Research on Winding Deformation Detection and Diagnosis Technology of Power Transformer

Wei Lu, Jun Ma, Bo Ma
Wolong Electric Yinchuan Transformer Co., China, 750004

Abstract: With the continuous increase of power grid capacity, transformer damage accidents caused by short-circuit faults are on the rise. Timely and effective measurement of transformer winding deformation can effectively prevent further deterioration of transformer deformation and ensure that transformer does not occur accidents. This paper summarizes the methods, principles, influencing factors and judging criteria of winding deformation detection, and summarizes the important research results in the field of transformer winding deformation in recent years. Finally, this paper compares different detection methods from the aspects of detection methods, influencing factors of test results, detection information, detection sensitivity, deformation judgment methods and detection standards.

1. Introduction
In recent years, China's power industry has developed very fast. With the increasing capacity of power grid, the establishment of UHV and UHV power systems, and the coming formation of complex systems such as large capacity, large area interconnection and power transmission from west to east, higher requirements are put forward for the safe operation of power systems and power supply reliability. Power transformer is one of the key equipment in transmission network. With the increase of power consumption and the rapid development of China's power industry, the voltage level and capacity of a single transformer are getting larger and larger. With the in-depth development of power energy Internet and the promotion of power substitution in more fields, the dependence of human civilization on power will only increase. Less blackouts or no blackouts to improve the reliability of power supply is of great significance to improve customer experience and ensure the sustainable and stable operation of the current industrial system, and will have a far-reaching impact on the development of the power market.

2. Detection and diagnosis method of winding deformation of power transformer

2.1 Low voltage short circuit impedance method
For large power transformers, the proportion of resistance component in short-circuit impedance is very small. The value of short-circuit impedance is mainly the value of reactance component, that is, leakage reactance of windings. The leakage reactance of transformer can be divided into two parts: longitudinal leakage reactance and transverse leakage reactance. Usually, the proportion of transverse leakage reactance is small. The leakage reactance of transformer is determined by the geometric size of winding. The change of the structure state of transformer winding will inevitably lead to the change of leakage reactance of transformer, which will cause the change of short-circuit impedance of transformer.
Volt-ampere method is usually used in the field measurement of low short-circuit impedance. Before the test, one side of the transformer outlet is short connected. The short-connected conductor must have enough cross-section area and keep good contact between the outlet terminals to reduce the circuit resistance of the lead. On the other side of the transformer, the test voltage is applied to generate the current flowing through the impedance. At the same time, the current and voltage added to the impedance are measured. The ratio of the fundamental component of the voltage and current is the short-circuit impedance of the transformer under test. The typical test wiring is shown in Fig. 1. The transformer tested in this diagram is a single-phase transformer. The connection mode is short circuit at low voltage side and pressure applied at high voltage side.

![Test wiring](image)

**Figure 1. Test wiring**

2.2 *Frequency response method*

The basic principle of the frequency response method is to apply a stable low-voltage pulse signal at one end of the transformer winding, and record the voltage waveform of the terminal and other terminals simultaneously. By comparing the excitation and response in time domain, the state of the windings can be correctly judged. Low voltage pulse method has been listed in IEC and IEEE power transformer short circuit test guidelines and test standards. However, this method is still affected by lots of electromagnetic interference in the field test, and has poor repeatability, and is insensitive to the fault response of the winding head position, so it is difficult to judge the winding deformation position.

Each winding of a transformer can be regarded as a passive linear two-port network composed of distributed parameters such as linear resistance, inductance and capacitance. If the distributed inductance, longitudinal capacitance and ground capacitance of the winding are $L, K$ and $C$, respectively, and the resistance of the winding is neglected (usually very small), the equivalent network of the winding can be represented by Figure 2, and its internal characteristics can be described by the transfer function $H(j\omega)$. If the windings undergo mechanical deformation such as axial and radial size changes, the distribution parameters of $L, K$ and $C$ of the network will inevitably be changed, resulting in the change of zero and pole distribution of the transfer function $H(j\omega)$, which will change the frequency response characteristics of the network. By detecting the amplitude-frequency response characteristics of each winding of transformer, and comparing the test results horizontally or vertically, according to the difference of amplitude-frequency response characteristics, the possible winding deformation of transformer can be judged comprehensively.
The principle of frequency sweep impedance measurement system is shown in Figure 3. The sweep impedance method is used to detect transformer winding deformation. It is a longitudinal or transverse comparison of the test results by detecting the impedance frequency curve of each winding pair of the transformer, and the deformation of the winding can be judged according to the change of the curve. When transformer is tested by sweep impedance method, the winding of transformer can be regarded as a circuit system composed of a series of components such as resistance, inductance and capacitance. When one of the components changes, the sweep impedance of transformer will change correspondingly, and the specific parameters of these components are determined by the geometric size of the winding. Therefore, the change of winding size will inevitably lead to the change of sweep impedance value of transformer.

Based on the basic principles of various testing methods, the factors affecting the test results, the method of winding deformation judgement, and the analysis conclusion of the application cases, we can see that the above methods have different application occasions, and can be chosen according to the needs. The comparison results of various detection methods are shown in Table 1, in which A stands for Low Voltage Short Circuit Impedance Method; B stands for Frequency Response Method; and C stands for Sweep Impedance Method.
4. Conclusions
Frequency response method and low voltage short-circuit impedance method have been applied for many years, and the relevant standards have been promulgated. However, the two methods have their own shortcomings. When on-site testing, we should combine the judgment advantages of the two methods organically to improve the accuracy of judgment. Sweeping impedance method can make up for the shortcomings of low-voltage short-circuit impedance method and frequency response method, reduce test interference and improve the accuracy of winding deformation diagnosis. Although the criteria for winding deformation judgment of sweeping impedance method have been put forward, the accuracy of the criteria still needs to be verified by field application.

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