Proceedings of the International MultiConference of Engineers and Computer Scientists 2015 Vol II,
IMECS 2015, March 18 - 20, 2015, Hong Kong

Characteristics and Behaviour of Transient Current during Lightning Strikes on Transmission Tower

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***Abstract*—This paper investigates on the characteristics of current when lightning strikes on the conductor of transmission lines. The impedance of multistory model based on the 115 kV transmission tower is employed to simulate in EMTP/ATPDraw program. The location of lightning strikes on the conductor on transmission lines and the ground resistance is varied. The characteristics of the peak amplitudes and the first peak time of current waveform are observed. The obtained results show that when lightning striking occurs near the substation, the peak amplitudes of current tend to increase with decreasing distance between the substation and the lightning location. In addition, the first peak time tends to decrease with decreasing distance between the substation and the lightning location, and its change will be very useful in the development of lightning location scheme.**

***Index Terms*— Lightning, Multistory model, EMTP, Lightning location, Transmission line**

I. Introduction

Electricity is becoming increasingly more important for everyday life, and likewise, its demand by the population and the economic growth. Most modern facilities require power generated by electricity, facilities such as school, hospital, entertainment sector, government properties, and etc. Therefore, it is imperative that electricity must be stably secured with the effective control systems and transfer systems. These systems are installed in the form of transmission system, and injected the power without interruption. However, the complexity of transmission network that injects the power into wide area may likely cause the electrical failure or power outages due to, specifically, the natural lightning striking on the transmission network. This often leads to power outages in the power system. In the literature, there are many research studies [1-25] about lightning protection in power system.

Manuscript received January 9, 2015
This work was supported in part from King Mongkut's Institute of Technology Ladkrabang Research fund, Thailand
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A vertically grounded system that has a pure resistance of 5 Ohms (parameters of capacitance and inductance are negligible) was discussed in [1]. The most frequent issues with the power system were its shielding failures, which can affect the stability of the system and the economy to a large degree. Shielding of the lightning current with different models was analyzed in [2]. Nowadays, there have been many models which are used to approximate Shielding Failure Flashover Rate (SFFOR) such as Suzuki's model [3], Borghetti's model [4], Anderson's model [5] (which is not suitable to be considered), Eriksson's model [6], Armstrong's model [7], Wagner's model [8], and Mousa's model [9]. By considering in terms of performance and cost, the electro-geometric model is the most active, while the Eriksson's model [6] is based on unrealistic assumptions. Shielding Failure Rate (SFR) and SFFOR are both affected by height. Most researches that only calculate the amplitude of the current and samples used for analysis are insufficient. The lightning current waveforms are used to demonstrate the trend of current. It uses parameters such as the amplitude of the current, front duration, and the rate of rise. These parameters affect the overload as observed in power stations [10]. The effect of systems with different polarity of lightning and stimulation in the Alternative Transients Program/Electromagnetic Transients Program (ATP/EMTP) program was studied in [11]. The result examined how the system was affected when lightning strikes on different points of the system, such as the power pole, and various segments of the overhead ground wires by using many computer programs for simulation [12-16]. Although the lightning protection was studied, but the behaviour of current during the lightning strike is necessary to understand variation of current waveforms before doing a decision algorithm.

In this paper, the characteristic of the current waveforms is analysis about the variation of current waveforms. The lightning conditions will be simulated using ATP/EMTP due to it is probably the simulator for transient phenomena of electromagnetic [17-22]. The 115 kV Thailand's transmission system is considered for simulation. The behaviour based on the peak amplitude current and the first peak time, during the lightning striking on the conductor of transmission line, are investigated. The location of lightning and the resistance of ground transmission tower are varied and compared.

II. SIMULATION

Under this research as shown in Fig. 1(a), the transmission system under investigation is a length of transmission line of 88.5 km which is a part of Electricity Generating Authority Thailand (EGAT). This transmission system is simulated using ATP/EMTP program. By considering the Fig. 1(a), it can be seen that the 115 kV double circuit transmission line is connected between the sending end substation (RY2) and the receiving end substation (CT2). The total connected load as 30 MVA is installed at the receiving end substation (CT2). In addition, the current transformers (CTs) are installed at each substation end to detect the lightning current.

