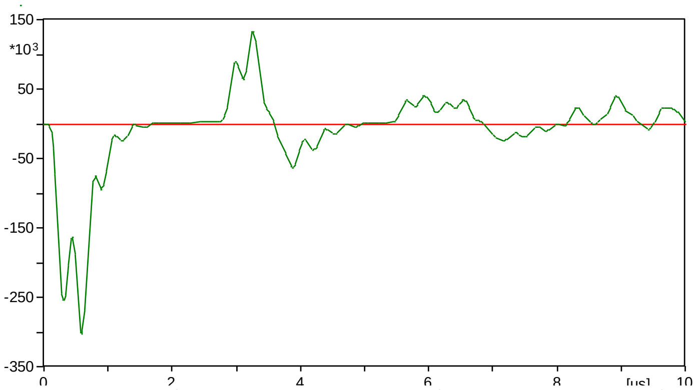


Figure 17. Range of voltages created on insulator from a tower in the simplified Multistory model

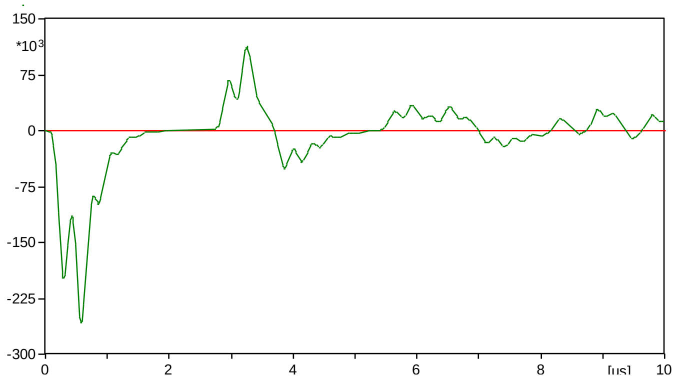


Figure 18. Range of voltages created on the insulator of the tower in a simplified wide line model of the tower

Figures 19-21 show waveforms of the voltage created on top of the adjacent tower with which lightning collides. It is clear that overvoltage created in this tower is below the tower with which lightning directly collides and it can be concluded that the major part of the voltage is discharged through the tower which is directly collided by lightning.

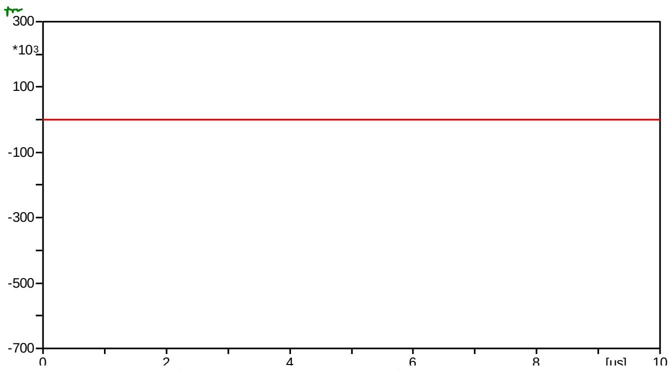


Figure 19. Range of voltage created on top of the lateral tower in Multistory model

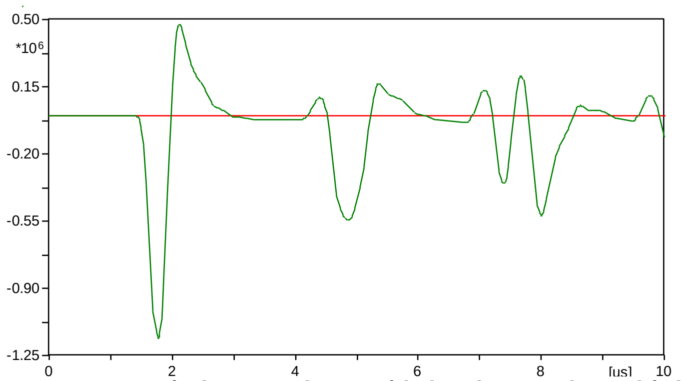


Figure 20. Range of voltage created on top of the lateral tower in the simplified Multistory model

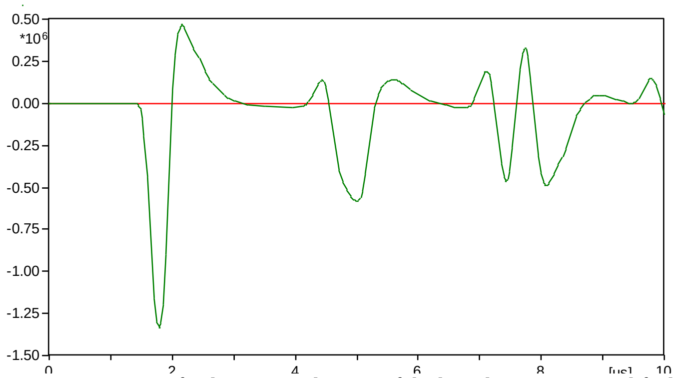


Figure 21. Range of voltage created on top of the lateral tower in a simplified wide line model of the tower

Figures 22-24 show single phase voltages in three models and diagram of phases A and B is placed on top of each other due to the physical structure of these towers.

