Mechanism Analysis and Experimental Study on Tree Faults in Transmission Lines

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Abstract. It is difficult to reclose transmission line successfully after tree fault occurs, which is easy to cause line outage. At present, most of the existing research focuses on the diagnosis and disposal of tree faults, while the mechanism of tree faults is relatively rare. Firstly, the formation process of tree faults and the typical discharge characteristics at different tree height stages are analyzed. Then, the process of tree-wire gap discharge at different stages is simulated in laboratory environment. With trees approaching transmission lines, corona discharge, hidden discharge and flashover discharge occur in turn, and the discharge increases from weak to strong, and the amplitude increases, while the frequency of discharge waveform tends to decrease.

1. Introduction

With the increasing scale of power grid construction, the number of UHV transmission lines is increasing, and various hidden dangers are constantly affecting the safe and stable operation of transmission lines[1-3]. Ground fault tripping of transmission lines caused by tree flashover is called tree fault. The main reason for tree fault is that trees grow too fast and too high, and some trees even exceed the height of overhead transmission line towers[4-5]. When the distance between the tree and the wire is close enough, the wire discharges to the tree, resulting in line fault tripping.

At home and abroad, some research on tree fault has been carried out and some progress has been made. In paper [6], the height of trees is obtained based on the mathematical model independently developed by statistics, and the grade is automatically recognized and divided. In paper [7]-[9], an online monitoring and alarming device based on ultrasonic technology and wireless network technology for ultra-high tree fault in transmission line corridor is designed.

At present, most of the existing research focuses on the diagnosis and disposal of tree faults, while the mechanism of tree faults is relatively rare[10]. Firstly, the formation process of tree faults and the typical discharge characteristics at different tree height stages are analyzed. Then, the process of tree-wire gap discharge at different stages is simulated in laboratory environment. Based on the analysis of waveform and spectrum characteristics, the characteristics and rules of tree discharge in different stages are given, and the formation mechanism of tree fault in transmission line is further elaborated.
2. Formation process of tree fault
As the trees grow taller and taller, the top of the trees keeps close to the transmission line, which makes the distance between the trees and the wires gradually decrease. At a certain critical distance, a complete flashover occurs, resulting in tripping fault[11].

![Figure 1. Sketch map of the development trend of tree discharge](image)

As the distance between the tree and the conductor decreases, the field intensity at the top of the tree increases gradually. According to the paper[2], corona discharge occurs when the field intensity at the top of the tree reaches 20-30 kV/cm, and more intense discharge occurs when the field intensity is further increased until the gap is completely broken down. The formation of tree faults is not instantaneous. When the top discharges, high frequency discharge current will enter the wire through the coupling capacitance between the tree and the wire, and propagate along the wire to both sides, that is, current traveling wave. In this paper, the discharge between interventional corona discharge and flashover discharge is called hidden discharge.

3. Tree discharge test
3.1. Test system
In order to study the fault discharge process of trees, this paper carried out different types of tree discharge tests. The test system mainly includes power frequency test transformers, composite insulators, wires, insulated ropes, high-frequency current sensors, and connecting wires and fittings.

The test equipment is arranged as shown in Figure 2. The analog wires are connected to the insulator and suspended under the cross arm. The cross arm is suspended from the crane by an insulated rope. Through the remote control of the crane, the suspension height of the crossbar can be changed arbitrarily, and the clearance distance between the tree and the wire can be changed.

In the test, the distance between any high voltage live component and any ground potential component is not less than 0.5 m per 100 kV test voltage, and in any case not less than 1.5 m.

![Figure 2. Experiment arrangement diagram of discharge of tree-wire gap](image)

1-voltage regulator; 2-transformer; 3-resistor; 4-voltage divider; 5-crane; 6-rope; 7-insulator; 8-wire; 9-tree; 10-oscilloscope; 11-current sensor; 12-insulation board; 13-metal plate; 14-current monitoring device

In Figure 2, the tree is placed on an insulating board and connected to the ground electrode by a grounding wire. When a discharge occurs between the tree and the wire, the discharge current will enter the ground along the tree body and through the grounding wire. In order to accurately measure the characteristics of discharge current, a high frequency current sensor is installed on the grounding line between tree and grounding electrode. The sensor is a Roche coil. Its measuring range is 5mA~15A, and the cut-off frequency of -3dB is 20Hz~60MHz, which meets the requirements of high frequency discharge current measurement. High frequency current monitoring device is used to...
monitor corona and hidden discharge current in test circuit. Its measuring range is 1mA~5A, and the cut-off frequency of -3dB is 50Hz~100MHz. It mainly includes power supply unit, sensor unit, GPS unit, 4G communication unit, acquisition and processing unit, etc. Its working principle is referred to in the paper[6].

The rated output voltage of the test transformer is 250 kV, the short circuit current is 6A, and the total capacity is 1500 kVA. The output voltage of the test transformer is connected to a standard capacitive voltage divider with a conversion ratio of 10000:1, and then connected to an oscilloscope for measurement.

3.2. Phenomenon of discharge
Because of the high applied voltage, corona discharge is unavoidable in the test circuit. The corona discharge is usually a high frequency signal. This discharge also produces discharge current, which is easily confused with the high frequency current generated by tree discharge. Therefore, the waveform characteristics of corona discharge need to be analyzed. The experiment includes corona discharge test and tree discharge test at different stages.

