THE SIMULATED EXPERIMENT OF LIGHTNING INDUCED OVERVOLTAGE ON THE DISTRIBUTION LINE

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ABSTRACT

The insulation level of 10 kV power distribution line is low, which is vulnerable to the direct lightning and induction lightning. Lightning is one of the important reasons for the accidents of distribution network. In order to reduce lightning accidents and improve the power supply reliability of distribution network, it's important in theoretic and engineering to run the simulated and real-model experiment of lightning induced overvoltage on the distribution line, which is able to get real lightning data to provide a basis for the simulation of lightning overvoltage. In this paper, the basic idea of the simulated experiment is introduced firstly. Then, a rational experimental plan is designed according to our aim. Finally, the results of our experiment and simulation is compared, which can confirm the validity of the experiment.

KEY WORD

The lightning protection of distribution network; Induced lightning overvoltage; Simulated experiment; Simulation

0. INTRODUCTION

Lightning is one of the important reasons for the failure of distribution network, which is more serious in the areas with intense lightning activity. According to the principle of lightning role, there are two main reasons for the lightning overvoltage: one is that the distribution line is struck directly by lightning; the other is an induced overvoltage on the distribution line by lightning striking on the ground nearby. There are few direct lightning flash accidents in urban distribution network due to the shielding effect of tall buildings and trees, so the lightning induced overvoltage is the major reason for the failure of urban distribution network. However, both direct lightning and induced lightning overvoltage are serious threat to the secure and stable operation of power transmission and transformation equipment of distribution network.

The experiment study of lightning induced overvoltage generally divides into two categories, the simulated experiment and the real-model experiment. The simulated experiment of lightning induced overvoltage on distribution line can reproduce the real-model experiment. Compared with the real-model experiment, it's relatively easy to carry out. Meanwhile, it's also convenient to make regular study by changing experimental parameter settings. However, the results of the simulated experiment is determined by the parameter settings, an appropriate experimental design is required.

In this paper, the basic idea of the simulated experiment is introduced firstly. Then, a rational experimental program is designed according to our aim. Finally, the results of our experiment is compared with simulation results, which can confirm the validity of the experiment.

1. THE BASIC IDEA OF THE EXPERIMENT

The designs of the simulated experiment of lightning induced overvoltage have greatly difference according to their experimental purposes. This is because you can't diminish the distortion of all aspects at the same time. Generally speaking, researchers design different experimental plans owing to their particular emphases. Therefore, it's very important for us to design our experiment according to clear aim, which can diminish the distortion of our primary focus.

For a running distribution line, the line trip rate is directly related to the reliability of power supply. And the line trip rate caused by lightning induced overvoltage is mainly related to the lightning withstanding level of distribution line and the local lightning activities, while the lightning withstanding level of distribution line depends primarily on the initial stage waveform of induced overvoltage on distribution line. So we hope the initial stage waveform of lightning induced overvoltage measured in our experiment is as real as possible.

The scaling factor is a key parameter in the simulated experiment. Because the lightning induced overvoltage on distribution line is non-linear, small scaling will lead to great distortion of the experimental results, while large scaling will greatly increase the cost and the difficulty of the experiment, which sacrifices the flexibility of the simulated experiment.

The scaling of the length S_a depends on the size of the experiment site. Because the propagating velocity of electromagnetic waves is very difficult to change, the scaling of the velocity is set to 1, and the scaling of the time is S_a. Furthermore, the scaling of the line capacitance and inductance is also S_a, the scaling of the resistance is 1. The scaling of the current amplitude is S_i, which depends on the power supply of our experiment, and has nothing to do with the length.

When the real lightning occurs, the lightning current channel is very long. Even if it times the scaling of the length S_a, it's still too long for the simulated experiment.

