THE POWER BEHIND POWER.

Transformer online partial discharge monitoring

Guideline

Partial discharges in transformers ...

Partial discharge (PD), as defined by IEC 60270, is a localized electrical discharge that only partially bridges the insulation between conductors. Partial discharge activity can be a symptom of insufficient design, Manufacturing or design error as well as degradation/aging of insulation material. It resembles a tiny, short-lived spark within the insulation system of a transformer and does not immediately cause a complete breakdown. However, repeated PD activity is a clear sign of insulation weakness and a major contributor to long-term degradation.

Origin and mechanism

PD typically occurs where the electric field exceeds the dielectric strength of the insulation, often due to defects such as:

- Voids or cavities in solid materials (e.g., air bubbles in epoxy resin)
- Bubbles in insulating liquids (e.g., transformer oil)
- Sharp edges on high voltage potential

These cavities have different dielectric properties than the surrounding material, leading to field amplification within them. When the local field surpasses the breakdown strength of the gas, a discharge occurs. This discharge is self-limiting, collapsing quickly due to the higher dielectric strength of the surrounding solid insulation. In AC systems, this process repeats with each voltage cycle.

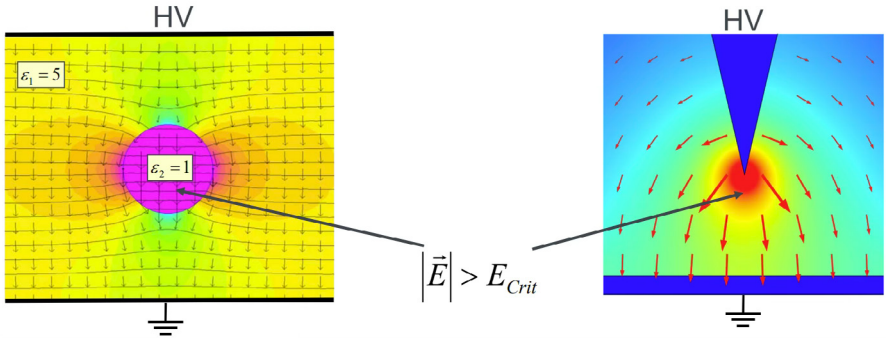


Figure 1:
Electric field exceeds the maximum Strength E_{Crit} of the insulation;
Left a cavitation;
Right at a pointed tip

Though each discharge releases minimal energy, the cumulative effect is destructive. PD causes:

- **Thermal decomposition:** Localized heating damages the insulation.
- **Chemical degradation:** By-products like ozone and nitrogen oxides chemically attack the material, making it brittle.
- **Physical erosion:** Material is gradually removed, forming conductive paths („treeing") that can lead to complete breakdown.

Over time, these effects weaken the insulation to the point where it can no longer withstand operating voltages, resulting in sudden and often catastrophic failure of the transformer.

