Case Studies of Electric Power Equipment Diagnostics Using Acoustic Emission

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Abstract

High-voltage power transformers and reactors are complex structures constituted by several major parts, such as magnetic core, copper windings, paper and board insulating media, electric bushings, all of them immersed in insulating oil. Acoustic emission technique is used in identifying evolving failures of electrical, mechanical or thermal nature, which can be identified by the characteristics of the signals received. In this technique, acoustic signals initiated by, for example, internal electric discharges, propagate through the insulating fluid reaching the equipment tank, where are detected by piezoelectric sensors with adequate sensitivity, mounted on its external surface. The technique has the advantage of being utilized with energized equipments, avoiding downtime to perform tests. Attenuation due to absorption in internal components can limit the sensitivity of the method and variable propagation speed due to different materials used in the various components of these equipments can affect the determination of location of the acoustic sources. So, analysis and diagnostic must be made carefully in order to avoid erroneous interpretation of the signals. Complementary diagnostic methods, such as dissolved gas-in-oil analysis (DGA) help improving the quality of the condition diagnostic of the equipment.

In this paper, case studies are shown with results of acoustic emission tests performed to condition monitoring of several high-voltage power transformers and reactors, rated 230 and 500 kV. Those that showed evidence of failures were subjected to internal inspection and repair. Results have demonstrated the effectiveness of the acoustic emission technique as a supporting tool for the condition diagnostic of power equipments

Keywords: Acoustic Emission; Fault Diagnosis; Partial Discharges; Power Transformers; Power Reactors

1. Introduction

Power transformers and reactors represent an important part of the assets of an electric utility company. Unexpected failures in these equipments can lead to large financial losses. In this way, assessing their operational condition is an important issue in evaluating the risk of failure and to plan maintenance actions in the mid- and long-term.

One of the available techniques to this assessing is the Dissolved Gas Analysis (DGA), which can identify failures such as partial discharges, electric arcs and overheating [1]. These conditions decompose the insulating oil producing characteristic gases, such as ethane, methane, hydrogen, acetylene and others, which dissolve in the oil and can be detected by chromatographic analysis. Although DGA is a proven, low-cost and widely used technique, it is not able to provide a valuable information, which is the location of the failure inside the equipment. This information can be given by the Acoustic Emission Testing which, together with the results of Dissolved Gas Analysis, and the knowledge of constructive details of the equipments, can be used in improving the quality of the diagnostic.

In this paper, Section 2 presents some constructive aspects of power transformers and reactors; Section 3 and 4 discuss some failure conditions and characteristics of acoustic signals originated from them. Finally, Section 5 presents cases studies of failure diagnostics in electric power equipments.

2. Transformers and Reactors Components

Transformers and reactors, although having distinct functions in electric power systems, have similar constructions [2]. Power transformers are used in converting relatively low voltage, as in the output of generators to a high voltage, necessary in transporting this energy through large distances with low losses. They are based on the electromagnetic induction principle, where the energy applied to a primary coil is transferred to a secondary coil. In this process, the voltages in the coils are related as the number of turns in each of them, the inverse occurring with the currents, in order to the energy be conserved. In order to provide a low-reluctance path for the magnetic flux linking the primary and secondary windings, they are wound on a core of ferromagnetic material, such as silicon steel. The same process is used in converting the voltage back to lower values, to be used by industrial, commercial or residential consumers in load centers. The magnetic material of the core presents losses, such as hysteresis loss, which is dependent on material, and eddy current loss, which can be minimized building the core from a stack of thin laminations and increasing the resistivity of the material. Addition of silicon on steel reduces hysteresis loss and increases resistivity, thus reducing also eddy current losses.

Windings are made of high-conductivity copper conductors covered with paper and cardboard spacers, in order to warrant electric insulation and mechanical support to withstand the dynamic forces appearing under normal and abnormal operating conditions of the transformer. All these components are mounted in a steel tank filled with mineral insulating oil. The oil serves the dual purpose of providing electric insulation and as a cooling medium to dissipate the electric and magnetic losses which are produced in the transformer in the form of heat. External heat exchangers provided with cooling fans are generally installed to improve the cooling process. Some designs include oil circulating pumps with this same objective.

