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Sensitivity of FRA measurements to various failure modes

Streszczenie. *W artykule przedstawiono wyniki badań FRA (ang. Frequency Response Analysis) w czasie deformacji przeprowadzonych w laboratorium na transformatorze o mocy 800 kVA. Symulowano odkształcenia poosiowe i promieniowe, jak również zwarcia. Wyniki umożliwiają identyfikację charakterystycznych częstotliwości związanych z badanymi defektami. Zostaną one wykorzystane wraz z rezultatami badań wykonanych na innych jednostkach do ujednolicenia identyfikacji uszkodzeń uzwojenia. Dodatkowo przedstawiono wyniki badań przeprowadzonych na autotransformatorze o mocy 160 MVA. Okazało się, że przy dużych gabarytach geometrycznych niebezpieczne deformacje mogą pozostać niewykryte przez metodę FRA. (**Skuteczność badania funkcji przenoszenia FRA w odniesieniu do różnych symptomów uszkodzenia**).*

Abstract. *The paper presents results of FRA measurements obtained from deformational tests in laboratory on the 800 kVA transformer. Tested unit had various failure modes simulated, such as radial and axial deformations and short-circuits. It allowed to identify characteristic frequencies affected by various failures, which will be used, with results from other units, to generalize identification of failures. Additional results come from similar tests performed on 160 MVA autotransformer. It was found that due to its geometrical size dangerous deformations could stay undetected.*

Słowa kluczowe: transformator energetyczny, odkształcenie uzwojenia, zwarcie, analiza odpowiedzi częstotliwościowej (FRA).
Keywords: power transformer, winding deformation, short-circuit, Frequency Response Analysis.

Introduction

Frequency Response Analysis (FRA) is one of diagnostic methods of power transformers. It is based on measurements of transfer function of windings in various connection setups and allows detection of changes in mechanic or electric structure of transformer's active part. The FRA is a comparative method, therefore it is important to know how various types of defects influence changes in measured curves. Such impact of different failure modes on FRA sensitivity depends on the type of defect, its location and scale [1, 3, 4].

This paper presents chosen results of detailed experimental study performed on real transformer and based on controlled deformations of windings and simulating electric faults. Over 600 measurements were taken with different failure modes present and in various connection setups. One of directions in analysis of gathered data is finding sensitivity of FRA method in detecting given defects and finding possible information on their scale and location. At present analysis of FRA curves is clear only in the cases of healthy transformers, but when some changes appear in FRA results it is difficult to state what and where has happened. Therefore presented experiment will be helpful in further analysis of real cases of transformers. Additional problem is different FRA sensitivity to defects appearing in various types and sizes of transformers. There is additional example of power autotransformer given, where FRA test could not give clear results for obvious deformation.

Test object

The transformer used for this experiment was dry type unit, T3Ch/D800/6, 800 kVA, 6.3/0.4 kV. Its construction allowed to perform deformations in windings and following measurements in its original casing with standard setup of inner leads with easy access to an active part. In addition this transformer is air cooled, therefore has bigger geometrical size than similar oil type units, which results in FRA response comparable to oil units with higher power rating. Fig. 1 presents the view of transformer's HV winding, which was used for simulation of defects. It consists of 22 double discs. There were several types of failure modes simulated:

- axial shifts in both directions (compression and extension of the winding), influence of the scale and location of deformation was considered,
- radial deformation (movement of the whole discs to the side), influence of the scale and location considered,
- short-circuits between turns and discs,

All measurement were performed step by step, for subsequent discs and various scales of deformations. The next chapter presents some chosen results to present exemplary influence of given deformation on FRA curve.

Fig. 1. The view of test winding (left) and an example of a radial deformation (right)

Examples of failure modes and frequency responses

The first type of failure mode was short circuit between turns and discs. Its influence on the FRA characteristic in low frequency strong and clear, however it also influences higher frequencies range. This range is affected in the way that can give information on the scale and place of such defect. An example is given on Fig. 2.

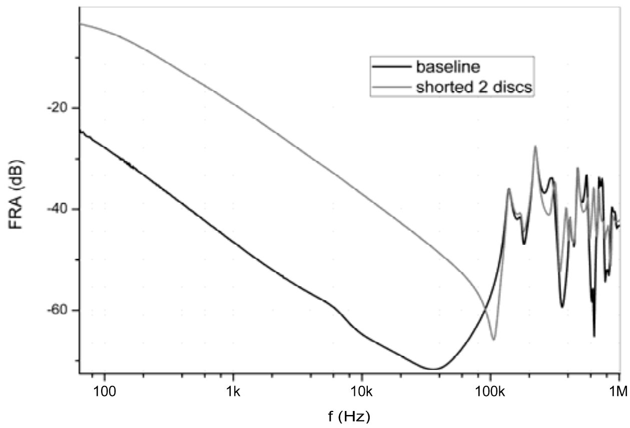

Fig. 2. The influence of short-circuits on frequency response (800 kVA T3Ch transformer)

The low frequency influence is well known and typical for short-circuits [1, 2]. Analysis of higher frequencies changes performed for transformer used in the experiment and also gathered from other units allows to determine universal influence of such failure mode on the response. It is worth mentioning that this influence is very strong and therefore other defects may not be detected.

