HZRZ-301B Transformer Winding Deformation Tester

User manual

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I. Overview

1. Terminology

Winding deformation: Winding deformation refers to the change of the axial or radial size of the power transformer winding under the action of mechanical force or electric force, usually expressed as winding local distortion, drum or shift and other characteristics. When the transformer is subjected to the impact of short-circuit current or in the course of transportation, it is possible to have the phenomenon of winding deformation, which will directly affect the safe operation of the transformer.

Two port network: A two port network is a network with a pair of input ports and a pair of output ports. If the network is composed of a linear resistor, inductance (including mutual inductance) and capacitor elements, and the interior does not contain any independent power supply, it is called a passive linear two port network. When the frequency is high, the transformer winding can be regarded as a passive linear two port network.

Transfer function: A transfer function is the ratio of the Laplace transform of the output of passive two port network to the Laplace transform of the input of passive two port network. The distribution of the poles and zeros of the transfer function is closely related to the internal component parameters, the connection mode and the impedance of the ports.

Frequency response: The relation between the transfer function $H(j\omega)$ of the network and the angular frequency $\omega$ in the sinusoidal steady state. The relation between the amplitude of $H(j\omega)$ and $\omega$ is called amplitude frequency response, and the relation between $H(j\omega)$ phase and $\omega$ is called phase frequency response.

Frequency scanning: The frequency of the sine wave excitation signal is changed continuously, and the ratio of the output signal to the input signal is measured at different frequencies, then the amplitude frequency response and phase frequency response curve are plotted.
2. Detection principle

Under the action of the high frequency voltage, each winding of the transformer can be regarded as a passive linear two port network composed of linear resistance, inductance, mutual inductance and capacitance and its internal characteristics can be described by the transfer function $H(j\omega)$, as shown in figure 1. If the winding deformation occurs, the internal distribution of winding inductance and capacitance parameters will inevitably change, leading to its equivalent network transfer function $H(j\omega)$ zeros and poles change, make the network frequency response characteristics change.

Detection of transformer winding deformation by frequency response analysis is to detect the amplitude frequency response characteristics of each winding of the transformer and compare the results longitudinally or transversely. According to the difference of amplitude frequency response characteristics, the transformer winding deformation can be judged.

The amplitude frequency response characteristics of transformer windings are obtained by means of frequency scanning in figure 1. We continuously change the frequency $f$ (angular frequency $\omega=2\pi f$) of the external sine wave excitation source $V_S i$, and measure the ratio of the response terminal voltage $V_2$ and the signal amplitude of the exciting terminal voltage at different frequencies to obtain the amplitude frequency response curves of the winding at the specified excitation and response. In figure 1: $L$, $K$ and $C$ represent the distribution inductance of the unit length, the distributed capacitance and the distributed capacitance, $V_1$ and $V_2$ represent the excitation voltage and the response voltage of the equivalent network, $V_S$ is the sine wave excitation signal source voltage, $R_S$ is the signal source output impedance, $R$ is the matching resistance.
3. Detection method

Transformer winding deformation test should be carried out before all DC test items or after full discharge of the windings. According to the wiring requirements and wiring methods, one by one to the transformer windings were detected, respectively, record amplitude frequency response curve.

3.1 Wiring requirements

3.1.1 All leads connected to the end of the transformer bushing should be removed before the test, and the removed leads should be as far away as possible from the transformer bushing. For transformer casing lead cannot be removed, can use the bushing tap as the response end to detect it, but should be marked, and compare with the detection results under the same condition.

3.1.2 The amplitude frequency response characteristic of the transformer winding is related to the position of the tap switch, it should be detected in the highest tap position, or should ensure that each test time tap switch are in the same location.

3.1.3 Because the detection signal is weak, all wiring should be stable and reliable, the contact resistance should be reduced.

3.1.4 The ground wire of two signal detection end should be reliably connected to the transformer case on the clear grounding (such as the core grounding), the grounding wire should be as short as possible and should not be winding.

3.2 Wiring method

According to figure 2, select the signal input (excitation) end and the measurement (response) convenient for the standardization of management of test
results.

Fig. 2 Several common detection wiring methods of transformer

4. Analytical judgment

The frequency response analysis method to judge transformer winding deformation, taking into account the short circuit impact of transformer, transformer structure, electrical test and analysis of dissolved gases in oil and other factors, is mainly on amplitude frequency response characteristics of the windings longitudinal comparison or transverse comparison. According to the size of the correlation coefficient, it can directly reflect the change of the transformer winding amplitude frequency response characteristics, which can be used as an auxiliary means to judge transformer winding deformation. With the correlation coefficient to assist in judging Transformer winding deformation methods see appendix.

