Partial Discharge and Asset Management

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Partial discharge or simply PD can be found in all types of medium and high voltage power equipment ranging from switchgear, transformers, cables, splices and terminations, to rotating equipment such as motors and generators.

For more than 50 years, companies have performed partial discharge testing on electrical assets as part of ongoing predictive maintenance programs. Data obtained through partial discharge testing and monitoring has provided critical information on the quality of insulation and its impact on overall equipment health. Since partial discharge activity is often present well in advance of insulation failure, asset managers have the ability to monitor PD activity over time and make informed strategic decisions regarding the repair or replacement of their equipment. Predictive diagnostics resulting from PD testing can assist companies in prioritizing capital and MRO (material, repair and overhaul) investments before an unexpected outage occurs.

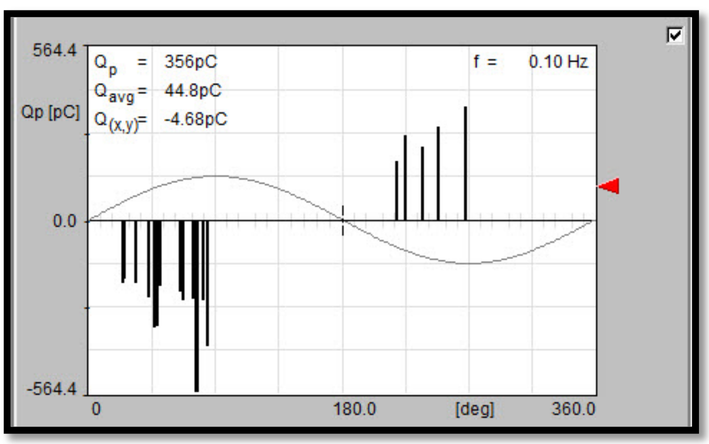

Figure 1: PD Activity as seen on an oscilloscope

A Partial Discharge (PD) is an electrical discharge or spark that bridges a small portion of the insulation between two conducting electrodes. PD activity can occur at any point in the insulation system, where the electric field strength exceeds the breakdown strength of that portion of the insulating material. When partial discharge is initiated, high frequency transient pulses will appear and persist for nanoseconds to a microsecond, then disappear and reappear repeatedly as the voltage sine wave goes through the zero crossing. Since the pulse characteristics are at high frequencies they attenuate quickly as they are transmitted or pass to ground. In solid dielectric systems, the PD happens near the peak voltage both positive and negative. The severity of the PD is measured by measuring the burst interval between the end of a burst and the beginning of the next burst. As the insulation breakdown worsens, the burst interval will shorten due to the breakdown happening at lower voltages. This burst interval will continue to shorten until a critical point is reached. At this point the discharge is very close to the zero crossing and will fail with a full-blown discharge and major failure [Figure 1]. PD activity usually begins within voids, cracks, or inclusions within a solid dielectric; at conductor-dielectric interfaces within solid or liquid dielectrics; or in bubbles within liquid dielectrics. Since these activities are limited to only a portion of the insulation, the discharges only partially bridge the distance between electrodes. PD can also occur along the boundary between different insulating materials.

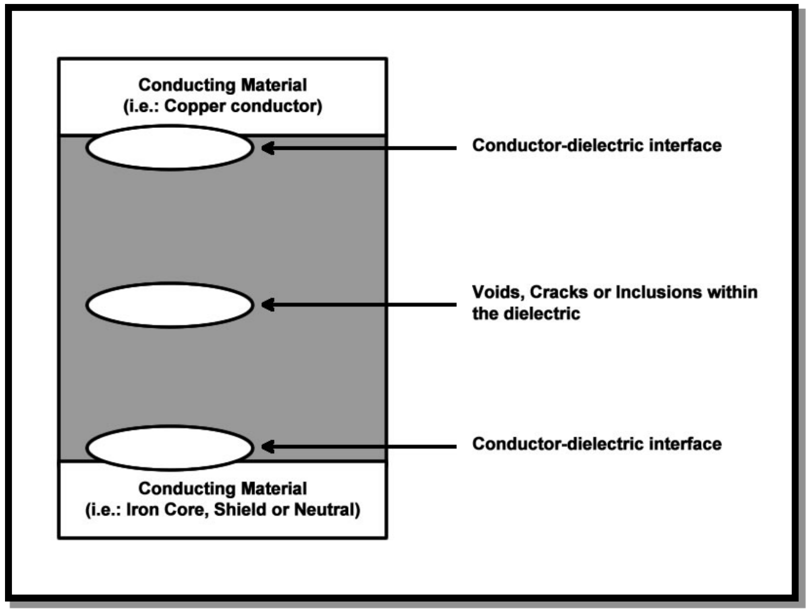

Figure 2: PD within Solid Insulating Systems

Partial discharges within an organic or polymer insulating material are usually initiated within gas-filled voids within the dielectric [Figure 2]. Because the dielectric constant of the void is considerably less than the surrounding dielectric, the electric field across the void is significantly higher than that across an equivalent distance of dielectric.

