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IMPACT OF REMANENT MAGNETIZATION IN THE AREA OF DISTRIBUTION TRANSFORMERS DIAGNOSTIC BY SFRA METHOD

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ABSTRACT: *The paper deals with the influence of core magnetization on its frequency response analysis. Remanent magnetization is a characteristic property of ferromagnetic materials. The core cans acquire different value of remanent magnetization in the process of diagnostic measurements. This fact is very important from the point of view of good representation of results from measurements. In the past, we made a couple of measurements on 3-phase dry transformer (3000VA). Nowadays, we had the possibility to measured 25MVA distribution transformer by SFRA method. This transformer has been connected in the network before the measurement and we have also results of measurements they were done one year before. That time the transformer was out of the operation for 9 months, so we have an anticipation to see some differences.*
KEYWORDS: *SFRA, remanent, magnetization, transformer, diagnostic, core*

INTRODUCTION

The principle of SFRA (sweep frequency response analysis) is recording of responses to an input signal. Input signal has a sinusoidal shape and a variable frequency. For each frequency, measured winding of the transformer has its unique impedance. The impedance of transformer consists of the net of many resistances, capacitances and inductances. The distances between the parts of the transformer have also influence on particular capacitances. Therefore, we are able to identify mechanical changes in the transformer by using the SFRA. It is an advance method of transformer diagnostic without its removal. It is convenient to apply SRFA analysis of distribution transformer during routine measurements, when it is disconnected from a network. The transformer should also be submitted to SFRA after its manufacturing, transport, or after some fault situations.

It is common to entitle SFRA as an impedance measurement. Is possible to detect following defects of the transformer with SFRA:

- deformation of winding and its dislocation,
- interturn short-circuits, open winding,
- fault in a tap changer,
- core movement or its bad grounding [1, 2, 3,7].

In order to evaluate results from a SFRA test correctly, it is necessary to know about any possible influences to impedance measurements. From a theory of an electromagnetic field it is known that state of core magnetization level should has an influence on the inductance of windings. The best way to confirm this theory is to compare results from two impedance measurements, which were made under different conditions of core magnetization.

THEORY. Transformer core magnetization

The inductance of winding can be defined as:

$$L = \frac{\Psi_m}{i} \tag{1}$$

where Ψ_m is a magnetic flux linkage and i is a current flowing through the winding. In the case of the transformer, Ψ_m depends on number of turns, geometry of winding and core permeability μ according to:

$$\Psi_m = \frac{N \cdot i \cdot S \cdot \mu}{l} \tag{2}$$

The basic equations are:

$$\begin{gathered} \mu = \mu_0 \cdot \mu_r \\ B = \mu . H \\ \chi_m = \mu_r - 1 \\ M = x_m . H \end{gathered} \tag{3}$$

where μ_0 is the permittivity of a vacuum, μ_r is the relative permittivity, B is a magnetic flux density, H is a magnetic field intensity, M is a magnetization and χ_m represent a magnetic susceptibility. From above equations we can easily write a formula:

$$B = \mu_0 . (H + M) \tag{4}$$

This relation is valid for linear isotropic magnetic materials. In case of transformers, μ becomes a tensor due to the anisotropic nature of steel cores and it is also frequency dependent. In ferromagnetic materials, magnetic susceptibility varies with the magnetic field, because of hysteresis of ferromagnetic materials.

It is clear from the Figure 1, that μ_r varies in dependence of the operating point position on the magnetization curve. Therefore, inductance also depends on the operating point position on the magnetization curve. (the value of μ_r close to the saturation is lower than value of μ_r at the remanent magnetization M_r). M_r is directly proportional to a remanent magnetic flux density B_r, and it modifies equation (4) as follows:

$$B = \mu_0 (H + M) + B_r \qquad (5)$$

Magnetic flux linkage is hence greater in the case when the remanent flux density is present. It results in a higher inductance.

