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**Frequency response analysis on winding deformation of  
power transformers**

电力变压器绕组变形的频率响应分析法

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# Frequency response analysis on winding deformation of power transformers

## 1 Scope

This standard specifies the basic requirements for detecting transformer winding deformation by frequency response analysis.

This standard applies to power transformers with voltage levels of 66kV and above and other transformers for special purposes.

## 2 Normative references

The following documents are essential to the application of this document. For the dated documents, only the versions with the dates indicated are applicable to this document; for the undated documents, only the latest version (including all the amendments) is applicable to this standard.

DL/T 1093 Guide for reactance method to detect and diagnose winding deformation of power transformer

## 3 Terms and definitions

The following terms and definitions apply to this document.

### 3.1

#### **Winding deformation**

Refers to the axial or radial dimensional changes of power transformer windings under the action of electric or mechanical forces, when they are subjected to short-circuit current shock or collision during transportation; it is usually manifested as local twisting, bulging or displacement of windings.

### 3.2

#### **Bilateral network**

Refers to a network with a pair of input ports and a pair of output ports. If the network is composed of linear resistors, inductors (including mutual inductance), capacitors, meanwhile it does not contain any independent power supply inside, it

$H(f)$  - Modulus  $|H(j\omega)|$  of transfer function at frequency  $f$ ;

$U_2(f)$ ,  $U_1(f)$  - Peak or effective value of voltage  $|U_2(j\omega)|$  and  $|U_1(j\omega)|$  at response end and excitation end at frequency  $f$ .

## 5 Requirements for detection instruments

### 5.1 Basic requirements for detection instruments

For the basic requirements of transformer winding deformation tester, please refer to Appendix A.

### 5.2 Sweep frequency detection range

The sweep frequency detection range shall include the frequency band of 1kHz ~ 1000kHz.

### 5.3 Sweep frequency detection method

It should adopt linear distribution frequency sweep detection method; repeat detection of single frequency point can be performed.

### 5.4 Sweep frequency accuracy

The frequency accuracy of the sine wave signal output by the signal source shall not exceed 0.01%.

### 5.5 Scanning frequency interval

The scanning frequency interval should be 1kHz.

### 5.6 Impedance matching method

The output impedance  $R_s$  of the sine wave signal output source  $U_s$  of the detection instrument shall be  $50\Omega$ ; the input impedance of the two signal detection terminals  $U_1$  and  $U_2$  shall not be lower than  $1M\Omega$ ; a  $50\Omega$  matching resistor  $R$  shall be installed between the signal response terminal and the common terminal (see Figure 1).

The length of the coaxial cable should be within 15m ~ 20m; the cable used shall be a RF cable with an impedance of  $50\Omega$ .

### 5.7 Detection accuracy

The detection instrument shall have a dynamic detection range of -100dB ~ 20dB; the absolute error of detection within the range of -80dB ~ 20dB shall be less than 1dB.

### 5.8 Frequency selection and filtering characteristics

The detection instrument shall have a frequency selection and filtering function; its 6dB bandwidth shall be less than 2% of the scanning frequency.

### **5.9 Data export format**

For the data export format of the frequency response characteristic curve, see Appendix B.

### **5.10 Data query function**

The search function can be used to query the historical data of the same model, the same manufacturer and the transformer.

### **5.11 Data display method**

The frequency coordinates of the amplitude-frequency response characteristic curve should be displayed in logarithmic coordinates.

## **6 Detection method**

### **6.1 Detection condition requirements**

**6.1.1** Detection shall not be carried out in thunderstorms, rain, snow and other weather. The detection shall strictly implement the requirements of the power safety work regulations; it shall strictly implement the organizational and technical measures to ensure safety. The test personnel shall be trained and have the ability to conduct on-site tests.

**6.1.2** Transformer winding deformation detection shall be carried out before all DC test items or after the winding is fully discharged; demagnetization treatment shall be carried out if necessary. According to the wiring requirements and wiring methods, each winding of the transformer shall be tested one by one; the amplitude-frequency response characteristic curve shall be recorded separately.

**6.1.3** Before testing, all leads connected to the end of the transformer bushing shall be removed; the removed leads shall be as far away from the tested transformer bushing as possible.

**6.1.4** The amplitude-frequency response characteristics of the transformer winding are related to the position of the tap changer. It should test at the maximum tap position, or ensure that the tap changer is in the same tap position each time the test is performed.

**6.1.5** The test site shall provide AC220V power supply. When the site interference is serious, the test equipment should be powered by an isolated power supply.

### **6.2 Wiring requirements**

end; detect the amplitude-frequency response characteristics of the three-phase windings of each voltage level of the transformer one by one.

## **7 Analysis and judgment of winding deformation**

### **7.1 Analysis and judgment principle**

The frequency response analysis method is used to judge the deformation of transformer windings. The frequency response data curves of three-phase windings of the same voltage level are mainly compared longitudinally, laterally, comprehensively; the changes in the amplitude-frequency characteristics of the transformer windings are judged by the correlation coefficient.

The method of using the correlation coefficient  $R$  to assist in judging the deformation of transformer windings is shown in Appendix C.

### **7.2 Longitudinal comparison method**

The longitudinal comparison method refers to comparing the amplitude-frequency response characteristics of the same transformer, the same winding, the same tap position, the different periods; judging the deformation of the transformer winding according to the changes in the amplitude-frequency response characteristics. This method has high detection sensitivity and judgment accuracy; however, it is necessary to obtain the original amplitude-frequency response characteristics of the transformer in advance, meanwhile the influence caused by changes in detection conditions and detection methods shall be excluded.

For an example of using the longitudinal comparison method to judge the deformation of transformer windings, see Appendix D.

