UTILITY WEEK EXPLAINS

Advances in Partial Discharge Monitoring

Utility Week

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In this report:

- Introduction
- The science of partial discharge
- How PD testing is conducted
- How PD testing can protect essential gas-insulated switch gear
- Wider and emerging benefits of PD testing

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Introduction

Keeping the power on is vital to the success of any network operator, and that means ensuring that high voltage assets operate at optimum efficiency. But Partial Discharge – a low energy electrical discharge that can occur in any insulating medium – can gradually erode insulation resistance in transformers, switchgear, generators, motors, cables and other electrical equipment. The cost of subsequent failures is likely to be measured in unplanned outages, missed performance targets and regulatory fines – or possibly in fires, explosions and serious injuries.

For network operators, monitoring Partial Discharge (PD) activity is therefore an essential element in safe and secure operations. But monitoring assets for PD isn't straightforward: it can be linked to faulty workmanship in the manufacturing stage, poor site practices at installation, or failures at any point in what is likely to be a long design life. In addition, PD at low levels might not trigger a need for action, if the fault falls below levels set out in the international standards document IEC 60270, often referred to as the 'bible' of partial discharge measurement.

Only by monitoring PD levels over an extended period, and identifying and tracking changes in PD activity as soon as it occurs, can asset owners be confident that they have identified red flag issues, or indeed be reassured that their equipment is operating at optimum efficiency.

With the operational integrity of valuable assets at stake, owners and operators need reliable, easy to use testing equipment backed up by after-care and expertise. Power Diagnostix by Megger, known for its range hand-held PD sensors for rapid diagnostic testing, has recently expanded its range of PD measuring equipment to suits the full range of testing needs among equipment manufacturers, distribution network operators and private or industrial network operators. The suite of products was expanded in 2019, with Megger's acquisition of Power Diagnostix, a German specialist in PD testing.

"We have a wide range of customers, from distribution network operators that might need to monitor across an entire region, to customers in the high tech manufacturing sector, where security of supply is vital," says Tony Wills, applications engineer at Megger.

In the UK, networks typically operate HV equipment that was originally installed in the 1970s and 1980s; PD testing activity is therefore becoming more critical as these assets age. Meanwhile, continuous monitoring technologies, where sensors are clamped to equipment so that signals are recorded and uploaded for analysis every few seconds, has been available for roughly the past two decades. As a result, Wills notes, these systems are more prevalent in countries with a more youthful energy infrastructure, such as in the Middle East and Africa. However, this type of monitoring is becoming more common in the UK, as assets are replaced or upgraded.

The science of Partial Discharge

When an insulating material is a subject to the stress of a higher than normal voltage, it can suffer a dielectric breakdown and temporarily become a conductor; in a partial discharge, the insulation is subject to a lower level of stress, so that the electrical charge "sparks" but does not complete a short circuit. A burst of PD activity will start to erode the insulator, and every future occurrence of PD will degrade it further; ultimately and inevitably, a short circuit failure will result.

The PD will occur where there is an imperfection, crack or inclusion in a solid insulator, a bubble or void in a liquid (such as oil) or around an electrode in a gas insulator. Defects can arise from poor installation – for instance when cables are cut back – or due to normal operational wear and tear.

But not all PDs are alike. A corona discharge into the air from an overhead HV network is relatively harmless, while other forms of PD will progress at different rates, triggering failure in anything from a few hours to several years. PD testing and monitoring therefore has to be able to accurately analyse the type and location of the PD failure, to differentiate between urgent cases where repair work needs to be scheduled and those where network operators can keep a watching brief.

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Tony Wills, Applications Engineer, Megger

How PD testing is conducted

Transformers, switchgear, motors and cable installations are typically not easily accessible for inspection or repair. However, PD monitoring techniques provide a variety of options to "see" what's happening inside these valuable assets. PD testing exploits the fact that PD activity emits both sound waves and high frequency electromagnetic signals: Megger's modular equipment ranges can provide both types of testing, in both "offline" and operational scenarios, for the full range of network applications. "It's an extensive range, and it's modular: customers can choose to grow their systems from basic to advanced," says Wills.

