Technical Report
ICM*system* and ICM*flex*

Power Diagnostix Systems

COST-EFFECTIVE OFF-LINE PD ANALYSIS FOR HV GENERATORS AND MOTORS WITH ICM*system* AND ICM*flex* FROM POWER DIAGNOSTIX

Partial discharge (PD) tests have long been an essential aspect of ensuring that factories accept a manufacturer's high-voltage (HV) generators and electric motors. However, energy suppliers, service providers and companies from industrial sectors such as oil, gas and chemical production are also increasingly using this method of testing. This technology has been continuously developed by Aachen-based company Power Diagnostix. Combining ICM*system* or ICM*flex* with Megger testing equipment is now providing an optimal overall solution for a wide range of measurements.

PD measurements provide a reliable and accurate method for determining the service life and quality of stator bars and stator windings in HV generators and electric motors. For this reason, PD detectors are now being used not only by manufacturers, but also increasingly by energy suppliers and service companies with a high degree of success. Since 1992, this high-end technology has been developed and manufactured by Aachen-based Power Diagnostix Systems GmbH, which has been part of the Megger Group since 2019. This technical report focuses on off-line PD diagnostics on HV machines.

Figure 1: The ICMsystem was the first instrument to provide a coloured phase-resolved pattern.

Insulation systems for stator windings

The design, materials and manufacturing techniques of stator winding insulation systems have undergone significant development since the beginning of the 20th century, with the silicate mineral mica first being introduced in the early 1950s. A combination of (muscovite) mica with high-quality epoxy resins continues to form the basis of the insulation system, as this offers excellent thermal, mechanical and electrical stability.

Unlike other common insulation systems such as XLPE (VPE), PE or (pressurised) sulphur hexafluoride SF6 in switchgear, epoxy-mica insulation systems are not free of partial discharge, but the material does have a high tolerance for PD. A key feature of this material is its resistance to continuous PD activity for an assumed electrical machine service life of up to 20 years under normal operating conditions. This applies to stator windings with Resin Rich technology stator bars and to fully assembled stators that have successfully undergone a vacuum pressure impregnation (VPI) cycle.

It's not about detecting PD — it's about analysing trends

Unlike in other industries, PD measurements on motors and generators are less about detecting PD and much more a case of trend analysis based on multiple measurements over a defined period of time. Factory specifications are used as a reference in this context. Ideally, all measurements should be performed using the same measuring technique and a previous reference calibration – this includes using the same frequency and bandwidth to ensure that the results can be compared. Having someone with the relevant qualifications then interpret the phase-resolved partial discharge patterns provides all key information down to the last detail.

Phase-resolved partial discharge patterns

Power Diagnostix released the first PD measurement device in the ICM series on the market in 1992. The ICM*system* digital PD measuring system was the first commercially available device to display a phase-resolved partial discharge pattern (PRPD; amplitude-phase frequency distribution) in colour to facilitate analysis. This was a big step forward, as each individual PD pulse decoupled either by a coupling capacitor or a high-frequency current transformer (HFCT). This could, depending on the frequency, now be graphically portrayed as a single-coloured point corresponding to its phase and amplitude. Light-grey dots represent a singular PD pulse, while colour transitions from orange, red and yellow to blue reflect pulses up to 64 k. By interpreting typical pulse distributions, symmetries, and the phase positions of the PD in relation to the synchronised test voltage, the coloured representation of the phase-resolved partial discharge pattern can be used to determine the physical cause of the partial discharge. However, knowledge of PD pattern properties, gas discharge physics, and a fundamental understanding of the composition of and processes involved in winding production as well as the specific properties of the insulation material are essential for qualified analysis.

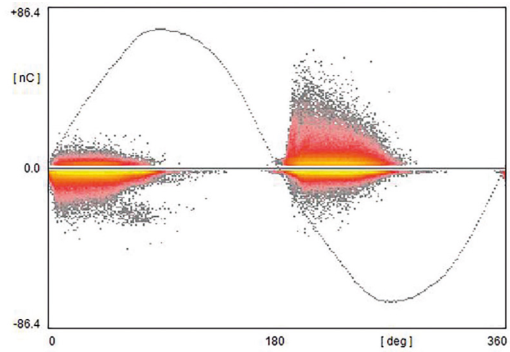

Figure 2: Phase-resolved PD pattern with discharges at the slot exit

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Example PD pattern analysis

The PD pattern generated by ICM*system* shown a triangular pulse distribution with a steep incline at the front and a dominant distribution in the negative half-wave. This pattern is typical for the early stages of defective terminal corona protection. Surface discharges lead to a further deterioration, to the point where the semi-conducting field control detaches from the earthed stator core.

