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Lightning monitoring method based on distributed traveling wave and lightning location system

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Abstract. In order to improve the accuracy of lightning strike fault location and identification based on the distributed traveling wave monitoring system and lightning location system, the location algorithm and recognition algorithm are improved and integrated. The distributed traveling wave monitoring device is regarded as the lightning detection sub-station, and the calculation results of the lightning location system are corrected to get the accurate lightning flashover tower position. The lightning flashover voltage of the positioning tower is calculated based on the lightning current amplitude and the procedure method. After the lightning fault type is predetermined, the recognition calculation based on waveform feature extraction can be carried out. The actual lightning tripping fault and waveform were used to verify, the results show that the proposed method can effectively improve the accuracy of lightning strike fault location and identification.

1. Introduction

Lightning strikes are the main reason for the trip of transmission lines with voltage levels above 220kV [1]. At present, distributed traveling wave monitoring system and lightning positioning system have been widely applied in China, which can accurately judge whether the cause of circuit trip is lightning flashover, and reduce the positioning range of lightning flashover pole tower to about 2 towers. However, due to the limitations of above methods, the distributed traveling wave monitoring and lightning location system cannot effectively identify the lightning tripping fault type and more accurately locate the lightning flashover tower.

Distributed electric wave monitoring sensors are installed on the transmission line, and the positioning can be obtained by calculating the time difference between arriving at different sensors. In addition, the fault type is identified based on the detected transient traveling wave shape. The lightning positioning system calculate lightning position by measuring the time difference between the transient electromagnetic wave generated at the moment of ground lightning and different detection stations. However, both distributed traveling wave monitoring system and lightning location system have distinct advantages and disadvantages. The distributed traveling wave monitoring system has high positioning accuracy and can obtain the lightning transient electric wave, but it cannot detect the lightning current waveform at the time of ground lightning. The lightning positioning system has a wide positioning range and can calculate the lightning current amplitude inversely. However, due to

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the influence of terrain and other factors in the electromagnetic wave propagation process, the positioning accuracy is lower [2]. Therefore, it is necessary to effectively integrate the advantages of distributed traveling wave monitoring system and lightning location system to improve the accuracy of fault location and identification.

In this paper, a lightning strike fault location and identification method combining distributed traveling wave monitoring and lightning location system is proposed. Through integrating the two methods, the lightning flashover tower is re-concluded. The lightning withstand level of the positioned tower is calculated based on the lightning current amplitude and the procedure method. The existing lightning trip type identification method is improved. Information extraction and waveform analysis are applied in a practical case of lightning tripping fault of different transmission lines. The calculation results show that the proposed method can effectively improve the accuracy of lightning fault location and identification.

2. Formatting the title, authors and affiliations

The positioning calculation model of the distributed traveling wave monitoring system is shown in Figure 1. After the lightning strike transient waveform is detected by the Distributed monitoring units, the position of lightning flashover tower can be obtained by calculating the time difference between the arrival of the monitoring device, as shown in Equations (1) and (2). Where, L is the line length, v is the traveling wave propagation speed, t_1 and t_2 are the time to reach distributed traveling wave monitoring device on both sides respectively, and the transmission tower number can be obtained according to the length of L_1 , L_2 and the tower spacing information.

$$L_{1} = \left[L + (t_{1} - t_{2})v \right] / 2 \tag{1}$$

$$L_2 = \left[L - (t_1 - t_2) v \right] / 2 \tag{2}$$

Because the distributed traveling wave system does not depend on the longitude and latitude coordinates for positioning and calculates by the distance between poles and towers, the positioning accuracy is higher. However, when the lightning flashover tower is far away from the distributed monitoring device or when the single-ended device is located, there are still some positioning errors.