For a short simulated lightning current channel, the initial stage waveform meshes well with the actual situation. But once the current reaches the top of the experiment channel, reflection occurs, which will make an obvious distortion. Luckily, we only care about the initial stage waveform of the induced overvoltage in our experiment. Even so, we must ensure that the time for the current reaches the top of the channel is greater than the rise time of current waveform. Moreover, the simulated lightning current channel should be roughly perpendicular to the earth. The construction of the simulated distribution line is relatively simple, which only need to meet the scaling of the length S_a and connect to matched impedance at both ends of the simulated line.

2. THE EXPERIMENTAL DESIGN OF THE SIMULATED EXPERIMENT

The overall program of the experiment is shown in Figure 1. At either end, the simulated distribution line is connected to matched impedance, whose resistance value is 620Ω. Under the simulated line, there is a piece of galvanized iron plate, whose size is 15 meters long, 2 meters wide and 1 mm high. As ideal grounding condition, there is also a piece of galvanized iron plate under the simulated lightning current channel, whose size is 4 meters long, 3 meters wide and 1mm high. The plate is grounded through a copper braided wire. The grounding body is consists of 4 iron rods, whose diameter is 1cm. The 4 iron rods are 1 meter apart, and plugged into soil 20cm deep, as shown in Figure 2.

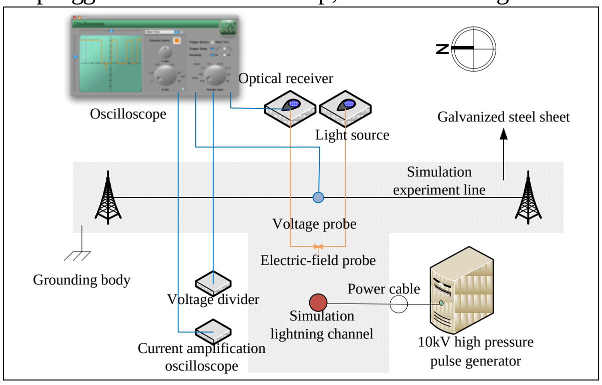


Fig1 the total scheme of the experiment

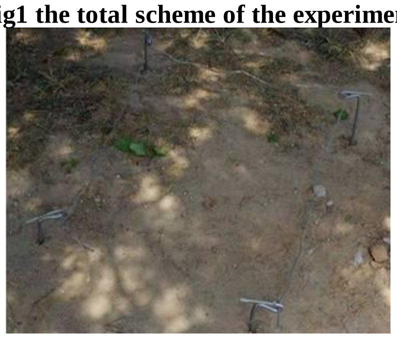


Fig2 the grounding body device

The high pressure pulse generator [1] is used as the experimental power, whose fundamentals are shown in Figure 3. 220V AC is changed into a DC high voltage through the rectifier, and then charges the pulse forming line up. When the voltage of pulse forming line reaches up to the flashover voltage of high-pressure nitrogen spark switch, a high pressure square wave is formed and spreads through a pulse transmission line. The picture of the high pressure pulse generator is shown in Figure 4. When the end of the pulse transmission line is connected to simulated lightning current channel, the current value is about several dozen amperes. Here, the scaling of the current amplitude S_i is about 1/1000.

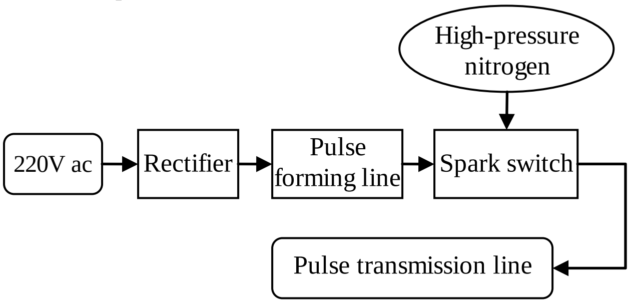
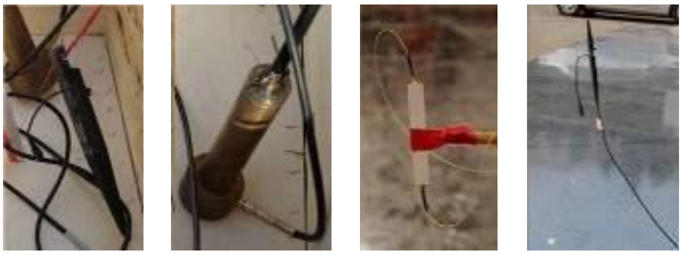


