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High frequency test measurements on physical model of power transformer with use of FRAX analyzer

Streszczenie. *W niniejszym artykule przedstawiono pomiary testowe SFRA wykonane na modelu fizycznym transformatora elektroenergetycznego 15/0,4 kV. Model fizyczny został wykonany w oparciu o transformator typu TRIHAL o mocy 250 kVA i, zbudowane na potrzeby eksperymentu, cewki z taśmy miedzianej, które symulowały uzwojenia wysokiego napięcia. Do pomiarów wykorzystano analizator FRAX 101 firmy Megger. Wykonano pomiary kalibracyjne model i testowe na w pełni sprawnym urządzeniu.* ***Pomiary testowe SFRA wykonane na modelu fizycznym transformatora elektroenergetycznego 15/0,4 kV***

Abstract*. In this paper some SFRA test measurements carried out on physical model of power transformer 15/0,4 kV are shown. The physical model of power transformer was constructed based on TRIHAL transformer with rated power 250 kVA and with build special for the experiment of copper tape coils, for simulating high voltage windings. For measurement FRAX 101 produced by Megger was used. Calibrating and test measurements were presented on fully operational device.*

Słowa kluczowe: charakterystyka częstotliwościowa, transformator, test SFRA
Keywords: frequency characteristics, transformer, SFRA test

Introduction

Transformers are one of the most vital components in transmission and distribution systems. Their life time varies from 24 to 40 years, so it is consider as a long-term investment [1]. Institute of Electrical and Electronics Engineers (IEEE) in 1998 prepared a report of transformers failures working in power system [2]. The main conclusions are:

- transformers are devices with high failure rate – for 15 years 96 distribution companies noted 152 failures
- 63% of all failures were noted during exploitation
- 20% of all failures were noted during diagnostic tests
- regular diagnostic tests allow for early detection of faults and planned withdrawal device.

In table 1 the amount and cost of transformer failures are shown. Total cost is based on the cost of property damage and cost of business interruption. The statistics were made on 94 power transformers in USA with power above 25 MVA [3].

Table 1. Amount and cost of transformer failures in USA [3]

Year	Amount of failures	Total cost [$]
1997	19	40 779 507
1998	25	24 932 235
1999	15	37 391 591
2000	20	150 181 779
2001	15	33 343 700
SUM:	94	286 628 812

The high cost and time of replacement or repair of transformers to improve the reliability of electricity distribution is very often not justified economically. This fact is the main motivation to develop new, more reliable and less time-consuming methods of diagnostics and fault detection transformers. The main and also the most expensive cause of the damage – in [3] 24 failures - are the problems associated with the insulation system and mechanical failures of the transformer core.

The FRA method, developed by Dick and Ereven [4], is suitable for very precise detection of the electrical, i.e. shorted turns or open circuit windings, and mechanical faults like winding deformations and movement, partial collapse of winding, core displacement, broken or loosened winding or clamping structure [5, 6].

Conventional analysis of FRA results is based on the graphical analysis of the frequency courses. Trained experts are needed to interpret the results and to find irregularity. Solving that problem, many studies were made to research some numerical indicators, i.e. weighted normalized difference number or correlation coefficient [7]. One of possibilities is to build an electrical circuit model of a device. Other one is to create a physical model of power transformer with movable windings. The attempt ie. to measure frequency response of power transformer for the earth fault damage was shown in [8].

Authors of this paper show a test measurements of frequency response of the physical model of power transformer with use of FRAX analyzer. Measurements were carried out in Short Circuit Laboratory in Warsaw University of Technology, Institute of Electrical Power Engineering.

Physical model of power transformer

A physical model of power transformer was built from TRIHAL transformer from 1997. The basic parameters are shown in Table 2; the picture of the transformer was shown in Fig. 1.

Table 2. Basic parameters of TRIHAL transformer used to build the physical model

Parameter	Unit	Quality
Rated power	kVA	250
Upper side rated voltage	V	21000
Lower side rated voltage	V	400
Short circuit voltage	%	6
Connection system	---	Dyn11
Production date	---	1997

Fig. 1. Photo of TRIHAL transformer [Schneider]

To build a model, first the high voltage windings were dismantled (in Fig. 2 transformer without high voltage winding and without upper yoke is presented).

Fig. 2. Picture of TRIHAL transformer without upper yoke

To simulate low voltage windings, 12 coils were produced – 4 coils for each limb. Coils were made from 30 turns of copper tape 20 mm width and 0,1 mm thickness. In Fig. 3 applied physical model of power transformer is shown.

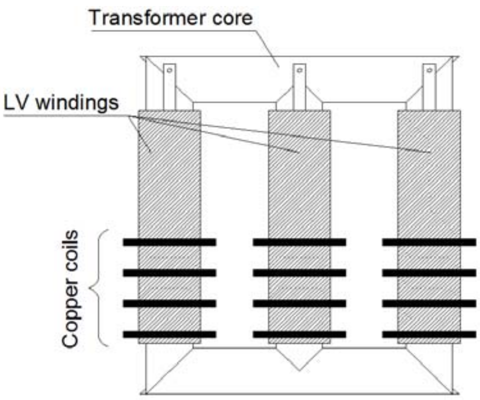

Fig. 3. Physical model of power transformer

Low voltage windings build from the aluminum sheet were left untouched. During measurements they can be used as a shield.

Measurement technique

To measure the frequency response of a physical model of power transformer sweep frequency analyzer FRAX (shown in Fig. 4) was used. The basic frequency range is from 1 Hz to 10 MHz with measurement voltage 0,1 - 10 V (peak-to-peak). Accuracy is ±0,5 dB down to -100 dB. Sampling is simultaneously on 100 MS/s [9]. To communicate with FRAX 101 a PC computer was used with dedicated software.

