Research status of partial discharge detection of power transformer based on pulse current method

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Abstract—There are many important equipment running in the power grid, and the power transformer is one of them. It plays an extremely important role in the stable operation of the power system. Therefore, whether the power transformer can operate safely and stably becomes particularly important. When the power transformer is running online, partial discharge will occur if there are insulation defects, which will further develop into breakdown without timely detection and treatment. The insulation inside the transformer often has certain defects and produces certain partial discharge, and the partial discharge signal is often a high-frequency pulse signal. In this paper, the definition of partial discharge, the generation process of pulse current and the detection method of transformer partial discharge based on pulse current method will be introduced in detail. Several common methods are combed and summarized, the current development status of pulse current method is introduced, and the possible research direction in the future is prospected.

1. Introduction
These faults often exist when electrical equipment is running: conductor fault, insulation fault and mechanical fault. In practice, insulation is the fault that accounts for the largest proportion of all faults, so it is the most common. In recent years, the AC voltage level of power grid equipment has been continuously improved, and the power system is also constantly improving the measures to limit overvoltage. In this case, the electrical equipment will be directly affected by the higher working voltage, and the probability of insulation circuit fault will increase accordingly. Insulation failure is often accompanied by partial discharge, which further promotes the aging of insulation and finally develops into breakdown [1-3].

At the Gottingen Royal Society meeting in 1777, Lichtenberg showed the world his new progress in partial discharge test. In 1873, Maxwell deduced four equations describing electromagnetic field. In 1896, the basic hypothesis of the existence of electromagnetic wave and its propagation characteristics in space and time was verified by Hertz's experimental results for the first time, which provided a new theoretical and experimental basis for the detection of a large number of local discharge and the research and development of instruments and equipment [5]. Xilin bridge was first proposed in 1919. This research method has laid a solid foundation for the integral bridge technology developed by Dakin and Malinaric in 1960. It can be clearly considered that the partial discharge integral measurement method used on two parallelogram is the original ancestor of modern partial discharge detection technology using integral bridge. Up to now, the integral bridge method is still widely used in many experiments to measure partial discharge [4-5].
At present, the insulation fault of power equipment has attracted great attention at home and abroad. It is committed to looking for the partial discharge and its related characteristics that develop rapidly and seriously threaten the insulation of transformer. Canada, Japan and other countries first studied the occurrence of partial discharge in the operation of power equipment, and put the developed detection system into online operation. The occurrence of partial discharge in transformers has attracted the attention of power operation departments and major power equipment manufacturers in the 1950s. Since the 1960s, many scientific research institutions have begun to study the partial discharge characteristics of transformers. Up to now, the detection methods of transformer partial discharge can be roughly divided into two main categories: using the electrical physical quantity of transformer for measurement and using non-electrical physical quantity for measurement. The pulse current measurement method belongs to the method of using electrical quantity for measurement. Pulse current method has mature technology and wide application. At present, the relevant standard (IEC-270) formulated by IEC (International Electrotechnical Commission) is widely used to detect partial discharge by pulse current method [6-7].

This paper is divided into three parts. The first section summarizes the definition, causes and process of partial discharge in power transformer; The second section summarizes the partial discharge detection methods of transformer based on pulse current, and the third section looks forward to the possible research directions in the future.

2. Generation mechanism of partial discharge and pulse current

When the power transformer is running online, partial discharge will occur if there are insulation defects, which will further develop into breakdown without timely detection and treatment. Therefore, it is of great significance to deeply study the relevant theories of partial discharge in transformer and explore various parameter characteristics when partial discharge occurs for the application of pulse current method to identify and protect the internal discharge defects of transformer [8].

2.1. Definition and causes of partial discharge

Partial pulse discharge is usually a kind of pulse discharge between two local electrodes that have not been filled with insulating gas medium and have not completely formed conductive communication. A partial pulse discharge of the equipment is generally considered to be caused by the partial concentration of the electric field in an insulator or on the surface of other insulating media, resulting in short-term partial discharge, that is, it is caused by some defects that may be caused by some equipment in the actual production and use process or some weaknesses of the insulating media in the equipment. When a partial pulse discharge occurs in the equipment, it will directly produce a pulse discharge with a duration of usually less than 1μm, often accompanied by mutual reactions such as light, heat, sound and chemistry. In case of partial discharge, the energy released is very small, so the damage to the equipment can be ignored. However, if there is partial discharge in electrical equipment for a long time, the weak effect caused by partial discharge will gradually accumulate and eventually develop into insulation breakdown [9].

When partial discharge occurs in the insulation of power transformer, in addition to pulse current due to uneven distribution of insulation electric field, heating and luminescence of gas in corresponding dielectric, high-frequency ultrasound and decomposition of insulating grease may also occur, resulting in changes in the composition of insulating gas [10-11].

