Research on Three Phase Signal Separation Method and Device for Live Detection of Circuit Breaker Contact Ablation Degree

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Abstract. A three-phase identification method and device for live detection of arc extinguishing performance of circuit breaker are proposed. In this paper, a sensor with three antennas is used to detect the electromagnetic wave radiated by the circuit breaker, and the three-phase identification is realized by controlling the receiving angle of the antenna and comparing the amplitude of the received electromagnetic wave. The method proposed in this paper has the technical advantages of simple implementation and low cost of detection device, and can realize the three-phase identification of live detection of circuit breaker arc extinguishing performance.

1. Introduction
The safe operation of high voltage transmission and transformation equipment has become an important factor affecting the safe, stable and economic operation of power system. The number of high-voltage switches in the power grid is huge, which plays the role of control and protection. When it breaks down, it will directly cause the power grid accident or further expand the accident, causing considerable economic and social losses. [1-3]How to effectively detect the working state of the high-voltage switch, find the early defects of the switch in time, deal with the defective parts in advance, and prevent the switch explosion and other malignant accidents, is of great significance to ensure the safe and reliable operation of the power grid.

Circuit breaker is responsible for the dual functions of control and protection in the power system, and plays a vital role in the safe operation of the power system. Arc extinguishing performance is the most important performance of circuit breaker. The electromagnetic wave radiated by the interrupter during the opening process of the circuit breaker can be used to evaluate its arc extinguishing performance. The ablation degree of circuit breaker contact is one of the decisive factors of circuit breaker life.[4-6] The electromagnetic wave signal radiated during the breaking process of the circuit breaker can reflect the ablation degree of the contact. When the contact of the circuit breaker is seriously ablated, the electromagnetic wave signal radiated will be distorted. When the circuit breaker breaks, each phase radiates an electromagnetic wave signal. When an electromagnetic wave signal is distorted, it can be judged that the circuit breaker has serious contact ablation.

There are a large number of circuit breakers in the power grid, and the lack of effective detection and evaluation means of contact ablation degree has become one of the major hidden dangers in the safe operation of power grid. The traditional detection method of contact ablation degree is electrical life
method, which determines the change of contact ablation degree of circuit breaker by weighted calculation of breaking times and breaking current.[7-8] This method can only reflect the gradual deterioration of contact ablation degree of high voltage reactive power switching switch, but can not reflect the sudden or abnormal deterioration of contact ablation degree. The switch of circuit breaker radiates radio frequency electromagnetic wave signal in the process of opening and closing, which contains abundant information reflecting the degree of contact ablation.[9-10]

When the circuit breaker is abnormal, it is necessary to identify the phase of the abnormal signal to determine the maintenance object. The method of determining the phase after dismantling the interrupter of the circuit breaker brings great inconvenience to the maintenance work.[11] The current three-phase identification methods mainly rely on the time difference of electromagnetic wave signal arriving at each antenna. The principle of the method is simple, but because of the close distance between phases of the circuit breaker, a very high sampling frequency is needed to effectively read the time difference. Because the opening process is usually in milliseconds, it requires high performance of data acquisition system.[12] This makes the cost of the detection device is very high, the time of data processing is long, and the detection efficiency is low, which is not conducive to the development of field work. In view of the above problems, this paper proposes to use the sensor with three antennas to detect the electromagnetic wave radiated by the circuit breaker. By controlling the receiving angle of the antenna and comparing the amplitude of the received electromagnetic wave, the three-phase identification can be realized without comparing the time difference of the electromagnetic wave signal, which can greatly reduce the cost of the detection device and improve the detection efficiency.

