Power Transformer Winding Fault Detection based on SFRA

Alberto Avalos, Jaime Cerda

Abstract— **Dispersion and Sweep Reactance in the Frequency, in this work, results of transformer diagnostics are shown where both conventional and non-conventional tests become complementary, allowing the identification of the fault only by those tests that are able to excite said failure. Emphasis will be placed on the effectiveness of the frequency sweep test for fault modes that most other tests fail to excite. These types of faults will be those reflecting a change in the geometric structure of the transformer due to mechanical movements in the windings and / or core of the transformer. The detection of incipient failures in power transformers requires a meticulous analysis of the results obtained in conventional tests such as low voltage TTR, excitation current and power factor. However certain faults are not excitable by this set of conventional tests and therefore being necessary to perform additional unconventional tests such as: TTR in high voltage, Dispersion Reactance and Sweep Frequency Response. In this work, results of transformer diagnostics are shown where both conventional and non-conventional tests become complementary, allowing the identification of the fault only by those tests that are able to excite such failure. Emphasis will be placed on the effectiveness of the sweep frequency response test for failure modes that most other tests fail to excite. These types of failures will be those that reflect a change in the geometric structure of the transformer due to mechanical movements in the windings and / or core of the transformer.**

Index Terms—**Power Transformer, SFRA, Fault Diagnostics, TTR.**

I. INTRODUCTION

Solid faults occurring in power transformers such as short circuits, problems in the tap's changers, etc. are easily identifiable by routine tests, phenomena such as the telescope of the windings represent changes in the geometry of the windings that can be identified by tests such as the power factor due to the change in the capacitances measured in this test, dispersion reactance detects the change in the inherent impedance of the transformer always and when this change is significant and finally the sweep test in the frequency will clearly show the changes in the operation modes of the transformer due to the change in the geometry of the same. On the other hand, tests of excitation current, TTR in low and high voltage will not be able to excite this fault for its detection unless there is a break in the insulation of the winding that allows the arcing between turns or between winding and core that clearly excites the fault evidencing it, however, the presence of these arcs will be reflected in the accumulation of gases dissolved in the oil that a chromatographic test of it would detect its presence. It is interesting the case in which these arcs do not appear yet and that there is loss of insulation due to the breakage of the paper between turns, due to the rubbing of the windings originated by axial or radial movements, originated by the presence of intense fault currents. This can only break the paper but not the enamel of the drivers. In these conditions the tests of excitation current and TTR in high tension obviously do not manage to excite this type of faults, however, the sweep test in the frequency will be able to identify the changes in the geometry of the windings originated by the displacement of the same. thus identifying the incipient failure that has originated. Such fault will eventually evolve to a solid failure that will cause imminent damage to the winding. However, at this point, the disjunction over the level of damage enters to make the decision to operate or not the transformer for inspection.

The sensitivity of the frequency sweep test bases its analysis on the fact that the internal structure of a transformer represents a set of multilayer RLC circuits, which reflect inductive and capacitive couplings between windings, core and the transformer tank itself where The presence of the oil in which the transformer is immersed will accentuate the capacitive effects inside the transformer. In different frequency ranges, elements such as the core for low frequencies will come into play with predominant effect, the fastening elements of the windings will allow the displacement of the windings that will accentuate the inductive effect of them, which will be reflected in a range of frequencies from 400 Hz to 7 KHz. As can be seen, any displacement of the windings or the transformer core will cause the resulting impedance for each excitation frequency to be modified, thus allowing to detect the different faults that appear inside the transformer that are reflected as a change in their geometry, compared these against a plant reference or on site in non-faulty conditions [1].

II. SFRA

In this work, the Sweep Frequency Response Analysis (SFRA) method was used to identify solid or incipient failures in transformers [2]; this technique allows the excitation of a small voltage in a frequency range of 20 Hz to 2 MHz (or greater) to excite the resonance frequencies of the transformer, thereby identifying the transformer's own geometry, whereby any change in its geometry will be reflected as a displacement of the resonance points or in the trajectory of the obtained response, thus allowing to detect internal faults in the transformer.