Another failure mode simulated was axial displacement of discs. There were many combinations of various discs moved along the axis up or down of a winding, single or in groups. It allowed to draw conclusions on the influence of such deformation on FRA response. An example is given on Fig. 3 and 4.

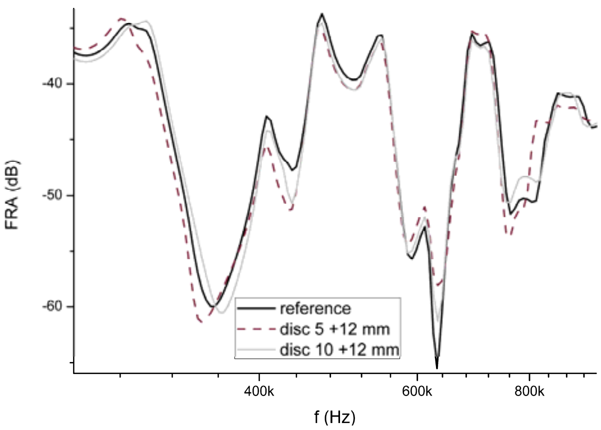

Fig. 3. The influence of axial shifts for single discs on frequency response (800 kVA T3Ch transformer)

Fig. 3. presents characteristic frequencies affected by shifting discs one-by-one, in other words in the winding there was always only one gap between discs expanded. The scale of deformation was the same for all cases. The influence clearly depends on the location of the defect. For example the resonance at approx. 350 kHz is shifted along frequency depending on the location of deformation to the left or right. Also resonances at 450 kHz and, 600 kHz and 780 kHz are strongly affected. These results confirm data measured by author on other units [3].

In the case of deformations performed in the same place, but with various scale (Fig. 4) it can be seen that curves are changes in the order, depending on the scale. Frequency ranges are the same as for previous example, as the deformation is of the same type – axial displacement. It can be concluded that the scale of deformation can be also derived from such analysis.

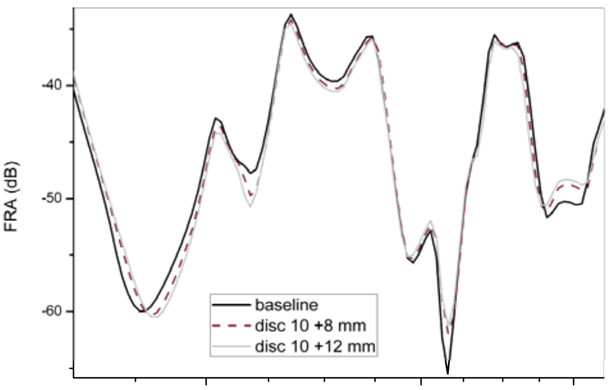

Fig. 4. The influence of deformation scale on frequency response (800 kVA T3Ch transformer)

The problem is that various transformers, depending on size and construction, may be affected in different way. The author is gathering data to prepare some universal conclusions for such failure modes.

The next failure mode were radial deformations. These in the case of transformer used in the experiment were performed as radial shifts of the whole discs. Such displacement (presented on the Fig. 5) showed influence mainly in the frequency 650 kHz, but also at 800 kHz and 1.2 MHz.

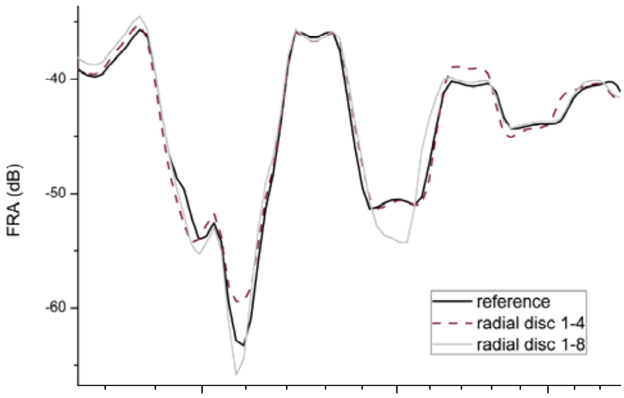

Fig. 5. The influence of radial displacements on frequency response (800 kVA T3Ch transformer)

The results presented on above graphs allow to draw conclusion that it is possible to distinguish the type and scale of the defects in transformer winding. In the case of tested unit quite characteristic are resonances at 350 kHz and 650 kHz. The axial deformation influences both of them, which results from changes of interwinding capacitances for HV winding, but also changes in capacitances to LV winding and core. The radial deformation affects mainly 650 kHz area, which is a result of interwinding capacitances change, and therefore it is easy to identify the type of deformation. It gives also additional changes in higher frequencies related to the scale of deformation. In the case of short-circuit there is clear influence in low frequency range due to reduction of inductance. However additional information on the scale and location of short-circuit can be taken from its influence on higher frequencies range, due to self-inductances and interwinding capacitances changes.