Without earth contact, the field control loses its reference to the stator core. This leads to what is known as “floating potential” from the end corona protection to the stator core and/or of the pressure finger with levels exceeding amplitudes up to 100 nC. The white powder deposit on the discharges at the slot exit is a by-product of the chemical attack of ozone O3 generated by the PD with components of the mica.

Seminars and webinars to facilitate qualified interpretation

The interpretation of phase-resolved partial discharge patterns is based on experience and requires some background knowledge. While such an analysis may seem complex at first, Megger offers a wide range of seminars and even free webinars to interested professionals on its homepage in order to facilitate qualified analyses by the user.

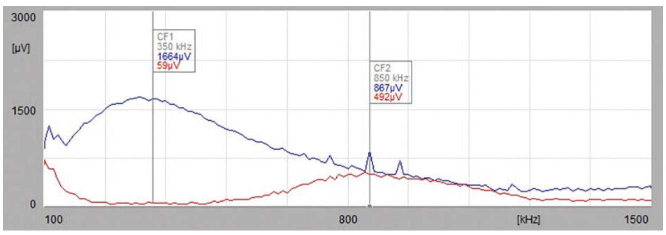

Figure 3: PD spectrum of a stator winding up to 1500 Hz

What the standards say

Mandatory factory acceptance tests according to chapter 9 of IEC 60034 (Rotating electrical machines: Rating and performance) solely include the measurement of winding resistance, insulation resistance and finally the withstand voltage test at twice the rated AC voltage plus 1 kV for 60 seconds. In 2007, the first version of the IEC TS 60034-27 on off-line PD measurements on the stator windings of rotating machines was published. In addition, CIGRE, IEEE, EPRI and ANSI/EASA also released several interesting guides and specifications regarding advanced off-line testing of stator windings. However, as yet there remains no standard definition of PD acceptance values in the insulation systems of high-voltage electrical machines.

How much PD is too much?

This frequently asked question therefore remains unanswered. As initially indicated, insulation systems in generators and electrical machines are “resistant” to PD, but unfortunately not PD-free. This finding is important because it fundamentally differentiates PD measurements on generators and electrical machines from other applications such as gas-insulated systems (GIS) or cables. In these cases, the focus revolves initially around detection of PD and then the exceedance of limit values.

As this report has previously established, PDs are an ever-present feature of HV machines. So how can the difference between permissible and impermissible PD be established? In order to avoid endless discussions, especially during factory acceptance tests, customers and suppliers could choose to agree on a maximum permissible PD level during the tender phase. Power Diagnostix is happy to offer the experience of its experts and consultants in this regard.

PD measurements in combination with loss factor measurement

PD measurements are usually carried out in parallel with a tan delta TD (loss factor) measurement. Where PD acceptance tests lack standardisation, this is not the case for TD measurements thanks to IEC 600034-27-3, published by the IEC in 2015. This standard defines the acceptance criteria for form-wound stator bars with slot corona protection and a nominal voltage of 6 kV or higher. Before this standard, manufacturers used previous reference values as guidelines for coils.

The maximum criteria set out in the IEC 60034-27-3 caused some excitement, with suppliers complaining that even the best bars could not meet these new acceptance levels. As a result, the A1 CIGRE study group performed an objective analysis of the target values set out in the IEC 60034-27-3; however, their results have still not yet led to a revision of the standard. Furthermore, it remains unclear whether a factory inspection of new coil batches should be carried out using a PD measurement as common practice or only if the customer specifically asks for it.

General information on stator winding inspections

Regular inspections of the stator winding on site include visual inspection and measurements using AC and DC voltage sources. Today, these are usually defined in an asset management system as part of a condition-based maintenance strategy. In the past, the focus here was mainly on vibration analysis and annual bearing inspections. IEEE and EPRI analysed the failures of around 10,000 motors and generators and found that they were caused by electrical and mechanical issues in roughly equal measure.
On-site stator winding inspections generally began by testing the inner conductor circuit using a winding resistance measurement and/or a surge test, also known as the Baker test (Baker has been part of the Megger Group since 2018). In this setup, the surface condition was then checked using typical Megger tests, such as measuring insulation resistance using DC voltage and measuring the polarisation index (PI). The results of these test routines determined the next steps to be taken with regard to AC tests such as TD and off-line PD measurements. While tan delta provides a good overview of the general condition of the slot area, high frequency PD measurements provide a precise assessment of both the discharge location and the degree of deterioration.