Figure 2:
Examples of PD damage

PD traces on pressboard

Demaged OLTC interconnection

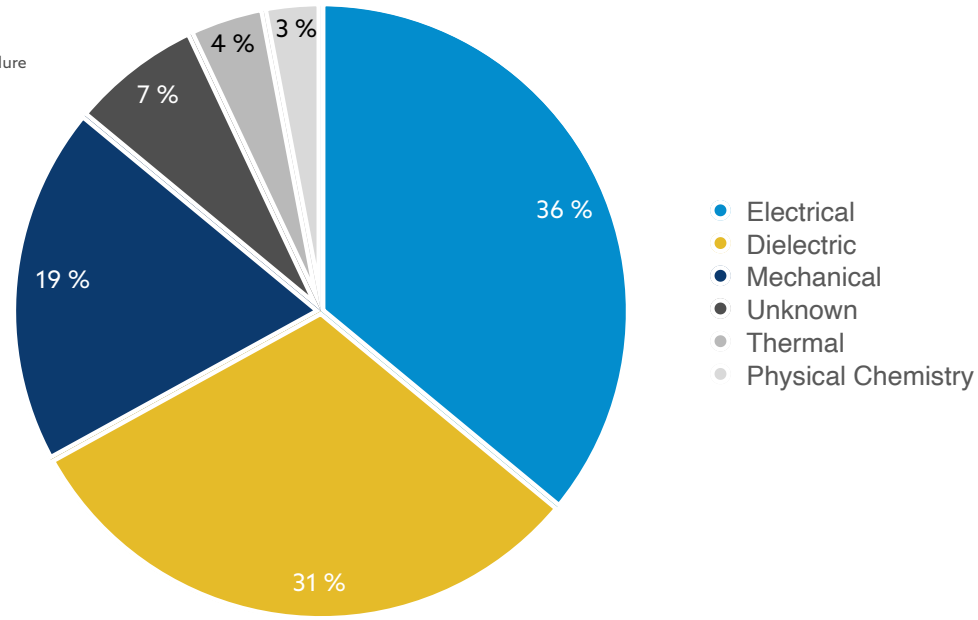
Demaged lead exit connection

Why online monitoring?

Undetected issues in manufacturing, damage during transport and installation, or aging processes of the insulation can lead to the occurrence of partial discharge. If this PD activity remains unchecked, it can cause a progressive breakdown of the insulation, eventually resulting in a catastrophic failure.

According to failure statistics (e.g., CIGRÉ), over 60 % of transformer failures are due to electrical or dielectric faults, many of which are linked to PD. Therefore, PD detection is a critical diagnostic tool for assessing the health of high-voltage equipment. Early identification of PD allows for timely maintenance, preventing costly failures and extending equipment life.

Figure 3:
Transformer failure mode analysis



Key benefits of online PD monitoring

Online PD monitoring offers continuous, real-time insight into the condition of insulation systems.

- **Early fault detection:** PD is a direct indicator of insulation degradation. Continuous monitoring acts as an early warning system, identifying weak points in the insulation before they can lead to a complete breakdown
- **Preventive maintenance:** By detecting and trending PD activity over time, asset managers can schedule maintenance proactively, avoiding unplanned outages, reducing repair costs, and improving overall system reliability
- **Quality assurance:** PD measurement is a fundamental quality control test performed during factory acceptance (FAT) and site acceptance (SAT) to ensure that the equipment is free from significant manufacturing or transport-related defects
- **Safety and risk mitigation:** Preventing catastrophic failures like transformer explosions or fires is paramount for the safety of personnel and the protection of surrounding infrastructure. PD monitoring is a key tool in mitigating these high-impact risks
- **Smarter asset management:** Real-time data supports better decisions about maintenance, refurbishment, or replacement—extending equipment life and optimizing investment.

Types of online monitoring

Partial discharges generate various physical phenomena that can be captured using different sensor technologies. The choice of methods depends on the application, environmental conditions, and the desired level of detail.

