

Interpretation of Sweep Frequency Response Analysis (SFRA) Traces for the Earth Fault Damage which is Practically Simulated on 10 KVA Power Transformer

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Abstract—This paper presents how Earth fault damage in the transformer can be detected by Sweep Frequency Response Analysis (SFRA). The test methods used by the authors for presenting the results are described. The power transformer of rating 10 KVA, 11000 V/440 V, 3-phase, 50 Hz, Dyn11 has been specially developed in-house for carrying out SFRA testing by practically simulated various transformer damages on it. Authors have discussed here earth fault damage. Earth fault has been practically simulated on HV “U” phase winding and LV “W” phase winding separately. The result of these simulated faults are presented and discussed. The motivation of this presented work is to extend the guide line approach; there are ideas to organize database containing collected measurement results. Since the SFRA interpretation is based on experience, such databases are thought to be of great importance when interpreting SFRA response. The evaluation of the SFRA responses against guide lines and experience have to be performed and conclusions regarding usefulness of each simulation has been drawn and at last overall conclusion has also been drawn.

Index Terms—Earth fault damage, Power transformer, Practical Simulation, SFRA traces, Transformer damages.

I. INTRODUCTION

SWEEP Frequency Response Analysis (SFRA) testing has become a valuable tool for verifying the geometric integrity of transformers. instructions.

When SFRA provides internal diagnostic information using nonintrusive procedures. The SFRA test method has been proven to provide accurate and repeatable measurements To established the guide line for the understanding the electrical parameter that govern the shape and features of the SFRA responses based on the experience from various data collected from the field and case studies can be utilized to analyze the experimental results. Identifying known fault conditions provides an analysis tool. On the other hand, having a known expectation of how “healthy” SFRA results

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behave can also provide a similar benefit. Since the majority of SFRA results do not indicate problems, it is easy to collect large populations of data and identify common characteristics.[1]

The comparison categories for the analysis are as follows:

- General observation for overall winding transformer measurements. Defining various properties for high voltage windings, low voltage windings, inter windings, series windings, and common windings.
- Comparisons of previous test results, sister units, and phases.
- Winding configuration: Delta and Star.
- Influence of testing error: open circuits, short circuits, and poor measurement ground. [1]

II. TRANSFORMER DESCRIPTION

Application:	Test Transformer
Capacity:	10 KVA ONAN
High Voltage Winding:	11000 V Delta Connection with a 10 taps NLTC
Low Voltage Winding:	440 V Star Connection

III. SFRA TESTING

Preparation: The Transformer to be tested must be completely isolated from the power system. This requires that all bushings of all windings be connected from any bus and insulators. This ensures that measurements are not adversely affected by interference.

Connections: Generally, an SFRA measurement is made from one terminal on the transformer (e.g. H1 (or U) or A) to another terminal (e.g. H2 (or V) or N). It is important to record all relevant information, which includes tap position, oil level and terminals grounded or shorted.

Where previous test results exist, the best testing procedure is to repeat those tests, taking note of tap position, shorted or grounded bushings, and any details for specific tests.[2]

IV. TYPES OF MEASUREMENTS

Open Circuit (End-to-end open circuit)

An open circuit measurement is made from one end of a winding to another with all other terminals floating. For example, for a delta winding, connections would be H1 to

H2 (or U to V) and for a star winding, measurements are taken from HV terminals to neutral, such as X1 to X0 (or U to N)

Short Circuit (End-to-end short circuit)

A short circuit measurement is made with the same SFRA test lead connections as an open circuit measurement, but with the difference that another winding is short circuited. To ensure repeatability, the three voltage terminals on the shorted winding be shorted together. This would mean, for example, shorting X1 to X2, X2 to X3 and X3 to X1 (or U to V, V to W and W to U). This ensures that all three phases are similarly shorted to give a consistent impedance. Any neutral connections available for the shorted winding should not be included in the shorting process.