The configuration of 115 kV transmission tower as shown in Table I is employed to calculate the impedance of multistory transmission tower model as show in Fig. 1(b). By considering the Fig. 1(b), it can be seen that the transmission tower is separated as four parts and each part has the surge impedance (Z), resistance (R), and inductance (L) as shown in Fig. 1(b). The multistory transmission tower model is calculated by using the equation recommended by The Institute of Electrical and Electronics Engineers (IEEE) and CIGRE [21]. The surge impedance can be calculated by the equation 1 which is normally used for inverted conical high-voltage transmission towers. In case of resistance and inductance can be calculated using the equation 4 and 5, respectively. The obtained parameters of multistory transmission tower model are presented in Table II.

TABLE I Transmission tower configurations

	Section			
	1	2	3	4
d_i (m)	4.64	5.50	5.60	6.00
r_i (m)	2.32	2.75	2.8	3
h_I (m)	30.20	26.90	23.20	19.50
l_i (m)	3.30	3.70	3.70	19.50

$$Z_i = 60 log_e \cot\left\{0.5 tan^{-1}\left(\frac{r_i}{h_i}\right)\right\} \quad (1)$$

$$\Delta R_i = \begin{cases} \dfrac{2 \bullet Z_1}{(l_1 + l_2 + l_3)} \ln\left(\dfrac{1}{\alpha_1}\right) & (i = 1, 2, 3) \\ \dfrac{2 \bullet Z_4}{(l_4)} \ln\left(\dfrac{1}{\alpha_4}\right) & (i = 4) \end{cases} \quad (2)$$

$$R_i = \Delta R_i \bullet l_i \quad (3)$$

$$L_i = \frac{2H}{v} \bullet R_i \quad (4)$$

When

d_i = diameter of the high-voltage transmission tower (m)

Z_i = surge Impedance of each section of the high-voltage transmission tower (Ω)

r_i = radius of head of the high-voltage transmission tower (m)

h_i = height of each section of the high-voltage transmission tower (m)

ΔR_i = resistance of each section of the high-voltage transmission tower (Ω/m)

α_i = Attenuation along the tower $(\alpha_1 = \alpha_4 = 0.8944)$

l_i = length of each section of the high-voltage transmission tower (m)

L_i = inductance of each section of the high-voltage transmission tower (mH)

H = height of the high-voltage transmission tower (m)