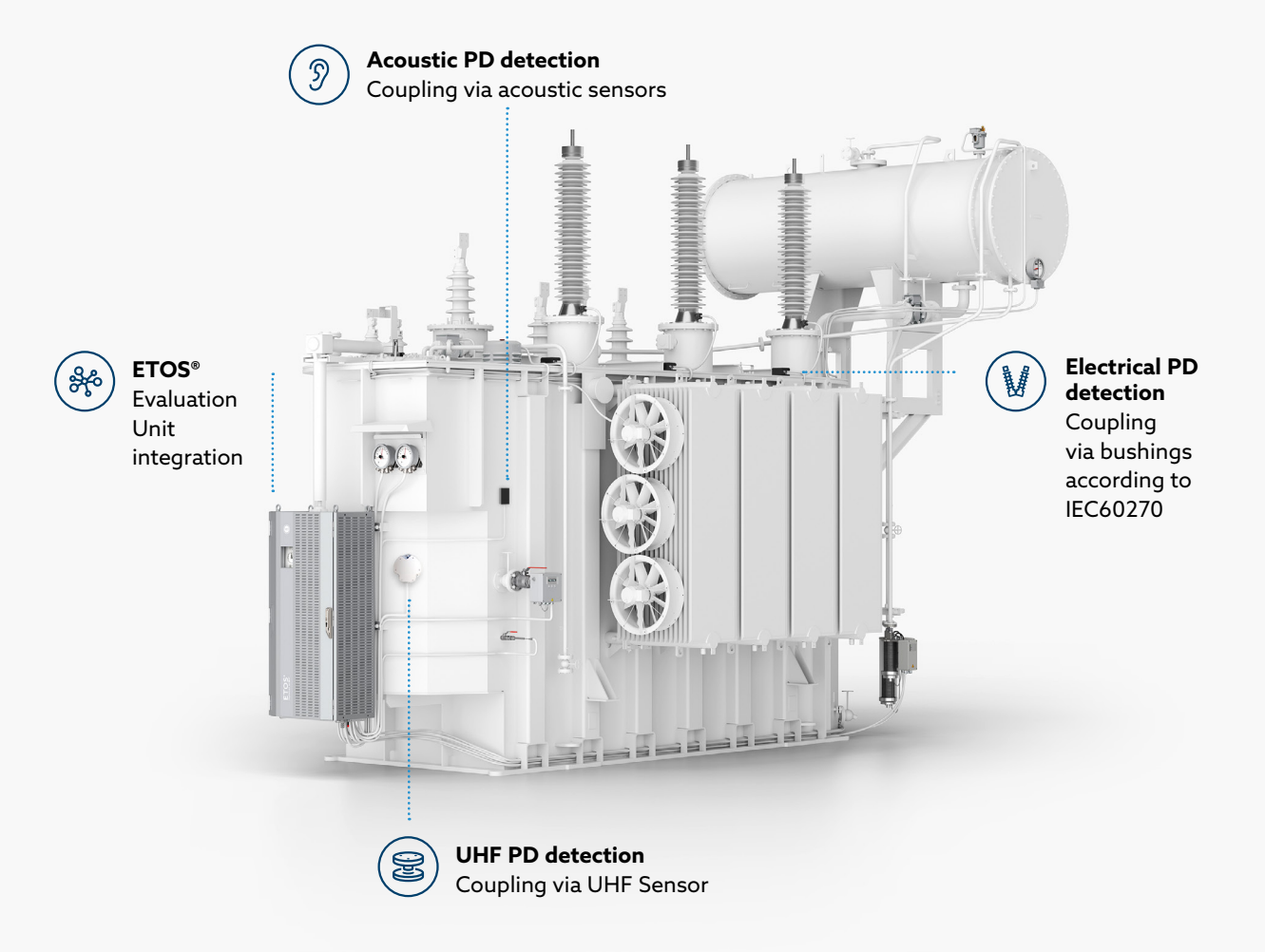


Figure 4: MSENSE® PDM - overview

Overview of PD detection principles		
Physical effect of PD	**Detection of**	**Detection method**
Electrical transient, Discharge of capacitance	Discharge current (HF)	**Electrical PD detection** Using connection over coupling capacitor (transformer bushing)
Fast electrical transient	EM radiation (UHF)	**UHF PD detection** Using UHF (Ultra High Frequency) antennas
Chemical degradation of insulating material (oil / paper)	Decomposition products dissolved in oil	**DGA** (Dissolved Gas Analysis) Using oil sampling/on-line sensor
Fast mechanical transients	Ultrasonic acoustic waves	**Acoustic PD detection** Using acoustic sensors

The most common detection methods for online PD monitoring include electrical PD detection, also referred to as HF (High Frequency) or IEC detection, UHF (Ultra-High Frequency) or acoustic detection. DGA is also common among online transformer monitoring, though DGA units have a wider scope of detection than only PD activities, thus seldom used for sole PD detection.

Electrical PD detection

Electrical PD refers to the detection by direct electrical coupling to the active part of the transformer.
The recommended setup for partial discharge (PD) measurement, in accordance with IEC 60270 and IEC 60076-3 standards, utilizes the bushing's C1 capacitance as a coupling capacitor. This allows high-frequency PD pulses to be decoupled for analysis.

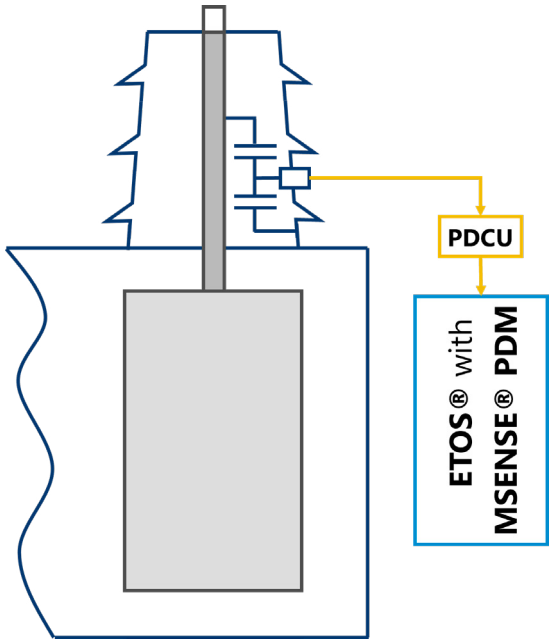


Figure 5:
Setup for electrical PD

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The test or voltage tap of the bushing serves as the connection point. With the use of specialized adapters and coupling units, PD signals can be extracted from this tap without interfering with the bushing's operation or its monitoring system. For coupling, a Partial discharge coupling unit (PDCU) is connected to the bushing test tap coaxial cables are used to connect the PD measurement system, ensuring reliable signal transmission.

