EFFECTS OF TRANSIENTS, IN POWER AUTOTRANSFORMER, DUE TO SUBSTATION SWITCHINGS – ANALYSIS BY ACOUSTIC EMISSION

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Abstract: In this paper, it is presented the results of Acoustic Emission (AE) tests carried out in two power transformers, in which acoustic activities were detected, due to switchings in the electric system where these equipment are connected. In the studies, it was looked for assessing the ability of acoustic emission technique for detecting these voltage transients, in an attempt to correlate the acoustic activity produced with possible stresses imposed on equipment.

1 INTRODUCTION

Switchings of circuit breakers, disconnectors and capacitor banks, among other operations, due to transients they produce, cause stresses to the electrical insulation of the substation equipment, which can, by the intensity and frequency they occur, put in risk their integrity.

Likewise, external events to the substation, associated to transmission lines, such as energizing and de-energizing, lightning strikes or short-circuits, also contribute to such stresses.

Among the most affected equipment, power transformers are a source of major concern due to its importance for the Electric System and the costs involved in case of damage to them.

Acoustic emission technique is a nondestructive, noninvasive, highly useful in detecting defects in internal active materials and equipment.

Although this technique has been extensively applied in many other technological areas, for which standards, test procedures and evaluation criteria have already been established, the application of Acoustic Emission to electric equipment should be considered a technique under development, because not all of its potentialities were exploited.

Among the advantages that it presents, in relation to other techniques, it can be distinguished by: its easy application, its low cost, the possibility of doing tests with the equipment under operation (eliminating the necessity of interruptions), the detection and analysis of faults in real time, its relative immunity from electromagnetic noises and the possibility of three-dimensional localization of defects. For these reasons, and due to efficacy obtained employing this technique, many utilities already adopt it in regular inspection programs.

At first, the technique was presented only for partial discharge detection in transformers, but later it was verified that this contribution is only one among many others possible from the Acoustic Emission technique. Due to its characteristics, the technique allows the detection of a great number of defects in these equipment, which could have either electrical or mechanical origins, both potential causes of catastrophic failures.

Acoustic activities, in equipment such as power transformers, are usually caused by mechanical, thermal and electrical phenomena, being the most common causes: mechanical vibration of components and accessories, switching surges, electrical system oscillations, hot spots and partial discharges. Regardless of their nature, these causes can result in the degradation of the insulation and lead to equipment failure.

2 NOMENCLATURE

Following are presented the definitions of the key measurement parameters used in this article for characterization of acoustic emission signals.

- Amplitude - peak voltage signal of Acoustic Emission, expressed in decibels referenced to $1\mu V$;

- Counts - number of times the acoustic emission signal exceeds a threshold adopted during the measurement;

- Energy - measured area under a signal rectified envelope in amplitude versus time coordinates. This parameter, how it is obtained, is a non-dimensional measure;

- Threshold - amplitude value, expressed in decibels, above which signals are detected. This limit is a reference to the electronic system so that it recognizes if the acquired signal should be considered in measurements.

3 PERFORMED TESTS

Acoustic emission tests were performed to identify internal defects in a 314 MVA converter transformer, voltage class 300 kV, in which it were detected acoustic activity signals produced by switching surges from another substation, connected to the same DC circuit. Based on these previous results, experiments in a 500 MVA autotransformer, voltage classes 765/√3 / 345/√3 / 20 kV, operating in a step-down substation were also carried out. The following results are presented.

3.1 Converter Transformer, 314 MVA, monophase, voltage class 300 kV, operating in a converter substation CA/CC

The tests consisted in monitoring the acoustic signals coming from inside the transformer, in normal operation condition.

For the tests, 20 piezoelectric acoustic emission sensors, with resonant frequency of 150 kHz, fixed on the outer surface of the transformer tank, were used. As reference for the location of the sensors, the lower left corner of the face located below the bushings X3 and X4 was taken as the origin of the measurements.

During the monitoring period, it was observed distinct acoustic behaviours in the transformer, as may be seen in Figure 1. Figure 2 shows the regions inside the transformer, where the sources of acoustic activity detected were located.