ν = the speed of the wave is 300 m/μs

Table II Parameters of 115 kV multistory transmission tower

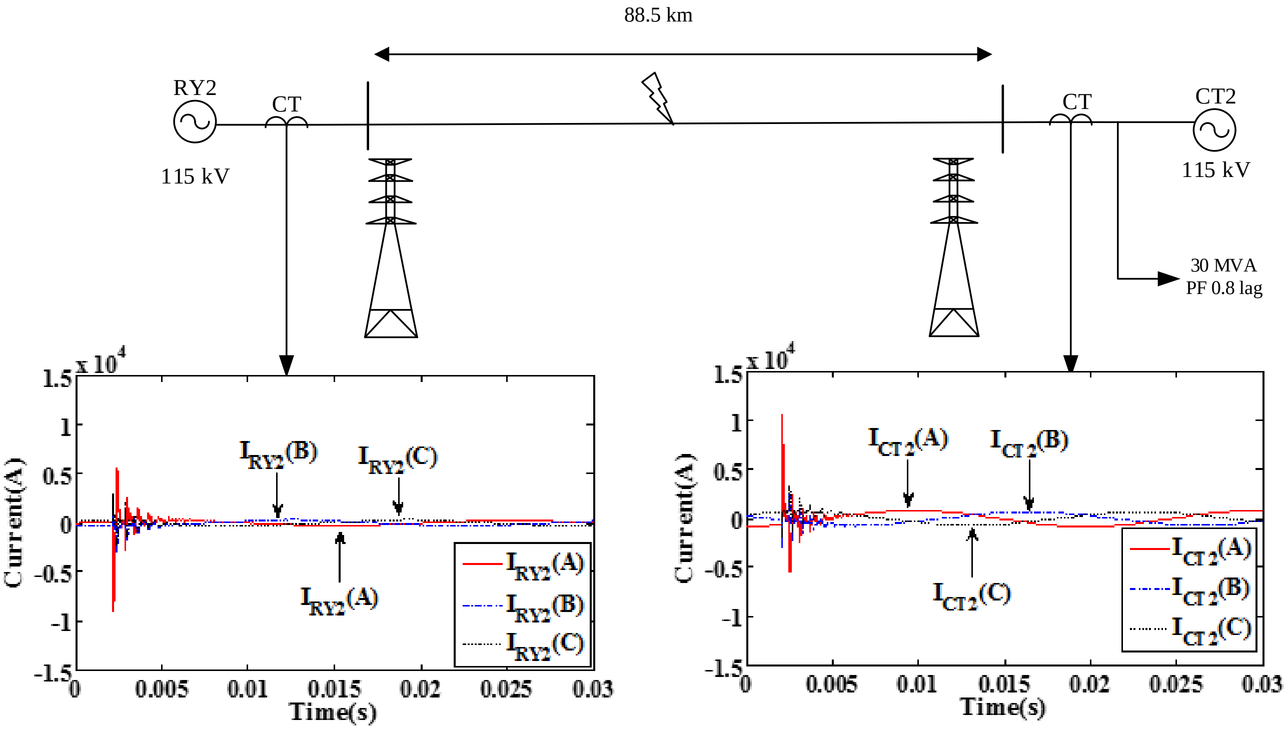
Parameter	ν = 300 m/μs
R_1	12.39092700
R_2	13.89290800
R_3	13.89290800
R_4	31.24855500
L_1	0.002494712
L_2	0.002797101
L_3	0.002797101
L_4	0.006291365
Z_1	180
Z_2	180
Z_3	180
Z_4	140

The components of a simulation model implemented in ATP/EMTP program are shown in Fig. 1(c). By considering the Fig. 1(c), the 1.2/50 μs standard impulse current of 20 kA is used to lightning strike at the conductor of phase A on transmission line. In addition, it can be observed that the transmission line with frequency dependent parameters can be calculated by supporting routing line cable constants (LCC) in ATP/EMTP the parameters of transmission tower can be calculated by using the multistory transmission tower model. To study the characteristics of current when lightning strikes on transmission lines, the simulations are performed with following changes of the system parameters:

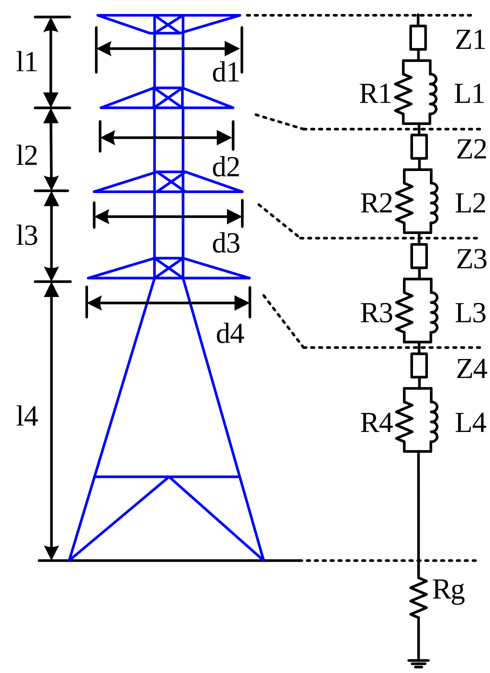
- Lightning locations on the transmission lines are at the distance of 10%, 30%, 50%, 70%, and 90%, measured from the sending end substation (RY2).
- Inception angles on a voltage waveform are varied between 0°-330°, with the increasing step of 30°. Phase A is used as a reference.
- The ground resistances (R_g) are varied as 1, 10, and 100Ω.

The all phase current is obtained in case of lightning strike at 50% of transmission line on the conductor of phase A, as shown in Fig 1(a). By observing the waveform in Fig 1(a), it can be seen that, after the lightning strike occurrence at 0.002 seconds, the amplitude of phase that lightning strikes has a sudden change when comparing to those before the lightning occurrence while the other phases has little impact.