The setup was build from:

- physical model of power transformer
- sweep frequency analyzer FRAX 101
- copper wires with clamps

The connection of analyzer to physical model of power transformer is shown in Fig. 5 [9].

In the “End-to-End Open” (Open Circuit Self Admittance shown in Fig. 5) the signal is applied to the one end of the each winding in turn, and the transmitted signal is measured at the other end. The low-frequency range of this test is basically a low voltage measurement of the voltage dependent single phase excitation current.

Fig. 4. Sweep frequency analyzer FRAX 101 [9]

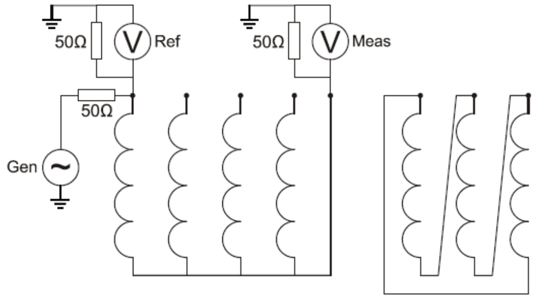

Fig. 5. Connection of FRAX 101 to physical model of power transformer [9]

Results

The test measurements were carried out on each stack of copper coils on the each limb. Authors performed few test measurements for exact calibration of the whole setup, ie. measurements of different grounding, etc. Each stack was precisely put on each limb, to simulate the proper conditions of power transformer. The results of measurements are shown in Fig. 6-8.

The next step was to try to simulate mechanical faults of coils. On one column the upper coil was moving 5, 10, 15, 20, 25 and 30 mm. For each moving the measurement was performed. The results are shown on Fig. 9.

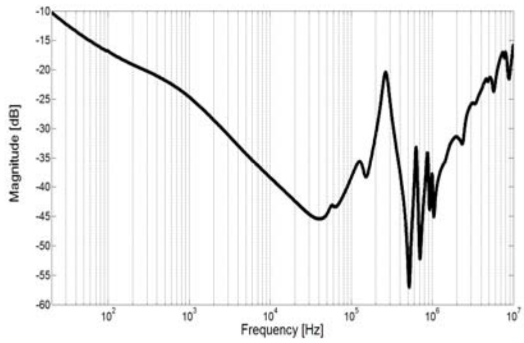

Fig. 6. Magnitude of the frequency response for the left stack of copper coils

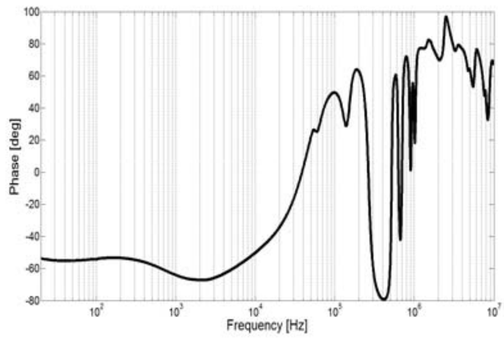

Fig. 7. Phase of the frequency response for the left stack of copper coils

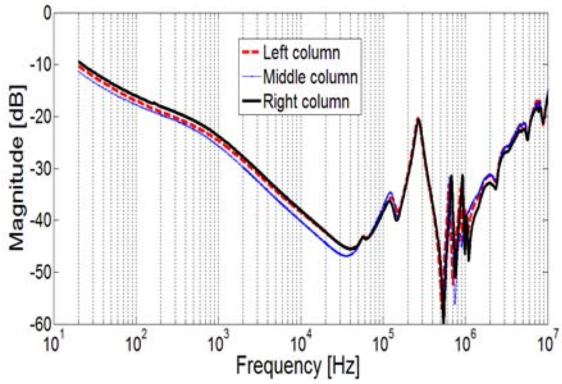

Fig. 8. Comparison of 3 measurements for the left, middle and the right column – magnitude

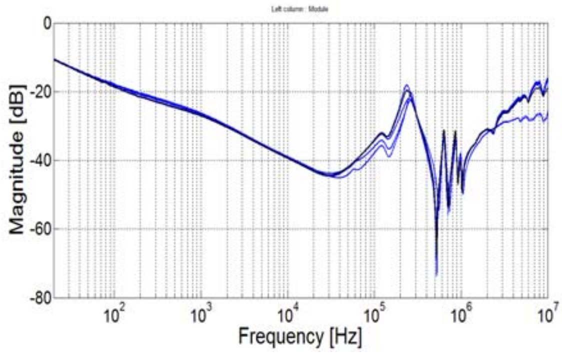

Fig. 9. Simulation of the mechanical fault on the one column – moving coil on 5, 10, 15, 20, 25 and 30 mm

Conclusions

In article authors presented test measurements of physical model of power transformer. Measurements were carried out with use of FRAX 101 analyzer. Authors prepared many calibrated measurements before prior testing. Performing measurements of the mechanical faults of coils, core, etc. can be a good tool for creating a quality and quantitative indicators for FRAX diagnostics of power transformers.

The next step is to carry out more measurements for different mechanical faults. Creating a FEM model of this setup can be also useful, for better understanding the physical phenomenon and it's characteristics observed during measurements.

FRAX measuremnts are the typical "fingerprints" measurements. Having such "fingerprint" of frequency response of the newly installed or repaired transformer the comparison measurements can be performed and the conclusion obtained e.g after 15-30 years in operation. Based on the comparison between frequency response measurements performed e.g. before repair and after repair the quality of repair and maintenance action can be judged.

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