Prediction of the Lightning Location for Transmission Systems using the characteristics of transient current waveform and travelling wave method

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Abstract

This paper proposes the travelling wave technique to predict the location of lightning on the transmission line. The conditions of lightning striking on the conductor of 115 kV Thailand's transmission line were simulated using ATP/EMTP program. The case studies were performed with changing various parameters such as inception angle, location of lightning, ground resistance of tower, amplitude of lightning strikes, and voltage level of transmission line, in order to evaluate the accuracy of the proposed technique. The characteristics of first peak time of current waveform are investigated as input data for travelling wave equation. The obtained results show that, the first peak time only tends to decrease with decreasing distance between the substation so that the lightning location can be calculated and gives a satisfactory accuracy.

Keywords: Lightning, Lightning location, Transmission line, Travelling wave, Transient.

1. Introduction

Nowadays, the technology is more developed and the population is increasing so it makes the demand of electricity increased. Hence, the transmission network has been expanded to transfer the electrical energy into wide area with the economic growth. Stability of power system is important because it is an indicator of the reliability of the system. Lightning is a natural event that can occur and cause malfunction to some electrical systems. When the lightning occurs, the transmission system could be damaged and then the transmission system is not reliable from the

power outage. Therefore, the behavior of lightning is necessary to make the electricity authority able to decrease damage because of the power outage. In the literature for lightning, there are many research studies ⁽¹⁻²³⁾ such as shielding failures ⁽¹⁻⁵⁾, lightning current ⁽⁶⁻⁷⁾, flashover ⁽⁸⁻⁹⁾, and lightning impulse test ⁽²¹⁻²²⁾. Although most of power outage causes the shielding failures but, when lightning strike on a transmission line, location of lightning should be analysed in order to rapidly repair the transmission system.

Hence, this paper is interested in predicting the location of lightning striking along transmission line. In previous paper ⁽²³⁾, the characteristics of the all phase current waveform in terms of the peak amplitude current and the first peak time were analysed about the variation of current waveforms. The obtained results showed that the variation of characteristics of transient current would be very useful in the development of lightning location scheme, so the travelling wave technique was considered in order to calculate the location of lightning. Generally, traveling wave method was divided into 4 types such as type A, type B, type C, and type D. In this paper, travelling wave equation of type D was used for calculating the location of lightning because travelling wave equation of type D used input data from double end substation, and did not depend on the reflection of travelling wave from substation. Moreover, the various parameters such as inception angle, location of lightning, ground resistance of tower, amplitude of lightning strikes, and voltage level of transmission line, are varied and compared in order to evaluate the accuracy of the proposed technique.

2. Simulation and Results

The 115 kV double circuit transmission system which is a part of Electricity Generating Authority Thailand (EGAT) was simulated with ATP/EMTP program as shown in Fig. 1. By considering the Fig. 1, the length of transmission line was 88.5 km, interconnected between the sending end substation (RY2) and the receiving end substation (CT) while the current transformers (CTs) were installed at each end substation in order to detect the lightning current. Moreover, the total connected load (30 MVA, 115 kV, and 0.8 lagging pf.) was installed at the receiving end substation (CT).

To study the characteristics of current waveform, the various case studies are performed with following changes of the parameters:

- Locations of lightning on the transmission line are the length of 10%, 30%, 50%, and 70%, measured from the sending end substation (RY2).
- Inception angles on a voltage phase A waveform are 0° , 90° , and 135° .
- The amplitudes of lightning strikes are varied as 10 kA, 20 kA, and 30 kA.
- The voltage levels of transmission system are 115 kV, 230 kV, and 500 kV.

- The ground resistances of transmission system tower are varied as $1\ \Omega$, $10\ \Omega$, and $100\ \Omega$.

After simulating the lightning strikes on the conductor of transmission line, the all phase current waveform was measured from the current transformers of each substation. After measuring the current waveform, it can be observed that all phase current has a sudden change and increases in short period of time as shown in Fig. 1. This indicates that the abnormal condition occurs on the transmission system. For the next step, the all phase current waveform obtained from the simulation results was calculated with Clarke's transformation so that the positive sequence current can be achieved as shown in Fig. 2 to Fig. 6.

After calculating the positive sequence current, by considering the Fig. 2 and Table 1, the case studies are divided into 4 cases, corresponding with location of lightning along the length of transmission line. By carefully considering the Fig. 2, the peak amplitude of positive sequence current of sending end substation decreases when increasing the location of lightning while the first peak time of positive sequence current tends to increase with the increase of the location of lightning as shown in Table 1. This indicates that the first peak time can be beneficial for predicting the lightning location on the transmission line.