The types of acoustic activities observed and the intervals during the day that they were detected were:

a) Between 9:34 am and 11:45 am – Non-significant acoustic activity, consisting of low intensity signals.

b) Between 11:45 am and 01:00 pm – slight increase in acoustic activity in terms of quantity of the detected signals. Source localization in regions 1 and 2 as indicated in Figure 2.

c) Between 01:00 pm and 01:40 pm – significant increase of acoustic activity, with high energy signals, in all regions indicated in Figure 2.

d) Between 01:40 pm and 02:07 pm – reduction of acoustic activity but also with sources located in regions 1 and 2.

e) Between 02:07 pm and 02:21 pm – intense acoustic activity with high energy signals. This behaviour was maintained until the switching of taps (02:21 pm).

f) From 02:24 pm to the end of monitoring (02:38 pm) – reduction of acoustic activity but also with sources located in regions 1 and 2.

Information obtained from the control room of substation realized that, in the interval corresponding to the more intense acoustic activity, there was occurring a technical intervention for removal of filters, in another converting inverting DC / AC substation, component of the same electric system, located about 800 km away. The regions, inside the autotransformer, in which were localized the more intense acoustic activity sources, and therefore, would be the most affected, correspond to: one set of coils (Region 1) and the base of the X3 bushing (Region 2).

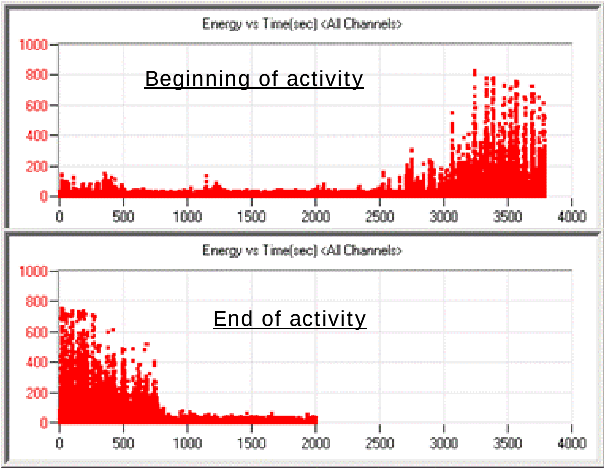

Figure 1: Acoustic activity – AE signals energy

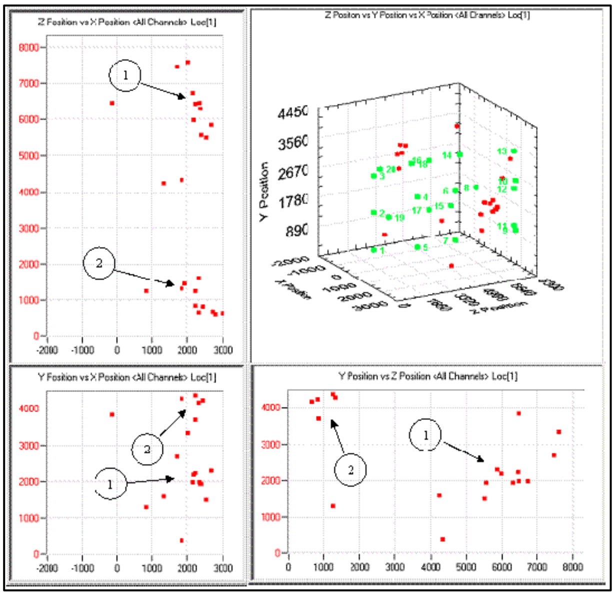

Figure 2: Acoustic activity – AE sources location (dimensions in mm)

3.2 Autotransformer, monophase, 500 MVA, voltage classes 765/√3 / 345/√3 / 20 kV

The tests consisted of continuous monitoring of Acoustic Emission signals from inside the autotransformer, over seven days of normal operation, in the substation, and aimed to identify and locate, using the technique of acoustic emission, acoustic activities produced by switchings in the electrical system where the equipment was connected.

For the tests, 24 piezoelectric acoustic emission sensors, with resonant frequency of 150 kHz, fixed on the outer surface of the autotransformer tank, were used. The distribution of sensors on the surface varied during the monitoring to enable a better source localization in specific regions of the equipment. As reference for the location of the sensors, the lower left corner of the face that contains tertiary bushings (20 kV) was taken as the origin of the measurements.

Continuous and intermittent acoustic activities were detected throughout the monitoring, Figure 3. In general, these activities consisted of low intensity signals, and mostly had their origin in the mechanical vibrations of the internal components of the autotransformer.

Acoustic sporadic activities, among which were those from switching surges were detected in large numbers during monitoring, with several levels of intensity and with different duration, Figure 3.

