Parameters Affecting Lightning Backflash Over Pattern at 132kV Double Circuit Transmission Lines

Dian Najihah Abu Talib[1,a], Ab. Halim Abu Bakar[2,b], Hazlie Mokhlis[1]
[1]Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[2]UM Power Energy Dedicated Advanced Center (UMPEDAC), Level 4, Wisma R&D, University of Malaya,
Jalan Pantai Baharu, 59990 Kuala Lumpur, Malaysia
[a] dnajihah@siswa.um.edu.my, [b] a.halim@um.edu.my

***Abstract*—**In this paper, an analysis study on parameters which affecting the backflash over pattern cause by lightning is done. A 132kV double circuit transmission line is modeled using ElectroMagnetic Transient Program EMTP software for backflash over simulation. A vertically configured double circuit transmission line can be modeled into several parts: towers, insulators, phase conductors, ground wire and tower footing resistance. The backflash over pattern is simulating by model the lightning current that hit the ground wire at the aim tower. The parameters that include in this study are the values of front, peak and tail of lightning current, striking distance and lastly the tower ground system. The pattern can also be analysis by taking into account the position of the phase conductors on the double circuit transmission tower.

Keywords- Double Circuit Transmission Line; Lightning Backflash Over Pattern; EMTP; Lightning Current;

I. INTRODUCTION

Backflash over generally occurs when lightning strikes the ground wire on transmission line. The potential power of the tower increases and affects the resultant voltage across the insulator. When the resultant voltage increases until exceeded the insulator limits, backflash over will be occurs. Many numerical simulations have been used to study the lightning backflash over on transmission line. One of the tools that can be used is EMTP software. The EMTP, [1]-[2] is a common tool to simulate transient events in power system, which had been introduced since 1980.

This paper presents the study on the backflash over pattern at 132kV double circuit transmission line, [3]. The lightning which strikes the ground wire of the line can create different pattern of flashover on phase conductors. The patterns are depending on many factors such as lightning current magnitude, front and tail time, the characteristics of transmission tower, the position of phase conductors, tower grounding and striking distance. The backflash over pattern will be studied for both circuits since each circuit have different behavior.

II. MODELLING

EMTP software is used to simulate the model of transmission line, towers, insulators and lightning current. The phase conductors and the ground wire are represented as frequency dependent line model due to line parameter which involved range of frequencies. Two set of wires circuit which represent double circuit transmission line are modeled with details between the towers

A. *132kV Double Circuit Transmission Tower*

The 132kV double circuit transmission tower with two ground wire is modeled. The tower is a vertically configured as shown in Figure 1 and the height is 28.22m. The phase conductors of double circuit line are arranged differently for each circuit. The first circuit, blue phase is arranged at the top follow by red and yellow. While for the second circuit the positions of the phase conductors are yellow, blue and red.

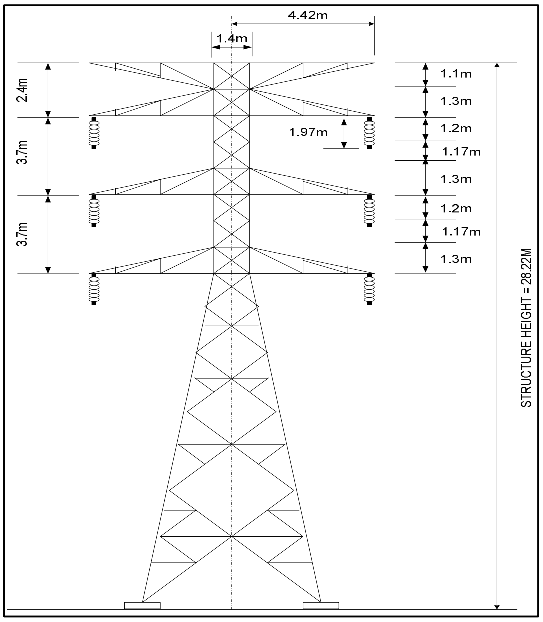


Figure 1. 132kV double circuit transmission line

The lumped inductance model, shown in Figure 2 is choose to represent the tower as it provide more accuracy for tower less than 30m, [4]. The surge impedance of the tower can be calculated using equation (1)-(3) which recommended by IEEE and CIGRE, [5]. The formula is created using waist tower shape theory, [2].