Fig3 the fundamentals of the high pressure pulse generator

Fig4 the high pressure pulse generator

The current generated by the high pressure pulse generator spreads to the simulated lightning current channel through a power cable. The current signal measured at the bottom of the channel is connected to the oscilloscope through a 10A/V current amplifier. The picture of the current probe is shown in Figure 5(a). The voltage signal measured at the bottom of the channel is connected to the oscilloscope through a voltage step-down divider, whose transformer ratio is 417:1, as shown in Figure 5(b). The optical signal produced by a light source spreads through fiber optics. The electric signal is modulated to optical signal through an electric-field probe [2], and received by an optical receiver finally. Then, the optical receiver decodes it as a voltage signal, and sends it to the oscilloscope. The picture of the current probe is shown in Figure 5(c). The induced overvoltage at the middle of the simulated line is measured directly by a voltage probe, as shown in Figure 5(d).



(a) current probe **(b) voltage divider** **(c) electric-field probe** **(d) voltage probe**

Fig5 measuring devices and their connections

The experiment site is indoors, which will not be affected by the weather, as shown in Figure 6. The simulated lightning current channel is lifted up by pulley block. Restricted by the site conditions, the scaling of the length S_a is set to 1/20. The simulated experiment line is 11 meters long and 50cm above the ground, whose wire diameter is 0.5mm, corresponding to a real line of 220 meters long, 10 meters above the ground, and it's wire diameter is 1cm. The simulated lightning current channel is 6 meters long and 1.1 meters away from the midpoint of the simulated line, corresponding to a real current channel of 120 meters long and 22 meters away from the midpoint of the real line. The time for the current spreading from the bottom to the top of the channel is about 60ns, after which the experimental results will have a serious distortion.

(a) side view **(b) positive view**

Fig6 the experiment field

3. THE COMPARISON OF SIMULATED EXPERIMENTAL RESULTS WITH SIMULATION RESULTS

As mentioned previously, the measured waveform in the experiment is relatively real at the stage of the first 60 ns. The current measured at the bottom of the simulated lightning current channel is shown in Figure 7.

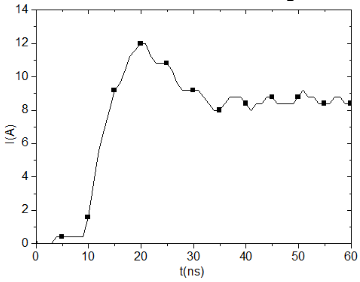


Fig7 the current waveform at the channel base

If we suppose the current spikes to be 10A, the comparison of the measured induced overvoltage at the midpoint of the line with simulation results are shown in Figure 8. Based on MTLE lightning current return stroke model, the measured current waveform is used in our simulation. The constant λ is set to 2000m, and the lightning current velocity v_f is set to 1.3 times 10 to the 8 meters per second. As we mentioned before, the simulated lightning current channel is 6 meters long, the simulated experimental line is 11 meters long and 50cm above the ground. The experimental system is considered to be linear to the amplitude of current.

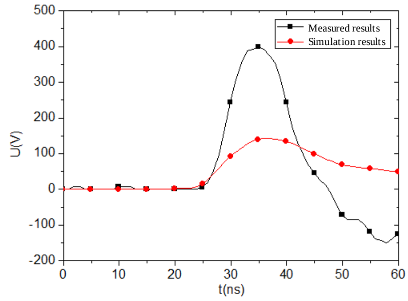


Fig8 the induced overvoltage at the midpoint of the line

As can be seen from the Figure 8, the measured voltage spike is about 3 times of the simulation results. The measured voltage waveform decreases rapidly to an inverse peak after it has a spike, while the simulation waveform decreases slowly to zero after its peak.

