Application of Acoustic Emission Discharge Detection Method for Online Condition Monitoring of Power Transformers: ERDA’s Experience

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Abstract-- This paper discusses the application of Acoustic Emission discharge detection technique for Online Condition Monitoring of Power Transformers and ERDA's experience in this field.

Index terms-- Partial discharge, Acoustic Emission method, online condition monitoring

I. INTRODUCTION

The Periodic Condition Monitoring of Insulation System of the power plant high voltage equipment will help to identify and foresee the trend of insulation degradation, prevent possible failures & enable to undertake corrective action well in advance to minimize the unplanned outages. Hence the continuous monitoring of service parameters of insulation system is a basic prerequisite of preventive remedial measures to ensure reliable services for sufficiently predictable long period under continuous service stresses.

Partial Discharge Detection Technology is widely used as an effective method of evaluating internal insulation status for any high voltage equipment. The inception or increase in partial discharge (PD) activity is usually a precursor to incipient dielectric faults. Once the presence of partial discharges is detected, the location of the same is also very important so that the defects can be pinpointed and solved effectively.

There are a number of very sensitive and sophisticated electrical detection techniques presently available for PD detection and measurements.

However, the electrical detection methods are very sensitive to the Electro-magnetic interference, also such interference signals may be controllable in a Laboratory or Factory set up, but often beyond control in the field set up. Hence, these electrical methods are practically impossible for condition monitoring purpose of already installed transformers. Also, electrical PD detection methods rarely provide a basis for location of the partial discharge in case of test objects with complex structure such as Power Transformers, Switchgear etc. In this context, the Acoustic Emission (AE) wave analysis is emerging as an important online condition monitoring tool for power transformers. The acoustic emission sensing offers a good real time solution to both PD detection and PD source location.

The Acoustic Emission (AE) Detection Methods have advantages over Electrical PD Detection Methods in many ways:

- The AE Methods can be very effectively used for the online PD Detection, since this method is immune to Electro-magnetic noise, which can greatly reduce the sensitivity of electrical methods, especially when, applied under field conditions.

- The sensitivity of AE Methods does not vary with test object capacitance, hence these methods can be widely applied to large Capacitors and Power Transformers.

- These Methods are online and hence most suitable for condition monitoring purpose.

- The location of discharge sources is possible by the Acoustic PD Detection Methods, once it is detected.

Electrical Research and Development Association (ERDA), Vadodara is one of the premier research organization in India, which is involved in the non-destructive diagnostic testing and evaluation of high voltage equipment for condition-monitoring purpose and residual life analysis at various fields such as Power Stations, Sub-stations, Petrochemical Plants, Oil Refineries, Railways etc. Its Laboratory is well equipped with sophisticated equipment and other facilities to undertake various testing, evaluation and research studies including the Acoustic Emission (AE) PD Detection System for online testing.

II. PD MEASUREMENT BY ACOUSTIC EMISSION (AE) TECHNIQUE

The partial discharge (PD) results in localized, nearly instantaneous release of energy. The energy released in a PD produces a number of effects such as chemical and structural changes in the material, Electro-magnetic effects etc. The Acoustic Discharge Detection is based on detection of the mechanical signals emitted from the discharge.

A fraction of the released energy from the PD source heats the adjacent material and can evaporate some of it, creating a small explosion. The discharge acts as a point source of acoustic waves that propagates throughout the insulation. The intensity of the emitted acoustic wave is proportional to the energy released in the discharge. Thus the amplitude of the wave is proportional to the square root of the energy in the discharge. As the energy is often proportional to the charge squared, a linear relationship between the amplitude of the acoustic wave and the discharge magnitude (in pico-Coulombs) is common.
A. ACOUSTIC PD INSTRUMENTATION

Acoustic PD detection setup is very simple, consisting of a sensor, filter, preamplifier, some type of data acquisition system (e.g. Storage Oscilloscope or Personal Computer) and some output device. The acoustic waves emitted from the PD source can be detected by a suitable sensor kept on the apparatus tank, the output of which can be analysed using a conventional data acquisition system.

The Acoustic Emission Sensor is a Piezo-electric Transducer, which converts the acoustic signals to corresponding electrical signals proportional to the velocity of the surface to which they are attached. These sensors can be of various frequency ranges (30 kHz/150 kHz). Such resonant Sensors are usually mounted with a thin layer of acoustic couplant (e.g. grease) to assure good contact and sensitivity and are fixed at the place by magnetic hold-downs, tape, elastic bands etc. The coupling from the apparatus under test to the sensor should be considered as an integral part of the system, as it strongly influences system characteristics. The output AE signals from the sensors are pre-amplified and filtered for spurious signals. These filtered signals are further amplified and are ready for analysis. These signals can be directly fed to a Computer and can be analysed using dedicated software.

B. LOCATION OF DISCHARGE

In order to determine the severity of a PD problem, it is necessary to locate its geometric location as well as its magnitude. The possibility of PD location is one of the major features of acoustic discharge determination. Location can be based on either measurement of time of signal arrival at a sensor or of signal level.