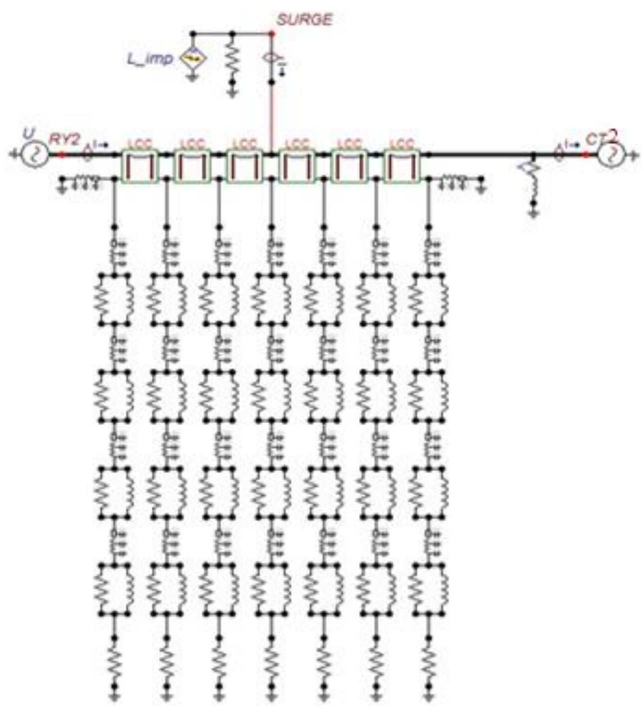
ISBN: 978-988-19253-9-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)



(a) One line diagram of the simulation circuit



(b) Multistory transmission tower model



(c) Simulation circuit model in ATP

Fig 1. Component model implemented in ATP simulation

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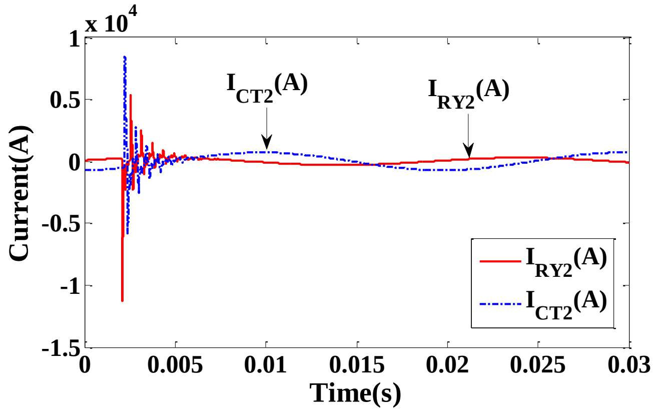
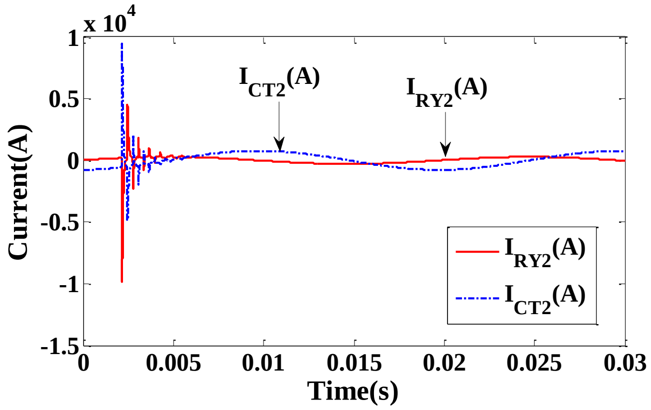
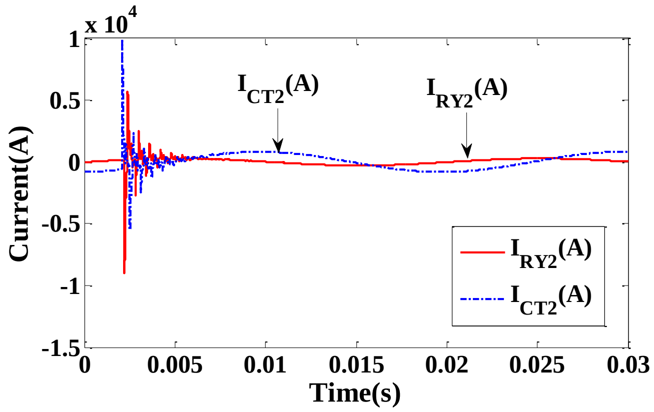