3.1 The relationship between the overvoltage and the distance d

If the simulated line is 50cm above the ground constantly, and the distance d between the lightning current channel and the simulated line is 0.94m, 1.1m, 1.16m, 1.35m, the overvoltage measured at the midpoint of the line is shown in Figure 9. (The current spike is set to 10A.)

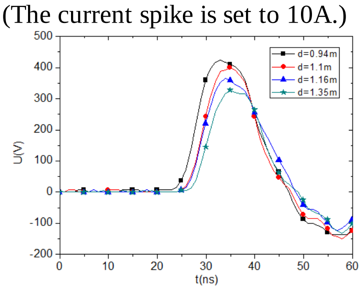


Fig9 the relationship between the induced overvoltage and the distance d

We can see from Figure 9 that the voltage spike increases with the decrease of the distance d, while the rising time of the voltage waveform decreases with the decrease of the distance d. The relationship between the measured and simulation voltage spike and the distance d is shown in Figure 10. In the simulation, the current waveform uses the waveform shown in Figure 7 uniformly. And for the convenience of observation, the simulation voltage spike is amplified 2.8 times uniformly.

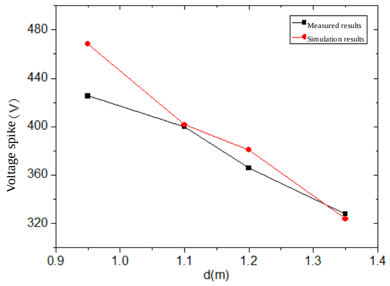


Fig10 the relationship between the voltage spike and the distance d

We can see from Figure 10 that the simulation and measured results are generally in agreement with each other, which decrease linearly with the increase of the distance d.

3.2 The relationship between the voltage and the height h

Again, following the situation of section 3.1, when the distance between the simulated line and the lightning current channel is 1.16m constantly, and the height of the simulated line above the ground is 0.94m, 1.1m, 1.16m, 1.35m, the overvoltage measured at the midpoint of the line is shown in Figure 11. (The current spike is set to be 10A.)

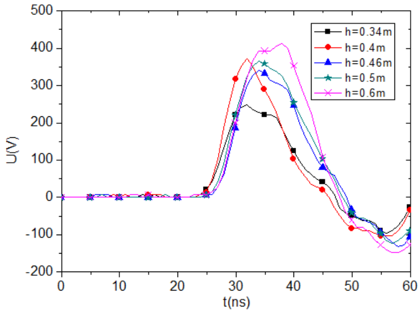


Fig11 the relationship between the induced overvoltage and the height h

The relationship between the measured and simulation voltage spike and the height h is shown in Figure 12. We can see from Figure 12 that the simulation and measured results are generally in agreement with each other, which increase linearly with the increase of the height h.

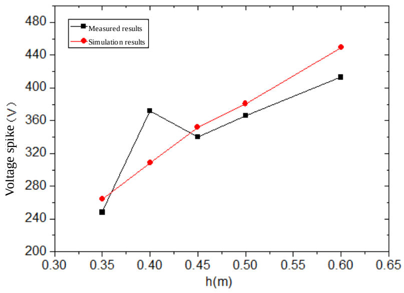


Fig12 the relationship between the voltage spike and the height h

4. CONCLUSION

1) The designs of the simulated experiment of lightning induced overvoltage have greatly difference according to their experimental purposes. Standing in the point of view of power network operation, the goals of this experiment focus on the line tripping rate. So we hope that the initial stage of the induced overvoltage waveform is as real as possible.
2) A rational experimental plan is designed according to our aim. The waveform measured at the stage of the first 60ns in the experiment is relatively real, after what it will be severely distorted.
3) The results of simulated experiment are compared with simulation results, which can confirm the validity of the experiment. Meanwhile, the relationships between induced overvoltage and the distance d & the height h are shown. The simulation and measured results are generally in agreement with each other. The overvoltage peak value increases linearly with the increase of height h, while it also decreases linearly with the increase of distance d.

Acknowledgments

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