Lightning Performance on Transmission Line Tower

By

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When a steep front lightning stroke current strikes the top of a transmission line tower, the tower top potential is influenced by the surge impedance of the tower, and there is a chance of a very high potential rise on the tower top during the round trip surge travel time along the tower. If such a voltage causes an inverse flashover of the string insulator of the phase conductor, a steep front surge voltage which has an extremely high crest does penetrate along the phase conductor. However, the lightning performance of a transmission line on the tower has not been investigated clearly for this steep front surge current, because the tower surge impedance and the performance of the string insulator in a very short time region has not been investigated satisfactorily.

Recently, the author investigated the surge response of a transmission line tower and some equivalent circuits for the surge response of the tower have been obtained.

The author estimated the lightning performance on transmission line towers by means of the tower equivalent circuit for a surge current together with an assumption in estimating the flashover characteristics of the string insulator.

1. Introduction

When a lightning stroke strikes the top of a transmission line tower, there is a chance of inverse flashover of the string insulator of the phase conductor caused by the potential rise on the tower top by the stroke current.

However, the characteristics of inverse flashover of the string insulator have not been elucidated completely, because the data with respect to the flashover characteristics of the string insulator due to a surge voltage with very steep wavefront, and the lightning current waveshape have not been obtained satisfactorily. Moreover the surge performances along the tower have not been investigated clearly.

Recently, the author investigated the tower surge response by means of miniature scale models, and as a result of the investigation some equivalent circuits for representation of the tower surge response were obtained.

The flashover voltage of the string insulator and the surge voltage produced on the phase conductor by the inverse flashover can be estimated by the use of the

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author's equivalent circuit, if appropriate assumptions are made for the short time flashover characteristics of the string insulator.

This paper describes the very high speed surge performances of a transmission line tower struck by lightning, which was analysed by a low speed surge analyser.

2. Tower Equivalent Circuit

For the analysis of the transient abnormal voltage of the tower due to a lightning stroke at the tower, the distributed constant equivalent circuit for the tower was used, which was obtained by the author[1].

In this equivalent circuit, the tower is represented as a distributed constant circuit, and the tower surge response is represented approximately by the response of a circuit composed of several series-connected conductors. Namely, the tower is divided into several parts, for example top middle and bottom, and if the surge impedance and the length of the conductor on the equivalent circuit which represents the respective part of the tower are selected appropriately, the equivalent circuit can represent the tower surge response approximately.

In this paper, the tower is represented by the series connection of three single conductors, which have the same length.

For the numerical analysis, the author used as an example a typical shape 20 m high and 77 kV double-circuit tower with a single ground wire, whose shape and dimensions are shown in Fig. 1.

The values of the surge impedances of the equivalent circuit of the tower are

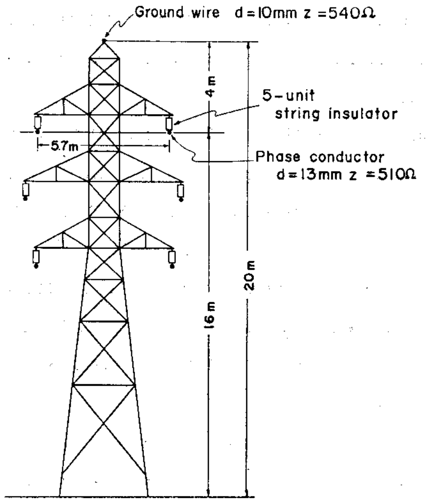

Fig. 1. The tower for the analysis.

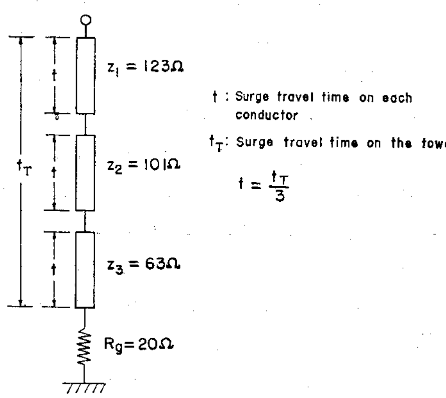

Fig. 2. The distributed constant equivalent circuit for the tower.

shown in Fig. 2, which were obtained by the author. And the tower footing resistance is assumed to be 20 ohms.