Table-1 gives the recommended tests with position of the red lead and black lead clearly identified. Reversing these test leads may provide small variation in higher frequency response. Therefore, care should be taken for attaching test leads appropriately.[2]

TABLE I
TWO WINDING TRANSFORMERS – 9 Tests

Test Type	Test	3Ø Delta – Wye Transformer	
		Red Lead of SFRA Test Kit	Black Lead of SFRA Test Kit
HV LV Open	Test 1	U	V
	Test 2	V	W
	Test 3	W	U
HV LV Short	Test 4	U	V
	Test 5	V	W
	Test 6	W	U
LV HV Open	Test 7	U	N
	Test 8	V	N
	Test 9	W	N

Two other investigative tests, i.e. Capacitive Inter-Winding measurement and Inductive Inter-Winding measurement can also be performed.

The choice of the list of the tests to perform should be adjusted depending on the purpose of the measurement.

To obtain benchmark test values for future comparison or for general condition assessment, the four main FRA test types presented above should be performed. If the test involves a winding with regulation (tap winding) the measurements should be performed at maximum tap. If there are limitations on the time available to perform all the tests, it is recommended to perform only the end-to-end tests on all windings. [4]

V. PRACTICAL SIMULATION OF EARTH FAULT DAMAGE

The power transformer of rating 10 KVA, 11000 V/440 V, 3-phase, 50 Hz, Dyn11 as shown in Fig. 1 has been specially developed in-house for carrying out SFRA testing by practically simulated earth fault damage on it. Earth fault has been practically simulated on HV “U” phase winding and LV “W” phase winding separately.



Fig. 1 10 KVA, 11000 V/440 V, 3-phase, 50 Hz, Dyn11 Power Transformer

Before doing practical simulation of transformer damages, first SFRA Testing has been carried out on healthy condition of the transformer. The SFRA Traces of this testing would be utilized as base line or previous data. The SFRA traces for the healthy condition of the transformer are shown in Fig. 2 to Fig. 4

Note : 1. For HV Delta connected winding, Red color indicates frequency response of U phase (1U 1V), Yellow color for V phase (1V 1W) and Blue color for W phase (1W 1U) in Figures 2, 3, 5, 6, 8 & 9.

2. For LV Star connected winding, Red color indicates frequency response of U phase (2U 2N), Yellow color for V phase (2V 2N) and Blue color for W phase (2W 2N) in Figures 4, 7 & 10.

