# PARTIAL DISCHARGE DETECTION ON METAL ENCLOSED SWITCHGEAR PANELS

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## ABSTRACT

*This paper details the detection of partial discharges by using acoustic emission measurements. The theory of partial discharge phenomena in metal enclosed switchgear is discussed alongside case studies of various failure modes within the switchgear compartments.*

## INTRODUCTION

Partial Discharge tests as specified in IEC 62227-200 is an agreement between user and manufacturer. Further, the maximum required value is not specified of which leaves the accepted values to the manufacturer of the equipment. The principle behind such a specification is that discharges below a certain value should cause minimal degradation of the various insulating materials over the life of the equipment.

eThekwini Electricity is responsible for the maintenance of approximately 4 500 metal enclosed switchgear panels operating at 11 kV with three different interrupting mediums i.e. oil, $SF_6$ and vacuum. The reliability of these aging switchgear panels is of paramount importance to the stability and performance of the network. eThekwini Electricity has embarked on a condition assessment program through the introduction of advanced diagnostic testing. The use of acoustic techniques seems to be an excellent starting point for the detection of partial discharges in 11 kV switchgear panels. This method of testing has proven itself invaluable in the detection of partial discharge within GIS. This non-invasive method has the ability to detect, locate and evaluate defects that may lead to the failure of the switchgear panels.

## 1.0 THEORY

Partial Discharge (PD) is an electrical discharge that only partially bridges the insulation between conductors and which may or may not occur adjacent to a conductor [1]. The discharge may be present in gas filled compartments, solid insulating materials and liquid insulating medium. When PD occurs in gasses, it is usually referred to corona. PD is generally accepted as the pre-dominate cause of long-term degradation and eventual failure of insulating materials. As a result, its measurement on individual components and complete assemblies of metal enclosed switchgear should be a factory routine test.

### 1.1 Acoustic Monitoring

Ultrasound is sound waves at frequencies higher than the human ear cut-off frequency of about 20kHz. Ultrasound can be used as a diagnostic tool for electrical insulation testing using Acoustic Emission (AE) testing.

### 1.2 Acoustic Emission Testing

AE testing involves listening to the sound energy emitted by partial discharge activity, arcing or corona in a high voltage system. The repetition rate, magnitude and frequency characteristic of this emitted energy may be used to determine the location and nature of the electrical source creating the sound energy.

### 1.3 AE Testing in Medium Voltage Plant

PD activity in medium voltage systems generates both electromagnetic and acoustic energy. Like electromagnetic energy, acoustic energy radiates in all directions from the discharge source. High frequency acoustic transducers may be used to detect this energy and capture it for analysis on an oscilloscope or dedicated system as in Figure 1 below. The transducers must be highly sensitive, tuned piezoelectric crystals.

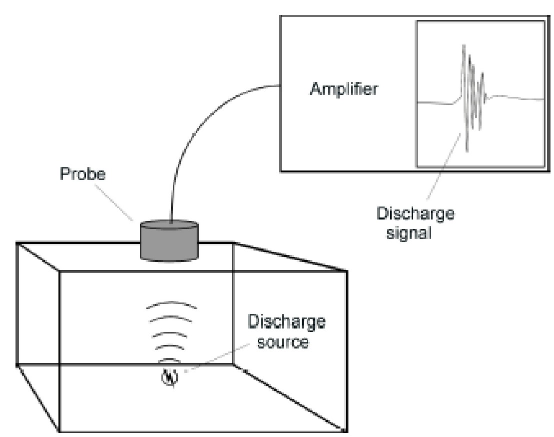


*Figure 1: Sound energy from a discharge source*

The frequency and magnitude of the discharge are dependent on the nature of the source. If the source is an electrically stressed void in an insulating system, the void size and shape affect the characteristics of the acoustic energy generated.

As the sound travels through the insulating medium it is attenuated, with the higher frequency components being attenuated at a greater rate. This causes the insulation to act like a low pass filter. The frequency distribution of the acoustic energy created by PD is therefore a function of the frequency content of the discharge and the length and nature of the transmitting medium.

Although the sound emanating from a discharge source may have components from the audible range up to hundreds of MHz, by the time it reaches an accessible monitoring point its spectrum is generally in the low hundreds of kHz range. It is often advisable to disregard lower frequency components due to the high level of interference from external and non-electrical sources. It is generally considered that the most useful inspection range is in the region of 30 kHz to 300 kHz.