The dimensions of the phase conductor and the ground wire are assumed to be as Fig. 1, and the values of their inherent surge impedances are shown in the figure.

3. Volt-time Characteristics of The String Insulator

The tower surge impedance affects severely the tower top potential in the time region less than the round trip surge travel time along the tower. The round trip surge travel time of a 20 m high tower is approximately 0.13 μs. However, the flashover delay volt-time characteristics of a string insulator when such a steep front surge voltage is impressed to the string insulator, have not been investigated completely.

Accordingly, the author estimated the volt-time characteristics of the flashover of a string insulator in the time region stated above, with an assumption regarding the area of the flashover voltage waveform which exceeds the static breakdown voltage[2]. The assumption is that, the area under the overvoltage portion of the voltage waveform in case of impulse flashover of the string insulator, namely the area that is enclosed by the static breakdown voltage line and the overvoltage waveform, is always constant as shown in Fig. 3.

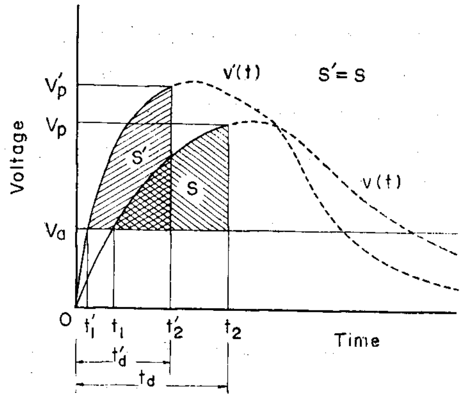

Fig. 3. An assumption for estimating a flashover voltage.

This assumption can be written as follows:—

$$S = \int_{t_1}^{t_2} [v(t) - v_a] dt = \text{constant}$$

In the equation

$v(t)$: impressed voltage wave
v_a : static breakdown voltage
S : area under the overvoltage portion
t_1 : the instant when the impressed voltage get over the static breakdown voltage
t_2 : breakdown time.

The short delay time flashover characteristics can be estimated by the assumption described above if some longer delay time denoted t_d in Fig. 3 and the flashover voltage waveform $v(t)$ during the time interval t_d are known.

4. Surge Analyser Circuit for Analysis

The computations were performed on a low speed surge analyser which consists of electronic time delay devices and a low speed analog computer[3].

The lightning stroke current flows separately into the tower and the ground wire first. When an inverse flashover of the string insulator occurs, the surge impedance of the phase conductor does influence the tower top potential because a part of the stroke current flows into the phase conductor. But on this occasion, the mutual surge impedance between the phase conductor and the ground wire must also be considered.

In this analysis the author adopted the following values as the surge impedances:—

Surge impedance of the ground wire seen from the tower top: 270 ohms,
Resultant surge impedance of one of the phase conductors at the top arm of the tower and the ground wire: 161 ohms,
Resultant surge impedance of both the phase conductors at the top arm and the ground wire: 139 ohms,
Surge impedance of the lightning channel: 400 ohms.

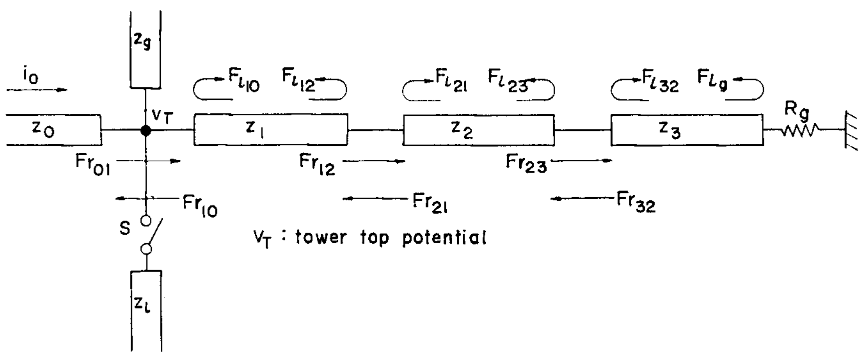

Fig. 4. The travelling wave circuit for the analysis.

