

SFRA Method - Frequency Analysis of Transformers

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Abstract. *This article deals with a description of methods of an experimental analysis concerning the actual condition of windings and magnetic circuit of the transformer, which is required in power distribution companies all over the world.*

Keywords: *transformer, frequency analysis, measurement methods*

1. Introduction

Considering a significance of power transformers in the electric system, their price and possible damages arising in accidents, it is necessary to pay attention to higher prevention of these devices. Windings of power transformers should be designed to avoid various mechanical or thermal deteriorations caused by short-circuit currents occurring in operation.

Besides the permanent deformation effects of short-circuit current, there is also gradual aging process of the electrical device, which can worsen its mechanical properties. Heat shocks can cause decrease of mechanical strength of transformer and consequent unexpected damage of transformer during the operation.

To prevent a damage state of transformers, we perform different types of the measurements that should illustrate an actual condition of the measured equipment. It is therefore important to choose a suitable diagnostics for the right prediction of such conditions.

2. Theory of SFRA method and its importance in transformer diagnostics

SFRA method belongs to current most effective analyses and allows to detect the influences of short-circuit currents, overcurrents and other effects damaging either winding or magnetic circuit of the transformer. This all can be performed without a necessity of decomposition of device and subsequent winding damage determination, which is very time consuming.

The method of the high-frequency analysis (Sweep Frequency Response Analysis – SFRA [2]) is also one of the methods of undisassembling diagnostics of transformers. No intervention to the construction of tested device is demanded, the whole measurement is performed on detached device (not under the voltage). This method is applicable mainly for determination and measuring immediately after the manufacturing of device, i.e. for measuring of reference values. These parameters are consequently compared to the other measurements performed on the transformer, which is decommissioned, after the damages or revisions of transformer etc.

There is possible to detect by SFRA:

- a deformation of winding and its movements or a partial breakdown of winding,
- a short-circuited turn or opened winding,
- a loose and a damaged switching system,
- a core connection problem and a core movement or its wrong grounding.

Results measured on the new transformer can be used as the reference parameters for further comparison with values measured later after certain operation time of the transformer. They can be also compared with the test results performed after the transformer breakdown (or after the n-short-circuits) or repair or it can be used as a diagnostic test, when vibration sensors indicate some potential problem in transformer.

According to [3] SFRA method determines the transformer responses in a time or frequency area. The time response measurement provides curve determination of the time response to the specific voltage impulse applied to winding input connection. The frequency response measurement consists in determination of amplitude eventually phase response to the harmonic voltage of variable frequency applied to winding input. While the time response is the record of time behavior of voltage, frequency response is the amplitude response dependence on frequency.

A relation between the response and the winding condition is definite, otherwise it is complicated. It is impossible to expect the assessment of concrete damage of winding from differences in response behaviors. The measurement results lead us only to a statement of the fact that some change of winding condition really occurred. Such test results are very helpful to decide, whether it is unavoidable to open and revise the transformer or not.

3. Measuring principles

The frequency response characteristics of windings can be obtained using either the impulse frequency response analysis (IFRA) method in the time domain or the sweep frequency response analysis (SFRA) method in the frequency domain [4]. In principle the two methods give the same results if the same connection method is used. However a frequency domain measurement using a method which records the ratio of the input and output voltages over the frequency range by using a sequence of narrow band spot measurements has been found to be particularly suitable for obtaining measurements in an electrically noisy environment. Making a series of narrow band measurements increases the signal to noise ratio and the dynamic range available. Measuring only at the exciting frequency also prevents any non-linearity of the test object (not usually a problem at the small signal levels employed) from affecting measurements at different frequencies. The measurement using this technique is conveniently made using a network analyser or similar instrument. This produces a frequency-varying sinusoidal voltage signal, applied to one terminal of the test winding with the input voltage being measured by a separate cable at that terminal and the response to this input measured at another terminal.

The three FRA measurements (SFRA or IFRA) connection methods most commonly employed in the industry are chosen for comparison [4]. These FRA connection methods are identified as:

- a) End-to-end voltage ratio measurement (FRA_{ee})
- b) Input admittance measurement (FRA_{ad})
- c) Transfer voltage ratio measurement (FRA_{tr})

FRA measurements can be expressed using terminal voltages and currents as shown in Fig. 1. All measuring cables are terminated with matching impedance of the cable, R_c (typically 50 Ω) and the winding terminal voltages are measured across R_c as shown in Fig. 1. For input admittance measurement, a resistive impedance r (typically $r = R_c$) is used to measure the input current.