Fig. 1 One line diagram of the simulation circuit ⁽²³⁾.

(a) Lightning strike at 10% of transmission line.

(b) Lightning strike at 30% of transmission line.

(c) Lightning strike at 50% of transmission line.

(d) Lightning strike at 70% of transmission line.

Fig. 2 Positive sequence current waveform for various lengths of the transmission lines.

Table 1. Comparison of variation of peak current and first peak time at various lightning locations of transmission line.

Location of lightning	Maximum current (kA)		First peak time (ms)	
	RY2	CT	RY2	CT
10%	-12.708	8.014	2.033	2.280
30%	-10.918	8.6604	2.096	2.220
50%	-9.8357	9.4707	2.158	2.158
70%	-9.0247	10.5882	2.219	2.096

After varying the location of lightning, similarly, the inception angle is varied in order to observe the characteristics of positive sequence current as shown in Fig. 3 and Table 2. By considering the Figure 3, the amplitude of positive sequence current of both substations has a little-impact while the first peak time of positive sequence current of both substations is unchanged as shown in Table 2.

By changing only the amplitude of lightning strikes as shown in Fig. 4 and Table 3, it can be clearly seen that the amplitude of positive sequence current of both substations

tends to increase with the increase of amplitude of lightning strikes, but the first peak time of positive sequence current of both substations is also unchanged; this indicates that its change plays an important role for the lightning detection decision algorithm but not for predicting the lightning location.

By changing the voltage level of transmission system as shown in Fig. 5 and Table 4, it can be clearly seen that the amplitude of positive sequence current of both substations tends to decrease with the increase of voltage level of transmission system, but the first peak time of positive sequence current of both substations remains also unchanged; this indicates that the lightning detection decision algorithm obtained is beneficial but not for predicting the lightning location.

By changing the ground resistance of transmission system tower as shown in Fig. 6 and Table 5, the similarity between these waveforms can be clearly seen in terms of the amplitude and the first peak time of positive sequence current for both substations; this indicates that its change has the same behavior as in case of the inception angles.

(a) Lightning strike when angle is 0 degree.

(a) Lightning current of 10 kA.

(b) Lightning strike when angle is 90 degree.

(b) Lightning current of 20 kA.

(c) Lightning strike when angle is 135 degree.

(c) Lightning current of 30 kA.

Fig. 3 Positive sequence current waveform in case of various inception angles.

Fig. 4 Positive sequence current waveform in case of various amplitude of lightning strikes.

Table 2. Comparison of variation of peak current and first peak time at various inception angles.

Inception angle	Maximum current (kA)		First peak time (ms)	
	RY2	CT	RY2	CT
0	-9.0247	10.5882	2.2193	2.0960
90	-8.9638	11.7384	2.2193	2.0959
135	-9.1504	12.0033	2.2193	2.0960

Table 3. Comparison of variation of peak current and first peak time at various lightning currents.

Lightning current (kA)	Maximum current (kA)		First peak time (ms)	
	RY2	CT	RY2	CT
10	-4.4280	4.9932	2.2193	2.0960
20	-9.0247	10.5882	2.2193	2.0960
30	-13.6210	16.1832	2.2191	2.0960

(a) Voltage level of 115 kV.

(a) Ground resistance of 10 ohms.

(b) Voltage level of 230 kV.

(b) Ground resistance of 10 ohms.

(c) Voltage level of 500 kV.

(c) Ground resistance of 100 ohms.

Fig. 5 Positive sequence current waveform in case of various voltage levels of transmission system.

Fig. 6 Positive sequence current waveform in case of various ground resistances of transmission system tower.

Table 4. Comparison of variation of peak current and first peak time at various voltage levels of transmission systems.

Voltage level (kV)	Maximum current (kA)		First peak time (ms)	
	RY2	CT	RY2	CT
115	-9.0247	10.5882	2.2193	2.0960
230	-8.8559	9.9865	2.2192	2.0960
500	-8.4597	8.5737	2.2192	2.0960

Table 5. Comparison of variation of peak current and first peak time at various ground resistances of transmission line tower.