To perform testing based on the ultra high frequency electrical signals emitted by PD activity, pulses of known charge values are applied to the test circuit for calibration, then deviations from the expected impedance values can be measured to determine if PD is present. If the PD is lower than accepted and no increasing tendency in present, equipment has "passed" the PD test. The values are set out in the international standard, IEC 60270.

Measurements rely on coupling devices that detect the PD pulses; the high frequency signal is then converted and sent to the data acquisition unit, often passing through a preamplifier that tunes out other background signals. To detect PD currents in cables, or in the earthing cable of transformers, Radio Frequency Current Transformers (RFCT) are often the preferred coupling device; these can easily be clamped on to cable terminations.

Power Diagnostix by Megger's digital monitoring equipment plots the electrical PD signal as "Phase resolved partial discharge patterns" [PRPD], where characteristic graph patterns are associated with different types of molecular breakdown. The evaluation of the PRPD pattern can therefore help to identify the type of defect. Some PRPD outputs show typical and recognisable problems, for example, delamination within paper layers in a transformer has a very clear PRPD pattern; in other cases, more advanced analysis may be needed to pinpoint the exact fault to within a few centimetres. "You often need expertise to interpret the data; colleagues in Germany offer this analysis," says Wills.

Every application requires robust kit that can withstand life in the field, but sturdiness becomes a key consideration when continuous monitoring of equipment is required. "With continuous monitoring, the kit you're using to do the monitoring becomes critical. It needs to be reliable, when a transformer has a life of 40 to 50 years, you need to be able to monitor it for that time so the equipment needs to be resilient and robust. But our modular system allows customers to swap out the components or sensors, for instance, while retaining the rest of the assembly. It has a high specification, it's easy to use and easy to upgrade," says Wills.

PD activity will also produces sound waves at audible frequencies. Compared with electrical signals, acoustic signals travel relatively slowly, at speeds determined by the medium they are travelling in, whether oil, metal or gas. By using several acoustic sensors, it is possible to locate PD faults by analysing differences in the delay of acoustic signals. However, acoustic measurements alone are unlikely to provide actionable information, says Wills. "Usually it's just a reference measurement – a first step for locating the PD."

In the case of oil-filled transformers, a decision to test for PD will often be triggered by the results of Dissolved Gas Analysis tests, as PD activity will liberate gases inside the unit. The rate at which the gas is being generated can also indicate the severity of the PD activity. However, DGA provides little or no useful information about the location of the PD activity.

The equipment that tests for PD

Power Diagnostix by Megger offers a complete range of testing systems, each of which comes with interchangeable accessories, including sensors, cables, frequency convertor units and pre-amplifiers, which help to tune out other background signals that might reach the monitoring unit.

ICMSystem

The **ICMSystem**, incorporating sensors for both UHF and acoustic signals, is engineered to test HV power transformers; testing can be carried out "offline" in factory or laboratory conditions, or online under normal operating conditions. The measuring unit is used with Megger's line of coupling devices, which include quadrupoles, current transformers and coupling capacitors, that adapt the basic detector unit to different measuring tasks.

ICMcompact

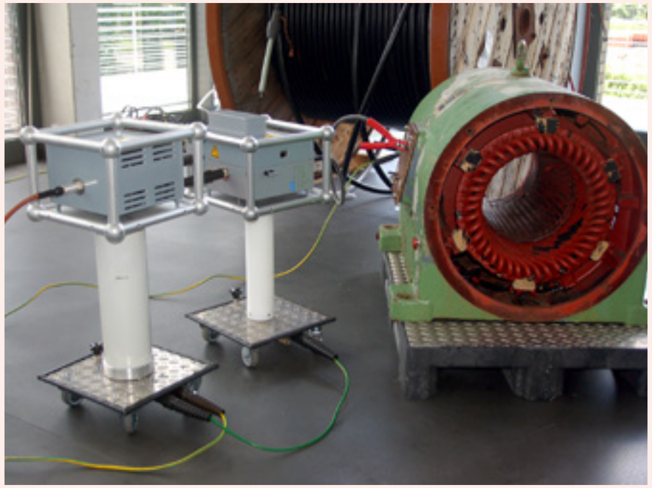
The **ICMcompact** is a versatile tool that can test instrument transformers, switchgear and components, cables and insulators, as well as individual components within assets. Again, it can be used for acceptance testing in quality control laboratories, or by engineers in the field. It is used in conjunction with a laptop running ICMcompact software.