2. Principle of electromagnetic wave signal in circuit breaker

When the circuit breaker operates, the electric arc generated by contact breakdown will generate electromagnetic wave signal with frequency of several GHz in space, which can reflect the arc extinguishing performance of the circuit breaker. After a long time of breaking, the contact surface of the circuit breaker will be ablated, and the electromagnetic wave signal will also change when the arc extinguishing performance is reduced. Due to assembly, wear and other reasons, the metal particles produced in the arc extinguishing chamber will also affect the electromagnetic wave signal waveform. In addition, the breaking speed, voltage level and load type of the circuit breaker contact may affect the radiated electromagnetic wave signal. In view of the above factors, the laboratory simulation experiment is carried out to study the influence of the radiation signal on the circuit breaker opening and closing process, and to provide materials for the evaluation of circuit breaker arc extinguishing characteristics based on the radiation electromagnetic wave signal.

When the circuit breaker switches, the switching arc between the contacts will generate high frequency electromagnetic waves.

When the breaker is closed, the distance between the moving and static contacts decreases gradually. When the resistance of SF6 medium between contacts is lower than the voltage between the contacts, the dynamic and static contacts will break down and then generate arc. At the moment of breakdown, the current between the dynamic and static contacts increases rapidly, and a sudden magnetic field is generated in space. The magnetic field then excites a sudden electric field, which then excites a sudden magnetic field, and circulates repeatedly, and then generates an electromagnetic wave signal in space. After breakdown, the arc between the dynamic and static contacts is a good conductor. The current change in the arc is close to the power frequency current, and it will be extinguished at the zero crossing point naturally, and the high frequency electromagnetic wave signal will not be excited again. Therefore, when the high voltage development is closed, only one RF signal will be excited, and the electromagnetic wave signal will not be excited during the subsequent arc combustion.

When the circuit breaker is opened, when the moving and static contacts are just separated, the resistance of SF6 medium between the contacts is lower than the voltage between the moving and static contacts, the moving and static contacts will break down immediately, and then generate an arc, and then excite an electromagnetic wave signal. After the breakdown, the current change in the arc is close to the power frequency current, the distance between the moving and stationary contacts increases...
gradually, and it goes out naturally at the zero crossing point, and the high frequency electromagnetic wave signal will not be excited again. Therefore, when the switch is opened, the RF signal will only be excited once, and the electromagnetic wave signal will not be excited during the subsequent arc combustion.

However, when the switch performance decreases, due to the increased ablation of the contact surface, multiple spikes will be formed, and then multiple extremely uneven electric field areas will be formed. When the breakdown occurs between the moving and static contacts, these extremely uneven electric field areas will be broken down successively, and multiple electromagnetic wave signals will be excited.

3. Three phase signal separation device for double antenna live detection
The working principle of the three-phase signal separation device with double antennas for live detection is that when the circuit breaker is opened, the switch arc will be generated, and then the RF electromagnetic wave will be excited to spread around, and multiple antennas around the circuit breaker will receive the RF electromagnetic wave signal. Because the distance between each contact of the circuit breaker and each antenna is different, the three-phase signal can be separated by calculating the time difference between the electromagnetic wave signal and each antenna.

Firstly, two antennas are arranged around the circuit breaker to receive the electromagnetic wave signal generated by the switch arc when the circuit breaker is opened. Secondly, the time difference of the electromagnetic wave signal received by the antenna is calculated. Finally, the corresponding phase of each electromagnetic wave signal is determined by calculating the time difference of the electromagnetic wave signal to realize the separation of three-phase signals.

![Fig. 1. Module diagram of three phase signal separation device.](image)

The advantage of this method is that two antennas are used to receive the electromagnetic wave signal generated when the circuit breaker is opened at the same time, and the three-phase signal is separated by calculating the time difference of the electromagnetic wave signal. The detection can be completed to determine the defects, without the subsequent dismantling of the circuit breaker interrupter one by one, which can be targeted for maintenance, greatly improving the efficiency of detection and maintenance. The device module diagram based on this method is shown in Figure 1, including antenna, signal acquisition and processor.

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due to the close distance between each phase of the circuit breaker, it needs a very high sampling frequency to effectively read the time difference. Because the opening process is usually millisecond level, it requires high performance of the data acquisition system. This makes the cost of the detection device very high, the time of data processing is long, and the detection efficiency is low, which is not conducive to the development of field work.