4.1 Longitudinal comparison method

The longitudinal comparison method is to compare the amplitude frequency response characteristics of the same transformer, the same winding, the same tap switch, and different periods, according to the change of amplitude frequency response characteristic to judge transformer winding deformation. The method has high detection sensitivity and accuracy, but it needs to obtain the original amplitude frequency response characteristic of the transformer in advance, and exclude the influence of the detection condition and mode.
Figure 3 is a transformer response curve before and after the shock from sudden short-circuit current measured by the low voltage winding frequency. Compared with the curve before the impact, it is found that the frequency distribution of some peaks and troughs shifted to the right, and it is judged that the transformer winding is deformed.

![Amplitude frequency response curves of a transformer](image)

**Fig. 3** Amplitude frequency response curves of a transformer before and after short circuit current

### 4.2 Transverse comparison method

The transverse comparison method is to compare the amplitude frequency response characteristics of the three-phase windings of the same voltage level. If necessary, the amplitude frequency response characteristics of the same type of transformer manufactured in the same factory at the same time are used to determine the deformation of the transformer winding. The method does not require the original amplitude frequency response characteristics of the transformer and is convenient for field application, but should be excluded that the three-phase winding transformer has a similar degree of deformation, or normal three-phase winding of the transformer and the amplitude frequency response characteristics of the possibility of itself has the difference.

Figure 4 is low voltage winding amplitude frequency response characteristics of a three-phase transformer which is measured when the three-phase transformer is after the short circuit current shock. Compared with the curves LaLb, LbLc, the frequency
distribution and the number of distributions of the peaks and valleys are different, that is, the amplitude-frequency response characteristics of the three-phase windings are poor. However, the frequency response characteristics of the three-phase windings of the same type transformer manufactured in the same factory at the same time were better than those of the same type (Figure 5). So it can be determined the winding deformation of the transformer after the sudden short circuit current.

**Fig. 4** Amplitude frequency response curves of three phase low voltage winding after a sudden short circuit

**Fig. 5** Amplitude and frequency response curves of the three phase low voltage winding of the same type transformer with figure 4

4.3 Analysis of winding deformation

Typical transformer winding amplitude frequency response curve, usually contains a number of obvious peaks and troughs. The empirical and theoretical analysis shows that the variation of the position and the number of the peaks or
troughs in the amplitude frequency response curve is an important basis for the analysis of transformer winding deformation.

The peak or trough of low frequency band (1kHz~100kHz) of the amplitude frequency response curve are changed obviously which usually indicates that the inductance of the winding is changed, and there may be a short circuit between the turns and the pancake. When the frequency is low, the capacitance of the winding and the capacitance between the cake are large, but the inductance is small. If the inductance of the winding changes, it will lead to its frequency response characteristics of low-frequency part of the peak or trough position of a significant movement. For most transformers, the response characteristics of the three-phase winding low-frequency response curve should be very similar, if there are differences should be timely to identify the reasons.

The peak or trough position of the mid-band (100kHz ~ 600kHz) of the amplitude-frequency response characteristic curve is obviously changed, which usually indicates the distortion of the winding and the local deformation of the drum. The amplitude and frequency response characteristics of the curve in the frequency range of (100kHz ~ 600kHz) has more peaks and troughs, which can be sensitive to reflect the winding distribution inductance, capacitance changes.

The peak or trough position of the high frequency band (> 600 kHz) of the amplitude response curve changes significantly, which usually indicates that the winding of the ground capacitance changes, and there may be the overall coil shift or lead displacement and so on. When the frequency is high, the inductance of the winding is larger and the capacitance resistance is smaller. Because the capacitance between the windings of the windings is much larger than that of the ground capacitance, the distribution of the crests and valleys is mainly dominated by the capacitance.
II. Main technical parameters

1. Working power supply: single phase AC 220V±10%, 50Hz (47~63 Hz)
2. Working temperature: -30℃~50℃ (Test host)
3. Working humidity: ≤90%RH, No condensation
4. Sweep range: 100Hz~2 MHz (Customizable 10MHz)
5. Frequency accuracy: 0.005%
6. Sweep mode: linear or logarithmic
7. Sweep interval: < 1 kHz
8. Measuring frequency range: -100dB~20dB
9. Sweep excitation output: 20Vpp
10. Detection accuracy: Better than ±0.5dB
11. Output impedance: 50Ω
12. Input port impedance: 1MΩ
13. Data storage format: Excel data format, can be opened in plain text
III. Device composition

1. Overview

The HZRZ-301B tester consists of the tester host, test notebook, test cable and other accessories, as shown in the following figure.