Figure 4 shows the travelling wave circuit involving the tower, the ground wire, the phase conductors and the string insulators. In this figure, the circuit indicated by z_1, z_2, z_3 and R_g is the tower equivalent circuit which is described in section 2. And z_g, z_l and z_0 denote the surge impedance of the ground wire seen from the tower top, the effective surge impedance of the phase conductor and the surge impedance of the lightning channel respectively, and the length of the ground wire and the phase conductor are assumed to be infinitely long.

Moreover F_{lij} and F_{rij} denote the voltage reflection coefficient and the voltage refraction coefficient respectively, at the junction of z_i and z_j for the travelling wave toward z_j from z_i. These coefficients have the following values:—

$$F_{lij}=\frac{z_j-z_i}{z_i+z_j}\,,\;F_{rij}=\frac{2z_j}{z_i+z_j}\,.$$

Switch S represents the string insulator, and the flashover of the string insulator is equivalent to the closing of the switch.

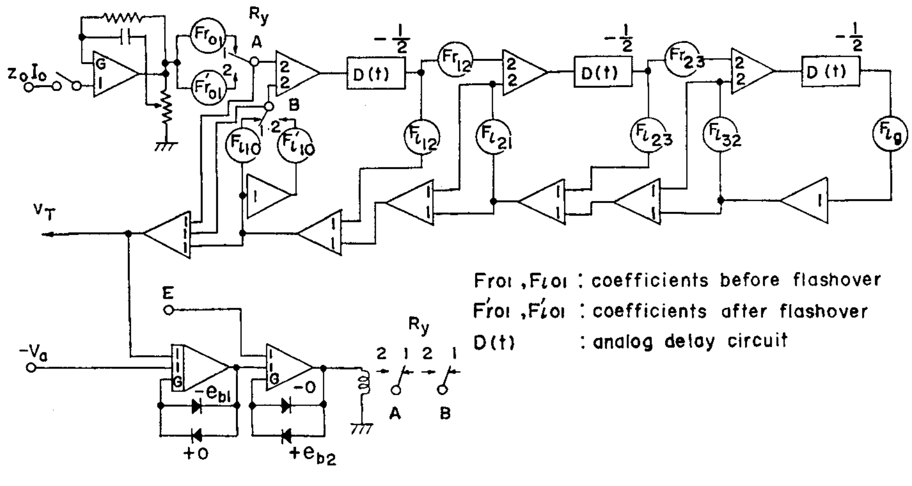

Fig. 5. The schematic diagram of the low speed surge analyser.

Figure 5 shows the schematic diagram of the surge analyser circuit for the travelling wave circuit shown in Fig. 4.

In order to present the surge travel time in the tower, only three analog delay circuits are used, and each delay circuit gives round trip surge travel time on each conductor of the tower equivalent circuit, because the equivalent circuit of the tower is assumed to be lossless.

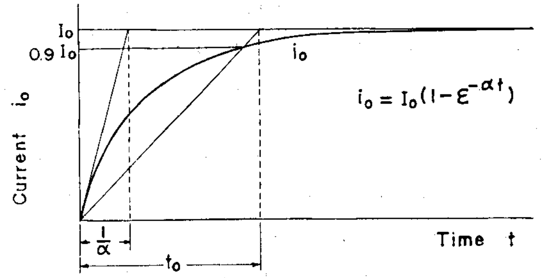

Fig. 6. The definition of the stroke current wave-front rise time.

The wave front rise time of the stroke current t_0 is defined as Fig. 6, and the wave tail is assumed to be infinitely long.

5. Computation Results

The stroke current amplitude which causes the inverse flashover, and the flashover delay time can be determined by the method which was described in the forgoing sections.

In the present case, the potential at the top arm of the tower is assumed to be the same as the potential at the top of the tower, but in practice the potential at the tower arm ought to be somewhat lower than the potential at the tower top.