MR recommends combining **MSENSE® BM** and **MSENSE® PDM** to enable a comprehensive monitoring strategy. Although both systems utilize the bushing's test tap for signal acquisition, they serve distinct purposes: **bushing monitoring** focuses on assessing the long-term health of the bushing by tracking changes in capacitance (C1) and dissipation factor (tan∂), while the **PD system** is capable of detecting fast-developing faults both within the bushing and inside the transformer.

PD monitoring identifies rapid, localized discharges that may indicate emerging insulation issues, whereas bushing monitoring provides insight into gradual insulation degradation. Integrating both functionalities into a single **ETOS®** platform offers a powerful solution for applications requiring simultaneous surveillance of insulation aging and early fault detection.

This setup measures apparent charge in pC or nC, similar to factory acceptance testing (FAT) for PD, allowing for meaningful comparisons. The method is highly sensitive to ambient noise, which must be considered during installation and calibration. A key advantage is the seamless integration with bushing monitoring, as both systems can share the same interface.

UHF PD detection

Ultra-high frequency (UHF) sensors detect electromagnetic radiation in the gigahertz range (300 MHz to 3000 MHz) generated by partial discharges (PD) inside the transformer. The principle of measurement is based on using an UHF antenna to measure the electromagnetic emissions from a PD source.

This method is significantly less susceptible to external interference and is therefore particularly suitable for the reliable detection of internal partial discharges.

This is because the metal surface of the transformer tank acts as a natural Faraday cage, filtering out external electrical interference. Additionally, the C1 capacitance of the high-voltage bushings acts as a low-pass filter, further reducing external noise.

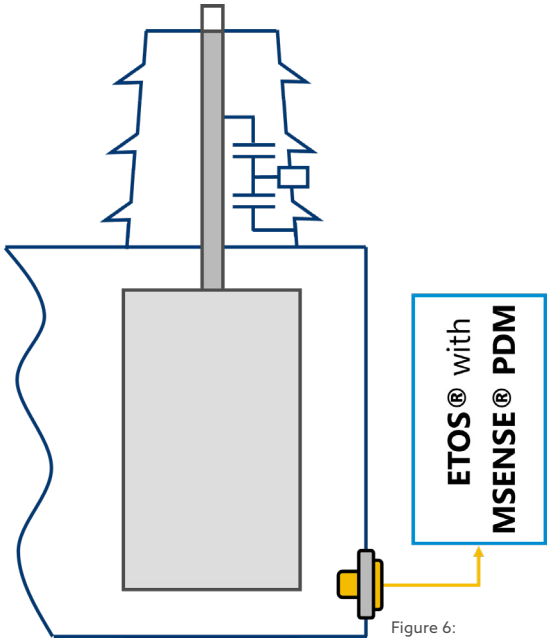

Figure 6:
UHF PD installation

Two main types of sensors are available for measurement: Window- and drainvalve sensors

Window sensors are most common among new installations. They are installed in special dielectric windows, which are welded to the transformer tank. These windows need to be installed during the construction phase of the transformer. The sensor is designed in accordance to CIGRE technical brochures.

For existing transformer designs and retrofit applications, suitable drain valves can be used for the installation of a drain valve sensor. The sensor is mounted to the flange of the drain valve and inserted into the transformer tank. This procedure can be performed, while the transformer is online.

Other detection methods

While electrical coupling via transformer bushing capacitance and UHF sensors remain the primary technologies for online PD monitoring, a range of additional detection methods can further enhance system insight and diagnostic capability. These complementary solutions require no mechanical modifications to the transformer, making them exceptionally easy to deploy and ideal for retrofit applications – especially where UHF drain valve ports are not available.