2.Tester host

The HZRZ-301B tester host is used to receive test commands issued by the test notebook, and send the test results back to the test notebook. The tester host and tester notebook are connected via an Ethernet cable.

3. Tester notebook

Test notebook pre-installs transformer winding deformation testing software. The test software is used to set the test parameters, start or stop the testing process, store the test results, analyze and compare the test results.

4. Test cable

The test cable and connector provided by the tester should not be changed in any way.

The test cable is made of low loss RG-58 RF coaxial cable, the number of the cable is 3. One end of the cable is connected to the test panel with a standard BNC connector and the other end of the clamp is connected to the measured winding of the transformer. Among them, two cables which connected to the panel excitation
interface and the reference interface are connected to the excitation end of the winding, the cable connected to the panel response interface is connected to the response end of the winding.

The shield of the cable and the ground connection of the transformer shell should be connected reliably.

**Device components:**

HZRZ-301B Split: Transformer winding deformation tester host, test notebook

Annex:

a. Test cable 1 set
b. Dedicated ground wire 1 root
c. Host power cord 1 root
d. Ethernet communication cable 1 root
e. Device chassis 1 set
IV. Testing process

1. Preparation of transformer

1) The tested transformer must be completely isolated from the power grid and all coil leads are disconnected from the bus and away from the transformer terminals. Transformer winding deformation detection must be carried out before the DC test project or after the full discharge of the transformer windings, otherwise it will affect the repeatability of the test data and even lead to damage to the test equipment.

2) The amplitude frequency response characteristic of the transformer winding is related to the position of the tap switch, it should be detected in the highest tap position, or should ensure that each test time tap switch are in the same location.

2. Connecting cable

Wiring requirements:

1) All leads connected to the end of the transformer bushing should be removed before the test, and the removed leads should be as far away as possible from the transformer bushing.

2) Due to the weak signal detection, all wiring should be stable, reliable, and the contact resistance should be reduced. The metal part of the test clamp should be removed prior to connection.

3) The BNC end of the test cable is connected to the BNC end with the same color identification on the host. The red and black test clamps are reliably connected to the input and the measured ends of the measured winding. The input of the coil and the definition of the measuring end are shown below.
4) The ground wire of the test clamp should be connected reliably to the grounding terminal on the transformer shell (such as the grounding end of the iron core) and the grounding wire should be as short as possible without winding.

5) Device must be reliable connected with the ground row of transformer base by randomly provided grounded cable.

3. Execute test

The following tests are performed:

Open the power switch on the front panel of the device.

Open the PC machine to measure the start of the software set the end of the frequency, sweep mode, sweep the number of points, etc.;

Monitor the testing process to ensure the results are correctly received;

Complete the test and store the test results or click the frequency characteristic curve to terminate the test process.

4. Turn off tester

Turn off tester just need turn off the power switch on the front panel, exit PC on the measurement software, turn off the PC.
V. Test software

1. Overview

Double click “Transformer Winding Deformation Test Software” icon on the desktop, you can open the following software interface. Click the button in the upper right corner of the software to close the software. The whole software can be divided into "Measurement interface", "Analysis interface", can use the left mouse button to switch the interface. The following will explain the specific functions of the two interface.

2. Measurement interface

The software when it is opened displays the measurement interface, as shown above. The measurement interface consists of three wave windows on the left, the right measurement parameters and the "Measurement" button.

The excitation signal and response signal window display the sampling waveform of the excitation signal and response signal in real time. They are used to monitor the measurement process. Amplitude frequency characteristic window display amplitude frequency and phase frequency characteristics in real time. Click the right mouse button on the window to open the menu as shown below:
This menu allows you to fine-tune the display.

From the top to the bottom of the "measurement interface" is the “Measurement duration” button, “Measurement parameter settings” button, “Measurement start” button.

The settings for the measurement parameters include:

"Start frequency" can be set to 100 ~ 2MHz. The following unit selection buttons can be selected as "Hz", "KHz" or "MHz" and click to select.

"End frequency" can be set to 100 ~ 2MHz. The "End frequency" must be greater than or equal to the "Start frequency". The software will check the legitimacy of the frequency range settings, if not legitimate, click on the "Measurement", the software will pop up a dialog box to prompt the user error.