Figure 7 shows the relations between the stroke current amplitude causing the inverse flashover and the flashover delay time under several rise times of the stroke current. In Fig. 7, the stroke current amplitude is shown on the vertical axis and the flashover delay time t_d is shown on the horizontal axis. In the case of this paper, it is assumed that each of the phase conductors of the 77 kV line is suspended by a 5-unit standard string insulator from the tower arm, and as the values of the flashover voltage of the string insulator for commercial ac voltage and for linear rise surge voltage at flashover delay time 2 μs, 460 kV (peak value) and 770 kV are adopted respectively. Therefore the value of the surge flashover voltage for the tower top voltage at flashover delay time 0.11 μs

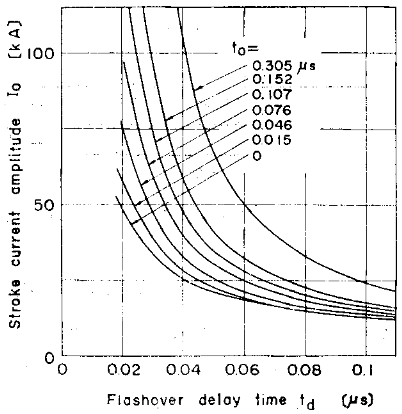

Fig. 7. The relations between the stroke current amplitude and the flashover delay time.

is estimated to be 2125 kV when the stroke current rise time is 0.305 μs.

Therefore the stroke current amplitude at this condition is 22 kA.

The vertical scale of the figure is graduated by the values as stated above.

Figure 8 and Fig. 9 show the peak values of the surge voltages, which are produced on the conductor after a flashover caused by the current as shown in Fig. 7. Figure 8 shows the peak voltage on the conductor caused by a single top string insulator flashover and Fig. 9 shows a similar voltage caused by the simultaneous flashover of the two top string insulators.

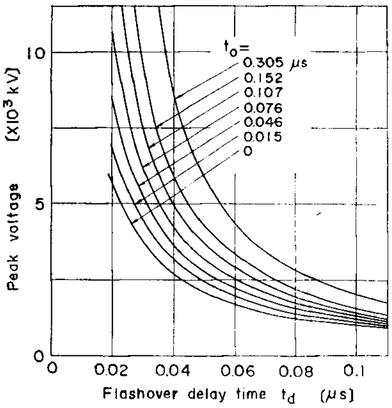

Fig. 8. The peak voltage on the conductor caused by a single top string insulator flashover.

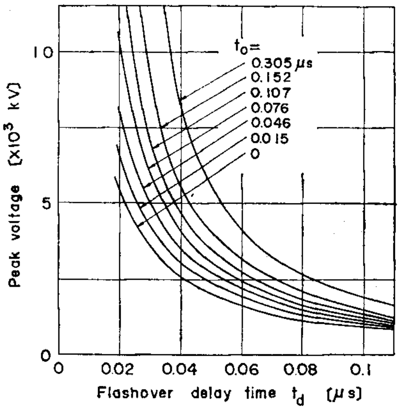

Fig. 9. The peak voltage on the conductor caused by the simultaneous flashover of the two top string insulators.

The difference between Fig. 8 and Fig. 9 is not so much, because the resultant surge impedance of the tower and the ground wire is fairly smaller than the effective surge impedance of the phase conductor.

6. Conclusions

In the previous sections, the surge performances along the transmission line tower due to a lightning stroke at the tower top, in which the inverse flashover is are considered, and are estimated by means of a distributed constant equivalent circuit of the tower under an assumption for flashover volt-time characteristics of the string insulator.

As the result of the analysis, it is found that, if the flashover occurs in the time region that the tower surge impedance influences the tower top voltage, a surge voltage with an extremely high crest value and steep front appears on the phase conductor and such a surge voltage does affect the insulation of the transmission system. Therefore, in such a case, further investigations must be necessary concerning the insulation and the surge protection in the transmission system against a steep front surge voltage.

Besides, in the longer time region when the tower surge characteristics have almost no effect on the tower top potential, the flashover voltage and the surge voltage produced on the conductor by the flashover of the string insulator can be gotten by an ordinary method namely by the product of the tower footing ground resistance and the stroke current amplitude.

Acknowledgment

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