A QUICK GUIDE TO

Identifying HV infrastructure deterioration through Partial Discharge monitoring

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Introduction

There are two main constituents to the High Voltage (HV) grid: cables and switchgear. Gradually, over time, their insulation deteriorates until they reach one of two outcomes: replacement or failure. The same can be said for transformers and, to a lesser degree, overhead lines.

Substation failure can be devastating. Apart from creating outages and halting production and other day-to-day activity, necessitating crisis management, it could cause a reportable health and safety incident. In a worst-case scenario, the outcome could even be injury or fatality.

Cables, underground cables and switchgear in particular, are tricky to test during routine maintenance. For thorough inspection, they need to be isolated, there is, however, a way of identifying those elements that are in danger of failing via the predominant cause of insulation degradation: Partial Discharge. Research has shown that a massive 85% of disruptive failures in HV and MV equipment are linked to PD damage.

Left unaddressed, PD causes flashover and failure. It's no exaggeration to say that failure of your High Voltage switchgear and cabling could cost you millions – in repairs, replacements and fines. But most failures don't happen out of the blue – they can be predicted from warning signs, most notably Partial Discharge (PD). Detecting and measuring PD activity gives a unique insight into the condition of HV assets without the need for expensive shutdowns or invasive testing technologies available, it's hard to disagree with the statement that running equipment to failure is an outdated approach.

Essentially, predictive maintenance is all about getting to the heart of the root cause of any potential issues, predicting time to failure and maximising uptime. The clear advantage of predictive maintenance for High Voltage power systems is that catastrophic failure can be avoided, avoiding costly disruption, emergency maintenance and even loss of life.

In this concise ebook, you'll gain an understanding of predictive maintenance as a strategy for protecting High Voltage assets and how techniques and software have evolved to offer new actionable insights that can save time, money and, potentially, lives.

"Research has shown that a massive 85% of disruptive failures in HV and MV equipment are linked to PD damage."

Understanding Partial Discharge

Before looking at how to spot the damage that PD can do, it's useful to gain an understanding of what this phenomenon is and how it occurs.

What is Partial Discharge?

PD is best described as a failure of part of the insulation system to withstand the electrical field applied to it. This can be a result of poor design, poor workmanship, defective materials, contamination, or aging. The result of this failure is a high frequency, unipolar discharge and accompanying current that flows through or on the surface of the insulation from the conductor to ground. This current pulse is low energy due to its short (microsecond) duration, but it can negatively affect the insulation and eventually cause catastrophic failure.[1]

Where does Partial Discharge occur?

Generally, PD only arises on equipment working at 3.3 kV phase to phase or higher, including switchgear, transformers, stator windings and power cables. For PD to occur, there has to be a gas present between the two conductors, whether air, sulphur hexafluoride (SF_6) or hydrogen. In addiction, there must be a high voltage between the two conductors that creates an electric stress.

How does Partial Discharge happen?

The discharge spark erodes the insulation from within through its heat and ionisation. If occurring on the surface, the discharge also causes the breakdown of air molecules into oxygen (ozone) and nitrogen (nitric oxide). The nitric oxide forms nitric acid, which erodes the insulation from the outside.[2]

1 Higinbotham, William G. "Online vs offline PD Testing of cables" in NETA World, Spring 2017
2 Ibid

Different types of Partial Discharge

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Internal PD

This takes place within the insulation. There is nothing to give this occurrence of internal PD away, and the absence of any sound, odour or visual clue to an issue before failure is a real challenge. In situations where an insulated cable box failure succumbs to this silent defect, the accumulation of pressure can cause a significant, disruptive and dangerous explosion.

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Surface PD

Tracking across insulation's surface, which produces a crackling sound and ozonic odour. Factors in the occurrence of PD include the use of alternative materials to porcelain in switchgear and dry terminations, ignoring some essential design and installation implications. This oversight increases surface PD-related failure rates. Factors such as insulation surfaces or cracks contaminated with dirt or a high conductivity path from the conductor to the insulation's surface are frequently present in cases of surface PD.

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Corona PD

Occurring from a sharp electrode into gas, such as the end of a single strand of cable into the air. Corona PD can be heard in outdoor switchyards, notably when the weather is humid. While this type of PD doesn't usually cause damage outside, it can trigger surface PD and its associated problems when it takes place within a closed chamber without any airflow.

PD is the most common cause of disruptive failure of switchgear, so the detection of critical indicators will assist you in identifying those parts of the network that require more urgent attention. Using simple measuring techniques, you can show the rate at which assets are ageing, identify at-risk components, and justify future funding for replacement or maintenance.[3]

Progress and signs of deterioration

Partial Discharge causes insulation to overheat. The repeated occurrence of localised PD energy pulses multiple times in a second has a cumulative effect that can lead to damage through chemical breakdown.