Ground resistance (Ω)	Maximum current (kA)		First peak time (ms)	
	RY2	CT	RY2	CT
1	-9.0508	10.6206	2.2193	2.0960
10	-9.0247	10.5882	2.2193	2.0960
100	-8.8303	10.3655	2.2192	2.0960

3. Identification of lightning location using travelling wave method

After the characteristics of positive sequence current have been analysed with various case studies, the characteristics of positive sequence current are necessary to understand variation of first peak time of positive sequence current before calculating the lightning location. The location of lightning can be calculated by using the equation 1.

$$X = \frac{L + v(T_{1RY2} - T_{1CT})}{2} \quad (1)$$

Where:

X is the location of lightning, measured from the sending end substation (RY2) or lightning location (km)

L is the length of total line of transmission line on which the fault is detected (km)

v is the velocity of the travelling wave (m/μs)

(In this paper, the travelling wave speed is 298.85 m/μs)

T_{1RY2} is the time of first peak time, arriving at sending end substation (ms)

T_{1CT} is the time of first peak time, arriving at receiving end substation (ms)

After calculating the travelling wave equation with the various case studies, the obtained results were presented in Tables 6-8. By considering data in Table 6, case studies were performed with various inception angles, the amplitude of lightning current, and the ground resistance of transmission tower; it can be seen that the obtained results is satisfactory with a mean error of less than 1 km.

Similarly, case studies were performed with various voltage levels of transmission system including the variation of inception angle, lightning current, and ground resistance as shown in Table 7; it can be seen that the accuracy of lightning location from the predication of the proposed technique was also satisfactory. However, when the location of lightning was varied as shown in Table 8, it can be seen that the error of lightning location from the proposed technique tends to decrease with increasing the distance between lightning point and sending end substation and tends to increase with decreasing the distance between lightning point and receiving end substation. In order to overcome this problem, a new technique should be developed in order to able to predict the lightning location more precisely.

4. Conclusion

In this paper, the travelling wave technique was employed in order to predict the location of lightning along the transmission line. Time of first wave arrival at both ends of line, detected by current transformer (CT) at both sides, are investigated as input data for travelling wave equation. The case studies were performed with various parameters such as inception angle, location of lightning, ground resistance of tower, amplitude of lightning strikes, and voltage level of transmission line, in order to evaluate the accuracy of the proposed technique. By considering the overall results, it can be seen that the average error of proposed technique is less than 1 km. The further work will be the improvement of the new technique to be able to predict the lightning location more precisely.

Table 6. Results of lightning location for various case studies (Lightning at 61.95 km).

Real location of lightning (km)	Inception angle	Lightning current (kA)	Ground resistance (Ω)	First peak time (ms)		Lightning location (km)	
				RY2	CT	Calculation	Error
61.95	0	20	10	2.219	2.096	62.629275	-0.679275
	90	20	10	2.219	2.096	62.629275	-0.679275
	135	20	10	2.219	2.096	62.629275	-0.679275
61.95	0	10	10	2.219	2.096	62.629275	-0.679275
	0	20	10	2.219	2.096	62.629275	-0.679275
	0	30	10	2.219	2.096	62.629275	-0.679275
61.95	0	20	1	2.219	2.096	62.629275	-0.679275
	0	20	10	2.219	2.096	62.629275	-0.679275
	0	20	100	2.219	2.096	62.629275	-0.679275

Table 7. The results from travelling wave method for lightning location in case of various voltages level of transmission system.

Voltage Level (kV)	Inception angle	Lightning current (kA)	Ground resistance (Ω)	First peak time (ms)		Lightning location (km)	
				RY2	CT	Calculation	Error
115	0	20	10	2.219	2.096	62.629275	-0.679275
	90	20	10	2.219	2.096	62.629275	-0.679275
	135	20	10	2.219	2.096	62.629275	-0.679275
230	0	10	10	2.219	2.096	62.629275	-0.679275
	0	20	10	2.219	2.096	62.629275	-0.679275
	0	30	10	2.219	2.096	62.629275	-0.679275
500	0	20	1	2.219	2.096	62.629275	-0.679275
	0	20	10	2.219	2.096	62.629275	-0.679275
	0	20	100	2.219	2.096	62.629275	-0.679275

Table 8. The results from travelling wave method at different locations of lightning along the transmission line.

Real location of lightning (km)	Inception angle	Lightning current (kA)	Ground resistance (Ω)	First peak time (ms)		Lightning location (km)	
				RY2	CT	Calculation	Error
8.85	0	20	10	2.033	2.280	7.282255	1.567745
17.70	0	20	10	2.065	2.250	16.576490	1.12351
26.55	0	20	10	2.096	2.220	25.825897	0.724103
35.40	0	20	10	2.127	2.189	35.075305	0.324695
44.25	0	20	10	2.158	2.158	44.250	0
53.10	0	20	10	2.189	2.127	53.439637	-0.339637
61.95	0	20	10	2.219	2.096	62.629275	-0.679275
70.80	0	20	10	2.250	2.065	71.893625	-1.093625
79.65	0	20	10	2.280	2.033	81.068320	-1.41832

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