Abstract: The occurrence of partial discharges (PDs) in power transformers is a phenomenon inherent to their operation and one of the factors that can cause failure of these devices, leading to major disruptions and high financial losses, and compromising the image of the electric energy provider.

Dissolved gas analysis (DGA) is a widely accepted predictive technique, but its sensitivity is low when used for the detection of partial discharges, and it does not identify the location of incipient faults in power transformers.

On the other hand, the detection of partial discharges by the acoustic emission (AE) method allows the levels of partial discharges inside transformers to be monitored and their location to be pinpointed. However, to increase the quality of the analyses of results, it is important to observe some requirements and to carry out several procedures that contribute to a more effective diagnosis. This paper describes a methodology that increases the analyst’s efficacy in evaluating the results of acoustic detection tests of power transformers in operation.

Index Terms: partial discharges, power transformers, predictive technique

I. INTRODUCTION

Accidental or unscheduled transformer shutdowns cause serious impacts and significant financial losses. A variety of defects can lead to the failure of a transformer, including the occurrence of partial discharges, which are the subject of discussion in this paper.

The occurrence of PDs in transformers may result from a defect or an incipient fault, which can produce an unexpected interruption and which appears and develops without being easily detectable.

Aging and faults in insulating systems of electrical equipment originate from chemical, mechanical, thermal and electrical processes that can occur during operation and even in the manufacture of the equipment. During these processes, defects appear that can lead to localized reduction of the dielectric capacity of the insulating system [1].

There are various methods for detecting PDs, including the electrical method, the chemical method – Dissolved Gas Analysis (DGA), radio interference voltage (RIV), acoustic emission, etc. [2]. Among these methods, we highlight dissolved gas analysis in insulating oil (DGA) and detection by the acoustic emission method.

DGA is widely used as a predictive maintenance technique because it allows for the detection in incipient faults in power transformers. However, it does not allow for the identification of the site where the incipient fault occurs, which may make pinpointing its location difficult. Moreover, DGA has low sensitivity for the detection of partial discharges [3]. This may sometimes lead to imprecision in analytical methods, possibly resulting in errors by the person analyzing test results.

In contrast, the detection of partial discharges by the acoustic method offers the advantage of allowing one to pinpoint the region where partial discharge activity occurs. Moreover, as in DGA, this method can also be used without requiring the shutdown of the transformer to be tested. These characteristics make this method a powerful tool as a predictive maintenance technique. However, its effectiveness depends on the observance of several procedures and requirements.

As a power transformer maintenance strategy, it is important to monitor the activity of partial discharges in order to check the evolution of this problem, so that an intervention can be scheduled before the actual occurrence of a failure causing the collapse of the equipment.

Based on several studies, this new methodology was therefore devised, whose application is economically viable in view of the high costs inherent to the acquisition of replacement of power transformers. Thus, the objective of this paper is to present this methodology and the procedures that contribute to the more effective use of the method of acoustic detection of partial discharges as a predictive maintenance technique.

II. ACOUSTIC DETECTION AS A PREDICTIVE MAINTENANCE TECHNIQUE

The predictive technique consists of establishing a diagnosis and analyzing tendencies based on test results and on the analysis of phenomena that occur during the operation of a device. When the diagnosis is final and conclusive, if an abnormality has been detected, the necessary measures should be taken to correct it. To this end, preventive or corrective maintenance can be scheduled for the equipment in question. Thus, the predictive maintenance technique is extremely important in foreseeing equipment defects and incipient faults, especially in power transformers, which are costly devices.

Figure 1 illustrates a typical wave of an acoustic
signal inside a transformer, resulting from a partial discharge and captured by a sensor attached to the external face of the tank.

The detection of partial discharges by the acoustic method can be used as an excellent predictive technique in the maintenance of power transformers. However, to use acoustic detection effectively as a predictive technique requires the observation of various requisites and the application of a procedure involving the steps listed below.

a) Full knowledge of the geometry and design of the active part, tank and bushings of the transformer.

b) Mapping and definition of the signature of the partial discharge activity specific to the device in the acoustic detection test upon receipt of the equipment from the manufacturer.

c) Analysis of comparative diagnoses against transformers with the same design (identical).

d) Duration of the test matching the typical load cycle of the transformer under evaluation, in order to cover the different operating conditions to which the equipment is subjected.

Each of the above requisites and procedures is described below in the form of steps to be followed.

**Step 1 – Identification of the geometry and design of the active part, tank and bushings**

The principal element of power transformers is their active part, since their main function, which is to transform voltages and currents, is carried out by the set of windings and the core. The active part contains the main elements of the transformer that are subject to mechanical vibrations as well as the principal points susceptible to partial discharge activity. Partial discharges can be formed for various reasons, including a higher intensity of the electrical field in some portion of the active part or the bushings, or discharges to the tank structure resulting from the design characteristics of each device.

Electrical fields are established as a function of the values of permittivity of materials (and not of their nature). In fact, a more intense field is formed in the zones where the electrical permissivity ($\varepsilon$) is lower.

Moreover, the occurrence of transient voltage surges due to electrical shunting or atmospheric discharges may produce electric fields inside the transformer that far exceed its upper design limit. Thus, transformer designers should be concerned about the correct dimensioning of the insulating system of transformers, based on parameters such as the electric fields inside those devices.

In view of the above, it seems clear that partial discharge activities occur preferentially inside the active part of transformers, although it should be kept in mind that other components – such as the inside of bushings – may also show the presence of PDs.