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J. Avalos is with the Universidad Michoacana, Morelia, Mexico. e-mail: javalos@umich.mx

J. Cerda is with the Universidad Michoacana, Morelia, Mexico. phone: +52 443 3223500 ext. 1177; e-mail: jcerda@umich.mx.

This method bases its analysis on two ways in which the first one consists of having the factory test of the transformer [3], known as its fingerprint, which allows to monitor the internal condition of the windings and transformer core. Through its comparison with subsequent tests, carried out periodically or after the transformer is submitted to high electrical stresses due to severe failures or to the displacement of the transformer due to possible relocation or to highly relevant seismic movements. This will allow detecting variations in the response of the sweep in the frequency to determine the possible existence of internal faults in it. The second way consists of not having a previous test of the transformer response, leading this to compare the results either with twin units or between the response obtained in the different phases of the tested transformer, starting from the base of that the lateral phases must behave identically to each other because the magnetic paths are identical and prior knowledge of the typical responses expected for the different connections of a transformer.

The SFRA test bases its analysis mainly on having a factory reference test of the transformers, however, in most countries you can find transformers with more than 20 or 40 years in operation, of which there is no with a benchmark test, however, it is necessary to have information on the current status of the same that guarantees its safe operation both for the personnel and for the electrical network as a whole.

The SFRA test in conjunction with other electrical tests allows detecting those units that must leave operation as well as those that can continue to operate with an adequate margin of safety. Some countries, and in particular in the CFE-DCO, have been opted for those transformers with several years of operation, identified with an acceptable level of safety, to remain operating them with relatively low load levels that allow them to increase their useful life, thereby reducing the investment costs of the electric company in the short term. Below are the typical responses expected when performing the basic tests established by the SFRA tests performed on power transformers, depending on the connection of the windings and the type of open circuit test or short circuit applied, identifying the frequency ranges of affectation for the main faults that occur in a transformer.

III. $\Delta - Y$ TRANSFORMER TYPICAL RESPONSE

The main tests performed on the transformer with this method consist of: high and low voltage open circuit tests and short circuit tests in which the high voltage side is fed while shorting the low voltage side. The typical responses of these tests on a transformer are shown in Figure 1.

Figure 1 shows the typical response for open circuit tests for both a delta connection and a star connection, and the response of the short circuit test is shown. From here it is observed that the response in the open-circuit test of the lateral phases for both the delta connection and the star connection are identical while the central phase in both cases reflects a greater impedance due to the difference in the trajectories of the magnetic structure of the transformer, as well as different resonance points. On the other hand, the short circuit test presents an identical behavior in the three phases below 4 KHz and later the fact that the lateral phases have an identical behavior is fulfilled while the central phase reflects in its response an increase in its impedance and changes in different resonance points. It is important to note that different frequency ranges are associated with the different possible faults within the transformer in windings and core, as shown in Figure 2.

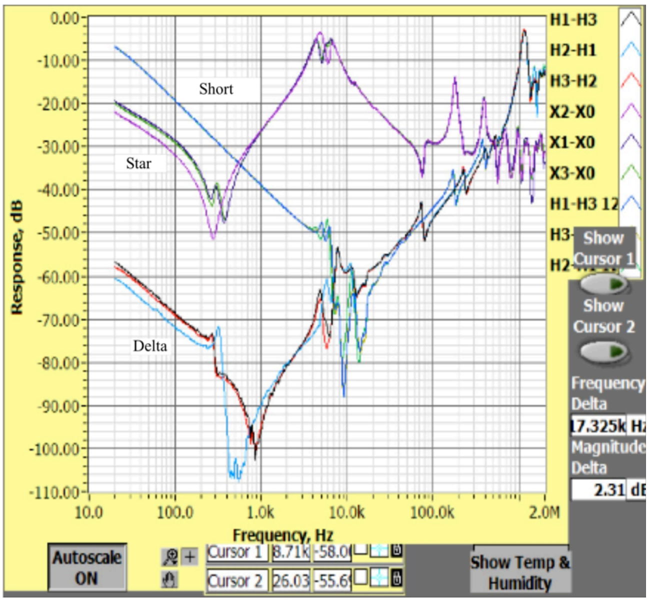

Fig. 1. Typical response for a $\Delta - Y$ connection.