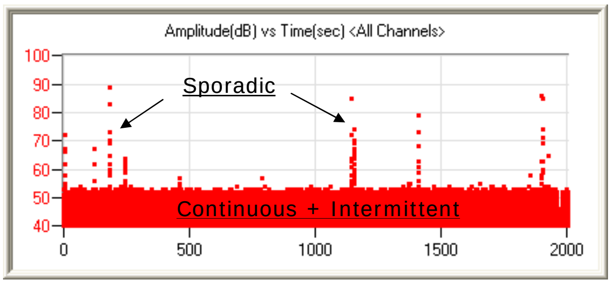

Figure 3: Types of acoustic activity

The identification of acoustic activities related to events of interest was based on information obtained from substation operation reports, considering: the coincidence of the instant of occurrence, the repetition of similar switchings, duration and form of activity.

Among these activities, two distinct types were observed: short duration activities, in order of milliseconds, which appeared mostly as a result of the operation of circuit breakers, tap-changers and capacitor banks, and long-duration activities, above tenths of seconds, due to openings and closings of disconnectors.

Several other sporadic events detected could not be identified. Their most likely causes can be attributed to: changes in operating conditions, internal defects of the autotransformer, or not registered switchings due, among other reasons, to occur in points of the electrical system distant of the substation.

3.2.1 Acoustic acivities due to disconnector opening and closing

During the monitoring period, several switchings were performed for disconnection and normalization of transmission lines at different distances from the autotransformer. These switchings involved especially disconnector opening and closing.

Figures 4 and 5 (detail) show the results of a sequence of operations performed for normalization of the HV bus, near the autotransformer, at distances ranging from 40 to 300 meters. Figure 6 shows the location of the sources of Acoustic Emission detected.

Disconnector switchings, related to these operations were those that produced acoustic activity of longest duration and with greater greatest levels of intensity, among those performed externally to the autotransformer.

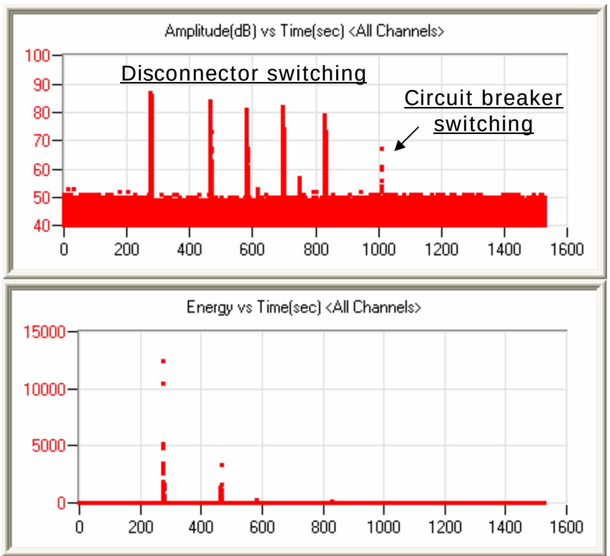

Figure 4: Disconnector and circuit breaker switchings

As can be seen in Figure 4, the energy of acoustic signals sharply decreased with increasing distance from the place where the switchings were performed.

Figure 5 shows, in detail, aspects of the acoustic activities produced by one of disconnector switchings.

Acoustic activity of long duration, about 4.5 seconds, composed of signals with high amplitude and energy, is observed.

The resulting electromagnetic induction due to switchings was so high that, at certain instants, affected the acoustic measurement instruments, resulting, in some cases, switching off them. Even channels of instrumentation, whose sensors were disconnected from the autotransformer tank showed acoustic activity as a result of this induction. This fact interfered in the source location of activities, at least for those switchings performed near to the autotransformer, Figure 6.

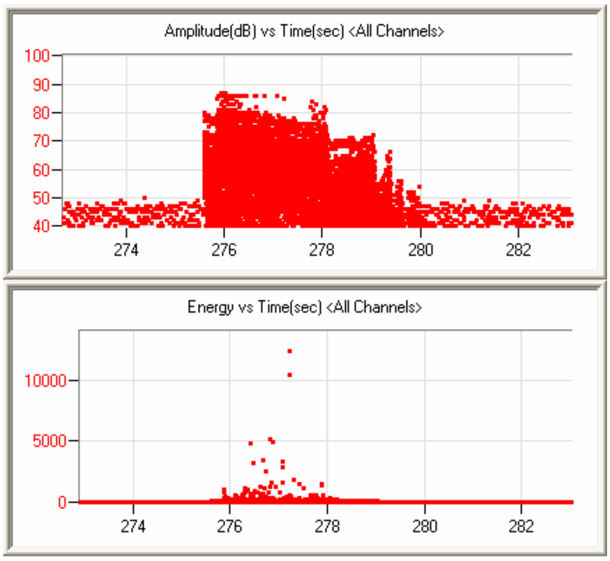

Figure 5: Disconnector switching (detail)