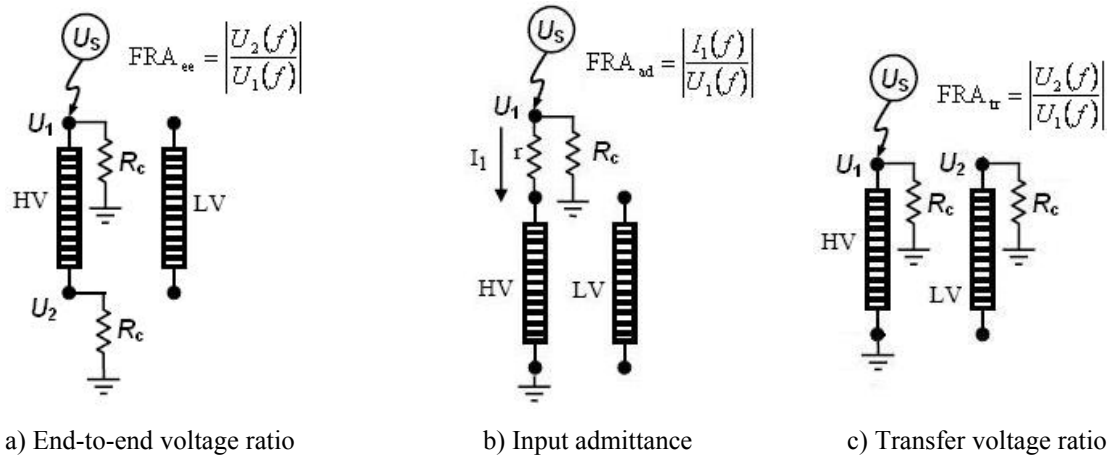


Fig. 1. Test connection for FRA (SFRA or IFRA) measurements.

4. Behaviors of transformer winding responses by SFRA method

The behaviour of transformer winding response reflects e.g. electromagnetic couplings between the winding and transformer tank, also between the primary and secondary (eventually tertiary) 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 (Fig. 2), whereas there is necessary to follow the right measuring technique to prevent various inaccuracies and faults. Input parameter of measuring system is voltage with value 10 V and its output parameter is current response (0÷90 dB) to change impedance for respective default frequency.

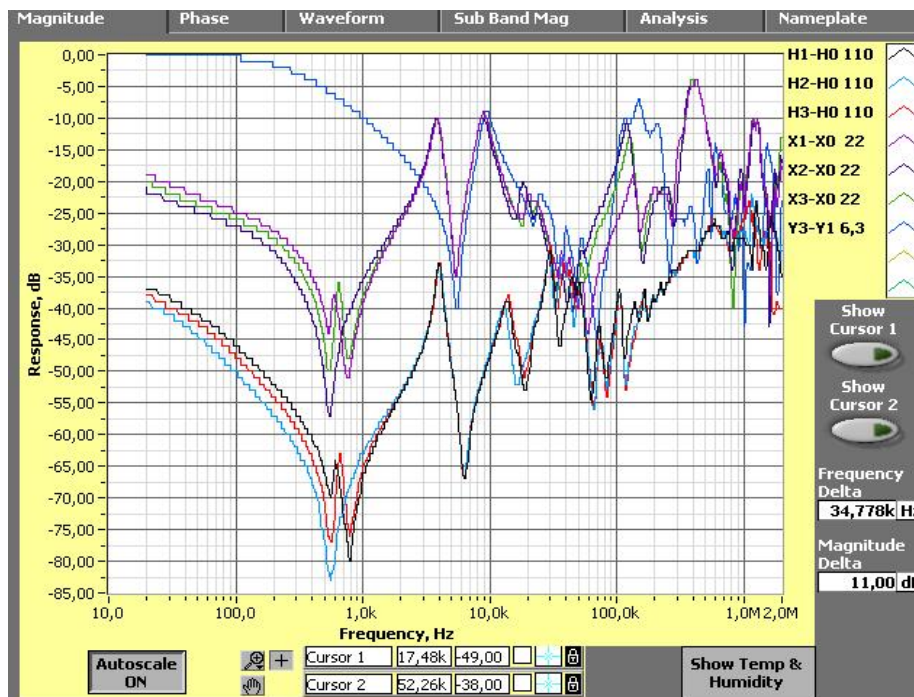


Fig. 2. Magnitude Chart of three-winding transformer by M5100 measuring system

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.

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.

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 transformer is detected. This measurement notifies reliably of deformation of inner winding and its movement as a result effects of short-circuit currents.

5. Conclusions

Problem of the frequency analysis of transformers by SFRA method is very comprehensive and its application becomes interesting for many transformer manufacturers and operators. From the long-term point of view the SFRA method is supposed to be very useful and it provides enough information on tested transformers. These transformers have their reference data obtained by the manufacturers, suitable for the comparison with further data of particular transformer.

SFRA testing method represents one of the most effective alternative diagnostic methods compared to visual check. This method allows to detect the effects of the short-circuit currents, whereas we are able to evaluate the mechanical strength action on the transformer winding during previous operation. It is also possible to identify the specific winding phase, which has been mostly influenced by the short-circuit currents, without a necessity of transformer dividing, which would be very time consuming.

There is also possible to identify the size of parameters of other electric machines as well as the position of their resonance frequency from particular curves (analysis of damage winding).

Acknowledgements

This work was supported by the Grant Agency VEGA from the Ministry of Education of Slovak Republic under contract 1/0548/09.

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