A number of AE detection sensors can be placed on a number of locations on the tank of the equipment for PD location in case of transformer for the on-line measurements. The AE signals from the PD source will be sensed by all the sensors, but the signal amplitude and the time of arrival of the signal will be different in the various cases. From the analysis of the difference in signal magnitude and the time delay of the signals, the location of the PD source is determined.

III. ERDA’s EXPERIENCE

For the experimental investigation, the acoustic PD Detection System with software has been used by ERDA Laboratory. The main components of the system are the integrated preamplifier with sensors, appropriate length of cables, one digital signal processing card, personal computer and software.

A. ERDA’s LABORATORY EXPERIENCE

ERDA has conducted a number of experiments in its Laboratory in order to make a meaningful correlation between these measured AE signals and the electrical pulse data received from the conventional electrical detection and measurement systems. A typical waveform is shown in fig. 1.

![Fig.1](image1.png)

- For initial experiments:
  - A test chamber of transformer model was designed and fabricated for the experiment purpose in the laboratory. (Fig.2)
  - The partial discharges have been simulated inside the chamber by applying high voltage to the electrode system and performed various experiments by simultaneously measuring the apparent charge and the acoustic amplitude of a number of PD events by conventional electrical methods & AE detection methods on the model set up
    - Apparent charge by IEC 270 straight detection method
    - Acoustic amplitude using two sensors placed at various relative angles
  - Checked variation of AE signal with respect to voltage for different electrode gap lengths.

The performance of AE method (level of attenuation) were analysed, when
- Press board barrier is introduced in between PD source and the sensors
- With change in location of press board barrier in between PD source and the sensors
- A no. of press board barriers are introduced in between PD source and the sensors
- Metal barrier is introduced in between PD source and the sensors

- And then tried to make correlation between the maximum discharge magnitude in pC (Electrical) & the acoustic PD counts/signals in each case.

- A linear relationship between the amplitude (dB) of the acoustic waves and the peak value of the discharge magnitude (pC) in a wide spread-through was observed. A typical example is shown below. (Fig.3 & Table 1)

![Fig.3](image)

- The variable parameters were:
  - The location of the PD source with respect to the AE sensor position.
  - The insertion of attenuating materials such as press board/s and metal plates at various distances from the AE sensor and PD location.

- In each experiment, the peak value of the discharge magnitude (Electrical), the amplitude of the AE signal detected, the acoustic counts and the energy have been recorded.

- In general, as the test voltage is increased, the discharge process becomes vigorous and along with the peak value of PD magnitude, the AE amplitude, no of counts and the energy also increase.

- In both laboratory set up and the testing on actual test objects, a linear relationship between these values with definite accuracy has been found.

- Interestingly, in a few cases as the voltage is higher, the electrical PD value became more or less stable, whereas there were sharp increase in AE characteristics such as amplitude, counts and energy.

- Various materials inside the actual transformer attenuate the AE signals considerably. The same was verified by introducing a number of attenuating materials in between the PD site and the sensor location.

- While a pressboard barrier is introduced in between, the detection was possible only at a higher voltage where the PD was very high (due to attenuation of the signals).

- Small effect was observed when the position of the pressboard was shifted from near the PD source to the sensor location.

- When a number of pressboards are introduced, the attenuation was more, even though the rate of attenuation is less with more number of pressboards.

Based on the three characteristics of AE signals, the amplitude and the average signal level, the counts and the energy level, the correlation can be performed with reasonable level.

- For further experiments:
  - A bigger tank filled with transformer oil and a few capacitor elements connected in series, some of the elements destructed have been used as the active PD source.

<table>
<thead>
<tr>
<th>Time (kV)</th>
<th>Voltage (dB)</th>
<th>AE amplitude (pC)</th>
<th>PD magnitude (pC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-40</td>
<td>10</td>
<td>40</td>
<td>100</td>
</tr>
<tr>
<td>40-160</td>
<td>14</td>
<td>55</td>
<td>800</td>
</tr>
<tr>
<td>160-240</td>
<td>16</td>
<td>60</td>
<td>950-1200</td>
</tr>
</tbody>
</table>
2) ERDA’s SITE EXPERIENCE

A number of large power transformers are being tested at Site conditions by using the acoustic PD Detection System. The transformers are selected based on the DGA test results of the transformer oil where electrical discharges are detected. In a classical example, the DGA analysis of one 66 kV transformer detected the presence of low energy discharges inside the transformer. The Acoustic Emission Detection Test was performed on the above transformer by using two Acoustic sensors of the resonant frequency 150 kHz and the exact location could be pinpointed as the lower end of one of the HV bushing (Fig.4). Further opening of the transformer proved the results of the Acoustic Emission Detection Test as perfectly correct. Some of the strands of the conductor near the bushing terminal were came out and it caused the low energy discharges. In another case where the DGA analysis showed thermal fault, the test results indicated the transformer as discharge free. Further experiments for getting a correlation between various online and offline condition monitoring methods are going on.

IV. ACKNOWLEDGMENT

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V. REFERENCES:


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