Power Transformer – Test Specification

Transformer Frequency Response Analysis (FRA) Test

Introduction

This specification is generic in that it provides guidelines for an FRA test on transformers which does not constrain the test process to use a particular test device.

Contents

1 Scope and Application

Frequency Response Analysis (FRA) testing is a diagnostic test that provides:

- an indication of the health of the transformer
- a baseline set of reference results for comparison in the future

The aim of FRA testing at the factory is to provide a baseline set of reference results before transport of the transformer to its final destination.

These specifications shall apply to all power transformers purchases.

These specifications cover the requirements for Frequency Response Testing at the factory and for field commissioning tests. The factory and commissioning test data will be used by the purchaser as baseline data for comparison to future field tests.

All tests shall be performed by qualified test personnel who are familiar with the test equipment and capable of basic interpretation of the test results. The test personnel must be able to recognize valid and invalid results, or have access to support.

2 Test Parameters

2.1 Frequency Range

The test shall be made over the 20 Hz to 2 MHz frequency range. Additional results at lower or higher frequencies may also be made and recorded.

2.2 Resolution

Frequency response measurements shall be made using a uniformly spaced log scale for frequency. That is, the gap between successive measurements shall have a consistent percentage gap of 2% or less across the frequency range.

For example, if a 2% step is used, after a measurement at 100 Hz, the next measurement at a higher frequency would be 102 Hz. The next measurement after that would be at 104.04 Hz, etc.

In accordance with industry best practice, an interference bandwidth (IBW) of less than 1/5 of the measured frequency must be used for each measurement frequency.

2.3 Magnitude

The test shall record the magnitude of the response on a decibel (dB) scale for each measurement point. The measured input voltage, V_i, and the measured output voltage, V_o, are combined to give a dB reading via:

$$\text{Magnitude (dB)} = 20 \log_{10} (V_o/V_i)$$

The dB accuracy must be within 1 dB at every measurement point, using calibrated equipment.

2.4 Phase

The test shall record the phase, in degrees, for each measurement point.

The accuracy must be within 2 degrees at every measurement point, using calibrated equipment.

3 Test Equipment

3.1 Test Signal Parameters

All test equipment must be approved by the purchaser.

Test equipment must utilize a calibrated network analyzer and perform a frequency test with these characteristics:

- 15 dBM, or greater, output power range over the frequency range
- 85 dBM, or better, measurement capability over the frequency range

The excitation source should be capable of providing consistent and controlled peak to peak voltage over the entire frequency range.

3.2 Test Cables

Test cables must be high frequency coaxial cables, with a 50 ohm matched impedance.

A three lead system must be used which consists of a signal, a reference and a test measurement lead.

All cables must be of the same length; a maximum of 60 feet (~ 18.5 m) is recommended.

3.3 Grounding

The test set must have a ground connector available so as to connect the test set ground to the transformer.

4 Test Data and Test Records

Test equipment must produce a test report file that can be viewed by standard spreadsheet applications. Test data must be able to be viewed without editing, reorganizing or

reformatting of data required by the purchaser. A sample file in the proposed format shall be supplied by the manufacturer, or the test company, for approval by the purchaser prior to performing the tests.

The test record shall include the following transformer nameplate data:

- Manufacturer
- Year of manufacture
- Serial Number
- Number of windings
- Number of phases
- HV/LV/Tertiary voltages
- MVA under different cooling regimes
- Tap changer manufacturer
- Tap changer type
- Load Tap Changer details
- De-Energized Tap Changer Details

The test record shall include the following test data for each measurement made:

- Location of signal and reference lead
- Location of test lead
- Tap position on any tap changers
- Previous tap position if test is at neutral tap
- Date and time of test
- Any bushings which are connected
- Any bushings which are grounded
- Any test specific details which may affect test results

The test record shall include the following relevant data for each transformer tested:

- Location of test
- Test operator identification
- Test set serial number

5 Test Procedures

The tests shall be performed with the transformer assembled and oil filled.