Transformers also provide the option for compensating for small system voltage regulation (around +/- 10%), by means of tappings, selecting the adequate number of turnings in their windings connected to the external circuit. These tap changers have different basic designs: in the simpler one, the “no-load tap changer” the transformer must be de-energized in order to the taps be manually changed. The other design, the “on load tap changer”, more complex, allows the taps to be changed with the transformer in service with load, by means of a motor-operated mechanism, which can be automatically commanded. While the no-load tap changer is seldom adjusted (mostly once when the transformer is firstly energized), the on-load tap changer must be reliable enough to withstand several automatic operations in a day, during years, without failure.

3. Failure Mechanisms and Effects

The major cause of failure in power transformer and reactors is insulation breakdown. Even conditions of mechanical or thermal failure can evolve to a catastrophic failure due to insulation breakdown. Partial discharges [3] consist of an electric discharge located in a point inside a dielectric appearing when the electric field is higher than its dielectric strength. This condition generally occurs in cavities, bubbles or cracks inside the dielectric. Although with low energy levels, partial discharges recurrence can progressively degrade the dielectric, leading to insulation collapse and even to catastrophic failure of the equipment.

Partial discharges cause decomposition of the insulating oil, producing mainly hydrogen and other gases, which dissolve in the oil and can be detected by gas dissolved analysis. From the acoustic point of view, partial discharges are fast phenomena, producing signal of short duration, of the order of microseconds, low energy and relatively high average frequency (100-300 kHz). [4]

On the other hand, in the electric arc situation, all the distance in a dielectric separating two conductors is crossed by an electric current. As it releases a greater amount of energy, the oil decomposition produces mainly acetylene. Acoustic signals produced by electric arcs inside transformers and reactors show lower average frequencies (typically 50 – 100 kHz) and longer durations than that produced by partial discharges [4]

4. Acoustic Emission Testing of Transformers and Reactors

The acoustic emission testing of power transformers and reactors is made with the equipment energized and under normal load [5]. It is convenient to perform the test under a time period of about 24 hours, during which the equipment undergoes all the cyclic load and voltage variations. In this way, it is possible to establish correlations between load or operating voltage levels and the acoustic activity. Acoustic sensors are properly distributed over the lateral tank walls, fixed with magnetic holders. Normally, four to six sensors installed on each wall give a good coverage for signals detection.

The characteristics of the detected acoustic signals can reveal the nature of the phenomena that originates them. As an example, a repetition rate of one hit in each power line semicycle, indicates that the signals are voltage-driven, as is the case of partial discharges, or current-driven, as is the case of signals generated by magnetic forces or by magnetostriction. These two phenomena can be discriminated by their frequency characteristic. As mentioned before, partial discharges are very fast phenomena, and produce signals with frequencies typically in the range of 100-300 kHz. On the other hand, signals originated due to mechanical forces, typically have average frequencies below 50 kHz. Other phenomena, that also originate acoustic emission, such as mechanical friction, fluid flow or thermal effects do not exhibit such characteristic synchronization with the power frequency.

5. Case studies

A – Monophase autotransformer, 230 / 138 kV 50 MVA

This equipment, illustrated in Figure 1, showed presence of acetylene, as result of dissolved gas analysis, suggesting occurrence of internal electric arc. Due to this, it was scheduled an acoustic emission test, whose results of event locations are shown in Figure 2, which represents the projection of the located points over an horizontal plane. In this picture, three regions are evidenced as showing relevant acoustic activity. One of them, indicated as Region 3, which showed higher activity level, is coincident with the no-load tap changer of the transformer.