As it can be seen in Figure 2, the frequency range from 20 Hz to 2 KHz excites the failure modes corresponding to deformations in the core, remaining magnetism, short circuits between turns and open circuits in windings [4]. On the other hand, the range of 2 KHz to 20 KHz allows detecting displacements of windings and loss of their supports. In the range of 20 KHz to 400 KHz it is possible to detect deformations in the windings and in the tap changers. The remaining frequency range from 400 KHz to 2 MHz

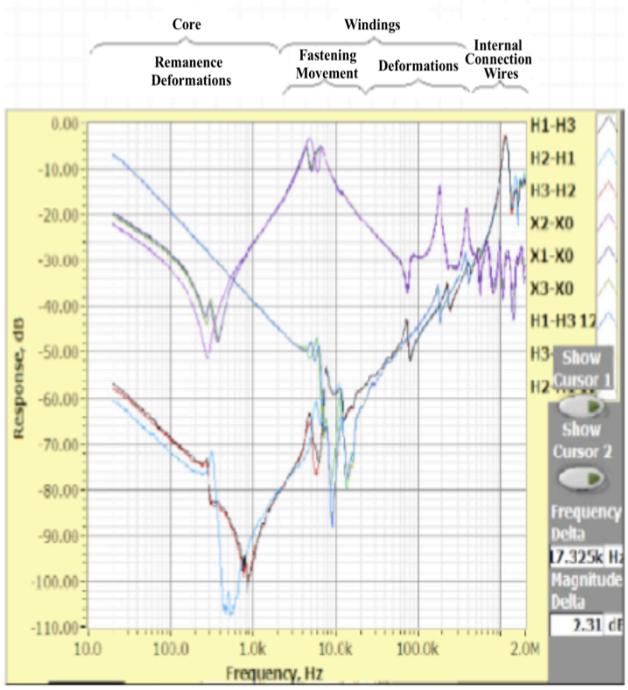

Fig. 2. Typical response for a connection $\Delta - Y$.

allows detecting movements in the internal connection cables of the windings and the tap changer.

There are several external factors that alter the response of the test and must be taken into account at the time of performing it [4], since it will normally be difficult to justify withdraw from operation the transformer due to an error in the test assessment, unless there are strong indications of faults inside the transformer in the responses obtained. The foregoing makes evident the need for a good training of the personnel that will perform the test for a correct decision making in the analysis of the response.

IV. TRANSFORMER TEST RESPONSES

Fig. 3. Transformer primary windings

Fig. 4. Phase B conductor damage

The transformer under analysis is of core type with a capacity of 5 / 6.25 MVA, transformation ratio of 115 / 13.8 KV, impedance of Z = 5.9% in nominal Tap (2), year of manufacture 1969 [5]. This transformer suffered a failure in the high nozzle of the central phase taking it definitively out of operation.

Routine tests were performed as TTR and no anomalies were found, the winding resistance test showed a 50% decrease in the winding of the central phase with respect to the windings of the side phases on the high voltage side. Based on this evidence, the transformer was removed from the tank for a physical inspection of the windings, and no anomaly was found in the windings on the high side of the transformer, as well as in the Tap changer, as shown in Figure 3
The tip of the conductor of the central phase shows the damage caused by the fault in the conductor, which was found to have considerably burned the insulating paper around the conductor, as shown in Figure 4.

Under these conditions it was decided to perform a set of tests such as TTR in high voltage (10 KV), Dispersion reactance and frequency sweep in order to try to verify the integrity of the windings or identify any possible failure in the secondary windings . The results of the tests were as follows:

TTR in high voltage:

Calculated transformation ratio in nominal Tap: 14.434
Measured transformation ratio:
Phase A: 14,438 Phase B: 14,445 Phase C: 14,447

As these results show, the transformation ratio is correct in all three phases, as it had been in the low voltage TTR test.

Dispersion reactance:

Plate data:
% Z = 5.9
Measured data:
% Z = 6.0

As it can be seen, there is a variation of 1.69% between the measured value and the plate data, which shows no signs of problems in the windings.

Excitation current:
Applied voltage:
10 KV
Measured current:
Phase A: 6,707 mA Phase B: 3,818 mA Phase C: 7,456 mA

As it can be seen, the current of Phase C presents an increase of 11% with respect to phase A, which should be very similar. This result shows the existence of a fault inside the winding in Phase C. Remember that in this case the currents in phases A and C must be similar and almost twice the phase B.