The transformer should be disconnected from any power systems or supplies except for auxiliary supplies to tap changers, pumps, fans etc.

Core ground bushings shall be connected to ground; they do not normally form a part of the test process.

All windings shall be tested as shown in the tables in section 7.

Tests on windings with tap changers shall be performed in 2 tap positions; (1) with the DETC and LTC (if equipped) in the neutral position and (2) in the tap combination that places all sections of the windings in the circuit.

The tap positions shall be noted on the test report for each test.

When tests are performed at neutral tap position, the previous tap position must be recorded as this will affect the test result.

Bushings not under test, including neutrals, shall be ungrounded and disconnected.

Test cable coaxial shields must be grounded at both ends (at the base of the test bushing flanges and at the BNC connection to the Test set).

The test set ground should be directly connected to the specimen ground.

6 Test Report

The test report shall be submitted in both hard copy and electronic formats.

The hard copy shall be included in the certified test report and the disk file shall be submitted with the electronic versions of the final drawings of the transformer.

The hard copy test report shall show all waveforms in graphical form with the response in linear scale dB units on the Y-axis and the Frequency in logarithmic scale Hz on the X-axis. The Y-axis shall autoscale and the X-axis shall display the range from 20 Hz to 2 MHz. Where results fall in the range 10 Hz to 10 MHz, these should be accommodated by the report.

The electronic version of the test report shall include the complete data on a floppy disk or CD in the format and organization that will permit the file to be viewed completely using standard spreadsheet software. The manufacturer or test company shall submit a sample file in the proposed format for approval by the purchaser prior to performing the tests.

Each waveform shall be identified by the applied and measured terminals ("H1-X1", for example, indicating that the signal is applied to H1 and measured at X1).

The tap positions shall be noted on the test report for **each** set of waveforms. At neutral tap position, the previous tap position will also be recorded.

The test report shall be evaluated by the manufacturer's test engineer and approved and certified as measuring the correct response waveforms for the transformer in its new condition.

7 Appendix 1 – Test Connections

7.1 Test Connection Protocol

In general, the smallest possible sections of a transformer winding should each be tested separately.

Check the nameplate for actual connection details.

Where a delta winding is completed externally, it should be left as three separate windings if possible, as is often found on a generator step up unit. If only one corner of the delta is brought out, it should be completed during tests on other windings; this ensures a degree of symmetry for those tests on other windings.

The test connections described here do not include repeat tests for different tap positions. These are required where a tap changer is present.

7.2 Open and Short Circuit Tests

Open circuit tests are performed on a winding with all other connections floating and disconnected; the only exception to this is where a delta winding has one corner completed external to the tank, providing symmetry between test set ups.

Short circuit tests are performed on a HV winding by shorting together the LV connections, without grounding. The neutral is not included in the shorting process.

7.3 Single Phase – Double Wound

	Open Circuit Tests		***Short Circuit Test***
	Other bushings float		***X1-X2 shorted together and floating***
	HV Winding	***LV Winding***	
	Test 1	**Test 2**	**Test 3**
Single Phase	H1-H2	X1-X2	H1-H2

Table 1 - Single Phase Double Wound

7.4 Single Phase – Autotransformer

	Open Circuit Tests		***Short Circuit Test***
	Other bushings float		***X1-N shorted together and floating***
	HV Winding	***LV Winding***	
	Test 1	**Test 2**	**Test 3**
Single Phase	H1-X1	X1-N	H1-X1

Table 2 - Single Phase Autotransformers

7.5 Two Winding Transformers

	Open Circuit Tests						***Short Circuit Tests***		
	All other bushings float						***x1-x2-x3 shorted together; x0 floating***		
	HV Windings			***LV Windings***					
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**	**Test 7**	**Test 8**	**Test 9**
Delta-Wye	H1-H3	H2-H1	H3-H2	X1-X0	X2-X0	X3-X0	H1-H3	H2-H1	H3-H2
Wye Delta	H1-H0	H2-H0	H3-H0	X1-X3	X2-X1	X3-X2	H1-H0	H2-H0	H3-H0
Delta-Delta	H1-H3	H2-H1	H3-H2	X1-X3	X2-X1	X3-X2	H1-H3	H2-H1	H3-H2
Wye-Wye	H1-H0	H2-H0	H3-H0	X1-X0	X2-X0	X3-X0	H1-H0	H2-H0	H3-H0