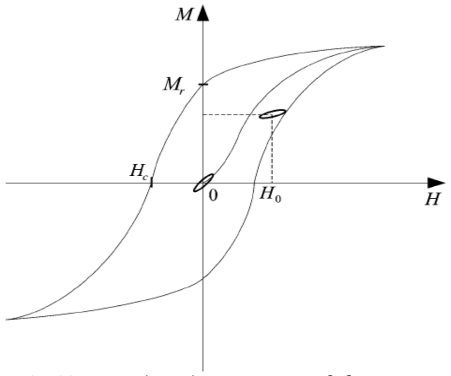

Figure 1. Magnetization curve of ferromagnetic material [5]

SFRA method uses an input voltage with small amplitude (up to 12 V) and it causes only small elliptical trajectory of M-H on the magnetization curve defined by magnetic field intensity H_0.

In the case when the magnetic field intensity is zero, inductance depends on the B_r and χ_{rev}. χ_{rev} is the reversible magnetic susceptibility and χ_a is the initial magnetic susceptibility. If the core is demagnetized, B_r is equal to zero, and $\chi_{rev} = \chi_a$, but if $B_r \neq 0$, $\chi_{rev} < \chi_a$. The relative inductance depends on the value of B_r and also on the value of χ_{rev} at a particular B_r value in comparison with the value of χ_a. [5, 8].

Magnetic viscosity

A magnetic viscosity is the time dependence of magnetization under the constant magnetic field. It is also called magnetic relaxation. The time dependent magnetization is described as:

$$M(t) = M_{irr}(t) + M_{rev}(t), \qquad (6)$$

where $M_{irr}(t)$ is the irreversible component and $M_{rev}(t)$ is the reversible component of magnetization.

The magnetic viscosity occurs in magnetic material when the magnetic field intensity is suddenly increased or decreased or completely removed. A new steady state occurs after much longer time in comparison with eddy current effects. The magnetic viscosity can therefore be expected when a power transformer is suddenly switched off from the network.

Another possible case of the core magnetization is a diagnostic measurement with applied high voltage. It can be for example measuring of an insulation resistivity, or measuring of a dissipation factor [5, 7, 8].

PRACTICAL MEASUREMENT

In [6] we made a verification of a remanent magnetization phenomenon by the means of impedance measurements of 3 kVA-dry transformer in laboratory conditions.

In this paper we concentrate on a result from measurement of distribution oil transformer with its 25 MVA of power. It is a type of transformer on which the SFRA tests used to be exercised in a practice. The first SFRA test of this transformer was carried out in the year 2011. That time, transformer was out of operation for almost 9 months. Based on the theory of the previous chapter, a value of remanent magnetization was minimal.

In 2012 the transformer was again subjected to SFRA test. Now, transformer was out of operation only for 24 hours. According to theory connected with magnetic viscosity, the level of remanent magnetization has to be of higher value in the comparison with previous test. The card entry of transformer is in Tab. 1. The comparison of waveform from these two tests is in Figure 2 to Figure 7.

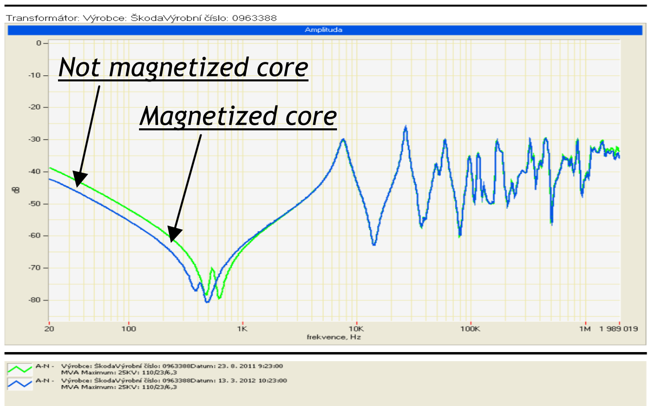

Figure 2. The comparison of phase A waveforms (open circuit test)