2.2. Generation process of pulse current

There is an air gap in the insulation medium of transformer winding due to insulation defects, the equivalent circuit of the whole system is the capacitance \( C_g \) of the air gap and capacitance \( C_a \) of the part of the medium connected in series with the air gap in series, and then with the dielectric capacitance \( C_d \) of the other intact parts in parallel. As shown in Fig.1, the total capacitance of the whole system is
\[ C = C_a + \frac{C_b C_g}{C_b + C_g} \]  

(1)

Under the action of power supply voltage
\[ u = U_m \sin(\omega t) \]  

(2)

The voltage on \( C_g \) is
\[ u_g = \frac{C_b}{C_b + C_g} U_m \sin(\omega t) \]  

(3)

When air gap capacitance \( C_g \) voltage at both ends reach discharge voltage \( u_s \), partial spark discharge will occur in the air gap \( C_g \) along circuit\( C_g \to C_a \to C_b \to C_g \) discharge when \( u_g \) drop to extinction voltage \( u_r \), the spark is extinguished, a partial discharge is completed, and a high-frequency partial discharge pulse current is generated in the circuit [12].

![Fig.1. Pulse current equivalent circuit.](image)

3. Partial discharge detection method of transformer based on pulse current

The pulse current method explores the situation of partial discharge by detecting the megahertz pulse current generated when partial discharge occurs. In the actual detection test, the pulse current method is to detect the amplitude and frequency of pulse current and discharge amount when partial discharge occurs in power transformer winding and other transformer structures [13]. The experiment analyzes and discriminates the collected information by detecting the propagation characteristics of pulse signal in the winding and the high-frequency pulse response of the winding, and cuts off the fault in time [14-15]. This method is sensitive and easy to operate. However, in the pulse current amplification detection circuit, the impedance of the current amplification circuit and the measurement circuit has a bad impact on the measurement of pulse current data, and the detection accuracy of the measurement instrument is reduced [16-23]. In recent years, with the increasing maturity of relevant detection theory and the continuous improvement of relevant measurement technology test quantization methods, the basic measurement methods and relevant measurement test quantization methods of partial AC discharge in transformer circuit have a more solid theoretical foundation [24]. At present, there are two types of transformer detection methods: on-line and off-line. The advantages of on-line detection are: it can detect the local discharge signal in real time. The disadvantages are: the equipment is complex, and it is easy to affect the normal operation of the power grid, the detection accuracy is low, it is easy to be disturbed by various signals, resulting in misjudgment and high investment cost. The advantages of off-line detection are: simple equipment, high measurement accuracy, low interference and low investment cost. The disadvantages are: the pulse signal of local discharge can not be detected in time and corresponding protective measures can be taken. The time interval between two tests is long. Some insulation defects can not be found immediately, resulting in further deterioration of the defects. The pulse current detection circuit is shown in Fig.2.
3.1. UHF detection method

UHF detection method is an off-line detection method. Through the real-time collection of various characteristics and variable information of pulse current, and the real-time analysis and judgment of the real-time collected pulse data information. We can obtain the partial discharge information and determine the fault point. This detection method usually collects the partial discharge signal on the grounding wire of the end screen of the power transformer bushing, the grounding wire of the iron core or the grounding wire of the winding neutral point by using the high-frequency detection instrument composed of the high-frequency detection CT connected by the high-frequency detection discharge impedance and the Roche detection coil. After completing the calibration, measure the apparent discharge, determine the fault position of the partial discharge, and take corresponding protective measures according to the specific situation.

At present, the computer-aided automatic test system is widely used in the practical work of transformer partial discharge detection in power grid. Reference [25] points out that this computer-aided measurement system is widely used in various UHF signal detection experiments. Firstly, various forms of partial discharge signals measured in the laboratory are successively amplified and filtered to complete various real or A/D signal conversion, digitize the signal, send the measured data to the computer processing system in turn, and process the high-frequency signal data to produce various statistical spectrum diagrams and ray diagrams, which can be used to analyze various forms of partial discharge. However, in the high-frequency circuit, the impedance of transformer winding is very large, and the pulse signal attenuates rapidly in the propagation process, which is very unfavorable to the measurement of pulse signal, and the difficulty of UHF detection increases greatly.

Reference [26] proposed an on-line detection and control system for partial discharge. It uses the broadband oscilloscope in the detection circuit of partial discharge pulse current to process the data of partial discharge. In addition, reference [27] also proposes a partial discharge detector composed of a high-frequency CT designed by Roche coil and a spectral frequency analyzer with high-frequency amplifier which can detect transformer partial discharge signals in different frequency bands of 100kHz-200MHz. It mainly places the high-frequency CT made of Roche discharge coil on the transformer bushing, so as to detect the partial discharge signals of the primary and secondary windings of the whole transformer.