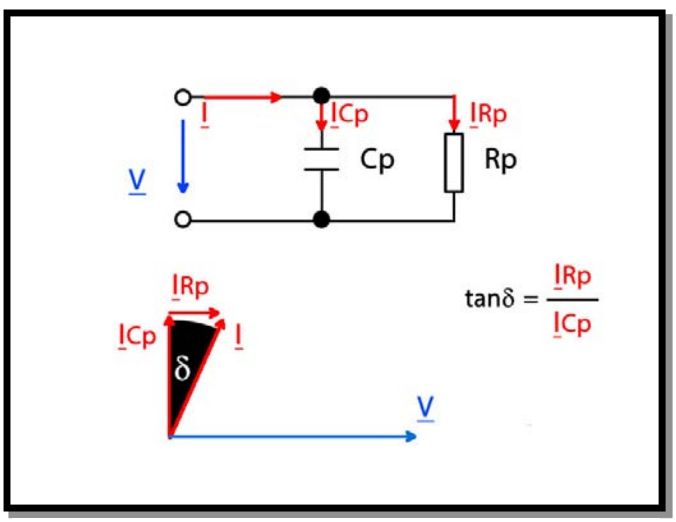

Figure 3: Simplified Model of an Insulating System

A simplified model of an insulating system can be represented by a capacitance and resistance in parallel [Figure 3]. If the insulation is free from defects, like water trees, electrical trees, moisture and air pockets, etc., the insulation approaches the properties of a perfect capacitor. It is very similar to a parallel plate capacitor with the two conductive surfaces being the two plates separated by the insulation material. In a perfect capacitor, the voltage and current are phase shifted 90 degrees and the current through the insulation is capacitive. If there are impurities in the insulation, like those mentioned above, the resistance of the insulation decreases, resulting in an increase in resistive current through the insulation. The insulating system is no longer a perfect capacitor. The current and voltage will no longer be shifted 90 degrees. The shift will be something less than 90 degrees. The extent to which the phase shift is less than 90 degrees is indicative of the level of insulation contamination. This is the concept employed in the use of Tan Delta testing of insulation systems. In the Tan Delta test the tangent of the angle delta is measured. This will indicate the level of resistance in the insulation. By measuring I_R/I_C we can determine the quality of the insulation. In a perfect insulation, the angle would be nearly zero. An increasing angle generally indicates an increase in the resistive current through the insulation, meaning contamination.

Simplified models of voids in insulating systems have been described as consisting of capacitance only; however, when we review the progressive failure mode of these voids, we can also see semiconducting films inside the voids. These films can also consist of carbonization of organic insulation material within the void due to the arching damage caused by partial discharge. Therefore, the model of the partial discharge void is similar to that of the insulation medium itself and can be represented as a capacitance and resistance in parallel.

Actual failure modes have indicated a drop in partial discharge intensity shortly prior to complete failure in solid dielectrics. This occurs when the internal arcing had carbonized to the point where the resistive component of the partial discharge void model was low enough to prevent a build-up of voltage across the void. This newly formed low resistive component would allow higher current to flow and additional heating and resultant insulation degradation. The partial discharge void model, including the resistive component correlates to the actual failure mode of a partial discharge void, where the resistive component passes more leakage current as the partial discharges increase with time.

Figure 4: Electrical Treeing

The cumulative effect of partial discharges within solid dielectrics is the formation of numerous, branching partially conducting discharge channels, a process called treeing [Figure 4]. Repetitive discharge events cause irreversible mechanical and chemical deterioration of the insulating material. Damage is caused by the energy dissipated by high energy electrons or ions, ultraviolet light from the discharges, ozone attacking the void walls, and cracking as the chemical breakdown processes liberate gases at high pressure.

The chemical transformation of the dielectric also tends to increase the electrical conductivity of the dielectric material surrounding the voids. This increases the electrical stress in the unaffected gap region, accelerating the breakdown process.

For partial discharge to occur, a sufficient voltage must be applied to the system under test to meet the minimum voltage required to start partial discharge activity. This is known as the partial discharge inception voltage (PDIV). Once the PDIV has been reached, voltage may be lowered, and PD will remain present at the lower voltages until finally they extinguish at what is referred to as the partial discharge extinction voltage (PDEV). The PDEV is therefore less than the PDIV [IEC 60034-27]. If the PDEV voltage level is lower than the system operating voltage (phase to ground) this implies that an over voltage surge on the insulating system could initiate PD, and then even when the system voltage returns to normal, the PD activity may continue. Partial discharge activity that can continue at operating voltage is therefore more likely to result in an insulation failure than PD that extinguishes above normal operating voltage. Provided that PD activity occurs at the operating voltage level it can be detected and/or measured through online detection methods and therefore testing for partial discharge activity can be performed either online at operating voltage levels or offline.