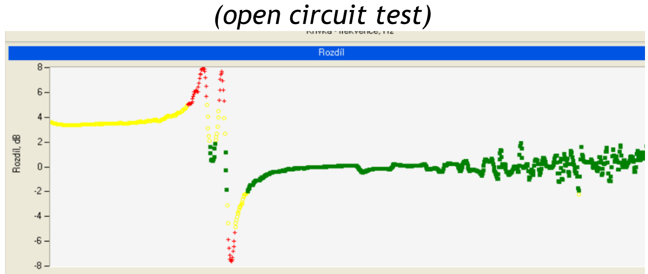

Figure 3. The cross correlation analysis of phase A waveforms (open circuit test)

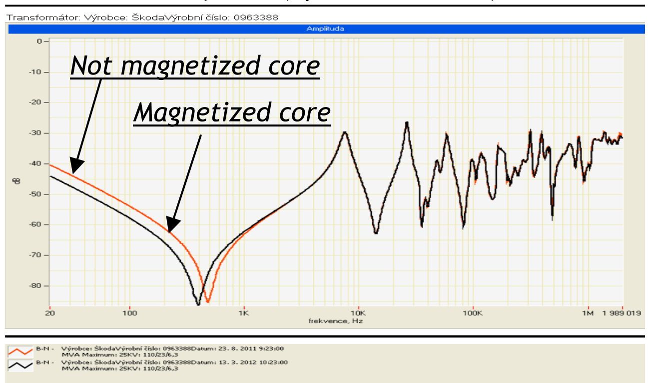

Figure 4. The comparison of phase B waveforms (open circuit test)

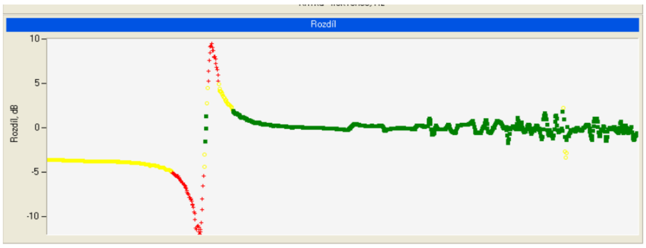

Figure 5. The cross correlation analysis of phase B waveforms (open circuit test)

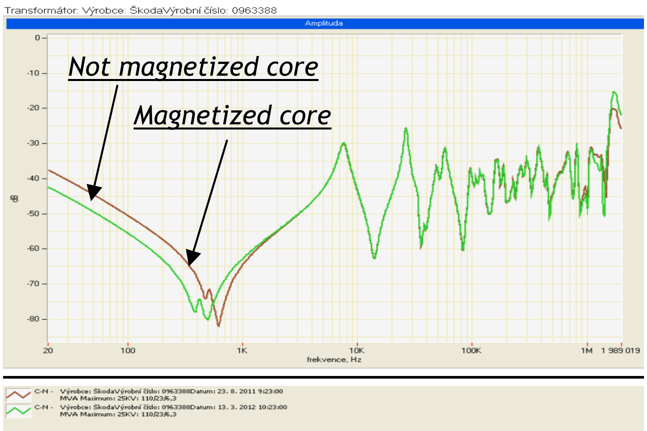

Figure 6. The comparison of phase C waveforms (open circuit test)

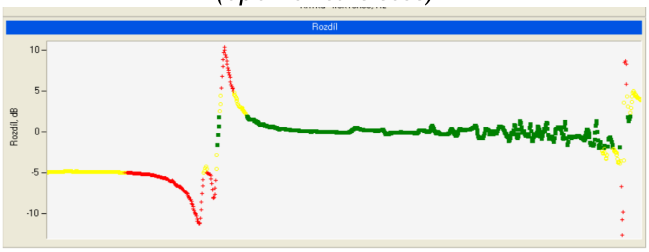

Figure 7. The cross correlation analysis of phase C waveforms (open circuit test)

We introduced only waveforms of primary phases in open circuit condition, because there is the major difference. It is known from the theory of SFRA tests, that core influence is sensible only at open circuit tests.