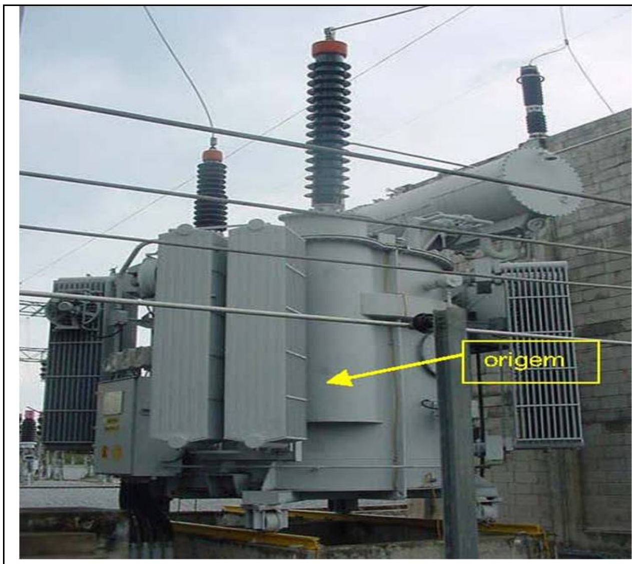

Figure 1 – Monophase Autotransformer 230/138 kV, 50 MVA

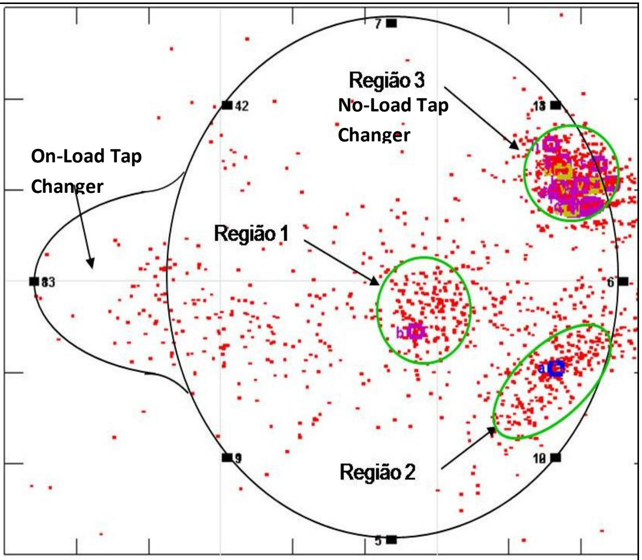

Figura 2 – Location of acoustic sources in the autotransformer

A scheduled visual inspection confirmed this indication, evidencing loose parts (spacers) in this component, as shown in Figures 3 and 4. The autotransformer was repaired in field, as well as two other similar equipments, which showed similar symptoms.

Figure 3 – Inspection of the autotransformer after removal of the tank

Figure 4 – Detail of loose parts found in the no-load tap changer

B- Single-phase 500 kV, 60 MVAR line reactor

In this reactor, shown in Figure 5, an acoustic emission testing showed two regions of relevant activity, as illustrated in fig 6. One of them, with continuous activity, located in the region of the high-voltage bushing, showed signals with average frequency in the range of 10-30 kHz, suggesting that its origin was not due to electric discharges. This diagnostic is in agreement with dissolved gas analysis, which indicated no evidence of gases associated with electric arc or partial discharges. Nevertheless, due to the critical importance of the bushing to the integrity of the reactor, it was scheduled an internal inspection in this area, when the fixing structures of the lower part of the bushing were found loose and re-tightened, avoiding a dangerous evolution of the failure.

Figure 5 – Single-phase reactor, rated 500 kV / 50 MVA

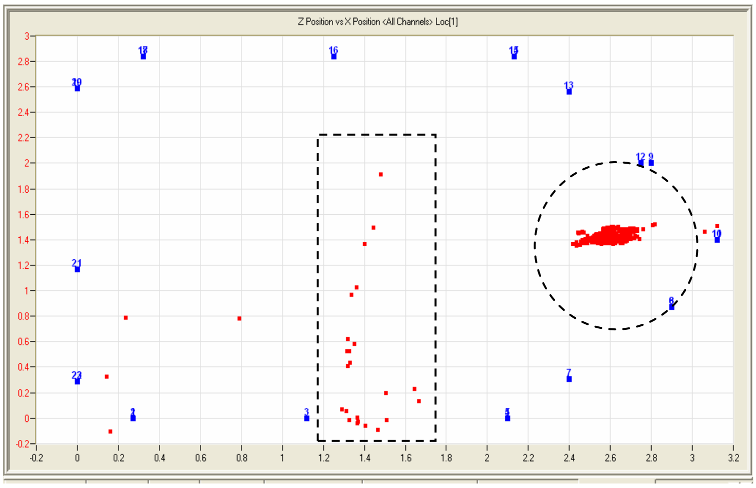

Figure 6 – Horizontal plane projection of located sources corresponding to acoustic activity in the reactor under test. The circled region corresponds to the area under the high-voltage bushing.