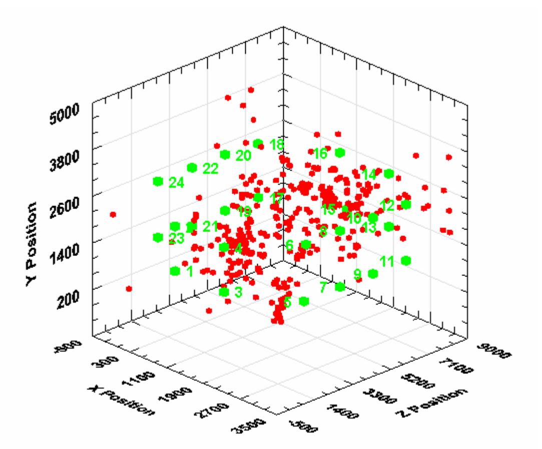

Figure 6: Disconnector switching - AE sources location (dimensions in mm)

3.2.2 Acoustic activities due to circuit-breakers switchings

The switchings for the isolation and normalization of transmission lines also involved circuit-breaker opening and closing. Figures 4 and 7 (detail) show the acoustic activity observed in one of these switchings performed during operations to normalize the HV busbar, near the autotransformer.

Short duration acoustic activity, in order of milliseconds, composed of signals with medium amplitudes and low energy, is observed in these figures.

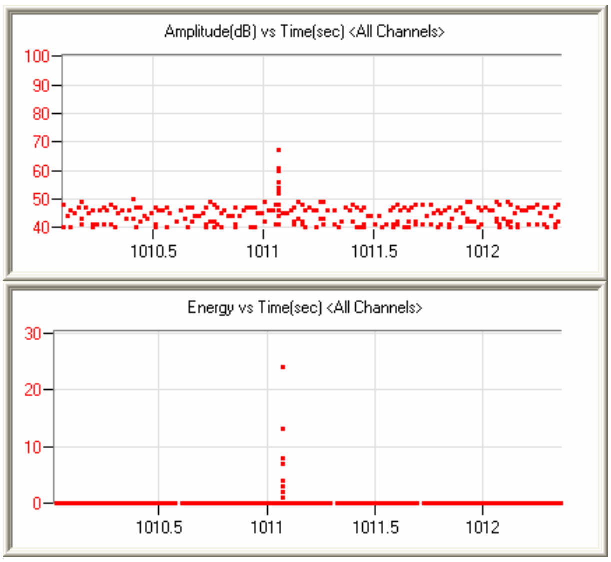

Figure 7: Circuit breaker switching (detail)

Figure 8 shows the location of the Acoustic Emission source detected. The marked region is in the vicinity of the on-load tap-changer.

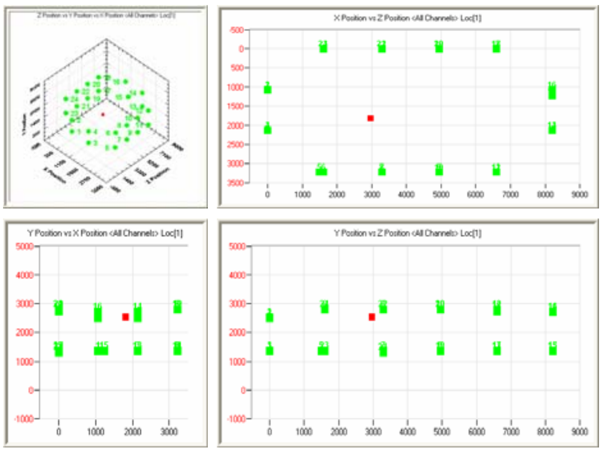

Figure 8: Circuit breaker switching - AE sources location (dimensions in mm)

3.2.3 Acoustic activities due to capacitor banks switchings

Figures 9 and 10 (detail) show the acoustic activity detected at the instant of a shunt capacitor bank of 200 Mvar switching.