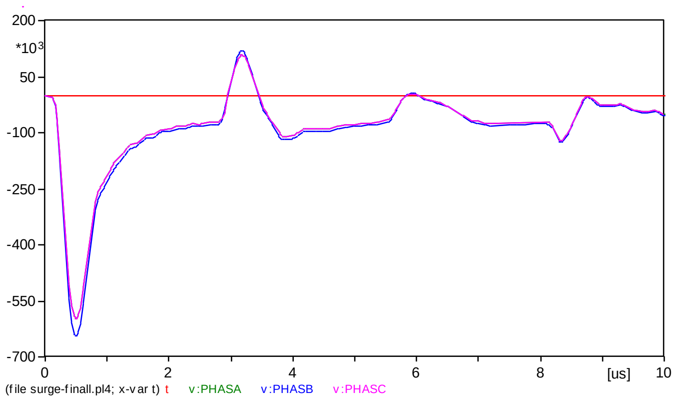


Figure 22. Voltage created in phases relative to earth in Multistory

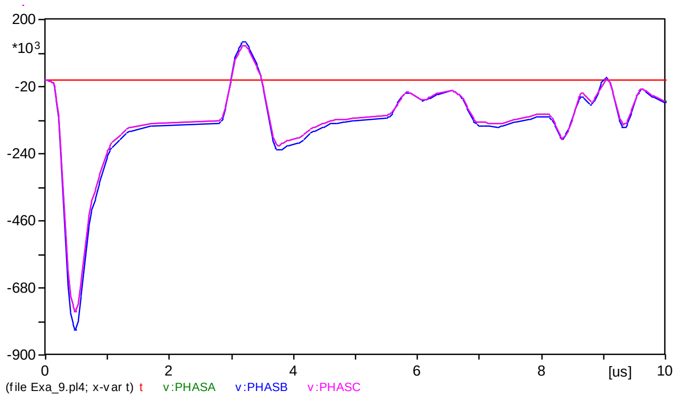


Figure 23. Voltage created in phases relative to earth in the simplified Multistory model

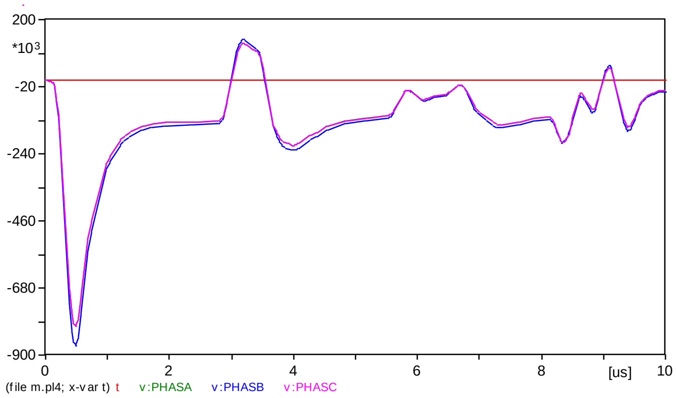


Figure 24. Voltage created in phases relative to earth in a simplified wide line model of the tower

CONCLUSION

Considering the results of the performed simulations for all types of tower models and by applying waves with negative polarity on the tower, the following results are obtained.

- For negative polarity of current wave, range of overvoltage caused by lightning is the lowest for the multistory model because parallel R-L circuits can model its transient behavior and simplified wide line model is between these two values.
- Considering the same negative polarity, range of voltages from arms to earth is the lowest for multistory model, highest for the simplified wide line model and the simple multistory model is between these two models. Because the difference between the ranges of phases is not high, it causes almost the equal possibility of back flash in all three phases.
- Range of voltage caused by lightning on the insulator is the lowest in multistory model, highest in wide line model and the simplified multistory model is between these two values.
- Results show that Multistory is better and more acceptable than the other two models for the studied line because this model has been designed for 500 kV lines , therefore, one can use it for analyzing 400 kV lines . Despite parallel R–L

circuits, wave motion of voltage is modeled along the tower.

- Generally, it can be concluded that multistory model is the best model for studying behavior, analyzing and modeling single circuit 400 kV transmission line. The simplified multistory model can be used under special condition.

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