ICMmonitor

The **ICMmonitor** is Megger's system for continuous PD monitoring; users can set alarms that will trigger when particular levels of PD are reached. The modular system can also be adapted to measure PD in different equipment, including switchgear, motors, generators and cables.

ICMFlex

The **ICMFlex** is designed to test distribution-class cables for PD and other types of loss factor; it covers the needs of an ageing polymeric cable distribution network as well as the increasing application of polyethene extra high voltage cables.



AIACompact

The **AIACompact** is a versatile instrument for assessing the condition of gas-insulated switchgear (GIS), combining both UHF and acoustic detection methods. For many network operators it offers a competitively-priced entry point to PD testing (for more details, see uk.megger.com/products/partial-discharge)

How PD testing can protect essential gas-insulated switch gear

Gas-insulated switchgear is of high importance for every grid: with high electric fields in comparatively small spaces, failure can lead to extensive damage and long outages. In addition, the SF6 typically found inside insulating chambers has to be handled with special care, as it has the highest global warming potential of any known substance. As GIS units reach the end of their projected life spans, systems such as Power Diagnostix by Megger's AIACompact solution (see box) can help to keep them in service for longer.

The signal emitted by a PD signal is of course trapped inside the GIS, but Power Diagnostix by Megger's AIACompact can detect and amplify those signals, converting them into actionable readings. PD failures can be detected with both acoustic and UHF sensors, with the combination making the portable, rugged and easy to use AIACompact suitable for a range of installations.

Inside a GIS, faults that can give rise to PD include free metal particles moving inside the chamber, loose contacts or surface protrusions. To detect these, UHF sensors can be attached to unshielded flanges, or the surface of an inspection window. On large GIS compartments, more than one measurement would be necessary.

Alternatively, most modern GIS systems are manufactured with embedded ultra high frequency (UHF) sensors to enable survey measurements to be taken; as the signals from embedded sensors can be strong, these are routed through an Input Protection Unit before reaching the monitor unit.

Free metal particles sometimes even "hop" due to the impulse given when a PD occurs; here, acoustic sensors - used with headphones - are particularly useful at detecting the fault. Acoustic sensors are often fixed underneath the tubes as "hopping particles" tend to be found at the bottom.

As well as PRPD patterns generated from UHF signals, the AIACompact will display results of acoustic tests in "time of flight" mode, indicating the distance travelled by particles, analysis that helps to quantify certain defects and their severity.

Wider and emerging benefits of PD testing

Typically, network operators implement PD testing as part of their Condition Based Maintenance (CBM) strategies; in order to avoid unplanned outages and improve network reliability; to deliver better safety outcomes; to extend the lifespan of existing assets and delay capital replacement.

In some cases, it may be possible to manage relatively low risk conditions by reducing the operational demands on a particular transformer or piece of switchgear until removing it from service is more convenient; in other cases, an immediate and urgent repair may be necessary.

PD measurements can provide information about the nature of the repairs before the repair process is started; eliminating the need for exploratory investigations to locate the dielectric damage, and making it easier to prepare for what is likely to be found when transformers or other equipment is opened up. This, in turn, helps shorten outage times and improve security of supply. Network operators usually expect a precise read-out of the PD status of new assets at purchase. "When a customer buys a HV transformer, they will set a PD specification so the manufacturer will have to prove the PD value at the factory gate to test the insulation is of good quality," says Wills. In addition, if switchgear has been taken offline for testing or maintenance, there must typically be a PD test measurement before the equipment can be put back into service. Testing during an asset's operational life often starts by comparing PD levels with site or factory acceptance tests, and previous diagnostic tests and measurements.