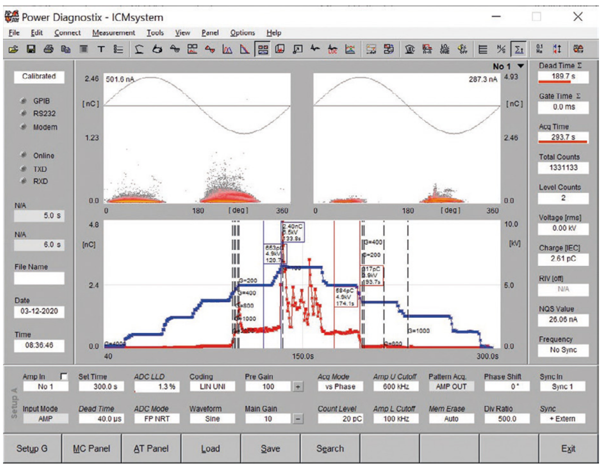

Figure 4: TE development vs. voltage

TRAX and DELTA4000: Ideal portable high voltage sources

Both on-site measurements and off-line PD/TD measurements for factory acceptance testing require a PD-free high-voltage source with a typical guaranteed PD output level of less than 5 to 10 pC. Common voltage sources are single-phase high-voltage transformers (Hi-Pots) with regulating transformers or AC parallel resonance test sets. Good alternatives to these heavy, high-voltage sources are compact, easy-to-use transformer and frequency converters with internal power sources. With TRAX and DELTA4000, Megger offers two perfect solutions that can be used in combination with ICM-series PD detectors for PD and TD testing on site. This ideal combination underlines the excellent synergies between Megger and Power Diagnostix. Figure 5 illustrates such a setup on a 10 kV stator winding with TRAX 220, the TDX 120 accessory with an integrated 12 kV/500 mA variable-frequency power source and the four-channel ICM*system* (Generation 5) from Power Diagnostix.

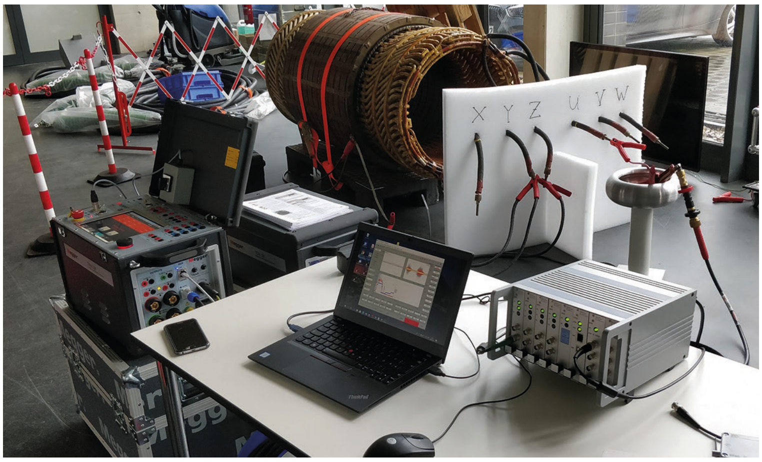

Figure 5: The combination of ICMsystem and TRAX underlines the excellent synergies between Megger and Power Diagnostix

Detailed PD diagnostics with ICM*system*

When it comes to applications that require advanced PD diagnostics or test equipment for unfavourable test conditions in the field, the multi-channel ICM*system* is the ideal solution as it enables PD to be measured in various frequency ranges. Wideband measurements in the range from 40 kHz to 800 kHz in accordance with IEC 60270 can also be performed, as can frequency-variable measurements (narrow/broadband) in the frequency range from 10 kHz to 10 MHz.