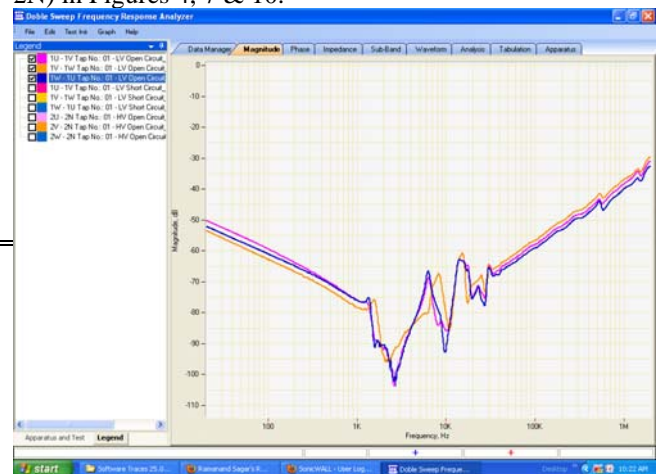


Fig. 2 HV LV Open – Healthy Condition

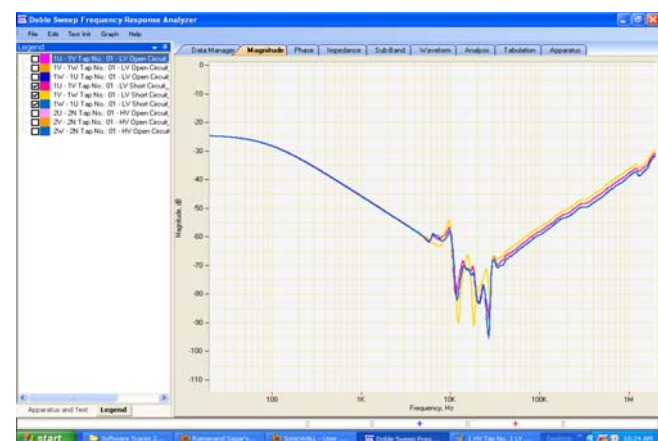


Fig. 3 HV LV Short – Healthy Condition

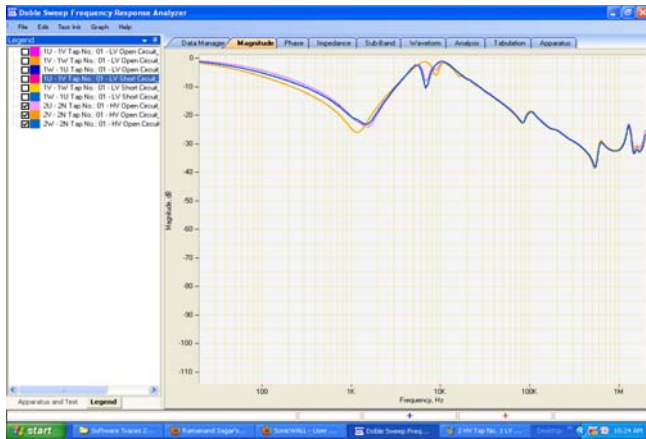


Fig. 4 LV HV Open – Healthy Condition

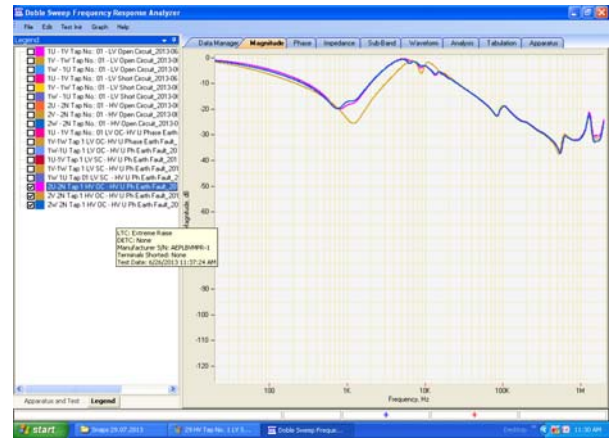


Fig. 7 LV HV Open - 1U Earth Fault

(A) HV “U” phase Earth Fault (i.e. 1U Earth Fault)

All 9 tests have been performed for practically simulated earth fault on HV “U” phase winding of the power transformer. The earth fault was applied practically at the terminal of HV U Phase of the power transformer. The Combination of SFRA responses of all 9 tests are shown in Fig. 5 to 7.

SFRA Data Analysis for 1U Earth Fault

Data analysis is performed on three phase comparison basis and following points are analyzed.

HV LV Open: Measured open circuit frequency responses of three phase of HV (11 KV, Delta) winding are shown in Fig. 5

It is clear from the Fig. 5 that there is a huge difference in the starting dB value of all the three phase responses.



Fig. 5 HV LV Open - 1U Earth Fault

- The starting dB value of open circuit SFRA response of “U” Phase (1U 1V) is -45 dB and have many disturbances at low frequency and also absence of core resonance at low frequency. No disturbances occur at high frequency. The overall response of phase “U” shows that it has problem.
- The starting dB value of SFRA response of “ V” Phase (1V 1W) is -62 dB. The first low frequency inductive resonance occur at 2 kHz frequency, then further resonances occurs at 6 khz to 30 khz frequency and after that no disturbances occur at high frequency. The overall response of phase “V” shows that Phase “V” is normal.

The starting dB value of SFRA response of “W” phase (1W 1U) is -92 dB and have many disturbances up-to 50 kHz frequency. The first core resonance in the low frequency is absent. No disturbances occur at high frequency. The overall response of phase “W” shows that it has problem.

HV LV Short Circuit : Measured short circuit frequency responses of three phase of HV winding are shown in Fig. 6 It is clear from the Fig. 6 that there is a huge difference in the starting dB value of all the three phase responses.