TABLE I. CARD ENTRY OF TRANSFORMER

Manufacturer	Škoda, v.č. 0963388
Year of manufacture	1991
Type	8ERH 31M-0
Connection	YNyn0/d
Frequency	50 Hz
Nominal voltage	110/23/6,3 kV
Nominal power	25/25/8 MVA
Position of tap switch	14
Temperature of transformer	10 °C

TABLE II. MEASURING METHODOLOGY

Open circuit tests		
Test n. 1	Test n. 2	Test n. 3
A-N	B-N	C-N

From Figure 2 to Figure 7 we can see that in waveforms for every primary winding, differences between two measurements are almost the same. In the case of three phase transformers, SFRA characteristics of phase A and C have to be the same and they have to be different from the phase B. This situation is caused by a geometrical alignment of a core and a winding. The cross correlation analysis shows a small difference between phases A and C. This should have many causations and it is probably very difficult to find it out. The important point is that there is a sensible difference between waveforms, which represent different states of the core magnetization. It is also known from the theory of SFRA, that core properties have an influence to SFRA characteristics only in low frequencies range (normally up to 1 kHz).

Figure 8. Measured transformer

CONCLUSIONS

The theoretical assumption about remanent magnetization is discussed in the introduction of this paper. The state of transformer core magnetization affects the comprehensive impedance of individual phases. This influence is sensible in a frequency range up to 1 kHz and only in the case of open circuit test. Our measurements confirm that the core magnetization depends on the time of the transformer disconnection from the network. This fact is caused by the phenomenon of magnetic viscosity.

The main aim of this paper was to advise of importance of correct SFRA test evaluation. In the case, if it this phenomenon is not considered, the shift between waveforms at low frequencies normally hints as core movement.

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REFERENCES

[1] http://www.doble.com/products/m5200_sfra.html

[2] http://imghost1.indiamart.com/data2/KF/OY/MY-557030/sfra.pdf

[3] http://ketsrv.fel.zcu.cz/diagnostika/konference/Sbornik/Sekce2/92.pdf

[4] M. Brandt, V. Mentlik, J. Michalik,: Condition assessment of oil-paper transformer insulating system., In: Journal of energy and power engineering. - ISSN 1934-8975. - Vol. 5, No. 2 (Serial No. 39) (2011), s. 173-178.

[5] N. Abeywickrama, Y. V. Serdyuk, S. M. Gubanski: Effect of Core Magnetization on Frequency Response Analysis (FRA) of Power Transformers, IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 23, NO. 3, JULY 2008, ISSN: 0885-8977

[6] J. Sedlák, R. Seewald: Influence of remanent magnetization on the diagnostic of transformer by SFRA method., Diagnostic of Electrical Machines and Materials 2th International Conference., February 8-9 2012. Papradno, Slovak Republic. ISBN 978-80-89401-69-7

[7] P. Prosr, R. Polanský, J. Piehra, P. Trnka: Influence of oil type on the oil-paper insulation properties. In: Conference on Electrical Insulation and Dielectric Phenomena. NEW YORK, USA: IEEE, 345 E 47TH ST NY, 2007, s. 77-80. ISBN 978-1-4244-1482-6. DOI: 10.1109/CEIDP.2007.4451537. Dostupné z: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4451537

[8] V. Mentlík, R. Polanský, R. Prosr: Influence of temperature aging on oxidation stability and activation energy of insulating liquids. NEW YORK, USA: IEEE, 345 E 47TH ST, NEW YORK, 2008, 546-549. ISBN 978-142442549-5; DOI: 10.1109/CEIDP.2008.4772789

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