The positioning calculation model of the lightning positioning system is shown in Figure 2. Similarly, according to the calculation method in Equations (1) and (2), the position range of lightning flashover tower can be obtained by calculating the arrival time difference of high-frequency electromagnetic wave generated by multiple detection sub-stations at the time of ground lightning. The specific calculation process is described in Literature [3]. Because each detector station of the lightning flashover occurrence time is very accurate, and the error is within 10ms. However, due to the attenuation of the high frequency component of the electromagnetic wave in the propagation process, and different terrain will affect the electromagnetic wave propagation, there are still some positioning errors. In addition,

considering information security, the positioning error is further increased because the longitude and latitude coordinates of the towers in the system were offset.

In this paper, the positioning calculation process of distributed traveling wave monitoring system and lightning positioning system is integrated, that is, the distributed monitoring device is regarded as the detection sub-station in the lightning positioning system, and the calculation results of the lightning positioning system are corrected to get the accurate lightning flashover tower position. The tower number of the fault point is calculated based on the actual distance between the towers and the time difference between the towers when the traveling wave arrives at different distributed monitoring devices and the lightning positioning system is matched by GPS. The calculation flow chart is shown in Figure 3.



3. Lightning strike identification method fusion

Transient voltage or current signals detected by distributed traveling wave units contain large lightning tripping fault information. Due to the difference in fault mechanism and flashover process between lightning counterattack and lightning tripping on transmission lines, lightning tripping fault types can be identified by extracting characteristic parameters of transient signals [4-6]. However, this method requires large number of transient signals for training, and the recognition accuracy of established model will be lower due to insufficient sample size. There is a certain difference between the lightning tripping transient signal waveform calculated by ATP-EMTP and PSCAD simulation model, which will also affect the recognition accuracy. These methods, which extract signal features and establish classification models, do not consider the physical causes and processes of lightning flashover. Therefore, this paper proposed calculating the lightning flashover voltage of the positioning tower by

using the regulation method, and compared it with the lightning current amplitude detected in the lightning positioning system, which can realize the pre-discrimination of lightning strike faults.

After calculating the lightning trip pole and tower positioning, the tower number can be obtained, and relevant parameters of the tower can be obtained from the Production Management System (PMS), including the type of tower, the height of the tower, the hanging point height of the guide wire, the type of insulator, the distance of the insulator dry arc, etc. According to the existing parameters, the lightning back flashover trip-out protection level I_1 of the tower can be calculated as shown in Equations (3) ~ (7).

$$I_{1} = \frac{U_{50\%}}{(1-k)\beta R_{SU} + \left(\frac{h_{a}}{h_{t}} - k\right)\beta \frac{L_{t}}{2.6} + \left(1 - \frac{h_{gv}}{h_{av}}K_{0}\right)\frac{h_{av}}{2.6}}$$
(3)

$$h_{av} = h_1 - \frac{2}{3} \times f_a \tag{4}$$

$$h_{gv} = h_2 - \frac{2}{3} \times f_g \tag{5}$$

$$L_t = h_t L_{ta} \tag{6}$$

$$k = k_1 K_0 \tag{7}$$

 h_a is the pole arm height of tower, h_t is the tower height, h_1 is the line of wire hanging point height, h_2 is the ground wire line point height, f_a is the conductor sag, f_g is the ground wire sag, K_0 is the geometric coupling coefficient between the conductor and ground wire, L_t is the tower inductance, L_{ta} is the tower inductance for the unit, $U_{50\%}$ is the impulse discharge voltage, β is the tower shunt coefficient, K is the coupling coefficient under the corona, K_1 is the corona correction coefficient when lightning strikes the top of the tower, and R_{SU} is the grounding resistance of the tower. Among them, K_0 , L_{ta} , β and k need to be valued according to different tower types, and $U_{50\%}$ need to be valued according to different insulator types. Specific value requirements are described in detail in Literature [6]. The lightning resistance level I_2 of the tower is calculated as shown in Equation (8). In the formula, Z is the wave impedance, and valued as 100Ω .

$$I_2 = \frac{U_{50\%}}{Z}$$
(8)

Then, the lightning current amplitude at the time of tripping is extracted from the lightning positioning system and compared with the lightning resistance level to prejudge the lightning tripping type. The specific calculation method flow chart is shown in Figure 4.