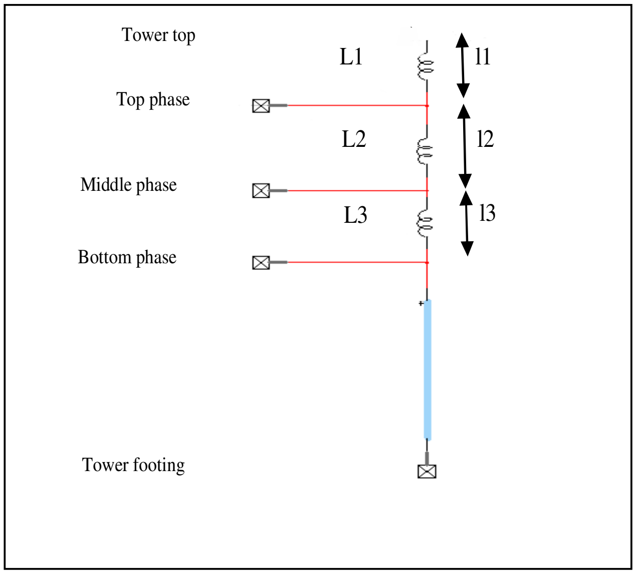


Figure 2. The lumped inductance model

$$L_n = \frac{Z_t}{c} \times l_n \quad \text{(H)} \tag{1}$$

$$Z_t = 60 \ln[\cot\{0.5 \tan^{-1}(\frac{R}{H})\}] \tag{2}$$

$$R = \frac{r_1 h_1 + r_2 h + r_3 h_2}{h} \tag{3}$$

Where:

Z_t = tower surge impedance (Ω)

c = speed of light (3 x 10^8 m s^{-1})

n = 1,2 and 3

R is the equivalent radius of the tower represented by a truncated cone, h= $h_1 + h_2$, and

r_1, r_2, r_3 = tower top, midsection and base radii [m];

h_1 = height from midsection to top [m];

h_2 = height from base to midsection [m]

B. Transmission Tower Footing Resistance

The value of tower footing resistance can influence the lightning performance of transmission line. Simple linear resistance, R_f is to be modeled in this paper. The value of the resistance to simulate the behavior of backflash over pattern is given in Table IV.

C. Insulator String Flashover Model

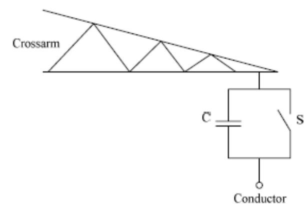


Figure 3. Insulator string flashover model

The figure 3 is shown the insulator string flashover model where a capacitor parallel with voltage controlled switch are connected together. The switch will be open when there is a flashover occurs at the insulator. Equal area flashover model, [4] are used to show the operation of the controlled switch. During lightning, the voltage across the switch will be increased and when it exceeds the critical flashover voltage (CFO), flashover will occurs. The CFO voltage can represent by equation (5).

$$\int_t^{t_0} \left(\left|V_{gap}(t)\right| - V_0\right)^k \geq D \tag{4}$$

$$V_o = 0.9V_{50\%} = 0.9(400 + \frac{710}{t^{0.75}})d \tag{5}$$

Where:

$V_{gap}(t)$ = voltage across insulator string

k =1

D = 0.2045 d

d =length of gap between arc horn

t = tail time of lightning current waveform

D. Lightning Current Model

The lightning stroke, shown in figure 4 is represented in double exponential function waveform which includes the front time and the tail time. The lightning peak current, I_O can be obtained from the following equation

$$i_0(t) = kI_0(e^{-\alpha t} - e^{-\beta t}) \tag{6}$$

Where,

I_0 = peak of lightning current,

$i_0(t)$ = instantaneous lightning current

α, β = wave-head and wave-tail attenuation quotient of lightning current
k = waveform correction index

Lighting current model, [6] is used in the simulation as it comply the behavior of double exponential function. Figure 5 shows the model where Z_O represent the lightning surge impedance, A represents lightning strikes point and Z represents the impedance between the breakdown point and the ground. Numbers of lightning waveform with different front time and tail time will be studied to show the relationship with the lightning backflash over pattern. Parameters corresponding to different lightning current waveforms are calculated according to standard waveform, as in Table I:

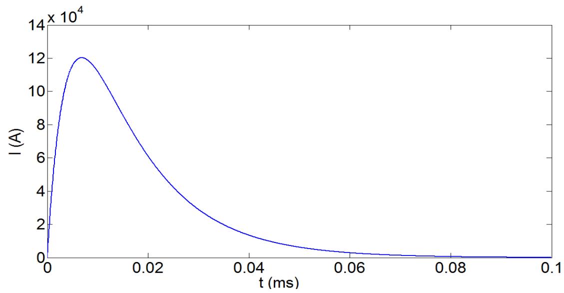


Figure 4. 8/20µs ligtning current waveform

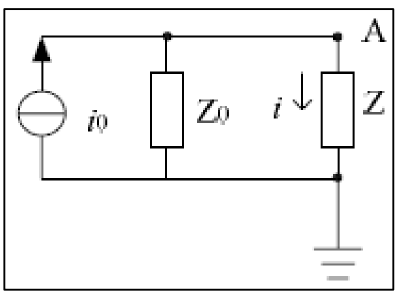


Figure 5. Ligtning current model

TABLE I. PARAMETERS OF STANDARD LIGHTNING CURRENT WAVEFORM

Lightning Waveform	Wave-head attenuation quotient, α	Wave-head attenuation quotient, β	Waveform correction index, k
1.2/50µs	1.473×10^{4}	2.08×10^{6}	1.043
4/300µs	2.394×10^{3}	6.47×10^{5}	1.025
10/200µs	3.914×10^{3}	2.31×10^{5}	1.091
10/700µs	1.028×10^{3}	2.579×10^{5}	1.026
8/20µs	7.714×10^{4}	2.489×10^{5}	2.45
10/350µs	2.127×10^{3}	2.461×10^{5}	1.051

III. DISCUSSION

In this section, the 132kV double circuit transmission line with two separate ac source is modeled using EMTP software as shown in Figure 8. Both of the sources are synchronous with each other's. The transmission line is connected with long cable from the source and the system is simulate using nine tower to represent balance system without reflected traveling wave from the far end of the transmission line.

A. *Striking Distance*

The lightning striking distance is studied in this section to show the relationship of flashover pattern on double circuit. Lighting stroke with magnitude of 120kV is strike on one of the ground wire, constant 10ohm tower resistance and constant ac source angle at 70 degree. At ac source angle of 70 degree, blue phase is at the highest voltage value and follow by red and yellow phases for both circuits which is shown in figure 6. The conductor with highest voltage value will get more possibility to trip when lightning strike because it can exceed the CFO faster compare other conductor.

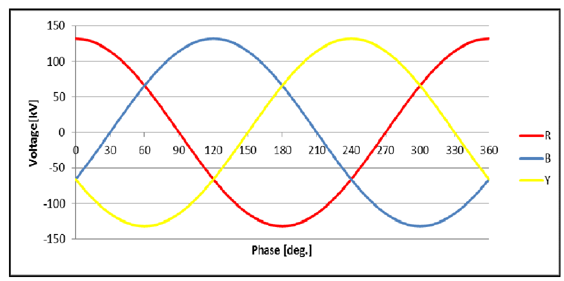
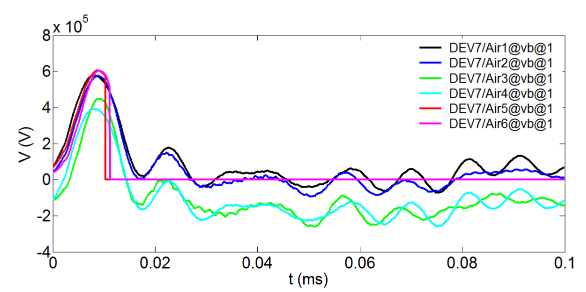


Figure 6. AC Source Voltage according to phase angles

Figure 7 shows the voltage across insulator string at the striking tower, 0 striking distance. It is shown that only blue and red phase of second circuit line are trip. This is due to position of the trip conductor which is near to the ground compare the same phase conductor at the first circuit or also can be called coupling effects.