## 1.4 Practical Plant Testing

Although the techniques involved in AE testing are applicable to most types of plant and insulation systems, in practice it tends only to be used for the detection of discharges in oil filled equipment and surface tracking or corona. This is simply because oil, steel, aluminum and air are all good conductors of sound compared to insulators like bitumen compound, polyethylene and oil impregnated paper.

## 1.5 Surface Tracking

Tracking is the formation of a permanent conducting path across an insulator surface. Usually the conduction path results from degradation of the insulation. For tracking to occur the insulation must be a carbon based compound.

Most high voltage plant is exposed to the environment. In industrial areas, insulators become contaminated with pollution and dirt from the atmosphere. Where substations are situated near the sea, salt very quickly covers the plant. In the presence of moisture these contaminating layers give rise to leakage current over the insulator surface. This heats the surface and through evaporation causes interruption in the moisture film. Large potential differences are generated over the gaps in the moisture film and small sparks can bridge the gaps. Heat from the sparks causes carbonization of the insulation and leads to the formation of permanent carbon tracks on the surface.

These small discharges can be detected using AE. The ultrasonic signals emitted can easily be picked up using sensitive detectors. As discharges that lead to tracking are often related to environmental factors, continuous monitoring is usually required in order to build up a clear picture of this type of PD activity.

## 1.6 Corona

Corona is very often present in substations and is not usually considered a problem unless it is detected at very high levels or is contributing to surface tracking. Damaged overhead insulators can however lead to flashover and corona detection provides a fairly cheap and easy means for detecting them.

Sound travels through air at lower frequencies than it does through solids, so corona detection is usually performed at frequencies between 30kHz and 90kHz.

When performing tests in a substation, absolute levels are likely to vary considerably with atmospheric conditions. An inspection should therefore concentrate on looking for significant variation in recorded levels between similar pieces of equipment.

**2.0 ACOUSTIC DIAGNOSIS**

**2.1 Instrumentation**

Acoustic measurements are performed during normal service operation of the metal enclosed switchgear panels (energized) by using an external, moveable sensor and a portable instrument as shown in Figure 2 below. The instrument is equipped with an acoustic emission (piezoelectric) sensor, which is located externally onto the metal enclosed switchgear panels during measurements. The sensor picks up the acoustic waves/sound that propagate in the enclosure due to emitted acoustic signals from flaws inside the switchgear and converts the sound to a voltage signal in the tens of kHz regime. Since acoustic measurements of PD cannot be calibrated directly in pC, the acoustic signals are measured and displayed in mV.


*Figure 2: Acoustic Insulation Analyzer (AIA)*

The acoustic method is a non-invasive and self supported technique. Experience shows that the technique offers several benefits:

a) Immune to most types of external noise;
b) Good sensitivity for detection of the most common types of defects;

c) Defects can be localized;
d) Different defects can be recognized/distinguished; and
e) Risk assessment is based on source characterization.

The acoustic signals from the defects may vary widely from continuous signals from internal corona to pulse shaped signals from for example moving particles. The shape of the acoustic signal will depend on the type of source, the propagation path of the signal and the sensor characteristics. The acoustic signals from the described flaws are generally wide banded - partial discharges in the range of 10 kHz to 100 kHz and particles up to several MHz. However, there are a limited number of parameters to describe such signals:

Continuous Signal

a) Peak value over one power cycle
b) RMS-value over one power cycle
c) Degree of modulation with the power cycle (50/60 Hz)
d) Degree of modulation with twice the power frequency (100/120 Hz)

Pulse Shaped Signal

a) Peak value of the pulse signal.
b) Phase angle of the pulse occurrence.
c) Time since last pulse.

The measured parameters of the acoustic signal can be displayed and evaluated in three different measuring modes – the continuous mode, the particle mode and the phase mode. The instrument is also equipped with a built-in loudspeaker that allows a skilled technician to immediately observe and recognize the signals. Measurements and instrument settings can be stored temporarily in the instrument memory and afterwards downloaded to a designated PC software/database for further evaluation and generation of reports. The instrument may be powered either from the mains or from an internal rechargeable battery.

In addition to the features mentioned above, built-in frequency filters are useful both for the measurements and for evaluation of results. Furthermore, when a signal that propagates in the enclosure hits a discontinuity, it will partly be reflected and partly transmitted. Because the materials used in most enclosures have a very low absorption, a signal may ring for several milliseconds due to multiple reflections. Time gating for discrimination of echoes in pulse shaped signals and setting of threshold levels for registration of pulse amplitudes are therefore essential features for achieving good results.

