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Winding Fault Detection in Power Transformer by SFRA with DOBLE M5100

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Abstract

The Doble M5100 is a robust and field proven instrument for detection of hidden fault in Power Transformer uses technique called Sweep Frequency Response Analysis (SFRA). SFRA is a tool that can give an indication of core or winding movement in Power Transformer this is done by performing a measurement, albeit a simple one, looking at how well a transformer winding transmits a low voltage signal that varies in frequency, Just how well the transformer does this is related to its impedance, the captive and inductive elements of which are intimately related to physical construction of transformer, Changes in frequency response as measured by SFRA technique may indicate a physical change inside the transformer, the cause of which then need to be identified and investigated. M5100 allow us to see inside the transformer and detect even suitable changes in the mechanical structure of the core and winding.

Keywords*: DOBLE M5100, SFRA, Power Transformer, Winding Fault.*

Introduction

A typical power system has many important and expensive types of equipment in it; a power transformer is one of the most important of them. SFRA is a powerful method for the detection and diagnosis of the defects in the active part of power transformers. It can deliver valuable information about the mechanical as well as electrical condition of core, windings, internal connections and contacts. No other single test method for the condition assessment of power transformers can deliver such a diversity of information. Therefore it is an increasingly popular test & value of fingerprint data is more and more recognized by users all over the world. Comparing the time and frequency domain FRA test methods is seems to be obvious the SFRA, measuring directly in frequency domain, prevailed. Reproducibility is the key for a successful application of SFRA. [1].

The other diagnostic techniques comparing the key advantages of FRA are its proven sensitivity to a variety of winding faults on previous reference measurements, but there is a need for an objective and systematic interpretation methodology. [2]

Sweep Frequency Response Analyzer

The SFRA test is non-destructive test. SFRA is an Off-Line testing and it can be carried out for any voltage rating of Power Transformer. The measurement of SFRA can be a part of regular transformer maintenance & the following abnormalities in the transformer before they lead to failure.

- Transformers are subject to immerse stress during service- impact, nearby or internal faults overloads.

- These stresses may cause winding deformation, Winding movement or core damage
- Allowing a transformer to enter service without detecting these types of problem is risking catastrophic failure of the transformer
- SFRA aids detection and permits diagnosis in a timely manner.

SFRA technique is a major advance in transformer condition monitoring analysis. This is a proven technique for making accurate and repeatable measurements.

- To obtain initial signature of the transformer sweep frequency response as a record for the future reference/ comparisons.
- Immediately after a major external short circuit, especially for faults electrically closer to transformer.
- Transportation or re-location of transformer.
- Earthquakes.[3]

Principal operation of SFRA

The deregulation of the electric power market involves increasing of economic pressure which requires a reduction in servicing and decreasing maintenance costs. On the other hand, we face aged and aging transformer fleets operating with increasing loads [4] all over the globe. Therefore, the diagnosis of this apparatus becomes more relevant in general but especially for strategically important or particularly risky transformers. In the last few years a fast-paced technical development regarding various aspects of measurements, data acquisition and analysis has taken place across the world. This is usually done by injecting a low voltage signal of variable frequency into one terminal of a transformers winding and measuring the response signal on another terminal (see fig. 1). This is performed on all accessible windings following according guidelines. The comparison of input and output signals generates a frequency response which can be compared to reference data.

The core-and-winding-assembly of power transformers can be seen as a complex electrical network of resistances, self-inductances, ground capacitances, coupling inductances and series capacitances as schematically (shown in figure 2) the frequency response of such a network is unique and, therefore, it can be considered as a fingerprint.