The total number of “Sweep frequencies “can be set from 1 to 10,000.

"Sweep mode" can choose linear or logarithmic interval. Linear time-frequency is mainly concentrated in the high-frequency, logarithmic is just the opposite.

"Restore the default parameters" can be set to the above parameters which are recommended by "DL / T 911-2004 power transformer winding deformation Frequency response analysis " 1kHz ~ 1MHz", "Linear" distribution of the sweep detection. The total number of sweep frequencies is 1000 by default.

Click "Measure" to enter the measurement process. During the measurement process, click the left mouse button in the "Amplitude-frequency characteristic" window to stop the measurement process.

After the measurement is completed, if the user chooses to store the measurement data, the data information setting window will be displayed as shown below.
3. Analysis interface

"Analysis interface" as shown below, which can be divided into measurement curve window, curve information table and curve button composed of three parts, is used to compare the results of multiple measurements for comparative analysis. The Measure Curve window and “Curve” buttons have a right-click menu.

**Note:** The sampling frequency of the selected curve can be different, the starting frequency and the end frequency can be different, the software will automatically interpolate the comparison. But the sampling interval must be the same, that is, the
The result of the linear interval cannot be compared with the logarithmic interval.

The measurement curve window can be switched from its right-click menu (as shown in the right) in the "Amplitude-frequency characteristics", "Phase-frequency characteristics", "Amplitude difference" and "Phase frequency difference". The other options for this menu are as follows:

"Database" is used to select the "Amplitude-frequency characteristics", "phase frequency characteristics" interface display curve. We can delete, modify and other operations on the database data in the pop-up dialog box.

The "Calculate correlation coefficient" is used to calculate the correlation coefficient between the displayed curves.

"Export Data" is used to export one or more sets of data selected by the user in the zip compressed package format. After selecting the data, the user can select the compressed file storage path and the compressed file name in the dialog box that pops up.

"Import data" is used for the import of external data. The format of the imported file must be the same as the data exported.

The "Generate report" is used to print the data report. After clicking, a dialog box will pop up, with "Print", "Generate WORD" and "Cancel" for the user to select.

"Coordinate form" is used to switch the coordinates of the waveform display window.

The "Band display" can be used to implement the subband display waveform.

"Curve zoom" can be used to achieve the magnified display of the waveform.

Click on the menu in the "Database" will pop up the selection window, as shown below:
In the "Database operation" sub-panel, you can read out the data in the database to open, delete, modify and other operations.

The tree structure on the left lists all the data that has been stored in the database, and the data is classified according to the measuring instrument, the test unit, the test location, the run number, the measurement time and so on. The first time to open, the tree only to the test site to expand this level and you can expand the tree by double-clicking.

When the selection is in the top, run number or measurement timeof these three levels, the tree on the right side of the display bar will display the corresponding transformer information, and the corresponding information is in a modified state. When the selection is at the level of the run number, each entry of the information bar on the right side of the tree structure becomes an input state, and the user can edit and modify the information. At the same time, "Save and modify" button also becomes available. After the user modifies the corresponding information, click "Save", the software will save the modified information, or maintain the original information unchanged.

When you select an item in a tree structure and click "Open", the corresponding data will be displayed in the "Amplitude-frequency characteristics", "Phase-frequency characteristics" window. You can open up to 6 sets of data at the same time.

When you select an item in a tree structure and click "delete", the corresponding
data will be deleted. Before deleting the data, the user will be prompted to confirm whether or not to delete the data.

Click "Cancel" to exit the subpanel and cannot do any operation.

Click on "Calculate the correlation coefficient", the software will pop up the calculation of correlation coefficient dialog box as shown below:

Curves 1 to 6 correspond to the curves currently being displayed. Users can use the left mouse button click to select the curves you want to calculate the correlation coefficient. The number of the curves which is selected is up to three at the same time. Select the curve and click the "Calculate" button, the table will show the results. The correlation coefficient is calculated according to the electric power industry standard DL/T 911-2004. The conclusions in the table need to be determined by the user whether the comparison curve corresponds to the same coil or different coils, and then select the "Longitudinal ratio conclusion" or "Transverse ratio conclusion". (Note: according to the standard DL/T 911-2004, this conclusion can
only be used as a reference for winding deformation).

Click "Exit" to exit the dialog box.

Click "Export Data" will pop up the same interface as the database operation sub-panel, select the data to be exported in the tree, click "Export" button, set the file storage path and file name in the pop-up dialog box. Get the exported zip file in the set path.