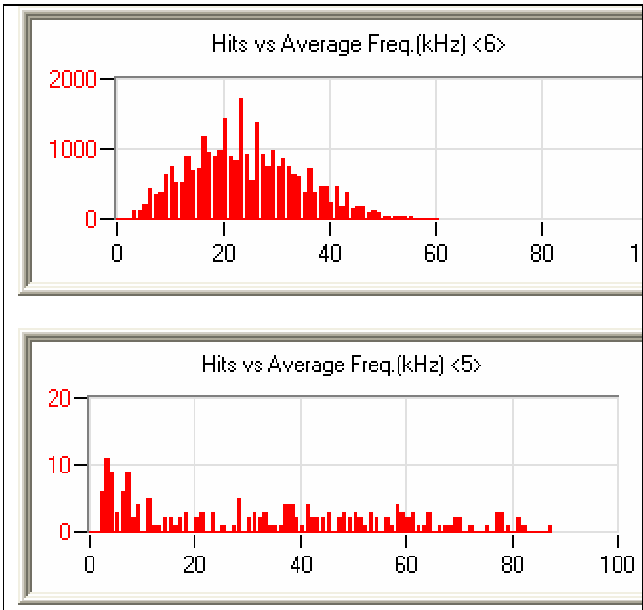

Figure 7 –Frequency distribution of the signals originated in the region under the high-voltage bushing (above) and in the center of the reactor (below)

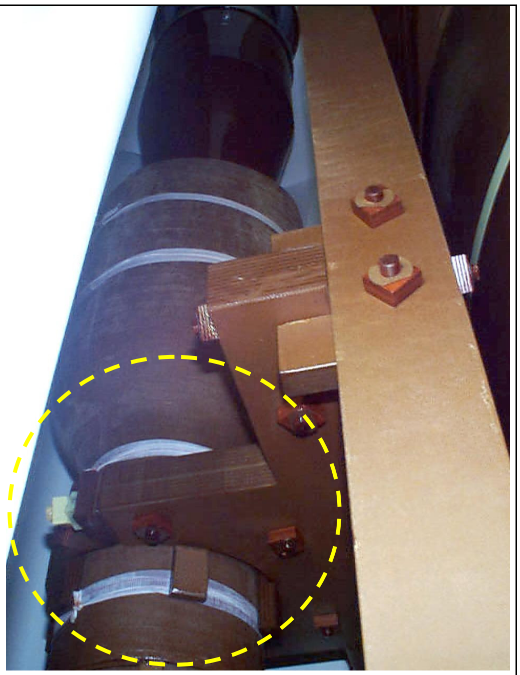

Figure 8 – Detail of the lower portion of the HV bushing, inside the reactor, showing loose parts

Another region, indicated in the rectangle in figure 6, showed sporadic activity, with higher characteristic frequencies, up to 80 kHz, suggesting the presence of partial discharges. Due to the difficult access to this region and no significant presence of hydrogen dissolved in the oil, no corrective action was taken relative to this region, but the equipment has been kept in close monitoring to detect any tendency of evolution of this condition.

6. Conclusion

Acoustic emission testing, although not yet fully disseminated in the electric power sector, has a potential to aid in assessing the operational condition of transformers and reactors. Its ability to locate the sources of acoustic signals and the possibility of performing tests with energized equipments are favorable characteristics of this method. Additionally, the characteristics of the acoustic signals, such as repetition rate, duration, average frequency can give an indication of the cause of the emissions. Used in conjunction with other techniques, such as Dissolved Gas Analysis (DGA), it can help improving the quality of the diagnostic of the equipment. Case studies have been presented, demonstrating the effectiveness in using acoustic emission to asses the condition of power transformers and reactors.

7. References

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