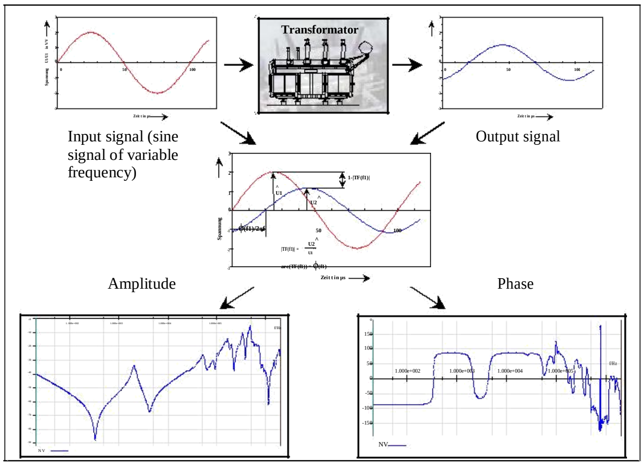


Figure 1: Principle operation of SFRA

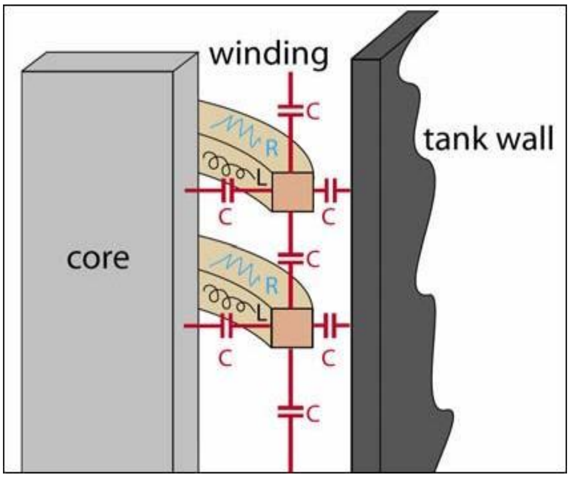


Figure 2: simplified network behavior of a transformer's active part

Geometrical changes within and between the elements of the network cause deviations in its frequency response. Differences between an FRA fingerprint and the result of an actual measurement are an indication of positional or electrical variations of the internal components. Different failure modes affect different parts of the frequency range and can usually be discerned from each other. Practical experiences as well as scientific investigations show that currently no other diagnostic test method can deliver such a wide range of reliable information about the mechanical status of a transformer's active part.

Test Setup & Connection

The M5100 SFRA instrument performs of line testing only. Therefore, its test connections are made to a transformer that has been safely grounded and isolated from the power system.

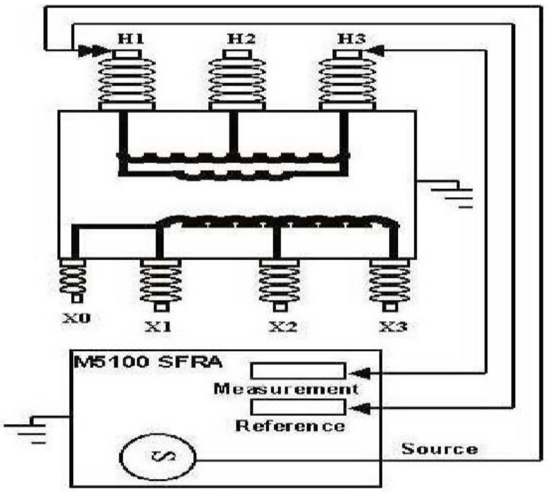


Figure 3:M5100 SFRA Instrument test connections

The above figure 3 shows the test connections for a typical transformer under test. Three cables are connected from the instrument to the bushings of the winding under test H1 & H3. The output of the instrument, a variable frequency excitation source is connected to the H1 bushing, along with the reference cable, by a single termination clamp. A measurement cable, the third connection is clamped on the return side of the windings bushing (H3) to measure any attenuation or phase shift as referenced to H1.The M5100 SFRA instrument outputs a 10 volt peak to peak waveform that will vary in frequency, at a control rate from a range of 10 Hz to 10 MHz in five selectable bands. The transfer function models the distributive RLC network of the transformer and determines its frequency dependent response. The M5100 SFRA instrument compares the signal into the specimen to the signal output & calculates attenuation and phase shift for all frequencies. A test for each of the windings can be performed and compared from winding to winding or from similar transformer to provide a reference for analyzing the test result.

Measuring Principal

The behavior of transformer winding response reflects e.g. electromagnetic couplings between the winding and transformer tank, also between the primary and secondary winding, between the windings of particular phases or between turns themselves of particular windings. The power transformer measurement requires a setting up of the frequency range from 10 Hz to 2 MHz, whereas there is necessary to follow the right measuring technique to prevent various inaccuracies and faults. According to [5] and [6], measuring technique of three- winding autotransformer 400/121/34 kV (Fig.4) is as follows (see Tab.1).

