

Root Causes of Partial Discharge

by **Corné Dames**

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Introduction

Power transformers are some of the most expensive components of any power generation system. Reliable operation of all the components within the system is crucial to ensure sustained power delivery. This reliability strongly depends on the ability of the insulation system to withstand the impact of the continued electrical and mechanical stresses on the system during its lifetime. During this service time, all the items forming part of the electrical system undergo deterioration to their insulation systems, this might be due to various contributing factors like electrical, mechanical, thermal, and chemical stresses. Due to this normal deterioration process taking place, some "weak" areas with a decreased capability to withstand dielectric stresses are potential sources of permanent partial discharge (PD) activity. PD measurement is one of the non-destructive methods available which can detect local defects in complex electrical insulation systems.

What is Partial Discharge?

For more than half a century, it has been a known fact that partial discharge is a symptom of several problems caused by thermal, mechanical (vibration and shock), electrical (voltage), environmental, and chemical processes.

Partial discharges are small electrical sparks that occur within the electrical insulation of switchgear, cables, transformers, and the windings in large motors and generators. Partial discharge is the small electrical sparks that occur when gas pockets exist within the high voltage insulation,

these gas pockets might occur due to thermal deterioration, stator winding movement during operation, or due to other reasons. As the deterioration of the insulation increases, the number and magnitude of the PD will increase. The breakdown of the gas inside the voids creates small voltage pulses that can be detected and measured, and therefore it is possible to monitor the PD. Although the magnitude of the PD pulses cannot be directly related to the remaining life of the winding insulation, the rapid increase in the PD activity or other indicators of insulation deterioration would be a clear indication that the reliability of the equipment is compromised. The testing to determine the presence of partial discharge is a proactive diagnostic measure to ensure the reliability of electrical equipment.

Partial discharge is defined as an electrical discharge that does not completely bridge the space between two conducting electrodes. Partial discharge can occur in various locations in medium and high-voltage equipment. We can differentiate between roughly four types of partial discharge. Each of these types of partial discharge can occur due to different reasons and each with the ability to cause varying levels of damage to the system. A minor defect or deterioration of the insulation encapsulating the conductor might be the cause for the phenomenon of partial discharge taking place. Partial discharge presents as a repetitive sequence of discharges propagating within the insulation and growing over time. Once the insulation is broken down sufficiently to form an unrestricted path for the charge to flow from one conductor to the other, it will result in an arc flash that might be fatal to the equipment.

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There might be various causes for partial discharge. The discharge always starts as a small insignificant scenario that might escalate to ultimate failure at the end of the day. Another definition for partial discharge might be the inability of a portion of the insulation to withstand the electrical field applied to it, or more formally, a flashover of part of the insulation system due to a localized electric field greater than the dielectric withstand capability of a part where the overall insulation system remains capable of withstanding the applied electrical field. [1]

Types of Partial Discharge

We generally differentiate between two types of partial discharge:

1. PD of the corona type

In a transformer this type of partial discharge will present as gas bubbles in the oil where the gas is ionized in cold plasma of low (ambient) temperature, it will mostly produce Hydrogen gas (H_2) together with some Methane (CH_4) and will not cause damage or carbonization of the paper insulation. PD of the corona type is also used to describe discharges into air or gas at the terminals of the transformer under test. If shielding electrodes are not used.

2. PD of the sparking type

This will occur in liquid (oil) or solid (paper) insulation. These are small arcs and therefore their temperatures are very high (more than $3000^\circ C$). They produce mostly C_2H_2 (Acetylene) and H_2 (Hydrogen) and this will damage the paper insulation (carbonized pinholes, tracking) and the oil will be decomposed, therefore dissolved gases would be present in the oil).

Defects possibly generating Partial Discharge in transformers. [3]

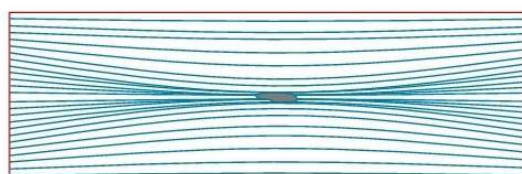
In a transformer with a good design and manufactured to the highest standard, it is very unlikely for PD to initiate during the early life of the transformer unit. However, some discharges might be present as noticed during oil sampling and PD measurement done during commissioning. For these discharges to initiate there has to be some defects present in the insulation system.

- a) Delamination may occur when the thinner pressboard sheets are glued together to form thicker barriers. Voids within these delaminations might remain for a long time.

Equipotential Lines [1]



Section through a homogenous insulator showing uniform electrical stress (equipotential) lines. A line indicates where the voltage potential is constant



The same insulator with a void. The lower dielectric of the void causes a concentration of the electrical field through the void high enough to cause breakdown at working voltages



- b) Voids – Voids may occur in glue and Connections with enameled thread, insufficient impregnation of the paper with oil might cause voids to form. It might be possible that these types of voids disappear from one day to the next as the gases are absorbed by the oil and the cavity is filled with oil! Voids might also be present in bushings, a high moisture content in combination with heat and mechanical and electrical fields may create a high local water vapor pressure with a resulting "puffing" effect of boards and winding insulation. Discharges in the "spongy" material may start shortly after this occurrence.
- c) Bubbles formation might be due to gas formation because of the discharges as well as evaporation of water droplets. It has been shown by field studies that a gas bubble in an open oil volume will be ripped into smaller bubbles, which will disappear quickly. Bubbles will therefore only exist in locations Where they are supported by solid insulation.
- d) Free metallic particles- possibly in the wood or stuck to the paper in the windings.
- e) Moisture – This will occur due to the aging of the insulation or might be introduced into the system during commissioning or maintenance work on the transformer. Moisture will contribute in various ways to discharge inception and extinction. During a heating cycle when the transformer is in service (after re-energizing a transformer that has been offline), moisture might be pressed out of the solid insulation. Due to the poor solubility of water in the oil, there might arise a supersaturation of the oil next to the cellulose surface with moisture. This might result in water droplet and bubble formation (2). Evaporation of the water will cause the formation of micro-bubbles and this will lead to discharges. An increase in the moisture content in cellulose paper will make the paper more conductive. Under these conditions, the cellulose fibers will start acting like metallic particles.