Acoustic PD detection

Partial discharges generate unique acoustic signatures that travel through the transformer structure. By capturing these ultrasonic vibrations with high-sensitivity acoustic emission (AE) sensors, operators gain a powerful tool for pinpointing and characterizing PD activity.

Mounted directly onto the transformer tank using magnetic holders, AE sensors can be installed quickly and without interruption to service. Acoustic PD detection offers a highly targeted diagnostic view, enabling precise localization of internal faults and supporting fast, informed decision-making.

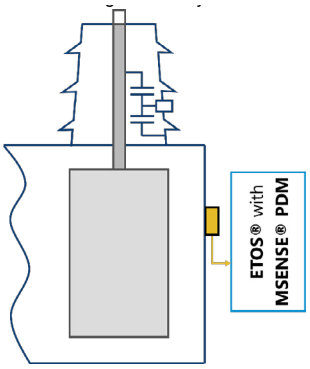

Figure 7:
Acoustic PD installation

Transient Earth Voltage (TEV) detection

The TEV measurement principle is based on high-frequency PD currents that propagate along the surfaces of metallic enclosures. This makes it an excellent fit for applications such as medium-voltage switchgear, transformer cable boxes, and other enclosed HV assets. With simple magnetic mounting, TEV sensors can be added to existing equipment in minutes, providing immediate visibility into insulation conditions and potential emerging issues.

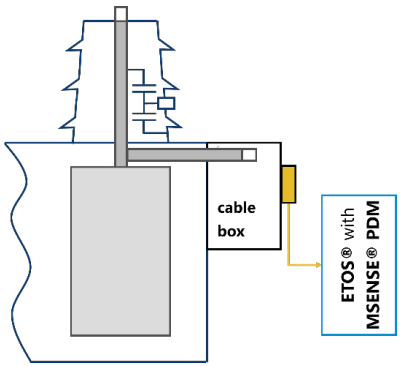

Figure 8:
TEV PD installatio

High Frequency Current Transformer (HFCT) detection

HFCT sensors – high-frequency current transformers or clamps – capture PD pulses directly from grounding paths, offering a non-intrusive and highly sensitive method of monitoring. Supporting both IEC 60270-aligned measurements and extended frequency ranges up to ~28 MHz, HFCTs deliver broad diagnostic coverage.

Typically installed at transformer grounding points or on cable shield grounding leads, HFCTs offer one of the fastest and most flexible retrofit options for enhancing an existing PD monitoring strategy.

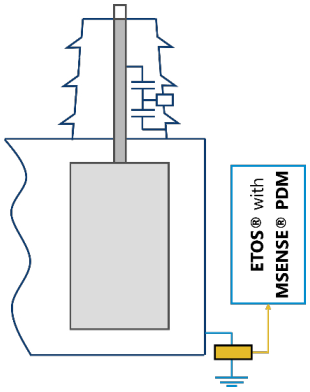

Figure 9:
HFCT PD installation

MR's recommendation and solution

As transformer designs widely differ, the optimum online PD monitoring solution can be highly individual. Please note that the following recommendations might differ for individual transformer designs and should be used as an indication.

Electrical PD-coupling: Recommended for existing transformer designs or retrofit applications. Generally, the combination with MSENSE® BM is recommended.

UHF-PD-coupling: Recommended for new transformer designs and applications where ambient noise is expected. The number of sensors depends on the application, but more sensors offer better results regarding early detection and enable a localization of the fault.

Combination of UHF and HF coupling: Recommended for more valuable assets. The combination of different detection methods, as recommended by Cigré TB 861, increases the early detection of faults of different nature.

Quantity recommendation of UHF Window sensors

Configuration type	Number of sensors
Economic (small transformer < 30 MVA)	**1 sensor** (in combination with HF coupling)
Simple configuration (transformers < 100 MVA)	**2 sensors** (minimum for performance check)
Recommended standard	**4 sensors** (minimum for localization purpose)
High-end	**6 sensors** (depending on vessel size and importance of the monitored transformer)

Placement of sensors

Whereas the location of electrical coupling is predefined by the layout of the transformer and therefore the placement of the bushings, UHF sensor needs to be carefully placed according to the transformer design.

For optimal detection of partial discharges, UHF sensors should be positioned to maximize sensitivity towards the transformer's active part. It is important to avoid locations where internal metal components, such as riser pipes, could cause electromagnetic shielding and reduce the effectiveness of the sensors.