Frequency sweep:

Figure 5 shows the response of the open-circuit tests on the high-voltage side, as it can be seen, phase C presents a decrease in the impedance at low frequencies as well as a significant variation in its response in the range of 400 Hz to 1.5 KHz, the above is evidence of a fault that may be present in the low voltage winding of this phase.

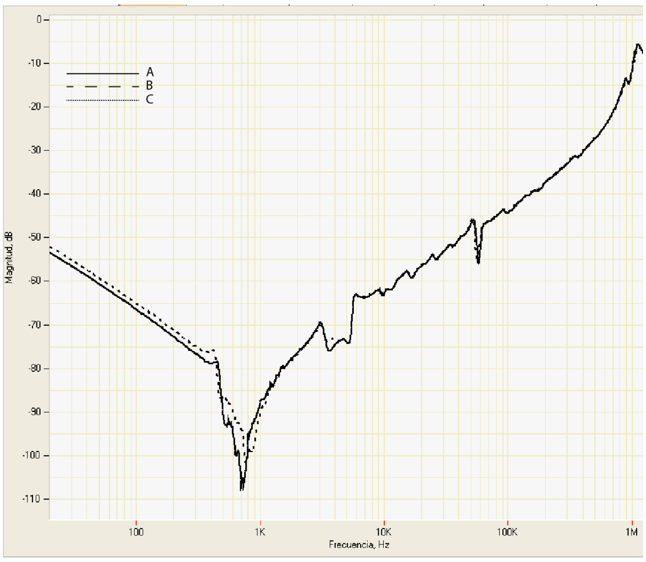

Fig. 5. Lateral windings high voltage side open circuit test

Figure 6 shows the corresponding response to phases A and B where, not having a reference test for comparing the response of the central phase, identifies a typical response acceptable for the winding.

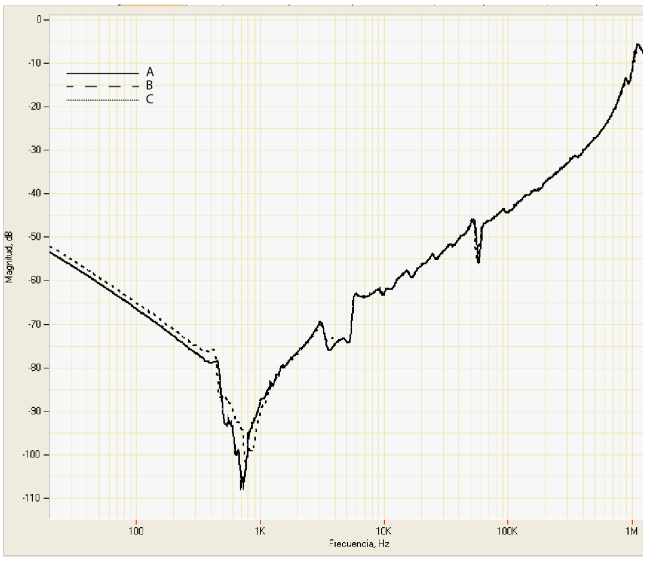

Fig. 6. Phases A and B responses

Figure 7 shows the corresponding response to the low side open circuit test of the transformer. As it can be seen, phase C has a behavior in the low frequency range that shows the presence of the short circuit in the winding, while phases A and B show an expected behavior.

As it can be seen, the excitation current tests and the Sweep Frequency Sweep Response tests are the only ones that managed to excite the fault in the winding of phase C. Figures 8 and 9 show the winding of the phase C inspected which they only show evidence of the winding movements and the obvious damage on the paper but it does not show the short circuit failure between the turns since as it is observed the enamel is in good condition and there is no physical contact between them.