Fibers sticking out from the cellulose surface or fibers moving in the oil might initiate discharges. Increased moisture content will also increase dielectric losses. During a cooling cycle, moisture might be absorbed locally by the pressboard. As a result, internal discharges may become prevalent in the cavities within the press board.

- f) A bad connection of electrostatic shields will give large discharges because the capacitance of the defect is large. The "bad" connection will usually have a defined breakdown voltage (U_{bd}). The result is the disappearance of charges on the rising flank with voltage-independent amplitudes.
- g) Static electrification – This will give rise to the deposition of local charges. The enhancement of the resulting field may initiate discharges. The discharge tracks due to these types of discharges have been noticed along pressboard surfaces during visual inspection.
- h) Surface tracking – This is a result of discharge propagation and has been found along barrier surfaces and supports. Carbonized tracks can act as conductive protrusions, and may over time increase in length.

Measurements of PD on transformers

1. Off-line testing in the laboratory

This is used for quality assurance and acceptance testing (Factory Acceptance Testing – FAT) to reveal contamination, manufacturing deficiencies, or incorrect design.

2. On-site PD diagnostic measurement

This could be done online or offline for Site Acceptance Testing. On-line monitoring for new or aged transformers, as a condition assessment tool. This is an on-site test for new or service-aged equipment. This is mainly used for the commissioning of new equipment or after repairs have been done, or for diagnostic purposes as part of the asset management program.

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The application of new diagnostic methods might be due to

1. The movement from a time to a condition-based maintenance strategy.
2. The early recognition of insulation degradation.
3. Detection of incipient faults.
4. Reduction of the cost of outages and unplanned apparatus repairs or replacement.
5. Staff safety
6. The reduction of risk to the environment.
7. To identify bad workmanship after final assembly.
8. Fleet characterization.
9. Optimization of investment decisions

In the past, on-site in-service PD source detection involved dissolved gas analysis based on the taking of oil samples from the transformer tank, using Hydrogen as the key indicator for PD activity in the active part of a transformer. DGA as an indirect measurement is slower to identify a rapidly evolving PD and is usually unable to localize the PD for additional risk assessment. DGA interpretation requires a minimum amount of gas formation to declare a PD activity as significant [Duval 2001]. There are also several practical examples where no increase of combustible gases was recorded despite a PD source being detected by electric and acoustic methods and confirmed through visual inspection of the transformer. It can be stated that electric, acoustic, and electromagnetic PD pulse-based measurements are more reliable in determining PD activity. These methods can be used for the in-depth analysis of PD activity and the assessment of the severity of the threat of PD to the safe operation of the transformer.

In the electrical system, we have the following measurable physical signs that occur as a result of PD.

- Electrical signals are measurable at the bushings of the transformer
- Electro-magnetic transient waves (up to GHz range) are measurable via antennas
- Acoustic sound waves are measurable via acoustic sensors on the tank of the transformer
- The decomposition of the insulating material (oil and cellulose) is detectable by analysis of an oil sample.

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Difference between online and off-line PD measurements

Advantages of On-line PD measurements

1. Online PD measurements can be performed while the generator is running. They can be performed at any time, while off-line PD measurements can only be performed when the generator is removed from service. This makes online measurements much more cost-effective. Online measurements also provide the possibility to monitor the PD activity of the generator.
2. The operating conditions of the generator influence its PD behavior. Taking the generator off-line

Advantages of off-line PD testing

1. It is possible to measure the PD activity at different voltage levels. This enables the operator to determine the inception and extinction voltage of PD activity and thereby helping him in the assessment of the stator insulation condition.
2. Generally, off-line PD measurements have a higher signal-to-noise ratio and the influence of disturbance signals is lower. This will result in higher sensitivity, selectivity, and resolution for the offline PD measurements.

Conclusion

From this information, it is clear that we only touched the tip of the iceberg. So much is left to be said about the test methods and interpretation of partial discharge data which should be addressed in a follow-up article.

It is important to notice that the on-site testing of partial discharge is a delicate science and the practical facts are that we are faced with a lot of "noise" – partial discharge in the background, generated by other equipment in proximity of the test object. The filtering of the signal when determining the partial discharge of the test object is the biggest challenge.

Many companies have equipment with the capability to filter out the background partial discharge originating from outside sources.

On-site it is most important to ensure the accurate and repeatable determination of the partial discharge, to monitor the deterioration as well as the rate of the deterioration. For this reason, it is crucial to use the same equipment for consecutive tests on a specific unit as different test sets might lead to a deviation in results.

The most important test is the initial partial discharge test after commissioning to establish a baseline parameter, or fingerprint, to build on and for future reference. Also, the initial PD reading is extremely important to ensure that no damage has taken place during the transport of the unit and the commissioning steps.

Reference data is crucial to ensure reliability.

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References

- [1] IEEE Alberta Partial Discharge by Tim Erwin of EA Technologies
- [2] V.G. Davydov, O.M. Roizman, W.J. Bonwick, "Transformer insulation behavior during overload." EPRI Substation Equipment Diagnostic Conference, V, TR 111282, 1989, pp II -53 to II -72
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