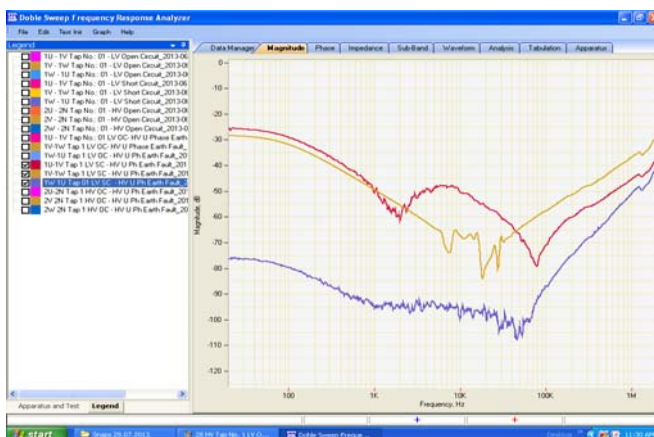


Fig. 6 HV LV Short Circuit - 1U Earth Fault

- The starting dB value of short circuit SFRA response of “U” Phase (1U 1V) is -25 dB. It consist many disturbances up to 80 kHz. No disturbances occur at high frequency. The overall response of phase “U” shows that it has problem.
- The starting dB value of short circuit SFRA response of “V” Phase (1V 1W) is -28 dB. It is clear that there is no disturbances in the response through the frequency range from low frequency

to high frequency. The overall response of phase “V” shows that Phase “V” is normal.

- The starting dB value of short circuit SFRA response of “W” phase (1W 1U) is -75 dB. It consist of many disturbances up-to 60 kHz frequency. No disturbances occur at high frequency. The overall response of phase “W” shows that it has problem.

LV HV Open : Measured open circuit frequency responses of three phase of LV (440 V, Star) winding are shown in Fig. 7

It is clear from the Fig. 7 that the two out side winding (U & W Phases) have the same general shape, while the inside winding (V Phase) is slightly displaced to the right at frequency 800 Hz to 6 kHz. Then after all three responses have the same shape and fall almost perfectly on top of each other after 10 kHz frequency. The overall open circuit frequency response of all the three phases of LV winding is normal.

Conclusion from Data Analysis:

LV Winding : Based on the above SFRA data analysis it is concluded that LV winding is ok.

- HV Winding :
1. Based on the above SFRA data analysis it is concluded that the transformer has developed HV “U” Phase Earth Fault.
 2. Due to HV “U” Phase Earth Fault, the measured open circuit frequency response and measured short circuit frequency response of HV winding shows the problem exist in HV U and W phase.
 3. The HV winding is delta connected. The earth fault has taken place at HV U phase and due to delta connected winding, it shows its effect on HV W phase also.

(B) LV “W” phase Earth Fault (i.e. 2W Earth Fault)

All 9 Tests have been performed for practically simulated earth fault on LV “W” phase winding of the power transformer. The earth fault was practically applied at the terminal of the LV W phase of the transformer. The Combination of SFRA responses of all 9 tests are shown in Fig. 8 to 10.