Sensors must only be installed in areas with low electric strength, and safety distances from high-voltage components must always be maintained. Additionally, sensors should not be placed too close to the corners of the tank; a minimum distance of 25 centimeters should be observed.

When multiple sensors are installed, they should be positioned on opposite walls of the transformer tank to ensure comprehensive coverage. Whenever possible, installing sensors on the top of the transformer provides a particularly suitable location for effective monitoring.

UHF-Ready

To enable a later installation of UHF sensors, Cigré Working Group recommends to always install dielectric windows on new transformers. When using windows designed according to Cigré Working Group brochure D1-37, any sensor compatible to this standard can then later be installed.

During the tank manufacturing, the dielectric windows are welded to the tank and are then sealed with a cover plate. During later retrofit of the window sensor, the cover plate is removed, and the sensor is screwed on. As the oil barrier is part of the preinstalled window, there is no contact with oil during the installation.

This is useful for reducing initial manufacturing costs of the transformer but enabling later online UHF monitoring.

MR standard packages

With MSENSE® PDM, a versatile and flexible configuration system is provided. The system can be adjusted for different needs, meaning the amount of measurement channels as well as the detection type for each channel can be individually configured.

Figure 10:
MSENSE® PDM system components

To provide aid for system setup, MR has four recommendations for different applications

	BASIC	ADVANCED	PRO	EXPERT
Electrical couplings	3	3	–	3
UHF sensors	–	1	4	3

BASIC package contains **3 electrical couplings** using the transformer bushings. This is the easiest solution for implementation on existing transformer designs or for retrofit applications. The combination with MSENSE® BM is recommended, as the bushing adapters are already included.

ADVANCED Package consists of **3 electrical couplings** as well as **one UHF sensor**. This contemplates the BASIC package with another detection method with an additional frequency range. One UHF sensor is also easier to integrate into an existing transformer design rather than multiple. For retrofit applications, this can be implemented by installing a drain valve sensor on a suitable existing valve.

PRO package consists of **4 UHF sensors** and is the recommended design for new transformer applications. This configuration is also recommended by the Cigré TB861, as it is the minimum configuration for proper localization analysis. With only UHF measurement, the system is less prone to environmental noise.

EXPERT Package takes full advantage of one evaluation unit with **3 electrical couplings** together with **3 UHF sensors**. This configuration is recommended for valuable assets or critical applications. The combination of HF and UHF measurements enables a full-scale PD analysis. Also here, the combination with MSENSE® BM is recommended for holistic asset assessment.

Additionally, with a flexible evaluation hardware platform of up to 12 channels, each individually configurable to electrical, UHF or acoustic coupling, MSENSE® PDM can be tailored to any specific needs.

Information provided by MSENSE® PDM

Like online DGA monitoring, online PD monitoring focuses on trend analysis. Therefore, the amplitude of the detected signal is the most important metric. If a measurement is continuously increasing and exceeds a defined threshold, this can be an indication for a growing fault inside the transformer.

While the amplitude of the PD measurement is used to trigger an alarm, far more important for early diagnostics is the information, when this event took place. For this, the system offers a Phase Resolve Partial discharge (PRPD) diagram, which can be accessed on the ETOS® unit. This PRPD can be displayed individually for every measurement channel. Via remote visualization of ETOS®, this can be accessed without the need of accessing the transformer.

As also with other intelligent MR monitoring functions, measurements and alarms can be passed on to SCADA systems using standardized communication such as IEC61850.

The strength of MSENSE® PDM comes the most, when combined with other intelligent monitoring functions such as for example MSENSE® DGA, MSENSE® BM or MSENSE®. With **ETOS® asset intelligence**, all sensors present on the power transformer are integrated and considered together. A Bayesian network checks which error patterns best match the warning messages that have occurred as well as those which have not occurred. In addition, the occurrence rates of typical transformer faults, as well as the false positive rates of sensors are considered.

The result is a probability estimate for all known transformer problems, with the most likely problems being displayed to the customer, along with a list of reasons for the findings. This allows the specialist to interpret the diagnostic results in a simplified and efficient way.