Streamer-like discharges, Townsend discharges, glow and pseudoglow discharges may all occur as a result of PD, as well as swarming partial microdischarges (SPMD), which have been detected appearing just before insulation breakdown.[4]

Insulating oil

While PD is usually understood to be a factor in solid insulation failure – holes or gaps in paper or low adhesion of varnishes, for example – it can also impact liquid insulation such as oil in transformers. However, PD's cyclic nature is linked to peaks in alternative voltage gradients, which results in low-intensity discharges through the oil. This arcing can cause carbonisation and gases that remain within the oil, with a knock-on effect on the oil's insulating properties. Mineral oil appears to be more stable than vegetable oil in this scenario.[5]

3 Maintenance and monitoring of high voltage infrastructure using Partial Discharge to identify deterioration trends, Jason Butler, Sector lead – industrials, EA Technology, June 2018, Maintenance & Engineering
4 M. G. Danikas, "Small Partial Discharges and their role in insulation deterioration," in IEEE Transactions on Dielectrics and Electrical Insulation, vol. 4, no. 6, pp. 863-867, Dec. 1997, doi: 10.1109/94.654733.
5 Seguchi L.J. et al. (2020) Degradation Caused by Partial Discharges in Insulation Oil: A Comparison Between Mineral and Vegetable Oils. In: Németh B. (eds) Proceedings of the 21st International Symposium on High Voltage Engineering. ISH 2019. Lecture Notes in Electrical Engineering, vol 599. Springer, Cham. https://doi.org/10.1007/978-3-030-31680-8_14

Monitoring techniques

PD monitoring has grown in status, benefiting from improvements in the capabilities of sensors, electronics and memory, and the decrease in their cost. Testing in the form of periodic surveys is now common place in the electricity industry, providing valuable insight into asset condition.

Beyond periodic surveys full-time system monitoring is the state of the art in PD detection, offering additional capabilities that:

- Warn of rapidly evolving PD situations that might go from inception to failure faster than a periodic survey interval.

- Allow trending of slowly evolving data to better confirm real degradation.

- Allow trending with external events such as load changes or environmental changes.

- Provide better data than periodic surveys through additional sensors or time-of-flight fault location.[6]

One of the most important aspects of detecting PD in HV switchgear is finding the PD without interrupting the electricity supply. The most practical ways of spotting irregularities live without interfering with supply involve detecting different radio frequency signals.

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6 Higinbotham, William G. "What's in a Partial Discharge Monitoring System?" in NETA World, Fall 2019

Transient Earth Voltages (TEVs)

Different types of PD can be easily identified through a combination of sensors. PD generates high-frequency electromagnetic pulses known as Transient Earth Voltages (TEV). These TEV signals move across the inside surfaces of switchgear, finding their ways to the equipment's exterior through any gaps in the metalwork, such as gaskets. A TEV sensor on the outside of the switchgear can be installed to measure these pulses, and is particularly effective for detecting internal PD.

Electromagnetic Field (EMF) detection

EMF detection picks up the radio waves generated by the Partial Discharge. As already mentioned, these radio waves can generate TEVs on the surrounding metalwork. Built-in UHF antennas or external directional antennas can be used to provide more sensitive measurement, especially at higher voltages.

High-Frequency Current Transformer (HFCT) Method

When installed around the earth connection or strap between the cable sheath and the earthed switchgear, it allows the high frequency current transients that are generated by PD activity within the cable, cable joints or local switchgear to be detected.

Acoustic (Ultrasonic)

Usually, acoustic emissions produced by PD are ultrasonic, meaning that their frequency is too high for the human ear, therefore an instrument is required to convert this into the audible range. As the PD gets worse, the frequency sometimes decreases into audible range. An airborne ultrasonic microphone is the most sensitive way to detect PD where there is an air path between the source and the microphone. For sealed chambers, contact ultrasonic sensors can be used. Ultrasonic methods are particularly effective at finding surface PD and corona PD.

Partial Discharge monitoring in practice

Partial Discharge testing involves collecting data which can be compared to measurement values collated during the acceptance-test or working to factory quality-control standards. In this way, the equipment's dielectric condition can be recorded, trends and irregularities are spotted, and appropriate maintenance and repair measures are scheduled as needed. Monitoring can be carried out remotely or through field testing.

The approaches to PD monitoring fall into three categories:

- Offline testing

- Online surveys

- Permanent monitoring

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Offline testing

Offline testing involves taking the equipment out of service and disconnecting it from the load and supply, before using a specialised energising supply and detector instruments. The energising supply is usually one of three types:

A power frequency voltage generator: the most straightforward sort of supply. Powering an electrical system to nominal operating voltage requires sufficient current to overcome the stray system capacitance, which needs a very high power system. This will usually be of a sufficient size to demand truck or trailer mounting when system voltages and power requirements increase.