All results presented above characterize only one transformer type and cannot be used straight for wider analysis. However author is gathering data from other units and preparing more universal approach to various failure modes identification. Another example of deformational experiments on FRA is given in the next chapter.

FRA measurements on 160 MVA autotransformer

Results presented for this unit were obtained from RTdxP 220/110/15.75 kV 160 MVA autotransformer, before scraping and therefore it was possible to perform controlled deformations in windings. The unit was measured with original bushings, in tank without tap changer and without oil. Tap changer's presence was simulated by short-circuiting necessary leads, however the lack of this device for sure affects high frequency range. Wider approach to this experiment was presented in [4].

Fig. 6 and Fig. 7 present exemplary influence of similar deformations as for previous unit on FRA response located also in HV winding. If compared directly, the scale of deformation was bigger than for 800 kVA transformer, however if compared to the geometrical size of the whole winging it was definitely smaller. Such deformations are for sure dangerous for transformer's operation. There were axial shifts and radial deformations simulated. However

FRA method wasn't sensitive enough to detect such changes. Changes visible on graphs are maximum 1 dB in vertical and very slight in frequency scale. Results are placed in order, e.g. according to the scale of deformations, but their influence is too small to be detected in typical industrial measurements. Usually changes between measurements taken in time, especially if performed by other personnel or when measuring device is used are bigger than described deformations' influence. Therefore such transformer would be assessed as healthy and weakened insulation (a gap between discs was reduced more than by half) would be a threat possibly causing more serious failure during next sort-circuit or overvoltage.

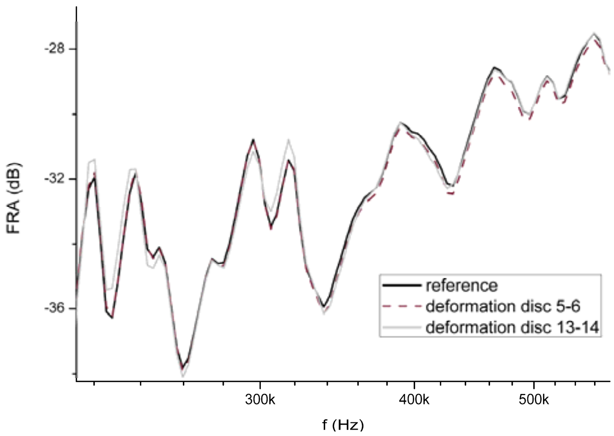

Fig. 6. The influence of deformation location on frequency response (RTdxP 160 MVA autotransformer)

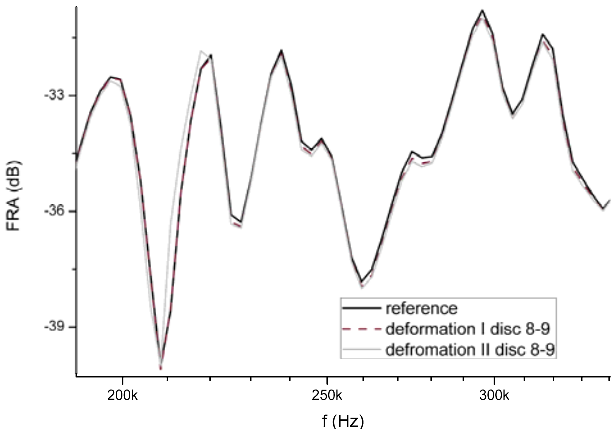

Fig. 7. The influence of deformation scale on frequency response (RTdxP 160 MVA autotransformer)

It can be seen that the geometrical size of the tested transformer should be taken under consideration in the process of data analysis. Also constructional details may be important, as two units with the same power rating may have various geometrical sizes.

Summary

Presented examples of various failure modes and their impact on FRA response will be used for algorithm assessing mechanical condition of transformers winding. These examples showed that it is possible to distinguish place and scale of defect in the winding's frequency response. Author is gathering data from various constructions of transformers and will perform analysis of such experimental results coming from several transformers to obtain universal dependencies.

It was also observed that deformations which are relatively small if compared to size of a whole winding can be undetected with FRA method. Such situation may take place in the case of large units and therefore lead to expensive and dangerous failures.

The examples given above lead to conclusion that analysis of FRA data should not be performed only by visual comparison by experienced personnel, but more detailed tools should be used. There are plenty of algorithms and AI methods proposed [5, 6]. However most of them are not based on many practical cases, as it is difficult to gather examples of FRA measurement with known type, location and scale of deformation. Therefore presented data, altogether with results obtained by author from other units (four already and two additional are planned) should be sufficient to prepare such algorithm allowing identification based on experiences drawn from real cases of FRA response.

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