Therefore, knowledge of the dimensions and positions of the windings, core, bushings, the arrangement of the leads from the taps and bushings, the position of the tap commuter and the other components (breech locks, metal screws, potential equalizer rings, etc.) is essential to analyze the results of a detection of partial discharges by the acoustic method, since the main information provided by this method is the identification of the coordinates of the site where the partial discharge activity occurs. Hence, detailed knowledge of the geometry of the equipment is a highly relevant factor for the correct identification of partial discharge activity inside a power transformer.

To meet this requisite it is necessary for the company purchasing the transformer to include in its regulations the specifications and procedures of the device, requiring the manufacturer to provide detailed drawings of the active part, the tank, the bushings, and the other components in the user manuals that come with the equipment it supplies.

**Step 2 – Initial record of the partial discharge activity in the transformer**

In monitoring the state of a device, it is important to have reference (or initial) values to aid diagnoses based on the verification of tendency curves, analysis of test results, etc.

Therefore, in the monitoring of PDs in transformers by the acoustic method, the methodology presented here considers it indispensable to have reference values from the moment the insulating system is new, i.e., when it has not yet undergone a continuous process of degradation. These reference values can be obtained from the transformer manufacturer. It should be noted that this practice is already widely employed by electric power providers with respect to power factor and insulation resistance tests.

When the PD detection test by the acoustic method is carried out immediately upon receipt of the device from the manufacturer, it is equivalent to recording the signature, i.e., the profile of the intensities and magnitudes of partial discharge
activity formed by that particular device. This initial record of PDs becomes the reference value, based on which the maintenance team will make its evaluations, checking the evolution of the occurrence of PDs inside the transformer.

Given the importance of this step during the receipt of new transformer units, it is therefore essential for electric power companies to include in their specifications the obligatoriness of carrying out this test upon conclusion of all the other receiving dielectric tests, such as atmospheric impulse, shunting impulse, applied voltage, and induced short and long duration voltage.

Because these tests check the supportability of the transformer’s dielectric system under extreme conditions, they may cause degradation (albeit slight) of the transformer’s insulation materials. Therefore, the moment these tests have been concluded is considered the “moment zero” for purposes of recording the formation of partial discharge activity, i.e., the PD “signature” of the equipment.

**Step 3 – Analysis of comparative diagnoses against other transformers**

As mentioned earlier, the comparative analysis is very important for the diagnosis of defects or incipient faults based on acoustic detection. Therefore, this step consists of making an analysis of a group of transformers of the same voltage class, design and fabrication (so-called similar devices). The behavior of these equivalent transformers tends to be similar when subjected to similar operating conditions. However, the comparative analysis of similar devices is a complementary parameter that enables the analyst to make a more accurate diagnosis of their performance, based on the acoustic detection results.

Therefore, a database is needed to store the information of the results of acoustic detection tests on similar devices. Also, as an auxiliary tool, it is advisable to use specific software to facilitate the search for and comparative analysis of such devices.

**Step 4 – Duration of the test matching the typical load cycle**

The operating conditions to which power transformers are subjected are parameters that should be observed for a good diagnosis of partial discharge activity. Hence, the variations in voltage and load that usually occur in the daily load cycle are factors that influence the lesser or greater occurrence of partial discharges inside a power transformer.

During the period of peak load of the system (heavy load), the voltage in the bars tends to decrease due to drops in voltage caused by load currents. Inversely, during the period of lighter load of the system, the voltage in the bars tends to increase. These effects have a direct impact on fixed tap transformers. In the case of devices equipped with tap commuters operating under loads, these effects cannot always be compensated by the commuting action of the taps, since the range of percentile variation of voltage in the system may be higher than the commuter’s range of adjustment. Thus, the level of PDs is expected to be higher in the periods of lighter load and lower in the periods of higher load.

On the other hand, because the electric field that is generated is also a function of the insulating medium in which it is inserted, the changes occurring in the transformer’s insulating material along the load cycle, and the amount of humidity contained in the insulating system of this equipment, are highly relevant in the formation of partial discharges [4, 5].

It should also be noted that the distribution of temperature along the windings of the transformer varies as a function of their height, as depicted in Figure 2.

Therefore, this step illustrates the importance of analyzing the behavior of the transformer during the load cycles, in order to determine the period and duration of the partial discharge detection tests by the acoustic method, ensuring the optimal efficiency of the results.

![Fig. 2 – Distribution of temperature along the winding](image-url)

**III. CONCLUSION**

The PD detection test by the acoustic method allows for online monitoring of PDs without requiring an invasive action in the transformer under observation. For this reason, the acoustic method is an important tool in the diagnosis of eventual internal faults, and can even be used as a predictive maintenance technique. However, for the effective use of this method as a predictive maintenance
technique, several procedures must be adopted and requisites observed, without which the diagnosis may be inaccurate and therefore inconclusive.

These procedures were described in this paper as steps to be followed and observed in the analysis of PD detection by the acoustic method.

Like other partial discharge detection methods, the acoustic method has its drawbacks. Thus, in addition to the items described herein, the ideal situation is to combine the acoustic emission (AE) method and the chemical method (DGA) to field test to provide the maintenance engineer with more precise data for his diagnosis of the state of a transformer.

The methodology presented here allows for the effective use of the acoustic detection method as a predictive maintenance technique, and is therefore feasible from the economic standpoint, since a good maintenance strategy based on the results of predictive techniques avoids the high costs incurred through accidental or unscheduled shutdowns of power transformers.

Therefore, aiming to improve their results according to the procedures outlined herein, the electric energy provider Celg-D, after its coming acquisition of a partial discharge meter, intends to apply this methodology and include it in its list of predictive techniques for power transformers.

REFERENCES