4. Three phase signal separation device for live detection of three antennas

In order to solve the problems of high cost and long data processing time of three-phase signal separation device with dual antenna live detection, this paper proposes a three-phase identification device for live detection of arc extinguishing performance of three antenna circuit breaker.

The working principle of the device is to use the sensor with three antennas to detect the electromagnetic wave radiated by the circuit breaker, and realize three-phase identification by controlling the receiving angle of the antenna and comparing the amplitude of the received electromagnetic wave. Firstly, three antennas with the same performance are used to form sensors to receive electromagnetic waves. The central receiving directions of antenna 1 and antenna 3 are arranged on both sides of antenna 2. Then, the receiving direction of the antenna 2 center of the sensor is aligned with phase B of the circuit breaker to be detected. When the circuit breaker is opened, the sensor is used to receive the electromagnetic wave signal, and the amplitude of the received electromagnetic wave is compared to realize three-phase identification.

See Figure 2 for the layout diagram of sensors implemented on site. The sensor is composed of three antennas with the same performance, which are respectively used to receive electromagnetic waves. The central receiving directions of antenna 1 and antenna 3 are arranged on both sides of antenna 2. Align the receiving direction of antenna 2 center of the sensor with phase B of the detected circuit breaker.

The central receiving direction of antenna 1 and antenna 3 is 45 degrees to the central receiving direction of antenna 2, and they are arranged on both sides of antenna 2. The receiving performance of antenna 1, antenna 2 and antenna 3 shall be consistent, and the receiving direction angle shall not be less than 160 degrees.
Fig. 3. Schematic diagram of three phase signal identification method.

The schematic diagram of three-phase signal identification method based on this method is shown in Figure 3. When a phase opening signal radiates electromagnetic wave, because the central direction of antenna 1 is closest to phase a, the amplitude of received signal is the largest, the central direction of antenna 3 is farthest from phase a, the amplitude of received signal is the smallest, and the amplitude of received signal of antenna 2 is in the middle; Similarly, when the signal of c-phase switch radiates electromagnetic wave, because the central direction of antenna 3 is closest to phase B, the amplitude of received signal is the largest, the central direction of antenna 3 is farthest from phase C, the amplitude of received signal is the smallest, and the amplitude of received signal of antenna 2 is in the middle; When the B-phase opening signal radiates electromagnetic wave, the amplitude of the received signal is the largest because the central direction of antenna 2 is closest to phase a, and the central direction of antenna 1 and antenna 3 is far from phase B, so the amplitude of the received signal is basically the same and less than that of the received signal of antenna 2.

Through the above description, the technical effect of the method and device proposed in this paper is to use the sensor with three antennas to detect the electromagnetic wave radiated by the circuit breaker. By controlling the receiving angle of the antenna and comparing the amplitude of the received electromagnetic wave, the three-phase identification is realized. There is no need to compare the time difference of the electromagnetic wave signal, which can greatly reduce the cost of the detection device and improve the detection efficiency.

Moreover, the equipment is easy to operate, small size, suitable for use in substation, accurate measurement results, and suitable for maintenance and detection.

5. Conclusion
At present, many serious safety accidents have occurred in the power system, which are caused by the contact ablation of high-voltage reactive power switching switch, and the breaking times are far lower than the rated times, so the existing detection methods can not detect this type of defects. Therefore, the method proposed in this paper is of great practical significance to solve such problems.

The electromagnetic wave radiated by the circuit breaker is detected by using the sensor with three antennas. By controlling the antenna receiving angle, the amplitude of the received electromagnetic wave is compared to realize three-phase identification. Without comparing the time difference of the
electromagnetic wave signal, the cost of the detection device can be greatly reduced and the detection efficiency can be improved.

Acknowledgments
Here, I would like to express my thanks to the leaders of State Grid Tonghua Power Supply Company for their support to our scientific research work. At the same time, thanks to all the members of our team.

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