**2.2 Applications And Diagnostic Procedure**

The way the acoustic instrumentation is applied to the metal enclosed switchgear panels is shown in Figure 3. As seen, the acoustic emission sensor is applied directly onto the enclosure. To improve the acoustic coupling between the sensor and the enclosure, silicon grease is used in the interface. When screening, the sensor is normally held by hand against the enclosure. If an acoustic signal is detected the sensor can be fixed to the enclosure by using a designated strap. In cases where steel enclosures are present a magnetic sensor holder can also be used. The location of the flaw is normally found by searching for the location with the highest signal amplitude.

*Figure 3: Implementation of acoustic instrumentation*

As a basic rule, each section of the enclosure should be tested with at least one measuring point. If no flaws are detected, each measuring point is tested in just a few seconds. Thus, the acoustic method is an efficient way of testing the insulation system, even though the number of tested locations may be large.

Before the acoustic measurements itself are started, it is recommended to record the so-called background noise in the substation. This is done by performing an acoustic measurement when the acoustic emission sensor is resting for instance on a table (at non-energized parts). The background noise is basically generated by the electronics in the acoustic instrumentation and is normally random noise. The background noise will then be the reference for the measurements, i.e. if the acoustic signal deviates significantly from the background noise, this may indicate a flaw that should be checked more thoroughly.

When searching for flaws in the insulation system, the continuous mode, which displays the described parameters as horizontal bars fluctuating continuously with time, is the main mode to be used. If indications of a flaw are found, the acoustic signal should be further investigated in the two pulse modes, i.e. in the particle mode and/or the phase mode.

The basic diagnostic procedure that should be followed when testing can be summarized as:

a) Screen the enclosure to reveal any defects by moving the sensor around, point by point;
b) Assess the validity of the signal/discriminate it from the noise;
c) Locate the defect;
d) Record the signals to establish signatures;
e) Recognise the type of defect;
f) Characterise the defect; and
g) Assess the risk for the switchgear.

## 3.0 CASE STUDY

### 3.1 Case Study 1: Current Transformer

| | |
|---|---|
| Year of Manufacture: | 1976 |
| Fault Rating of Switchgear: | 20 kA |
| Voltage Rating: | 12 kV |
| Cable Termination Compartment: | Air Filled |
| Cable Type: | Belted PILC |
| CT Compartment: | Air |

Note: CT and Cable compartment is combined.

The four horizontal bars are proportional in size to the signal content. The first bar is the rms value during power frequency cycle. The second bar is the periodic peak value during power frequency cycle. The third and fourth bars are the frequency 1 and frequency 2 content of the power frequency modulation.

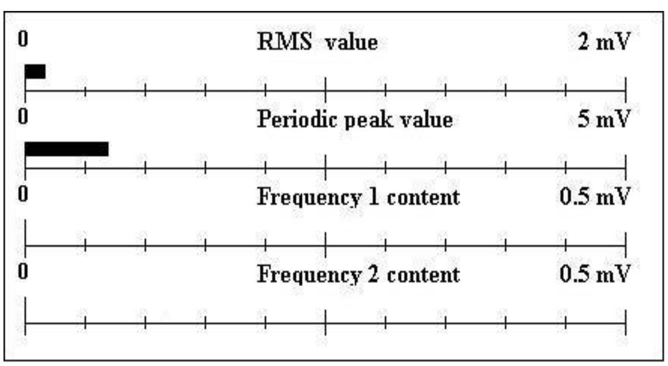

*Figure 4: Continuous measuring mode*

The acoustic signature recorded for case study 1 was captured in two modes; the continuous and phase mode. Results are provided below.

Figure 4 illustrates the background noise that is measured at the beginning of the test.

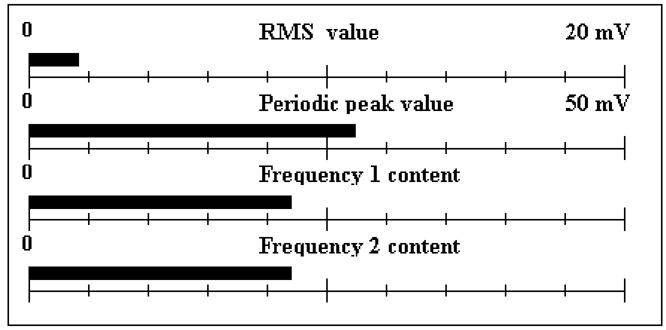

*Figure 5: PD detection in continuous mode*

Figure 5 shows the acoustic signature with a defect. The rms value and the periodic peak value have increased compared to a Figure 4.This illustrates that a flaw is present.

