RESULTS REPRODUCIBILITY OF FRA DIAGNOSIS METHOD APPLICATION AT POWER TRANSFORMERS

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***Abstract* - Frequency characteristic measurement at power transformers is a diagnosis method used to detect mechanical faults of the windings. The method consists in the measurement of impedance/ admittance or transformation ratio in a broad frequency range and measurement result comparison with the initial (reference) result obtained in the manufacturing company. The found differences are associated with deformations or displacements of the said transformer windings. The paper presents a description of the used measuring systems and a procedure for circuit checking with a view to ensuring measurement reproducibility.**

Keywords: power transformers, diagnosis, frequency characteristics, mechanical faults.

1. INTRODUCTION

The power transformer is one of the most important and costly component of an electric power transport and distribution network.

At present, there are complex power transformer monitoring systems intended to monitor the thermal duty, winding and bushing insulation condition etc, to send this information in the control room of the transformer substation or, in the case of interconnected networks, to the regional/national dispatcher to warn on the need to restore the cooling system (pumps, air fans) or on a disconnection with a view to checking after a longer or shorter while.

Among other failures, the loss of the mechanical stability due to the electrodynamic stresses owed to inrush and short-circuit currents could not be controlled very simple so far.

At present, in order to identify the change of the power transformer winding mechanical condition and position there are used different methods [1,2,3,4]. The most widely used is the drawing of the frequency characteristic (FRA) in a broad frequency range.

This diagnosis method is a comparison of the transfer functions determined at important time intervals in the same measurement conditions. There are compared two sets of measurements:

- initial measurements;
- diagnosis measurements.

The first measurement performed in the manufacturing company is the reference measurement (initial fingerprint). The other ones are measurements necessary to detect the possible mechanical failures and are performed after transportation to the mounting place and/ or at periodical revisions. When, for different reasons, there is no initial fingerprint, any characteristic drawn after the putting into operation of the said transformer can be considered as such.

The experience in operation shows that the creepage in the insulation materials owed to changes in moisture, temperature and insulation age as well as the mechanical stresses during transformer transport to its site have a doubtless influence on the preservation of initial clamping forces and these effects must be kept under control [5], [6].

In order to obtain a good reproducibility, the measurements should be performed in identical conditions, which is almost impossible in practice. It should be emphasised that FRA with its versions represents a non-destructive and non-invasive method that can be used independently or combined with other classical methods but it is not standardised yet [7].

Result reproducibility is an essential condition for diagnosis and it is the aim of this paper to propose methods to check it as a first stage in establishing the uncertainty budget of the method.

2. MEASURING EQUIPMENT DESCRIPTION

At present, in order to measure the frequency characteristics of the power transformers, there are used two versions:

- SFRA (Swept Frequency Response Analysis) method which uses a vector network analyser (VNA). The measuring principle consists in applying a sine voltage to the tested transformer and in measuring the response signal (current through the tested winding or voltage at the terminals of other winding). The characteristics are determined by varying the frequency in the analysed range and calculating the ratio between the signals measured at each frequency;
- IFRA (Impulse Frequency Response Analysis) method which uses a low voltage impulse with a duration of about 5μs and also rise and fall times as short as possible (below 1μs) to energise the test transformer.

Irrespective of the method, coaxial cables of the same length are used to apply and pick the signals: one to

apply the excitation signal, one to pick the excitation voltage and the third one to pick the response signal.
The two methods have different characteristics:
- IFRA is a rapid method but the wide band noise cannot be filtered and the injected signal spectrum is frequency dependent;
- SFRA is characterized by a high signal/ noise ratio and the used filters easily remove the wide band noise.
A high signal resolution can be obtained by dividing the frequency range of interest in several partial ranges.
In exchange, SFRA has disadvantages related to the low level of the used signals and longer data acquisition duration (6 min.).

3.PROPOSALS FOR MEASURING SYSTEMS CHECK

FRA method application for transformer diagnosis is an extension, in the heavy current technique, of a classical radio-electronic method widely used in many applications with no requirements referring to reproducibility.
When this method is used for transformer diagnosis, the reproducibility matter is essential.
There are two reproducibility types that must be taken into account: short term and long term one.
That is, if there is no short term reproducibility, the long term reproducibility is practically excluded; the last one is of interest because any difference appearing between two characteristics measured at long time intervals may indicate changes of the mechanical condition of the investigated transformer.
In order to solve the problems related to reproducibility, the parameters determining it in practice should be defined, namely:
- differences in resonance frequency amplitude;
- differences in resonance frequency value.
The working conditions must be the same in laboratory, in manufacturing factory and in service; this imposes the use of some identical coaxial cables that are long enough (for ex. 15 m).
The measurements reproducibility will be studied using two simple structures, considered working standards in this field, so that not to depend on the characteristics of an insulating structure in oil, as the real transformer.
The first standard structure is a transformer winding (in air) of continuous type in wafers with dimensions small enough to be transportable (height 380mm, outer/ inner diameter 220/184 mm, 130 turns, conductor 2,65x10mm) presented in fig.1.
An insulating cylinder, on which it is applied an Al sheet, is mounted inside the winding so that to simulate the presence of a secondary winding in the circuit. At the upper and bottom part of the winding, it is possible to mount two insulating cylinders by means of which a variable axial clamping force can be applied with a view to simulating a possible influence of winding height change on the frequency characteristics.