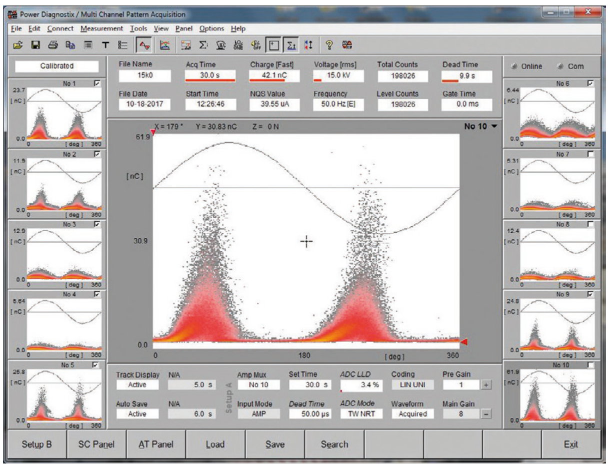

Figure 6: Multi-channel representation of PD patterns with ICMsystem

Increased cost-effectiveness for energy suppliers

ICM*system* software provides an option to optimise trigger settings in the analogue signal path down to the last detail, which helps to ensure that the shape and properties of the HFPD pulses are recorded correctly. This feature fundamentally distinguishes ICM*system* from other digital PD detectors, which pose a risk of falsely or incompletely recording HFPD pulses. The software also provides a separate recording panel for each channel so that the configuration of the setup can be displayed, customised, and optimised during data acquisition for each individual measurement channel.

Once all settings have been applied and the test is in progress, the user can select the multi-channel software panel to monitor the phase-resolved partial discharge patterns of all measurement channels in parallel. Such data presentation is essential to finding correlations between measurement points and drawing important conclusions. Finally, ICM*system* hardware provides the opportunity to set deadtime pulse detection. With settings ranging from 5 µs to 100 µs, ICM*system* can detect up to 20 times more pulses than other standard PD detectors in the same time frame. In summary, ICM*system* is an ideal PD measuring device for PD diagnostics in difficult conditions.

Extensive accessories for the perfect setup

In addition to advanced PD and TD measuring devices, Power Diagnostix offers a wide range of accessories. Additional high-voltage filters, for example, enable the test voltage source to be connected to the device under test (DUT) quickly and easily. Using coupling capacitors facilitates finding a suitable PD decoupling unit for all stator nominal voltages

Figure 7: CAL1B calibrator with 100 pC up to 10 nC.

across various voltage ranges. Various preamplifiers allow PD measurements in multiple bandwidths and guarantee optimum signal transmission with reduced interference signal coupling. PD measurements are relative measurements that require the apparent charge to be calibrated in accordance with IEC 60270. The total attenuation of the setup and the test object is taken into account during this process. This ensures that the PD detector displays the same detection variable as the calibrator pulse amplitude fed into the winding port. Charge injectors or “PD calibrators” are among the most useful accessories. For example, a common calibrator for stator winding setups is the CAL1B with 100 pC up to 10 nC. The test circuit shown in Figure 8 portrays the basics of how to calibrate a measurement setup for a single-phase measurement (open star point) in compliance with IEC 60270.

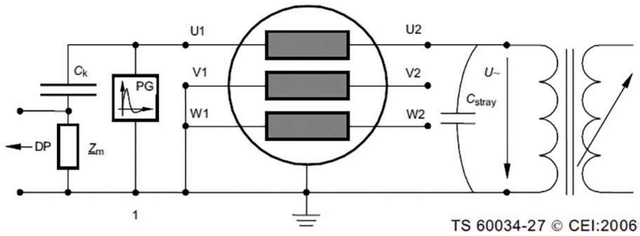

Figure 8: Test circuit for IEC 60270-compliant calibration of the measurement setup

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Simultaneous measurement of PD and TD with ICM*flex*

ICM*flex (*Figure 9) is a combined system for detecting PD, loss factors (TD), test sample capacities and test voltages. It has become a routine tool for manufacturers in factories and for service providers in the field, as the ability to simultaneously measure PD and TD simplifies the test setup and shortens testing times. This also makes it an ideal solution for energy supplier service engineers. ICM*flex* is very intuitive to use thanks to user-friendly control software. All recorded data such as voltage, TD or capacitance are clearly displayed in various graphs and diagrams. In addition to a multitude of trend charts (e.g., PD vs. voltage) and time charts, ICM*flex* software provides both unipolar and bipolar phase-resolved pattern detection. All data can be imported into log templates and exported to standard formats. Like the ICM*system*, the ICM*flex* complies with IEC standards.

The accuracy and efficiency of high-frequency off-line PD measurement complements low-frequency TD measurement and offers energy suppliers a cost-effective contribution to the assessment of their large HV electric motors and generators – a benefit that can also be felt by all industrial operators of high and medium-voltage plants. This high-end technology reliably detects problems in advance and prevents additional costs associated with unforeseen damage. It is also of huge benefit when it comes to maintaining the security of energy supplies.

Figure 9: The ICMflex for simultaneous measurement of PD and TD

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ISO 9001, ISO 14001
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