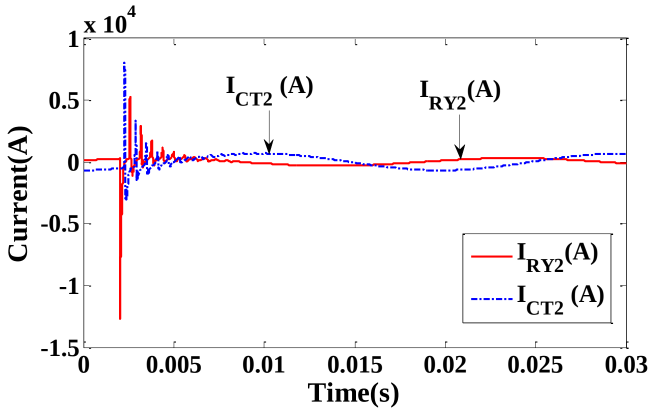
(a) lightning strike occurs at 10% of transmission line



(b) lightning strike occurs at 30% of transmission line



(c) lightning strike occurs at 50% of transmission line



(d) lightning strike occurs at 70% of transmission line

Fig. 2. Current Waveform for various lengths of the transmission lines that lightning strike occurs

III. RESULTS AND DISCUSSION

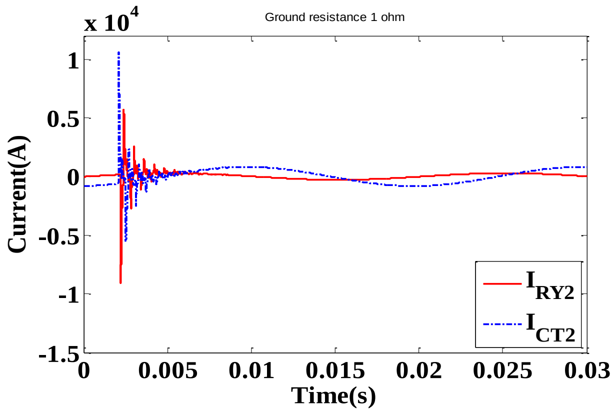
After simulating the lightning strikes when the location of lightning is varied along the length of transmission line, the example the current of phase A waveforms at the each substation is illustrated in Fig. 2. By observing Fig. 2, the similarity between these current waveforms can be seen obviously but the amplitude and the first peak time in these figures can be seen in Table III.

Table III Peak amplitude and first peak time of transient current for various lengths of the transmission lines that lightning strike occurs

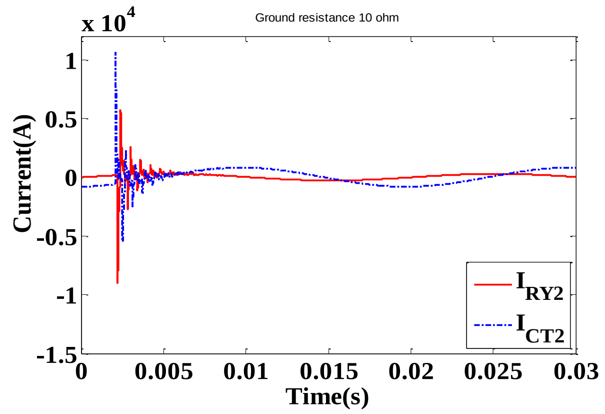
Location of Lightning	Peak amplitude of Phase A (kA)		First peak time (ms)	
	RY2	CT2	RY2	CT2
10%	-12.710	8.022	2.033	2.280
30%	-11.266	8.479	2.082	2.233
50%	-9.819	9.470	2.158	2.158
70%	-9.022	10.587	2.219	2.096