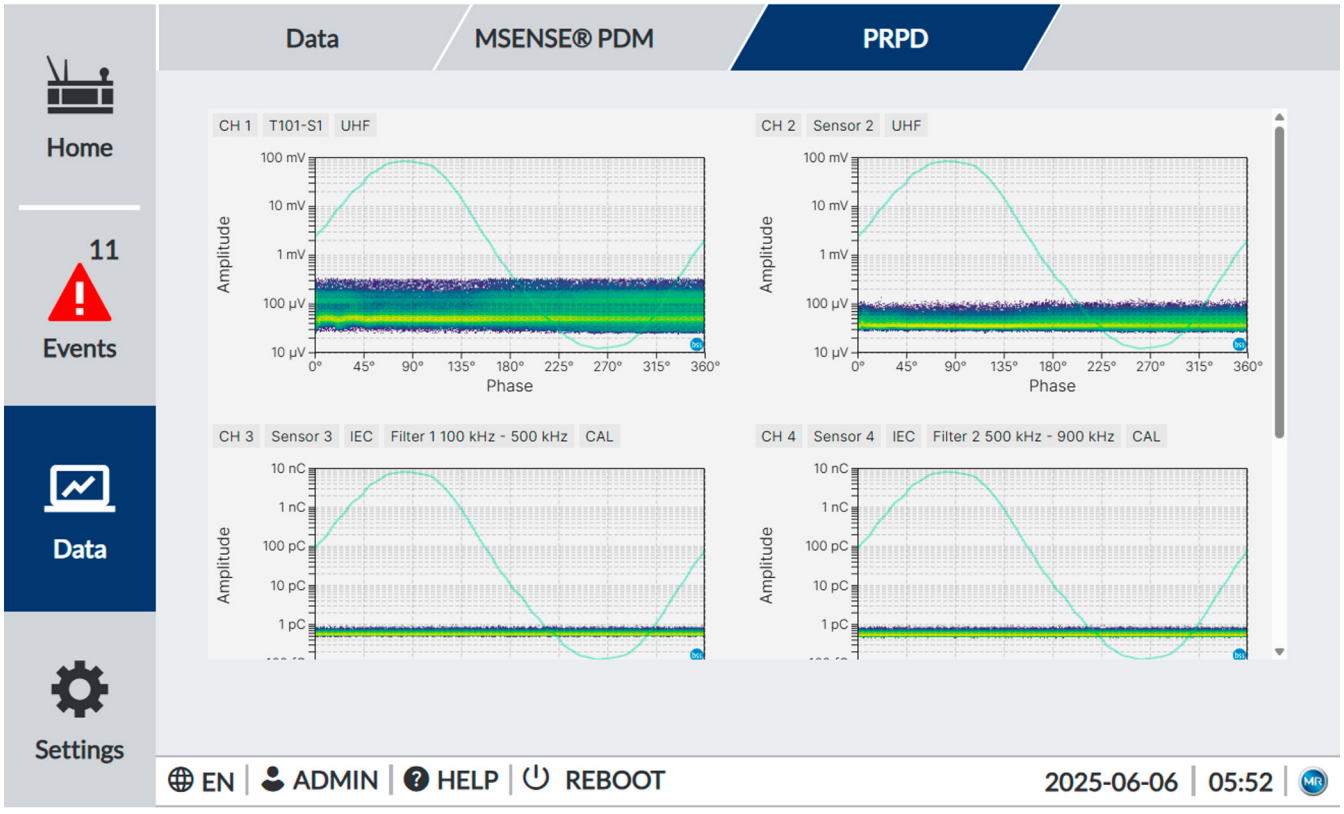

Figure 11:
Live view of MSENSE® PDM inside ETOS®

Commissioning and calibration

An online PD System must be properly commissioned, in order to provide reliable measurements during operation. The procedure for commissioning differs for the detection methods.

Electrical PD commissioning

High-frequency (HF) calibration must be performed on-site after the transformer installation is complete. The transformer must be shut down, disconnected, and not grounded. The goal of calibration is to minimize background noise and ensure accurate partial discharge detection. A calibrator is used to inject a defined charge into the system and the evaluation unit is calibrated to this injected charge. The procedure follows the IEC 60270. Afterwards, the transformer is energized and the alarm settings are individually set depending on the site conditions.