VLF or Very Low Frequency systems: these circumvent the charging current issue by running at very low frequencies (Less than 1 Hz). This AC supply means that space charge issues are avoided. Being lower in frequency, the power requirements are much smaller. Two-person portable units as high as 33 KV RMS are possible.

Pulsed resonant arrangement for EHV equipment, where a resonant circuit is formed to allow higher voltages with lower power requirements. These are often truck mounted but can test equipment above 132 KV.

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Once the equipment is energised, specialised instruments connected direct to the conductors being tested can make accurate measurements of the Partial Discharge.

The main advantage of offline testing is that you can vary the line voltage above and below nominal to find the points where PD starts and extinguishes. However, the disadvantages are clear: outage, very large and expensive test gear, and highly trained technicians. Testing just one circuit can take a whole day. For these reasons offline testing is generally reserved for commissioning or when problems are already suspected.

Online surveys

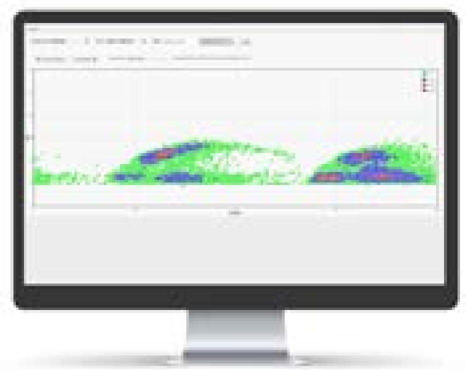
Online testing of equipment in service involves using conveniently sized handheld devices that can detect PD through TEV detection, ultrasonic detection, and HF current transformers mounted on cable ground straps.

The limitation of online testing is that the system voltage can't be varied, but several advantages balance this out. Personnel safety is protected as the high risk of offline testing is avoided, and the system is carrying load, so thermal effects that may not be present with offline tests can be observed. No outage is needed, and many circuits can be tested over the duration of a day without the need for a high level of expertise. Online test instruments need to be sensitive enough to detect PD accurately under in-service conditions.

Permanent monitoring

Advanced monitoring systems use environmental sensors and background EMI detection to evaluate the conditions associated with PD detection. Full-time monitoring can be used to eliminate the major limitation of other test methods – namely, the inability to detect intermittent PD. With any periodic test, the PD must be present on the day that the equipment is tested. If not, the problem may not be found. It has been proven that severe insulation damage caused by PD can exist and, under distinct environmental conditions, PD will not be present.

The investment involved in setting up permanent monitoring for Partial Discharge should not act as a deterrent. There are several reasons why this approach can pay back outlay many times over.



Phase resolved Partial Discharge graph

Trend analysis graphs

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Does everything have to be monitored permanently?

Avoidance of catastrophic failure
A single catastrophic outage could end up costing more than several years of permanent monitoring.

Early detection of faults
Enables repairs to be scheduled and managed at a time that suits you to keep the HV system operational.

Keeps productivity on track
Manages damaged switchgear, cables and other components without unplanned labour – no need for overtime or weekend pay.

Prevents outage fines
This factor is especially relevant for DNOs managing public power supply.

Protects reputational damage
The value of avoiding catastrophic failures is massive in terms of organisational reputation.

Continuous monitoring will detect changes in PD activity relating to environmental variables such as temperature and humidity. While the automated alerts that come with permanent monitoring are incredibly useful, weekly or monthly reporting might be adequate in some situations. Generally, most PD-related deterioration develops over several months, so in less critical situations, real-time monitoring may be substituted for regular monitoring, as long as the gaps between reporting are optimal.

There is a proviso, though. Not all PD events are cut-and-dry. Often, analysing and trending the data essential to find faults that are evolving slowly. Permanent monitoring systems can compare historical data in a way that offline testing and periodic surveys cannot.

2 Continuous monitoring is on the rise: can you adapt, William Higinbotham, EA Technology LLC, NETAWORLD, Fall 2018Prognostics, and Health Management II Peter K. Willett; Thiagalingam Kirubarajan, Editor(s)

Summary

Monitoring PD will benefit your organisation on three fronts: safety, safeguarding power supply and understanding the condition of your assets. Anyone visiting a switch room where PD is present is at risk from a fire or explosion – safeguarding their wellbeing should be your top priority. Maintaining a constant power supply and avoiding unplanned outages is business critical, whatever the nature or size of your organisation. And understanding whether any of your assets are at risk of failure is vital to keep them on stream through timely repair and maintenance.

The consequences of failing to address PD damage are far-reaching. By monitoring PD, you can spot and address infrastructure deterioration and assess trends in activity, compare the HV reliability of different parts of your network and plan ahead for future investment.

Award-winning PD monitoring technology

Time to up your game with better PD monitoring? To find out about EA Technology's award-winning Astute® Partial Discharge monitoring service, which provides the security of 24/7 PD monitoring of switchgear and cables.

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