Online partial discharge tests are performed at the fixed operating voltage level. To perform online tests, suitable partial discharge coupling methods are required. Over the years different sensors have been developed to detect PD events. The online coupling methods at switchgear can include:

- Capacitive coupling via pre-installed, coupling capacitors
- Capacitive coupling via already existing taps at current transformer, bushings (capacitive interface for voltage sensing / voltage detection system)
- Inductive coupling using Radio Frequency Current Transducers (RFCT)
- Transient Earth Voltage Sensor (TEV)
- Ultrasonic

Figure 5: Inductive decoupling using RFCT

Figure 6: Pre-installed coupling capacitors

Online PD testing has the obvious advantage in that it does not require disconnecting or an outage. The main disadvantage when testing stationary equipment is that the test is only performed at the operating voltage level and cannot be adjusted. Obviously if the applied voltage is fixed and cannot be changed the PDIV and PDEV voltages cannot be determined and therefore, in comparison to offline testing, where voltages can be adjusted to simulate transients or other over voltage conditions, a lower percentage of defects can be detected through online methods.

As stated earlier; for partial discharge to occur, a sufficient voltage must be applied to the system under test to meet the minimum voltage required to start partial discharge activity. The online testing approach uses the system voltage of a constant fixed magnitude. In an offline approach a temporary voltage source will be required. Considerations for an offline voltage source should include:

- The applied voltage should cause partial discharges in the insulating system under test that have characteristics close, if not identical, to those that occur when the insulating system is in service.
- The temporary voltage source should cause no appreciable damage to the insulating system during the time required to perform the measurements.
- The temporary voltage source should have a variable voltage output so that PDIV and PDEV tests can be performed.
- The size and weight of the equipment required to produce the voltage levels required for testing various assets needs to be considered. Is the equipment to be used in a fixed location or used in a field application?

Voltage sources that are used for commercially available field partial discharge measurement systems will fall into the general categories of power frequency and alternative voltage sources such as Very Low Frequency (VLF).

Depending on the type of defect, VLF voltage sources, usually 0.1 Hz, for extruded dielectric systems may require a higher test voltage to generate the same partial discharge level compared with tests performed with power-frequency voltages. For example, the conductivity of the surface of a cavity that has been exposed to PD increases, which allows any charges deposited on the surface by PD to leak away and thus lowers the electric field in the cavity. As more charge can leak away between polarity reversals at VLF than at power frequency, the PDIV at VLF will be larger than that at power frequency. If there has been no previous PD activity to increase the conductivity of the cavity surface, the PDIV at VLF and power frequency will be similar [IEEE Std. 400.3].

Another consideration that needs to be reviewed when comparing online and offline measurements is noise effect on the measurement. In the offline approach the detection equipment can be calibrated at the time of the test by injecting a known PD pulse level into the specimen under test. This is not possible in the online approach. Further, assets can be isolated during offline testing.

When detecting PD activity using online methods further analysis will typically be necessary to ensure that the suspect activity was not caused by external noise. It will also be advantageous to locate the source of the partial discharge activity and to quantify and assess the severity of the problem. This can be accomplished by measuring and analyzing activity over time to detect deterioration and to raise an alarm or call-to-action if PD activity reaches a critical level. As an example, if PD activity that is intermittent or possibly influenced by environmental conditions (changing temperature, humidity, vibration or electrical noise) is found, temporary installed multi-sensor systems that automatically monitor your plant can be utilized.

Partial discharge testing is a useful technique for assessing the condition of individual assets, but it is of far greater value when applied to groups of assets – for example a substation or an entire network.

Offline testing of equipment is a good start in establishing inception and extinctions levels. This can be done at any time during the life of the asset or as part of the acceptance testing process when the asset is new. Establishing diagnostic test values like dissipation factor at time of acceptance will also provide a good benchmark for moving forward on a predictive maintenance program. This can be viewed as a benchmark survey.

After the equipment has been put into service periodic online checks can be performed to determine if PD activity is taking place at operating voltage levels. To determine if PD activity is present at operating voltage levels a simple online general survey can be conducted. The purpose of a general survey is to conduct a basic first pass assessment of assets and to check for the presence of PD activity. This is a quick and efficient check that can rule out good equipment in an economic manner. In most cases nearly 90% of a facility's equipment will be "good." The other 10% will need further investigation and will advance onto a detailed survey.

If the presence of PD is detected in the general survey, a detailed survey is conducted while the equipment is online and is designed to locate and quantify PD activity in order to produce a detailed asset health report. Once a potential insulation issue has been uncovered further analysis will be necessary to ensure that the suspect activity was not caused by external noise. It is also advantageous to locate the source of the partial discharge activity and to quantify and assess the severity of the problem. During this process multiple sensors and couplers can be deployed for a more detailed survey. Depending on severity PD activity can be measured and analyzed over time to detect deterioration and to raise an alarm or call-to-action if PD activity reaches a critical level. As an example, if PD activity that is intermittent or possibly influenced by environmental conditions (changing temperature, humidity, vibration or electrical noise) is found, temporary installed multi-sensor systems that automatically monitor your plant can be utilized.

Trending diagnostic test data such as power factor, dissipation factor (Tan Delta) and PDIV/PDEV during scheduled outages will give further details on the degradation and quality of the insulating systems' in critical assets. Implementing an offline and online testing program is the foundation of true predictive based asset management, providing the information needed to develop data records of assets, including current condition and 'health' for each asset, timeline predictions of likely failure, and the ability to prioritize and schedule maintenance and replacement.