Table 3 - Two Winding Transformers

7.6 Three Phase Autotransformer

A three phase autotransformer may have a single common neutral (H0X0) or three separable neutrals (N1, N2, N3). A tertiary winding may be present; it is tested the same way in either version of neutral bushing arrangement.

	Open Circuit Tests						***Short Circuit Tests***		
	All other bushings float						***X1-X2-X3 shorted together; H0X0 floating***		
	HV Windings			***LV Windings***					
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**	**Test 7**	**Test 8**	**Test 9**
Wye-Wye	H1-X1	H2-X2	H3-X3	X1-H0X0	X2-H0X0	X3-H0X0	H1-X1	H2-X2	H3-X3

Table 4 – Three phase autotransformer - common neutral – main windings

	Open Circuit Tests						***Short Circuit Tests***		
	All other bushings float						***X1-N1 shorted together X2-N2 shorted together X3-N3 shorted together***		
	HV Windings			***LV Windings***					
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**	**Test 7**	**Test 8**	**Test 9**

Wye-Wye	H1-X1	H2-X2	H3-X3	X1-N1	X2-N2	X3-N3	H1-X1	H2-X2	H3-X3

Table 5 - Three phase Autotransformer - neutrals separable - main windings

If the tertiary winding is brought out as three separate bushings, the corners of the tertiary delta, then three separate tests may be performed.

If only one corner of the delta is brought out, as is done for external completion of the delta winding, then only one test may be performed.

	Open Circuit Tests			***Short Circuit Tests***		
	All other bushings float			***Y1-Y2-Y3 shorted together and floating***		
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**
Single Corner	Ya-Yb			***Not applicable***		
Full Delta	Y1-Y3	Y2-Y1	Y3-Y2	H1-X1	H2-X2	H3-X3

Table 6 – Three phase Autotransformer - Tertiary Winding

7.7 Three winding transformer Ydd

Wye Delta Delta	***Open Circuit Tests – all other bushings floating***								
	HV Windings			***LV Windings***			***LV Windings***		
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**	**Test 7**	**Test 8**	**Test 9**
	H1-H0	H2-H0	H3-H0	X3-X1	X2-X1	X3-X2	Y3-Y1	Y2-Y1	Y3-Y2
	Short Circuit Tests								
	x1-x2-x3 all shorted together and floating; other bushings float			***y1-y2-y3 all shorted together and floating; other bushings float***					
	Test 10	**Test 11**	**Test 12**	**Test 13**	**Test 14**	**Test 15**			
	H1-H3	H2-H1	H3-H2	H1-H3	H2-H1	H3-H2			

Table 7 - Three Winding Transformer – Wye-Delta-Delta

7.8 Three winding transformer dYY

Delta Delta Wye	***Open Circuit Tests – all other bushings floating***								
	HV Windings			***LV Windings***			***LV Windings***		
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**	**Test 7**	**Test 8**	**Test 9**
	H1-H3	H2-H1	H3-H2	X1-X0	X2-X0	X3-X0	Y1-Y0	Y2-Y0	Y3-Y0
	Short Circuit Tests								
	x1-x2-x3 all shorted together and floating; all other bushings floating			***y1-y2-y3 all shorted together and floating; all other bushings floating***					

	Test 10	Test 11	Test 12	Test 13	Test 14	Test 15			
	H1-H3	H2-H1	H3-H2	H1-H3	H2-H1	H3-H2			

Table 8 - Three Winding Transformers- Delta-Delta-Wye

7.9 Other designs

Where transformer winding test configurations are required which are not covered in the above tables, please refer to the Doble M5100 User Guide, or other available guides, for test technique.