3.2. Differential balance method

In the complex electromagnetic environment, the pulse current generated by partial discharge of power transformer is easily affected by electromagnetic interference, so it becomes very difficult to obtain useful information. In the whole online detection system, eliminating external electromagnetic interference has always been a difficult problem [28-32]. The experimental schematic diagram and the comparison between output and original waveform are shown in Fig. 3 and Fig. 4 respectively.
Differential balance method is an on-line detection method. Its working principle is to use high-frequency CT to detect current signals from high-voltage lead, winding neutral point grounding wire and bushing end screen grounding wire respectively. When electromagnetic interference enters a phase, high-frequency pulses in the opposite direction will be formed on the end screen grounding wire and high-voltage lead, The partial discharge signal of this phase winding forms a high-frequency pulse in the same direction on the end screen grounding wire and the high-voltage lead. Using the characteristics of this interference signal and partial discharge signal, the signal extracted by high-frequency CT can be input into the common mode differential circuit, which greatly weakens the external interference signal, enhances the internal partial discharge signal, well suppresses the common mode interference, improves the signal-to-noise ratio of the detection signal, and lays a foundation for further determining the fault location and taking corresponding protection measures.

Based on the above principle, reference [31] developed a direct ion sensor for on-line monitoring of transformer partial discharge. Based on the analysis of the relationship between sensor damping resistance and coil turns and sensitivity and frequency characteristics, reference [31] studies the sensor transmission characteristics based on closed-loop and open-loop forms, and then tests the anti-interference characteristics by using the differential balance method. The test shows that this method can effectively suppress external interference and help to identify internal partial discharge signals.

3.3. Pulse polarity identification method

Pulse polarity identification method is usually used in off-line detection experiments. Its working principle is that when there is insulation defect in the transformer, partial discharge will occur between two electrodes with insulation defect with the increase of test voltage level. The partial discharge signal will be transmitted to each outgoing terminal, and the signal detected by each detection terminal will have a certain polarity. Use these characteristics to locate the fault point [33-34]. The experimental schematic diagram and the waveform characteristics of pulse signals at the output and each outlet are shown in Fig. 5 and Fig. 6 respectively.
Reference [34] attempts to apply the pulse polarity discrimination method to the on-line detection of transformer partial discharge. It installs high-frequency CT at the base flange of transformer high-voltage outlet bushing to collect the partial discharge signal of high-voltage outlet. Considering that the sensitivity of the series circuit is greater than that of the parallel circuit and has a good filtering effect on the low-frequency signal, the filter capacitor and acquisition resistance are connected in series at both ends of the magnetic core high-frequency CT coil. The enclosed CT shell is made of metal, which can effectively shield external interference and collect high-voltage lead and casing end screen partial discharge signals. It can also prevent the influence of rain and dust on the sensor and improve the vibration resistance of the coil. Partial discharge and external electromagnetic interference are identified by collecting and comparing the polarity of pulses collected by two high-frequency CT.

3.4 Multi terminal adjustment method
References [35] and [36] mentioned a partial discharge signal detection and control method using multi terminal signal regulation. It can be used to effectively suppress high-frequency interference. Similar to the differential balance method, the control method is extracted from the four points of high-voltage bushing and its end screen grounding wire, transformer core and winding neutral grounding wire. The external interference is suppressed through the common mode differential circuit, and then the multi terminal operation adjustment method can be used to make the circuit effectively suppress various interphase interference signals. It includes suppressing the interphase interference of adjacent two phases and the interference of adjacent two windings of this phase. The multi terminal operation adjustment method has strong anti-interference ability in the experiment.

4. Conclusion
The improvement of voltage level and the continuous expansion of Wang have brought more requirements and challenges to the normal operation of power transformer, and the transformer
insulation fault, which accounts for a high proportion in many fault types of transformer, has high research value. Through the study of transformer partial discharge based on pulse current method, it is of great significance to distinguish and protect the defects of transformer internal insulation.

This paper summarizes the definition of partial discharge in power transformer, the formation mechanism of pulse current and various protection and discrimination methods based on pulse current method. The following are some personal prospects for the possible research directions of partial discharge discrimination and protection in power system in the future.

1) Further strengthen the research on internal partial discharge of power transformer, summarize the relationship between insulation aging of transformer winding and various types of partial discharge, and further work is needed on how to improve the detection accuracy of pulse signal generated by partial discharge;

2) In the research on the detection method of partial discharge of transformer, although some achievements have been made in eliminating electromagnetic interference, the external electromagnetic interference is very large in the actual on-line operation, and further research is needed on how to identify and suppress the interference more accurately;

3) The high-frequency impedance of transformer winding is large and the partial discharge signal attenuates rapidly. How to improve the partial discharge detection circuit so that the high-frequency pulse can be well coupled to the detection impedance still needs further research.

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