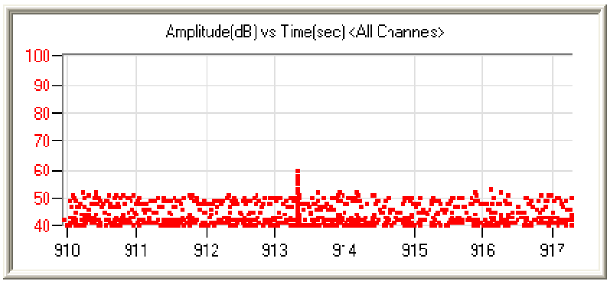

Figure 9: Capacitor bank switching – AE signals amplitude

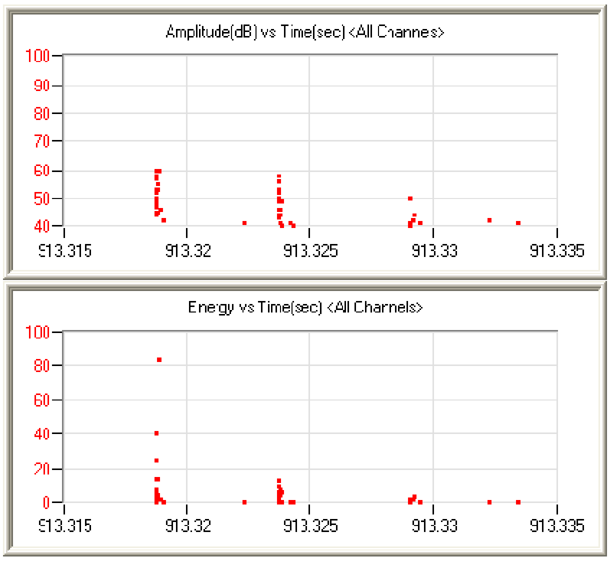

Figure 10: Capacitor bank switching (detail)

When viewed in detail, Figure 10, it was found that this activity was consisted of four events of decreasing intensity, composed of signals ranging from medium to low amplitudes and low energy. The duration of acoustic activity was around 15 milliseconds.

No changes were observed in the acoustic behaviour of the autotransformer after switching the capacitor bank.

Not all the capacitor banks performed switchings produced detectable acoustic activity in autotransformer.

Figure 11 shows the location, inside the autotransformer, of acoustic emission sources detected. In the indicated regions, there is an on-load tap-changer and a not well identified component, part of a winding or the autotransformer core.

4 REMARKS AND CONCLUSIONS

The results of tests performed on power transformers show that the acoustic emission technique is an important tool capable of detecting the activities and, therefore, the stresses due to electric transients caused by switchings in the electrical systems in which these equipment are interconnected.

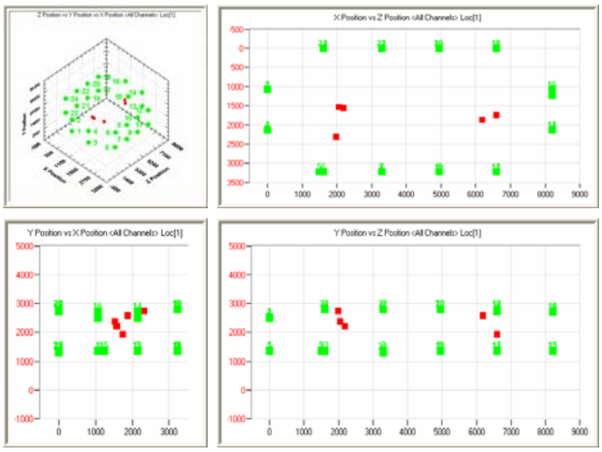

Figure 11: Capacitor bank switching - AE sources location (dimensions in mm)

At the current stage level of development, the application of acoustic emission technique does not allow, alone, an assessment of the criticality of the detected events. To achieve this goal, it is also necessary that the results should be analyzed together with other evaluation techniques and studies of supportability of the equipment projects.

Among the operations performed during monitoring of the autotransformer, the disconnector switchings closer the autotransformer were that caused most intense and longest acoustic activities.

The electromagnetic induction produced by opening and closing a disconnector, at certain time, affected the acoustic measurement instruments, resulting, in some cases, its shutdown.

Sensors, even when disconnected from the autotransformer tank, showed acoustic activity as a result of electromagnetic induction produced by disconnector operations.

The energy of the detected signals during disconnetor switchings sharply decreased as the distance increased from the place where such operations were performed.

Both circuit-breakers and capacitor banks switchings produced acoustic activity of short duration, consisted of signals of medium amplitude and low energy.

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