Fig.1 Standard winding and measuring equipment IFRA measuring system; 2. Standard winding; 3. SFRA Network Analyser

The second standard structure is even simpler. It is formed of an LC dipole chain mounted in series and tuned on different resonance frequencies, easy to calculate (fig.2).

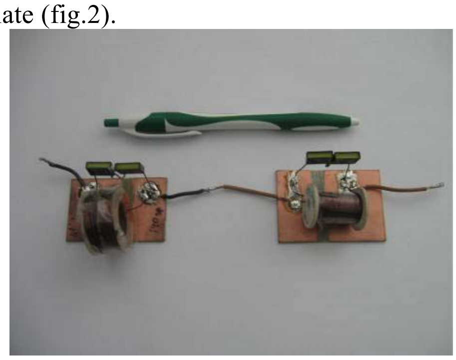

Fig.2 LC dipole chain in series

4. EXPERIMENTAL RESULTS

4.1 Comparison between the frequency characteristics determined by IFRA and SFRA methods

The comparison was made using an LC parallel circuit, tuned at 98kHz, for which the input admittance Y was determined in dB.
IFRA method (fig. 3a,b) uses usually an 1 ohm shunt to measure the current through the tested circuit while SFRA (fig. 3c) uses a 50 ohm standard input impedance reason why the two characteristics are not identical. If a 50ohm shunt – IFRA 50 (fig.3b) is used at IFRA, the frequency characteristics raised using the two methods are practically identical (fig.4).
The characteristics of fig.3a,b, c were achieved by 10 successive excitation applications in time domain (IFRA) respectively frequency domain (SFRA). On this basis, method reproducibility was determined calculating, for each frequency, the maximum

amplitude deviation of the input admittance (ΔY) presented on the right side of each graphic.

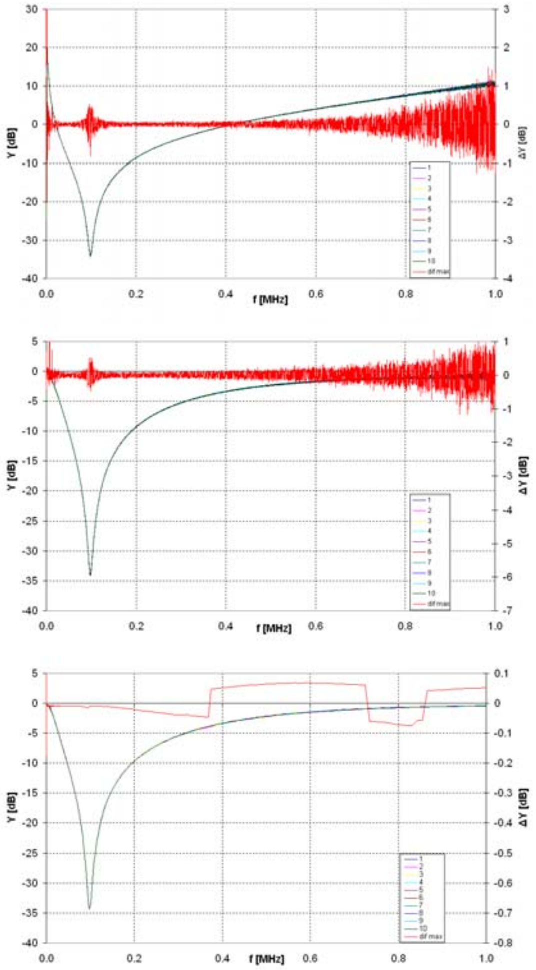

Fig. 3a,b,c Input admittance (Y) and the maximum deviation (ΔY) for 10 characteristics successively measured when using an LC circuit a-IFRA 1 (1ohm); b-IFRA 50(50ohmi); c-SFRA

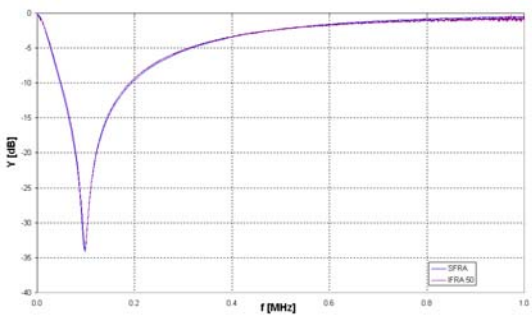

Fig. 4 Comparison between the input admittances determined by SFRA and IFRA 50 methods

It can be noticed that the maximum deviation for SFRA does not exceed ±0,1dB on the whole usual frequency range (max.1MHz).