No trees are placed, voltage equalizer is installed at both ends of the wire and high voltage end of the composite insulator. The corona discharge waveforms were measured by monitoring terminals. The experimental phenomena were observed and the corona discharge waveforms were measured. The higher the voltage is, the more obvious the discharge is. When the voltage reaches 120 kV, a fine brush arc can be observed on the equalizing ring.

The field of the gap between trees and wires is similar to that extremely uneven field. Within a certain gap distance range, the breakdown voltage of extremely uneven field is approximately linear with the gap distance. The average breakdown field strength is 4 kV/cm, so the critical breakdown distance between trees and wires at 110 kV voltage level is about $\frac{110}{\sqrt{3}} \div 4=15.9$ cm. In order to simulate the process of 110 kV voltage grade discharging from hidden discharge of trees to flashover, the gap between trees and wires should not be less than 15.9 cm. The distance between trees and wires is adjusted to about 25 cm, and the voltage is gradually increased, which makes the field strength between trees and wires increase, and simulates the process of natural trees approaching wires gradually.

When the voltage is less than 60 kV, no obvious discharge is observed. When the voltage continues to rise to 60-80 kV, the discharging arc appears on the top of the tree. Bright discharging spots can be seen in the dark, as shown in Figure 4. When the voltage reaches about 95-105 kV, the arc at the top of the tree spreads to the wire and forms a stable arc quickly. After a short period of time, the transformer protects and the arc disappears, as shown in Figure 3.
4. Analysis of discharge waveform characteristics

In this paper, the transmission characteristics of traveling waves are quantitatively analyzed by Discrete Fourier transform[12]. It is assumed that the traveling wave sampling rate is $f_s$, the length is $N$, and the traveling wave waveform sequence is $x[n]$, where $n=0, 1...N-1$. Discrete Fourier transform is performed on $x[n]$, and then a complex sequence $X[k]$ is obtained, where $k=0, 1...N-1$. According to the properties of the discrete Fourier transform, $X[k]$ corresponds to the component of the original signal with a frequency of $k*2\pi f_s/N$ ($1\leq k< N/2$), and the mode value is $N/2$ of the same frequency component of the original signal. Define as follows:

$$
\begin{align*}
P(i) &= |A(i)|^2 \\
f(k) &= k \times f_s / N \\
|A(k)| &= 2|X[k]| / N
\end{align*}
$$

In formula (1), $P(i)$ is the power of components of the original traveling wave which frequency is $i*2\pi f_s/N$. According to the formula (1), the power spectrum of traveling wave is analyzed.

Define the power spectrum distribution function:

$$
F(j) = \frac{\sum_{i=0}^{\lfloor N/2 \rfloor} P(i)}{\sum_{i=0}^{\lfloor N/2 \rfloor} P(i)}
$$

In the formula, $\sum_{i=0}^{\lfloor N/2 \rfloor} P(i)$ is the sum of the power spectrum distribution of the original waveform signal and $\sum_{i=0}^{\lfloor N/2 \rfloor} P(i)$ is the sum of the power spectrum components whose frequencies are between 0 and $j*2\pi f_s/N$.

Typical waveforms of corona discharge, hidden discharge and flashover discharge are selected and analyzed. The results are shown in Figure 4-6.
Waveform amplitude, pulse width and frequency distribution are important indicators of waveform characteristics. For corona discharge, the magnitude of corona increases with increasing applied voltage. When the applied voltage of the circuit reaches 120 kV, the maximum corona amplitude can reach 25 mA. For the tree-wire gap of about 25 cm, when the applied voltage reaches 60-80 kV, a more significant hidden discharge occurs. The amplitude of hidden discharge pulse is between 150 and 400 mA, which is much higher than that of corona discharge. When the gap is completely broken down by further increasing the voltage, a stronger flashover discharge occurs, and the discharge pulse amplitude can reach 300 mA~2 A. Corona discharge, hidden discharge and flashover discharge have significant differences not only in amplitude, but also in power spectrum distribution. Comparing with Figure 4-6, we can see that the power spectrum of corona discharge waveform is distributed in the range of 0~2 MHz, the tree discharge waveform is mainly concentrated in the range of 0~600 kHz, and the frequency components of flashover discharge are mostly in the range of 0~200 kHz. According to formula (2), the energy spectrum of corona discharge, potential discharge and flashover discharge waveforms at 0-100 kHz accounted for 8.6%, 45.8% and 86.6% respectively.
5. Conclusion
In this paper, the formation mechanism of tree faults is analyzed, and the formation process of tree faults is simulated through experiments. The discharge waveforms at different discharge stages are monitored. The characteristics and frequency distribution of series of waveforms are analyzed comprehensively. The following basic points are obtained:

1) With the growth of trees, when the height of trees reaches a certain value, corona discharges begin to form at the top of trees. If the clearance distance between trees and wires further decreases, the corona discharges develop into stronger hidden discharges and form more obvious arcs. If the trees grow taller, flashes may occur.

2) From the waveforms generated in different stages of discharge process, the corona discharge waveform has the lowest amplitude, but the highest frequency, and the highest amplitude at flashover time, but the lowest frequency, while the discharges generated by hidden dangerous discharge are between the two.

Monitoring traveling wave of hidden discharge and using traveling wave positioning theory can theoretically realize tree fault monitoring and warning, and related research needs to be further deepened.

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