The content of Frequency 1 means that their are discharges in one of the half cycles, and content of Frequency 2 means that discharges occur on both the positive and negative cycle.

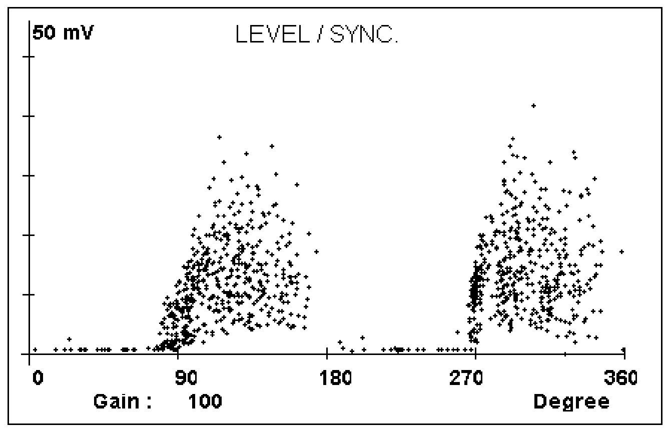

*Figure 6: The Phase Measuring Mode.*

Figure 6 shows the Phase measuring mode and confirms that PD is present in both cycles. Upon inspection, surface discharge was found on the CT as illustrated in Figure 7 below.

*Figure 7: Surface Tracking on CT*

### 3.2 Case Study 2: Cable Termination

| | |
|---|---|
| Year of Manufacture: | 1982 |
| Fault Rating of Switchgear: | 20 kA |
| Voltage Rating: | 12 kV |
| Cable Termination Compartment: | Air Filled |
| Cable Type: | Belted PILC |
| CT Compartment: | Air |

<u>Note</u>: CT and Cable compartment is combined.

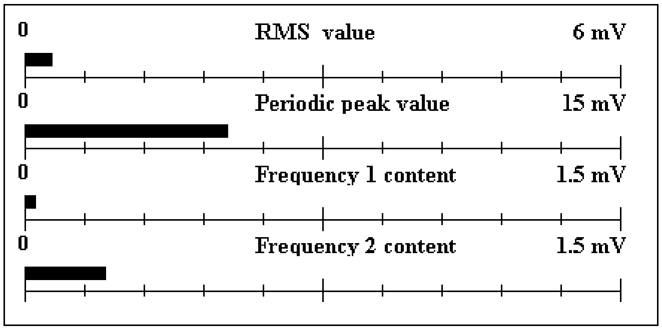


*Figure 8: Continuous measuring mode*

Figure 8 shows the acoustic signature with a defect. The rms value and the periodic peak value increased compared to the background noise.

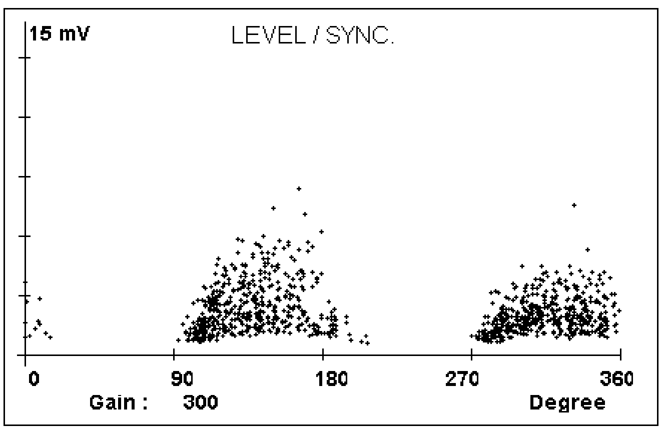


*Figure 9: The Phase Measuring Mode.*

Figure 9 shows that on one phase considerable discharges were detected with a very good correlation to 100 Hz, and the continuous plot also shows a clear indication of partial discharges.

Upon inspection, surface discharge was found on the cable termination (crutch) to the extent of which has degraded the surface of the insulating material. Figure 10 below shows the findings. It was recommended that this termination be replaced.

*Figure 10: Inspection on cable terminations*

## CONCLUSION

The acoustic method has proven to be a reliable diagnostic tool for condition assessment of GIS with respect to PD. eThekwini Electricity has experimented with the measuring device on medium voltage metal enclosed switchgear and partial discharge activity was detected within power compartments. Further investigations are being done to prove the reliability of this test method when used on metal enclosed air insulated switchgear.

## REFERENCES

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