DEV7/Air1@vb@1: Circuit 1- BLUE phase, DEV7/Air2@vb@1: Circuit 1- RED phase
DEV7/Air3@vb@1: Circuit 1- YELLOW phase, DEV7/Air4@vb@1: Circuit 2- YELLOW phase
DEV7/Air5@vb@1: Circuit 2- BLUE phase, DEV7/Air6@vb@1: Circuit 2- RED phase

Figure 7. Voltage across insulator string at 0 striking distance

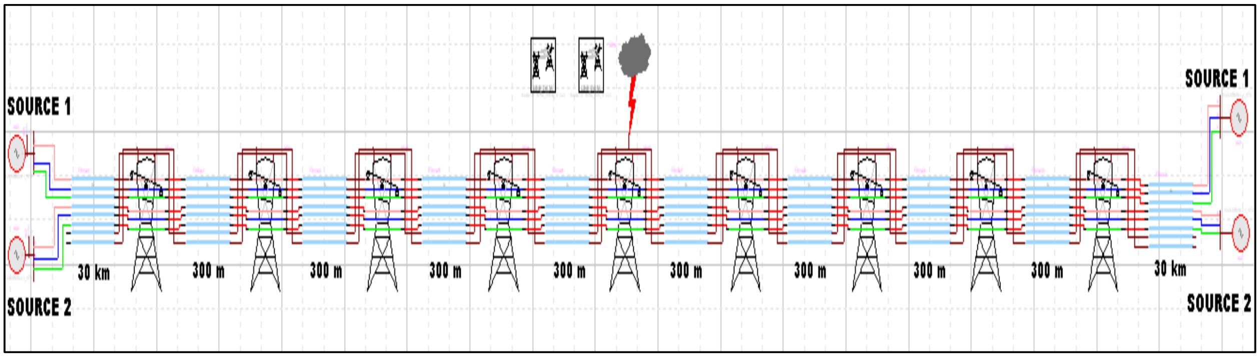
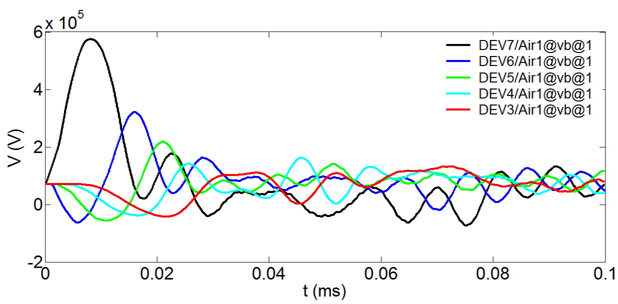


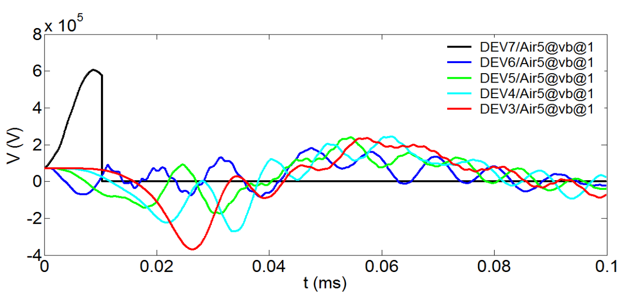
Figure 8. EMTP simulation of 132kV double circuit transmission line

The pattern of flashover is change at different striking distance; d=300, 600, 900 and 1200m. There is no trip conductors are found when the lightning strike away from the studied tower. It is found that the induced voltage magnitude at the insulator string is decreases when the striking distance is increases. Figure 9 and 10 shows the first circuit blue and the second circuit blue conductor induced voltage at insulator with increasing striking distances. There is some delay which follows the increases of the distance due to travelling time of lightning current to the studied tower.



DEV7/Air5@vb@1: 0 striking distance, DEV6/Air5@vb@1: 300m striking distance
DEV5/Air5@vb@1:600m striking distance, DEV4/Air5@vb@1: 900m striking distance
DEV3/Air5@vb@1:1200m striking distance

Figure 9. Voltage across insulator string at first circuit of blue conductor



DEV7/Air1@vb@1: 0 striking distance, DEV6/Air1@vb@1: 300m striking distance
DEV5/Air1@vb@1:600m striking distance, DEV4/Air1@vb@1: 900m striking distance
DEV3/Air1@vb@1:1200m striking distance

Figure 10. Voltage across insulator string at second circuit of blue conductor

B. *Front time and Tail Time of Lightning Current*

Referring to Table I, numbers of standard lightning current waveform (different front/tail time, µs) are investigated to studied the effects of flashover pattern on double circuit line. The results of flashover pattern are shown inside the Table II.