4. Case validation

At 14:44 on July 29, 2020, a 500kV line was successfully reclosed after a lightning strike and tripped. The positioning results of the lightning positioning system show that the location of the lightning falls is No. 42 or 43 tower. The distributed traveling wave monitoring system is installed at the No. 1 and No. 88 pole and tower of the line, and the wave shape of the detected electrical wave is shown in Figure 5. The starting sampling time of the distributed device of No. 1 and No. 88 pole and tower is 14:29:44.507086816 and 14:29:44.507114067 respectively, and the positioning result is No. 43 tower. Using the method in this paper, the positioning result is No. 44 tower. The lightning discharge channel and flashover trace were searched through on-site UAV shooting and tower climbing, as shown in Figure 6. The lightning flashover tower was determined to be No. 44 tower. The results show that the method presented in this paper can locate the lightning tripping tower more accurately. This is mainly because the positioning correction of distributed traveling wave monitoring system can effectively suppress the calculation error caused by electromagnetic wave propagation.

The methods proposed in Literature [4], [5] and [6] were used to analyse and calculate the wave shape of transient traveling wave and identify the lightning trip type. The collected 124 samples (42 lightning back flashover trip-out samples and 82 lightning shielding failure trip-out samples) of the measured lightning trip transient voltage signal of 500kV transmission line were used to train the identification model of each method. Among them, there were 74 samples in the training set (24 samples of lightning back flashover trip-out and 50 samples of lightning shielding failure trip-out) and 50 samples in the test set (18 samples of lightning back flashover trip-out and 32 samples of lightning shielding failure trip-out). Then, the method in the paper is used for pre-determination before recognition, and the recognition results are shown in Table 1. The results show that the proposed method can effectively improve the identification accuracy of lightning trip type. This is mainly because the lightning resistance level of the positioning tower is calculated based on the lightning current amplitude and the procedure method, and the lightning flashover process is analysed from the physical reasons, which can avoid the identification calculation error caused by the simple waveform feature extraction.

The monitoring results of the lightning location system show that the lightning current amplitude which causes the trip of the line is -70.6kA.According to the relevant book parameters of No. 44 tower in PMS, it can be calculated that the lightning resistance level I_1 of the tower is -22.6kA and the

lightning resistance level I_2 of the tower is -134.7kA.According to the method in Figure 4, it is necessary to carry out feature extraction and pattern recognition for the transient electrical prevailing wave shape measured by the distributed monitoring device, and finally determine the lightning trip type. The three models trained by the method in this paper are used to identify the transient traveling wave shape in Figure 5, and the recognition results are all circling.

By analyzing the discharge trace in Figure 6, it can be judged that the discharge channel is the lightning discharge on the hardware after circling to the B phase (middle phase) jumper, which verifies the accuracy of the lightning strike type identification method proposed in this paper.



Table 1. Identification accuracy of different methods.

Identification method	Before preliminary judgement		After preliminary judgement	
	Lightning back flashover trip-out	Lightning shielding failure trip-out	Lightning back flashover trip-out	Lightning shielding failure trip-out
Method proposed in [4]	83.3%	84.4%	88.9%	87.5%
Method proposed in [5]	88.9%	87.5%	94.4%	93.8%
Method proposed in [6]	88.9%	90.6%	94.4%	93.8%

5. Conclusions

In this paper, a lightning strike fault location and identification method combining distributed traveling wave monitoring and lightning location system is proposed. The distributed traveling wave monitoring device is regarded as the lightning detection sub-station, and the calculation results of the lightning positioning system are corrected, which can suppress the error caused by electromagnetic wave propagation and obtain more accurate lightning flashover pole tower position. The lightning flashover voltage of the positioning tower is calculated based on the lightning current amplitude and the procedure method, and the lightning fault type is predetermined, which can effectively improve the recognition accuracy of lightning trip type. Further fusion methods will be explored in the future to improve the recognition accuracy of lightning trip type.

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