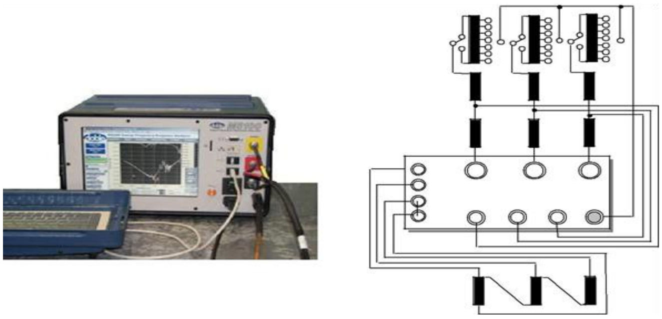


Figure 4: The three- winding autotransformer 400/121/34 kV tested by SFRA before its activation

Table 1: Measuring technique of three- winding autotransformer

Open Circuit Tests								
400 KV			121 KV			34 KV Tertiary Winding		
Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9
A-a	B-b	C-c	a-n	b-a	c-a	t3-t1	t1-t2	t2-t3

Short Circuit Tests								
a-b-a Short Circuited			t1-t2-t3 Short Circuited			t1-t2-t3 Short Circuited		
Test 10	Test 11	Test 12	Test 13	Test 14	Test 15	Test 16	Test 17	Test 18
A-n	B-n	C-n	A-n	B-n	C-n	a-n	b-n	c-n

During the open circuit tests a mechanical condition of tested winding and ferromagnetic core is detected. The following curves typical for this measurement provide us important information about changes in the core, which are visible in low frequencies, while higher frequencies refer to problems such as winding movements or turn-to-turn fault. Fig.5 illustrates a simulation of gradual increase of turn-to-turn faults via open circuit test on auto-transformer 400/121/34 kV (see Fig. 4) at transformer taps of 1, 9, 13 and 17.

The application of analysis of phase attenuation depending on frequency is suitable for more complete evaluation of winding condition. This analysis enables to assess the processes of winding movements during the particular short-circuits influences.

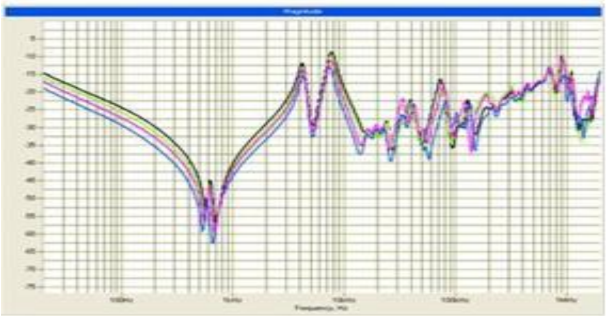


Figure 5: Simulation of turn-to-turn fault increase by open circuit test on auto transformer at transformer taps of 1, 9, 13 and 17

Problems with core grounding or shorted laminates in the core will typically change the shape of the lowest section of the curve (to 10 kHz). Mid frequencies (from 10 kHz to 200 kHz) represent axial or radial movements in the windings and high frequencies indicate problems such as e. g. winding knocking or problems with contacts. During the short circuit tests only the winding condition in primary or secondary part of trans-former is detected. This measurement notifies reliably of deformation of inner winding and its movement as a result effects of short-circuit currents.

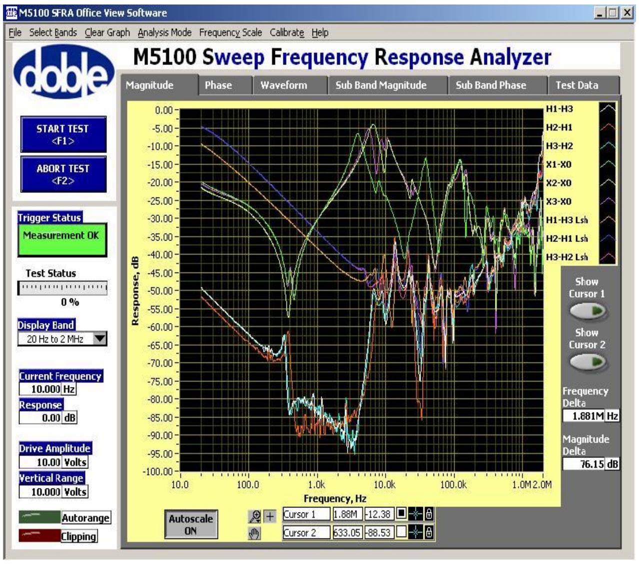
By comparing future traces with baseline traces, the following can be noted.