In exchange, for IFRA 1 and IFRA 50 the maximum deviation ΔY is about ±0,5dB up to approx. 0,8MHz after which, it grows to about ±1,5dB.

The results are the ones expected according to the considerations from paragraph 2.

Fig.5 presents IFRA 50 and SFRA characteristics in the case of an LC dipole chain with the eigenfrequency 99 respectively 184kHz.

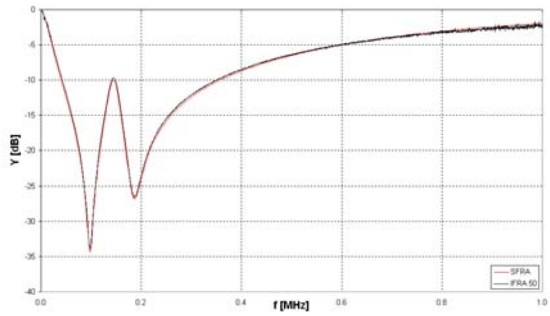

Fig.5 Comparison between the input impedances determined by SFRA and IFRA 50 methods when using two LC series circuits

4.2 Comparison between IFRA 50 and SFRA frequency characteristics determined on the standard coil

The measurement results are presented in fig.6.

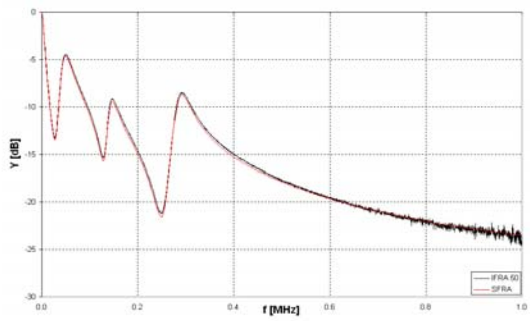

Fig. 6 Comparison between the input admittances determined by SFRA and IFRA 50 methods when using the standard coil

4.3 Measurement result reproducibility for SFRA method when the measuring circuit was repeatedly mounted and dismounted

Fig.7a,b renders evident the differences that can appear in the case, that is most frequently met in practice, when the successive remaking of the measuring circuit leads to the change of the contact (taking over) conditions for the measured signals.

The measurements were performed on the standard coil.

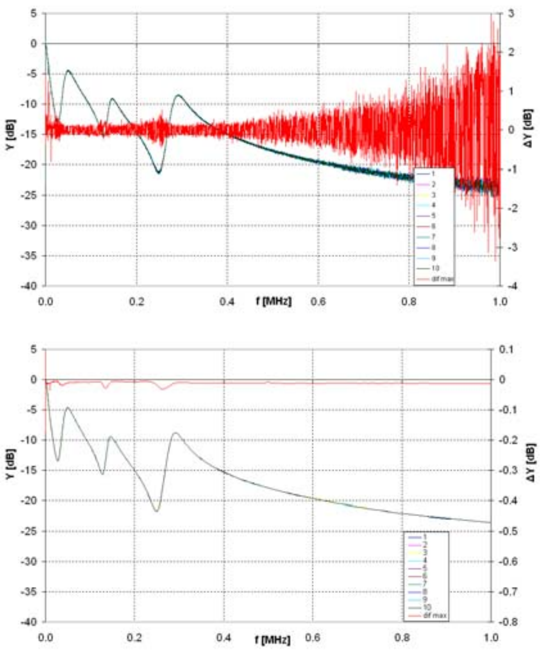

Fig. 7a,b Input admittance (Y) and maximum deviation (ΔY) for 10 characteristics successively measured when using the standard a - IFRA 50; b - SFRA; c - FRA

The extension of SFRA frequency range up to 10MHz outlines many eigenfrequencies of the standard winding but also contact problems at about 2,8MHz and over 8MHz.

4.4 Influence of measuring coaxial cable arrangement

According to the previous ones, the three coaxial cables have equal lengths and were used in the above experiments packed as cable flakes for the laboratory experiments.

In order to determine the differences appearing at measurements performed on real transformers when the cables are laid, there were performed measurements in the two situations (fig. 8a,b,c).