It is noticed that the smaller front time will create more flashover at the conductors. At 1.2µs front time, three conductors had experience flashover and similar with 4µs. As it increases to 8µs, two conductors are tripping. When the front time increases to 10µs, no more flashover are occurs. The induced voltage created at the insulator will increase more when the front time is faster and cause flashover.

TABLE II. DOUBLE CIRCUIT FLASHOVER PATTERN FOR DIFFERENT LIGHTNING WAVEFORM

Lightning Waveform	Double Circuit Flashover Pattern					
	Blue 1st Cct	Red 1st Cct	Yel 1st Cct	Blue 2nd Cct	Red 2nd Cct	Yel 2nd Cct
1.2/50µs	X	-	-	X	X	-
4/300µs	X	-	-	X	X	-
10/200µs	-	-	-	-	-	-
10/700µs	-	-	-	-	-	-
8/20µs	-	-	-	X	X	-
10/350µs	-	-	-	-	-	-

X- Flashover

Different from front time, tail time of lightning waveform did not give much effect on flashover pattern. The increases of tail time will give more time for the over voltage to be clear.

C. *Peak of Lightning Current*

Table III shows the results of flashover pattern of double circuit line on the effects of lightning current magnitude.

TABLE III. DOUBLE CIRCUIT FLASHOVER PATTERN FOR DIFFERENT LIGHTNING WAVEFORM

Lightning Current	Double Circuit Flashover Pattern					
	Blue 1st Cct	Red 1st Cct	Yel 1st Cct	Blue 2nd Cct	Red 2nd Cct	Yel 2nd Cct
100kA	-	-	-	-	-	-
120kA	-	-	-	X	X	-
140kA	X	X	-	X	X	-
160kA	X	X	-	X	X	-
180kA	X	X	-	X	X	-
200kA	X	X	X	X	X	X

X- Flashover

Table III shows the relationship between the magnitudes of lightning current with the numbers of conductor's flashover. More flashover occurs when the current magnitude increases. The pattern shows that blue and red phase conductor is faster to trip compare yellow phase due to the values of ac source voltage for each conductor. The conductor which has higher voltage will trip faster compare to lower voltage. The blue and red conductors at second circuit will flashover faster compare at the first circuit because the position of the conductor at transmission line. Closer conductor to ground will trip faster due to coupling effect of the conductors.

D. Tower Footing Resistance

Table IV shows the results of flashover pattern of double circuit line on the effects of tower footing resistance.

TABLE IV. DOUBLE CIRCUIT FLASHOVER PATTERN FOR DIFFERENT TOWER FOOTING RESISTANCE

Footing Resistance	Double Circuit Flashover Pattern					
	Blue 1st Cct	Red 1st Cct	Yel 1st Cct	Blue 2nd Cct	Red 2nd Cct	Yel 2nd Cct
5ohm	-	-	-	-	-	-
10ohm	-	-	-	X	X	-
15ohm	X	X	-	X	X	-
20ohm	X	X	X	X	X	-
25ohm	X	X	X	X	X	X

X- Flashover

Result in Table IV shows that the pattern of flashover at double circuit is dependent on tower footing resistance. Similar with lightning current magnitude behavior, the numbers of flashover also increases when the value of footing resistance increases. The pattern also shows that the blue and red for second circuit will trip first follow by first circuit. At 20 ohm, yellow conductor for first circuit is flashover faster compare to second circuit. This is due to the position of yellow conductor at first circuit is lower compare at the second circuit on the transmission line.

IV. CONCLUSIONS

This paper has presented an analysis of parameters that influenced the pattern of lightning backflash over on double circuit transmission line. The parameters that included in this study are lightning striking distance, front time and tail time of lightning current, peak of lightning current and lastly the tower footing resistance. The system study of this paper is simulated using EMTP software.

The main conclusions are summarized below.

- The striking distances give influences on the pattern of the flashover. As the striking distance increases, the induced voltage at the insulator string will decrease. So less numbers of conductors will be flashover.
- Standard lightning waveform with different front time and tail time will give different results of flashover pattern. Smaller value of front time will increase induced voltage at insulator which will cause more flashover at phase conductors when it exceeded the CFO of the insulator. Meanwhile the tail time does not show much effect to the patterns.
- Higher peak or magnitude of lightning current will cause more flashover at the transmission line. This due to higher current flow to the insulator and exceeded the maximum rating of the insulator.
- Similar with tower footing resistance, there also will be more flashover occurs when higher resistance is used.

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