Table 2:

Comparison of Future Traces with Base Line Traces	Nature of Problem / Fault
The traces will change shape and be distorted in the low frequency range(under 5,000 Hz)	Core Problem
The traces will be distorted and change shape in higher frequencies (above 10,000 Hz)	Winding Problem
Changes of less than 3 decibels (dB) compared to baseline traces.	Normal and Within tolerances.
From 5 Hz to 2 kHz changes of +/- 3 dB (or more)	Shorted turns, Open circuit, Residual magnetism, or Core Movement.
From 50 Hz to 20 kHz changes of +/- 3 dB (or more)	Bulk movement of windings relative to, each other.
From 500 Hz to 2 MHz changes of +/- 3 dB (or more)	Deformation within a winding.
From 25 Hz to 10 MHz changes of +/- 3 dB (or more)	Problems with, winding leads and/or, test leads placement.

Note that there is a great deal of overlap in frequencies, which can mean more than one diagnosis.

Figure 6 shows traces of a transformer with a problem. The traces have the same general positions on the graph as the good transformer. The lower traces are high voltage winding tests, while the upper traces are the low voltage winding tests. Note in the higher frequencies of the low voltage traces that “A” phase (X1-X0 green trace) is displaced from the other two phases more than 3 dB from about 4 kHz to about 50 kHz. With a healthy transformer, these would fall almost on top of each other as the other two phases do. Also notice that “A” phase (H1H3Lsh) is displaced in the test with the low voltage winding shorted. There is an obvious problem with “A” phase on the low voltage side. After opening the transformer, it was found that the “A” phase winding lead had burned off near the winding connection and re-welded itself on the winding at a different location, effectively shorting out a few turns. The transformer was still working, but hot metal gases (ethylene, ethane, methane) were actively generating and showing up in the DGA. Although other tests could have revealed this problem, SFRA showed the problem was with “A” phase and, therefore, where to concentrate the internal inspection. [7]



Trigger Status: Measurement OK

Test Status: 0 %

Display Band: 20 Hz to 2 MHz

Current Frequency: 10.000 Hz

Response: 0.00 dB

Drive Amplitude: 10.00 Volts

Vertical Range: 10.000 Volts

Frequency Delta: 1.881M Hz

Magnitude Delta: 76.15 dB

Cursor 1: 1.88M -12.38

Cursor 2: 633.05 -88.53

Figure 6: SFRA Traces of a Defective Transformer [7]

Application of SFRA

The evaluation of transformers transportation is an increasingly popular application of the SFRA method. This is reasonable due to the ability of SFRA to provide in-depth information about the core, the windings and the clamping structures, as well with one set of tests. All these parts are susceptible to transportation damage.

Usually the transformer will be equipped with bushing cover plates or transport bushings, which is strongly recommendable to facilitate testing, and without oil. Thus it is obvious that normal baseline data from factory or on-site fingerprint tests cannot be used for this purpose because the results will differ from each other. On the other hand it must be noted that transportation test results usually cannot be used as based line data for future tests in operational condition.SFRA is a comparative measurement method. This means results of an actual test – usually a set of curves (mainly the amplitude in dB's over the frequency) representing all windings of a transformer as separate as possible – are compared to reference or baseline data. Three methods are commonly used to assess the measured traces:

1. Time-based (current FRA results will be compared to previous results of the same unit)
2. Type-based (FRA of one transformer will be compared to another of the same design)
3. Phase comparison (FRA results of one phase will be compared to the results of the other phases of the same transformer) (1)

Conclusion

Sweep Frequency Response Analysis is a powerful tool for use in analyzing transformer health and mechanical integrity. It has proven value in the field and factory, As indicated in the case study given here. From the long term point of view the SFRA method supposed to be very useful and its provide enough information on tested transformer.

The DOBLE M5100 test instrument produces reliable, robust and repeatable results. These cover the full range necessary to make transformer health diagnose rating to the core, the winding in the tap changer. The DOBLE M5100 SFRA test set is vital tool for today's Engineer.

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