The maximum difference for SFRA (fig.8b) in the range 0-1MHz is almost negligible with respect to the other differences described previously. In exchange, for IFRA 50, the deviations are about 2dB in the range 0,8-1MHz and below 0,5dB at lower frequencies.

On the basis of the above results, it can be drawn the conclusion that the found deviations are due to IFRA method and not to the arrangement of the measuring cables.

Fig.8c presents the two characteristics superposed.

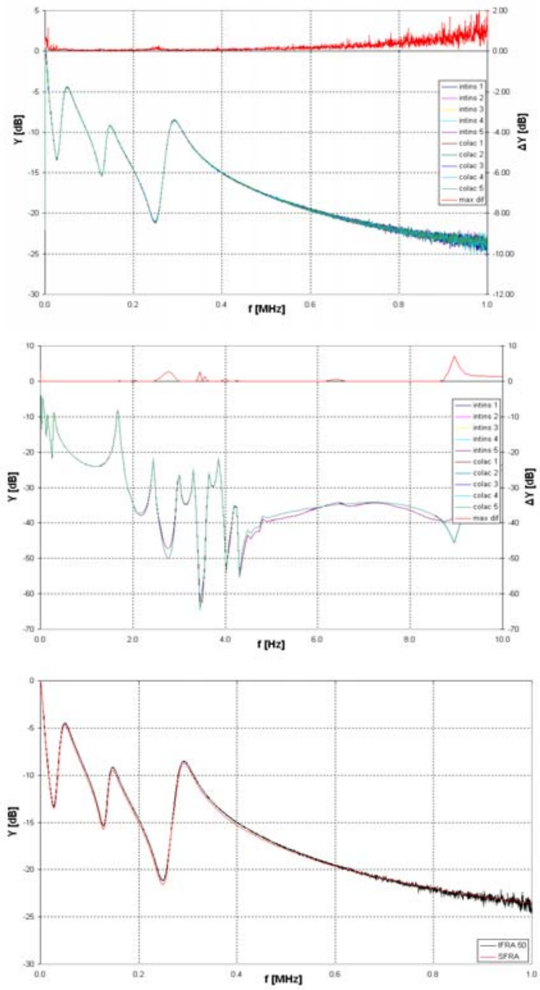

Fig. 8a,b,c Influence of the arrangement of the measuring coaxial cables with a total length of 15 m packed as cable flakes or laid
a – IFRA 50; b – SFRA; c – Superposed frequency characteristics (IFRA 50 and SFRA)

4.5 Comparative measurements on a real transformer

Fig. 9 presents the frequency characteristics of the input admittance at phase H1 (high voltage) of a 75MVA, 132 kV three-phase oil transformer, raised using IFRA 50 and SFRA methods.

At frequencies below 10kHz, where the magnetic properties of the circuit appear, practically only the SFRA method can be used.

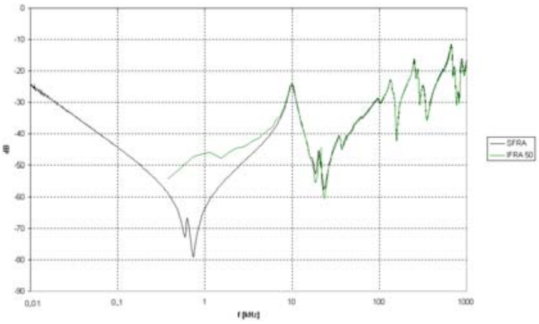

Fig. 9 Comparative frequency characteristics of admittance Y for the case of a 75MVA transformer measured using IFRA 50 and SFRA methods

5. CONCLUSIONS

In order to create an intercomparison base between the two measuring methods (IFRA and SFRA), the paper proposes the use of some standard structures that are independent of the magnetic and dielectric condition of a real transformer.
The standard structures are a transformer winding in air and LC dipoles in series with different eigenfrequencies, respectively. All these structures are intrinsically linear.
In order to compare the characteristics Y(f) point by point at IFRA and SFRA, the same measuring impedance of 50ohm must be used. Therefore, it is proposed that IFRA1 (1ohm) not to be used anymore.
Both used standard structures prove that IFRA method has amplitude deviations (ΔY) reaching to about 2dB especially at frequencies close to 1 MHz at successive application while SFRA method, as selective measuring method, leads to deviations not exceeding 0,1dB.
That is why, as far as possible, IFRA method should not be used anymore in the industrial applications where a maximum reproducibility of the characteristics on long term is required.
The arrangement way of the coaxial cables influences to a little extent the experimental characteristics up to 1 MHz.
Since FRA is not standardised yet, to apply it practically at repeated measurements performed at long time intervals, it is necessary to study and define the uncertainity budget on the basis of the results presented in the paper as for any measurement method.

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