"Improved insight into PD and the insulating health of the gas means that unnecessary maintenance work on GIS can be avoided, while also improving asset owner's ability to predict and pre-empt failures."

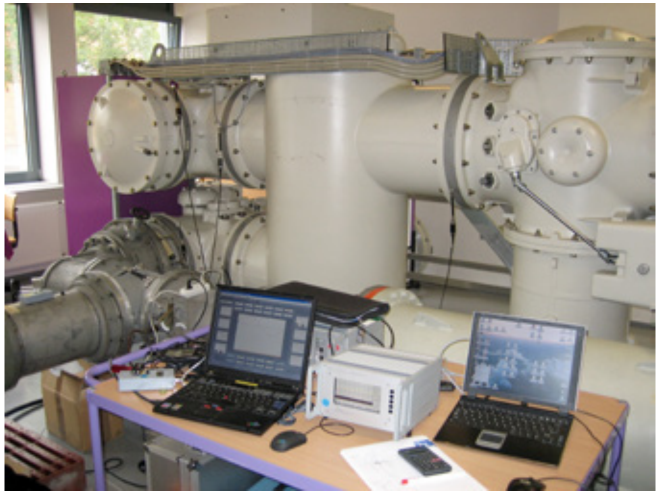
Insurance underwriters and brokers may also set out criteria on PD testing as a pre-condition of insuring operational assets, such as transformers and switchgear, where values are calculated in millions of pounds. "Testing means that they can be confident in their underwriting," notes Wills.

There are also environmental and sustainability arguments to managing PD. In the first place, networks are currently under pressure to accommodate an increasing number of import and export connections in order to assist with the transition to renewable 'green' electricity and electric vehicle charging. With many local networks offering little 'headroom' to safely accommodate new connections, better management of PD – including more accurate scheduling or when reinforcement work or capital investment is necessary – helps in the overall network management agenda.

But gas-insulated switchgear (GIS) poses a particular environmental challenge. The switchgear is typically housed in chambers filled with SF6 gas, which can extinguish arc flashes and stop short circuits. While SF6 is a highly effective insulation, it also has an extremely high global warming potential. New renewable energy connections added in recent years has resulted in an overall increase in switchgear installations, and although alternative gases are available, the majority of new installations over the past decade still use SF6 gas.

A 2018 study from the University of Cardiff that collated data from the UK's six DNOs found that the installed inventory of GIS switchgear rose every year from 2010-11 to 2015-16, by 30-40 tonnes per year. While the DNOs returns indicated that SF6 emissions did not increase, the increased volume of gas in operational use creates a higher potential risk of leaks. Improved insight into PD and the insulating health of the gas means that unnecessary maintenance work on GIS can be avoided, while also improving asset owner's ability to predict and pre-empt failures.

Health and safety is also an important driver. Under the Electricity, Safety, Quality and Continuity Regulations (ESQCR), DNOs report any unplanned outages that result in damage to equipment to the Health and Safety Executive. Overall incidence rates are not declining: from 2014/15 to 2018/19 there were 14,000 reported incidents a year on average, but this rose to 14,992 in 2018/19. While PD is only one factor of many, it is acknowledged as a leading causes of electrical failures.



Conclusion

Partial discharge has been present in HV electrical equipment for as long as there has been HV electrical equipment, and PD testing methodologies were first developed more than half a century ago. But with the number and type of network applications constantly growing, and the price of failure rising, network operators are constantly searching for new ways to improve their insight into the underlying health of assets. The PD testing range from Megger, with its modular, interoperable components that flex to suit the needs of every circuit, can upgrade operators from guidance-level PD test results to a full diagnostic picture. Today, better data is improving outcomes in multiple areas of our lives; in the arena of PD testing, Megger's comprehensive suite of tools offer the data needed to underpin robust maintenance and replacement strategies.