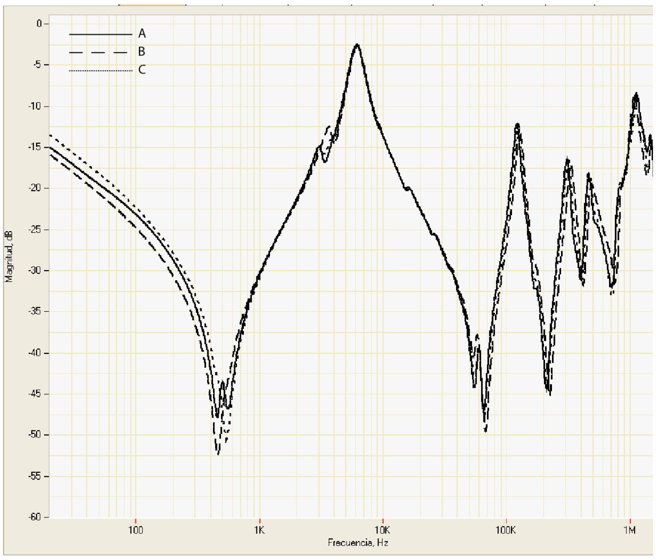

Fig. 7. Low voltage side open circuit test

Fig. 8. Phase C low voltage winding

Fig. 9. Phase C low voltage winding

Looking for alternative tests that evidenced the failure, the excitation current test was performed, now applied to the low voltage side, injecting 1 KV this test evidenced the failure since at the moment of starting the equipment the voltage injection a short circuit take place inside of the coil on the upper side of it that turned it into a solid fault.

Inspection of the winding has not been possible since the winding has not yet been repaired in order to observe the evident failure.

In the same way, Figures 10 and 11 show the winding image of phase B, in which the rupture of the paper is observed due to the rubbing of the conductors caused by movements in the coils, condition that was not possible to detect by the no existence of a previous reference of the SFRA test, which basically would be the only test which could excite this type of failure.

V. CONCLUSIONS

The detection of faults inside the transformers depends fundamentally on the fact that the tests carried out are able to excite the points of failure that allow to reflect the existence of the same. The detection of faults in transformers through the SFRA test has proven its effectiveness on multiple occasions. Failures are usually detectable by more than one of the conventional and unconventional tests. The failure in the winding of phase C was detected by both the excitation current test and the SFRA test. The loss of isolation in phase B was not detectable by any of the tests performed.

REFERENCES

[1] Luwendran Moodley, eTheKwini Municipality and Brian de Klerk, Sweep frequency response analysis as a diagnostic tool to detect transformer mechanical integrity, Congress The Association of Municipal Electricity Undertakings Southern Africa 2006.

[2] Nirgude, P.M.; Gunasakaran B.; Channakeshava; Rajkumar, A. D.; Singh, B.P., Frequency Response Analysis approach for condition monitoring of transformers, Electrical Insulation and Dielectric Phenomena, 2004, CEIDP appos; 04 2004 Annual Report Conference on Volumen, Issue, 17-20 Oct. 2004 Page(s): 186-189.

[3] Larry Coffeen, Charles Sweetser, Different Aspects of Frequency Response Analysis (FRA), IEEE/PES Transformers Committee Spring 2002 Meeting Vancober, B.C., Canada April 14-18, 2002.

[4] Lapworth J. A. and McGrill J.J. "Transformer Winding Movement Detection by Frequency Response Analysis (FRA)" Proceedings of the Sixty-Sixth Annual International Conference of Doble Clients, 1998, Sec 8-14.

[5] Sánchez Servando, Avalos Alberto, Pérez Carlos. "FIELD AND LABORATORY EXPERIENCES IN SWEEP FREQUENCY IN TRANSFORMERS", Doble Engineering Company- 75th Annual International Doble Client Conference, 2008.

Fig. 10. Phase B winding inspection

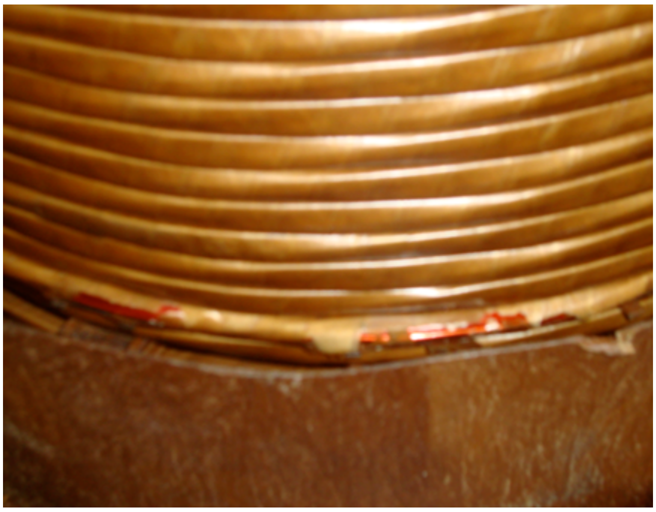

Fig. 11. Phase B winding inspection