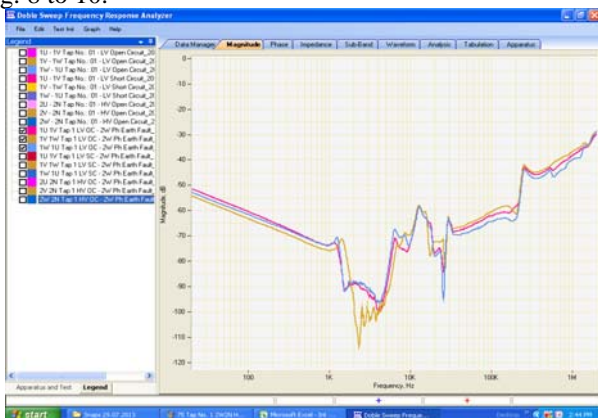


Fig. 8 HV LV Open – 2W Earth Fault

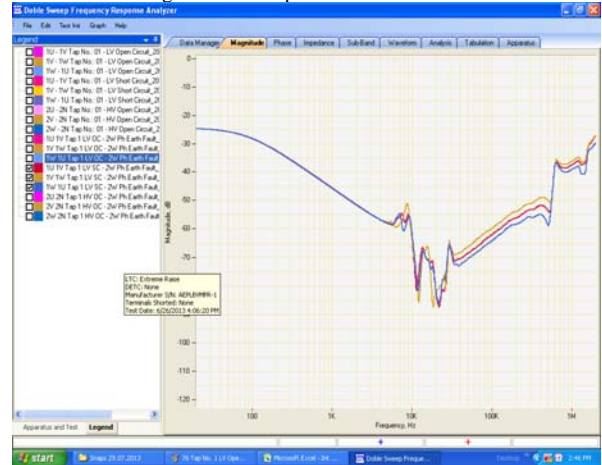


Fig. 9 HV LV Short Circuit – 2W Earth Fault

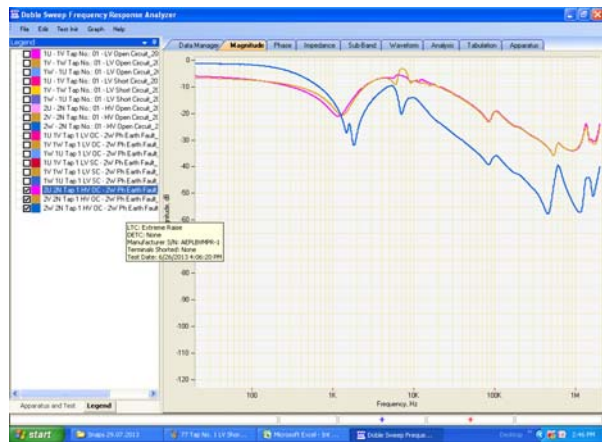


Fig. 10 LV HV Open – 2W Earth Fault

SFRA Data Analysis for 2W Earth Fault

Data analysis is performed on three phase comparison basis and following points are analyzed.

HV LV Open : Measured open circuit frequency responses of three phase of HV (11 KV, Delta winding) are shown in Fig. 8

It is clear from the Fig. 8 that the open circuit frequency response of all the three phases of HV winding are similar and having the same general shape as delta connected winding has.

HV LV Short Circuit : Measured short circuit frequency responses of three phase of HV winding are shown in Fig. 9 It is clear from the Fig. 9 that the short circuit responses of all the three phases of HV winding are similar and having the same general shape.

LV HV Open : Measured open circuit frequency responses of three phase of LV winding (440 V, Star) are shown in Fig. 10

It is clear from the Fig. 10 that the response of W phase (2W 2N) is different than the other phases and other phases appear to be normal. The starting dB value of phase W is -1.5 dB whereas starting dB value of other phases (U & V) is -7 dB. The impedance value of phase V is lower in low

frequency range (up to 1.2 kHz) and high in medium & high frequency range as compared to the other phases (U & V). It can happen if the SFRA signal is getting earth fault path.

Conclusion from Data Analysis:

Based on the above SFRA data analysis it is concluded that transformer has developed earth fault in W phase of LV winding.

VI. CONCLUSION

We can conclude from the above practically simulated earth fault damages that the nature of the SFRA traces related to an earth fault depends on the connection of the winding, i.e. winding is Delta connected or Star connected.

When transformer has developed earth fault in one phase of the delta connected winding, then following points are analyzed.

- There is a huge difference in the starting dB value of the three phase open circuit frequency responses. (In our case, it is -45 dB, -62 dB and -92 dB respectively)
- There is also a huge difference in the starting dB value of the three phase short-circuit frequency responses. (In our case, it is -25 dB, -28 dB and -75 dB respectively)
- The open circuit and short-circuit frequency responses shows the disturbances at low frequency in the two phases even though the earth fault has been developed at one phase.

When transformer has developed earth fault in one phase of star connected winding then following point is analyzed.

- The open circuit frequency response of that phase shows that the impedance value of it is lower in low frequency range and high in medium & high frequency range as compared to the other healthy phases.

It is possible to identify Earth Fault by other conventional method like Tan Delta, Exciting Currents, Insulation Resistance, TTR, etc. SFRA when used in conjunction with other diagnostic tools can provide a complete condition assessment of the transformer.

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