### **7.3 Lateral comparison method**

The lateral comparison method refers to comparing the amplitude-frequency response characteristics of three-phase windings of the same voltage level of the transformer. If necessary, the amplitude-frequency response characteristics of the same model transformer manufactured by the same manufacturer at the same time are used to judge whether the transformer winding is deformed. This method does not require the original amplitude-frequency response characteristics of the transformer; it is relatively convenient for field application. However, the possibility that the three-phase windings of the transformer are deformed to a similar degree or that the amplitude-frequency response characteristics of the three-phase windings of the normal transformer are different shall be excluded.

See Appendix E for an example of using the lateral comparison method to judge the deformation of the transformer winding.

## 7.4 Comprehensive analysis method

The comprehensive analysis method mainly compares the three-phase frequency response fingerprints of the transformer laterally and longitudinally; makes a judgment based on the differences in the three-phase frequency response fingerprints.

See Appendix F for an example of using the comprehensive comparison method to judge the deformation of the transformer winding.

## 7.5 Analysis process

**7.5.1** When conducting a transformer winding deformation test on site, the normal measured frequency response data curve shall be continuous and smooth; however, in a more complex field environment, the measured frequency response characteristic data will sometimes be interfered, which will affect the effect of the test data; the validity of the test data needs to be analyzed. See Appendix G for an example of a typical interference waveform when the transformer winding is deformed.

**7.5.2** When testing and analyzing the deformation of three-phase windings of the same voltage level of the transformer, a certain process can be followed; if necessary, it can be combined with other test results such as transformer operating conditions and short-circuit impedance. See Appendix H for the process of judging transformer winding deformation using frequency response analysis.

## 7.6 Winding deformation analysis

**7.6.1** The typical amplitude-frequency response characteristic curve of transformer winding usually contains multiple obvious peaks and troughs. The changes in the distribution position and number of peaks or troughs are important bases for analyzing transformer winding deformation. See Appendix I for the typical amplitude-frequency response characteristic curve of transformer winding deformation.

**7.6.2** The peak or trough position of the low-frequency band (1kHz ~ 100kHz) of the amplitude-frequency response characteristic curve changes significantly, which usually indicates that the inductance of the winding changes; there may be a short circuit between turns or between turns. When the frequency is low, the capacitive reactance formed by the ground capacitance and inter-panel capacitance of the winding is large, while the inductive reactance is small. If the inductance of the winding changes, the peak or trough position of the low-frequency part of its frequency response characteristic curve will move significantly. For most transformers, the amplitude-frequency response characteristic curve of the three-phase winding in the low-frequency band shall be very similar. If there is a difference, the cause shall be found out in time.

**7.6.3** The peak or trough position of the mid-frequency band (100kHz ~ 600kHz) of the amplitude-frequency response characteristic curve changes significantly, which usually

## Appendix B

### (Informative)

#### Data export format of frequency response characteristic curve

##### B.1 Naming method of data file

The data file name shall contain the information of excitation end, response end, measurement number, all of which is represented by 2 characters. Among them, the characters representing the winding voltage level are H (high voltage), M (medium voltage), L (low voltage), the characters representing the winding terminal name are A, B, C and X, Y, Z. Other letters can also be used to represent it; the characters representing the measurement number are two decimal numbers.

Example: The file name "HOHA03.csv" means that the excitation end is the neutral point O end of the high voltage (H) winding, the response end is the A phase of the high voltage (H) winding, the file is the data of the 03<sup>rd</sup> measurement.

##### B.2 Storage directory of data file

The frequency response characteristic test data of each winding of the same transformer shall be saved in the same file directory; the name of the directory shall be named with the operation number or factory number of the transformer.

##### B.3 Recording content of data file

- a) The first column of the first row is the frequency unit "kHz"; the second column is the amplitude unit "dB"; the third column is the starting frequency value of the sweep frequency measurement; the fourth column is the ending frequency value; the fifth column is the number of frequency points of the sweep frequency measurement.
- b) The third column of the second row is used to record the model and version of the test instrument, which starts with ";".
- c) The third row to the Nth row ( $N = \text{number of frequency points} + 3$ ) is used to record the test data, where the first column is the frequency (in kHz) and the second column is the amplitude (in dB).
- d) The third column of the (N+1)th row records the name information of the transformer, which starts with ";".
- e) The third column of the (N+2)th row records the test number, which starts with ";". For example, "; 01" means the first test.
- f) The third column of the (N+3)th row records the gear information of the



## Appendix G

### (Informative)

#### **Example of typical interference waveform when the transformer winding is deformed**

When analyzing the measured transformer winding frequency response characteristic curve, the validity of the test data shall be identified first. Under normal circumstances, the frequency response characteristic data curve of the transformer winding shall be continuous and smooth; its amplitude is mostly distributed in the range of -70dB ~ 0dB, only some may exceed 0dB or be lower than -70dB.

If the measured data curve is found to have burrs, spikes, overall translation or reversal, the cause shall be found out first and then retested after solving the problem until valid test data is obtained.

The following are several typical interference waveforms and their processing methods.

##### a) Burrs.

If the measured frequency response characteristic curve contains burrs as shown in Figure G.1, the following inspections and processing shall usually be performed:

- 1) It is caused by poor contact of the test circuit (such as unstable contact resistance). On the one hand, the test lead can be checked and replaced; on the other hand, confirm whether the contact of the sleeve end is good or the grounding is reliable.
- 2) Whether there are electric tools such as electric drills, electric welders, cutting machines around the test site; if necessary, the operation of such equipment can be suspended, then the wiring can be reconnected for measurement.
- 3) Whether the working status of the tester itself is normal; self-checking can be performed through the configured calibration unit.

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