By carefully considering the Fig. 2(a) and Table III, For the location of lightning strikes occurring at the 10% of length of the transmission line, it is found that, during the post-lightning condition at 2 ms, the amplitude of phase that lightning strikes has a change of more than 5 times of a normal condition and its change plays an important role in the abnormal detection decision algorithm. Based on a further behaviour of Table III, when location of lightning strike on the transmission line is varied and inception angles do not change, it is noticed that the peak amplitude of phase that lightning strikes decrease when increasing distance between the sending end substation and the lightning location as shown in Table III. Since the impedance between the sending end substation and the location of lightning strike tend to increase. The peak amplitude current measure at sending end of substation are decrease due to impedance in transmission line. Moreover, the first peak time is also considered when location of lightning strike on the transmission line is varied. It is found that the first peak time tends to increase when increasing distance between the sending end substation and the lightning location. This indicates that the first peak time can be beneficial for locating the lightning strike on the transmission line.

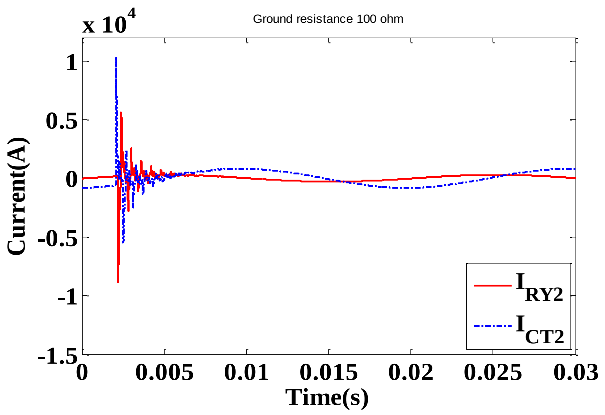
After varying the location of lightning strike on the transmission line, similarly, the ground resistance of transmission tower is also varied to observe the behaviour of the current waveforms as illustrated in Fig. 3 and Table IV. According to the behaviour presented in Fig. 3, the similarity between the behaviour of the current waveforms can be clearly seen. Based on a further analysis of Table IV, after the lightning strike occurrence at 2 ms, the first peak time of phase that lightning strikes does unchange; this indicates that the ground resistance of transmission tower is treated as a no-impact, but the amplitude of phase that lightning strikes has a little decrease when increasing the ground resistance of transmission tower.



(a) ground resistance is 1 Ohm.



(b) ground resistance is 10 Ohms.



(c) ground resistance is 100 Ohm.

Fig. 3. Current Waveform for various ground resistances of the transmission tower that lightning strike occurs.

TABLE IV Peak amplitude and first peak time of transient current for various ground resistances of the transmission tower that lightning strike occurs

Ground Resistance (Ω)	Peak amplitude of Phase A (kA)		First peak time (ms)	
	RY2	CT2	RY2	CT2
1	-9.048	10.619	2.219	2.096
10	-9.021	10.587	2. 219	2.096
100	-8.825	10.364	2. 219	2.096

IV. Conclusion

In this paper, the characteristics of the peak amplitude current and the first peak time obtained from the current waveforms during lightning striking on the transmission system have been analyzed the lightning has often struck on the transmission system so it is necessary to understand variation of current waveforms before doing decision algorithm. The transmission system is chosen based on the 115 kV Thailand's transmission and distribution system. The current waveforms are obtained from transient simulator using the EMTP/ATPDraw program. The LCC model is used for calculating the transmission line with frequency dependent parameters while the multistory model is used for calculating the parameters of transmission tower. To study the characteristics of current during lightning strike occurrence on the transmission lines, the lightning location and the ground resistance of transmission tower are varied. By performing many simulations, it has been found that, when location of lightning strike on the transmission line is varied, the both amplitude and time have a change in accordance with the location of lightning; its change plays an important role in the abnormal detection decision algorithm and lightning location algorithm. On the other hand, when ground resistance of transmission tower is varied, the amplitude only has a little change; this indicates that the abnormal detection decision algorithm can be beneficial. The further work will be development of the lightning location algorithm using discrete wavelet transform.

Acknowledgment

The authors wish to gratefully acknowledge financial support for this research from the King Mongkut's Institute of Technology Ladkrabang Research fund, Thailand

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ISBN: 978-988-19253-9-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)