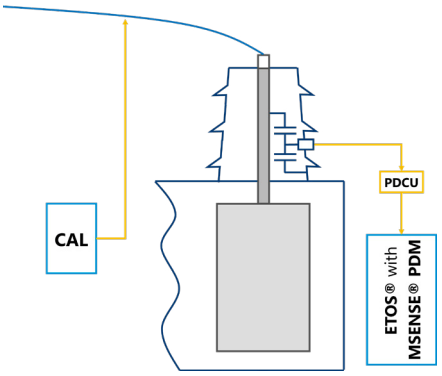

Figure 12:
Electrical PD calibration

UHF PD commissioning

A calib ration in accordance to IEC 60270 is not applicable, as UHF sensors measure electromagnetic amplitude (in mV or mV/m) and not an apparent charge.

Installation calibration

As the dampening of UHF signals is affected by the length and installation type of the wiring, the first step in commissioning is a calibration of the connection to the evaluation unit. This is achieved by connecting an UHF-calibrator in place of the UHF sensor and injecting a defined signal. This can be done at the OEM factory, if the wiring is not changed during transport and on-site installation.

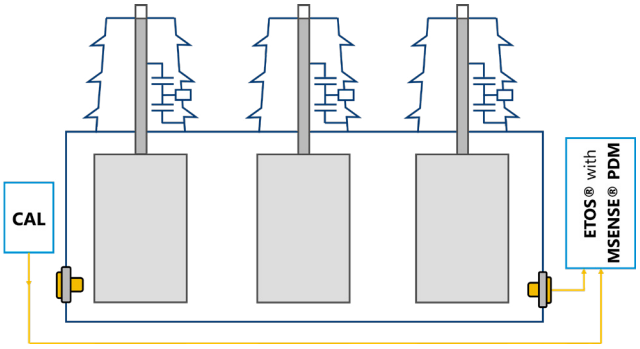

Figure 13: UHF PD
installation calibration

Performance check

Additionally, if multiple sensors are installed, a performance check can be made, to test whether all sensors are in clear view of the active part. This is not mandatory but recommended especially if internal shielding inside the transformer is expected or in retrofit application e.g. with the usage of drain valve sensors.

During commissioning, installation calibration (cables and connectors) and performance checks can be performed—either on-site or at the OEM factory, provided the sensors remain unchanged. For calibration, the sensor is temporarily disconnected and replaced by a calibrator that injects a defined voltage. The evaluation unit measures the response and calculates a system-specific K-factor.

Same as for electrical coupling, after the transformer has been set-up on-site and energized, the alarm setting needs to be set individually.

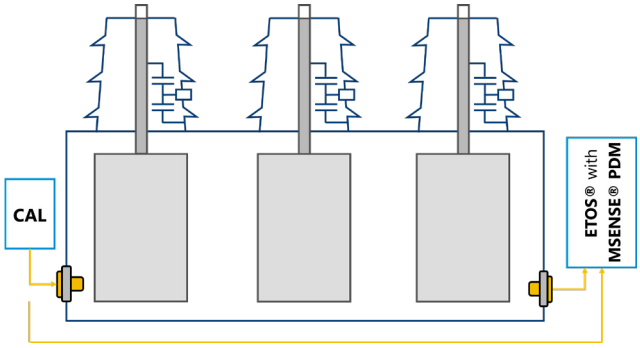

Figure 14: UHF PD
performance check

AE, TEV and HFCT comissioning

These detection methods do not require any special comissioning. Like conventional electrical PD, these detection methods are prone to enviromental noise interference, therefore careful onsite adjustment of alarm settings is required.

MSENSE® PDM – Cooperation with a strong partner

MSENSE® PDM shows the importance of cooperating with a strong partner: BSS Hochspannungstechnik.

BSS Hochspannungstechnik GmbH was founded in 2013 by PhD students from the Institute of Power Transmission and High Voltage Technology at the University of Stuttgart and specializes in the development of sensors and monitoring systems for PD detection. The company is a technology leader in ultra-high frequency (UHF) PD monitoring of power transformers.

With over 10 years of experience in the field of online partial discharge monitoring, it is an excellent addition to MR's holistic transformer assessment. For end users, it combines BSS' expertise with well-known and established MR quality products.

Accompanying documentation and publications

[1] CIGRE TB 861 – A2/D1, February 2022 "Improvements to PD measurements for factory and site acceptance tests of power transformers"
[2] CIGRE TB 761 – A2, March 2019 "Condition Assessment of power transformers"

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IN12604204/00 – F0437000 – Transformer online partial discharge monitorings – uw – 12/25
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