Click "import data", it will pop up dialog box for the user to select the imported data file. After the import data is completed, a pop-up prompt is displayed.

Before the data is imported, the software will check the data in the file. The error data will not be imported into the database. The software will give a prompt and give the number of imported data sets.

If you choose to import the data already exists in the database, it will pop up a prompt window, selected by the user whether to cover the data.

Click "generate report", it will pop up the corresponding dialog box, prompting the user to select the print mode.

"Frequency band display" includes "low frequency band" (1kHz ~ 100kHz), "middle frequency band" (100kHz ~ 600kHz), "high frequency band" (600kHz ~ 1000kHz) and "full band". The curves in the corresponding bands can be displayed separately.

"Curve Zoom" includes "Local zoom", "Pan watch" and "Restore". Select "Local zoom", the cursor will become into the zoom mode, then you can select the area within the graphical interface to enlarge. Click "Pan watch", the cursor will become into a hand, then you can pan in the display area to drag the observation curve. Click "Restore" the graphic will resume the original size and the cursor will restore to its original state.

When the mouse moves over the curve button, the corresponding curve information is automatically displayed in the curve information table. Click the button to toggle the display and hide status of the curve. Double-click the button, the data
selection sub-panel which is used to select the curve you want to view will pop up.

The "Comparison to" of button right-click menu can be used to select other curves and the current curve for comparison calculation. The results will be in the "Amplitude difference", "Phase frequency difference", "Correlation coefficient" interface displayed. The "Curve color" of button right-click menu is used to set the color of the curve corresponding to the bar.
VI. Appendix

Correlation coefficient R to help judge transformer winding deformation

From the "People's Republic of China power industry standard DL / T 911-2004".

The correlation coefficient can be quantitatively describe the degree of similarity between the two waveform curve and it is usually used as an auxiliary means for analyzing the transformer winding deformation. The specific results should also be based on the operation of the transformer and other information comprehensive judgment.

There are two length function N (X), Y (k), k=0,1 (K),..., N-1, and X (k), Y (k) is a real number, correlation coefficient R can be calculated according to the following formula.

A.1 Calculate the standard variance of the two sequences.

\[ D_x = \frac{1}{N} \sum_{k=0}^{N-1} [X(k) - \frac{1}{N} \sum_{k=0}^{N-1} X(k)]^2 \]
\[ D_y = \frac{1}{N} \sum_{k=0}^{N-1} [Y(k) - \frac{1}{N} \sum_{k=0}^{N-1} Y(k)]^2 \]

A.2 Calculate the covariance of the two sequences.

\[ C_{xy} = \frac{1}{N} \sum_{k=0}^{N-1} [X(k) - \frac{1}{N} \sum_{k=0}^{N-1} X(k)] \times [Y(k) - \frac{1}{N} \sum_{k=0}^{N-1} Y(k)] \]

A.3 Calculate the normalized covariance coefficient of two sequences.

\[ LR_{xy} = \frac{C_{xy}}{\sqrt{D_x D_y}} \]

A.4 According to the following formula to calculate the correlation coefficient Rxy.

\[ R_{xy} = \begin{cases} 10^{-10} & 1-LR_{xy} < e^{-10} \\ -\log_{10}(1-LR_{xy}) & others \end{cases} \]

A.5 Judge the degree of deformation of the transformer winding according to table 1.
Table A.1 Relationship between correlation coefficient and transformer winding deformation (for reference only)

<table>
<thead>
<tr>
<th>The degree of deformation of the transformer winding</th>
<th>Correlation coefficient R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe deformation</td>
<td>$R_{LF} &lt; 0.6$</td>
</tr>
<tr>
<td>Obvious deformation</td>
<td>$1.0 &gt; R_{LF} \geq 0.6$ 或 $R_{MF} &lt; 0.6$</td>
</tr>
<tr>
<td>Mild deformation</td>
<td>$2.0 &gt; R_{LF} \geq 1.0$ 或 $0.6 \leq R_{MF} &lt; 1.0$</td>
</tr>
<tr>
<td>Normal winding</td>
<td>$R_{LF} \geq 2.0$ 和 $R_{MF} \geq 1.0$ 和 $R_{HF} \geq 0.6$</td>
</tr>
</tbody>
</table>

Note:
RLF is the correlation coefficient of the curve in the low frequency band (1kHz ~ 100kHz)
RMF is the correlation coefficient of the curve in the middle frequency band (100kHz ~ 600kHz)
RHF is the correlation coefficient of the curve in the high frequency range (600kHz ~ 1000kHz).