The importance of partial discharge testing throughout the development and operation of power transformers

Ulrike Broniecki
OMICRON Energy Solutions GmbH, Berlin

Power transformers are exposed to intense stresses from various sources throughout their very long service lives. These stresses include high electric field strengths, but also temperature fluctuations and intense, brief mechanical forces. Among other things, this damages the electric insulation, which is very important for safe and reliable transformer operation.

A number of dielectric diagnostic methods make a crucial contribution to quality assurance and to maintaining the operation safety and reliability of power transformers, since they provide evidence about changes in the condition of the insulation. Measurements for this extended diagnosis includes those for parameters such as dielectric response, frequency response, winding resistance, short-circuit impedance, excitation current, transformer turns ratio, insulation resistance, capacity and dissipation factor, as well as partial discharge (PD).

Verified quality

Before a new transformer is ordered, quality assurance requirements must be clarified – the customer wants to be sure to acquire a flawless product. To review the design and ensure good quality, power transformers are therefore subjected to various standard tests in the factory during their development and production, ranging from incoming material inspections, through research and development tests and up to type tests.

The special complexity of high-voltage technology and the equipment it involves permits only limited simulation and requires many empirical tests. To provide evidence of the limit and long-term behavior of the equipment and materials used, high-precision tests and inspections are performed under laboratory conditions.

For devices produced in great numbers, each individual device is also subjected to routine testing. This ensures that the final product meets all production and assembly quality requirements. Besides standard tests that may be required in the relevant standards, further tests may also be specified in agreement between the customer and producer in order to verify special requirements.

Small damage – big consequences

Compared with other dielectric diagnostic methods, the

Partial discharge diagnosis of a power transformer

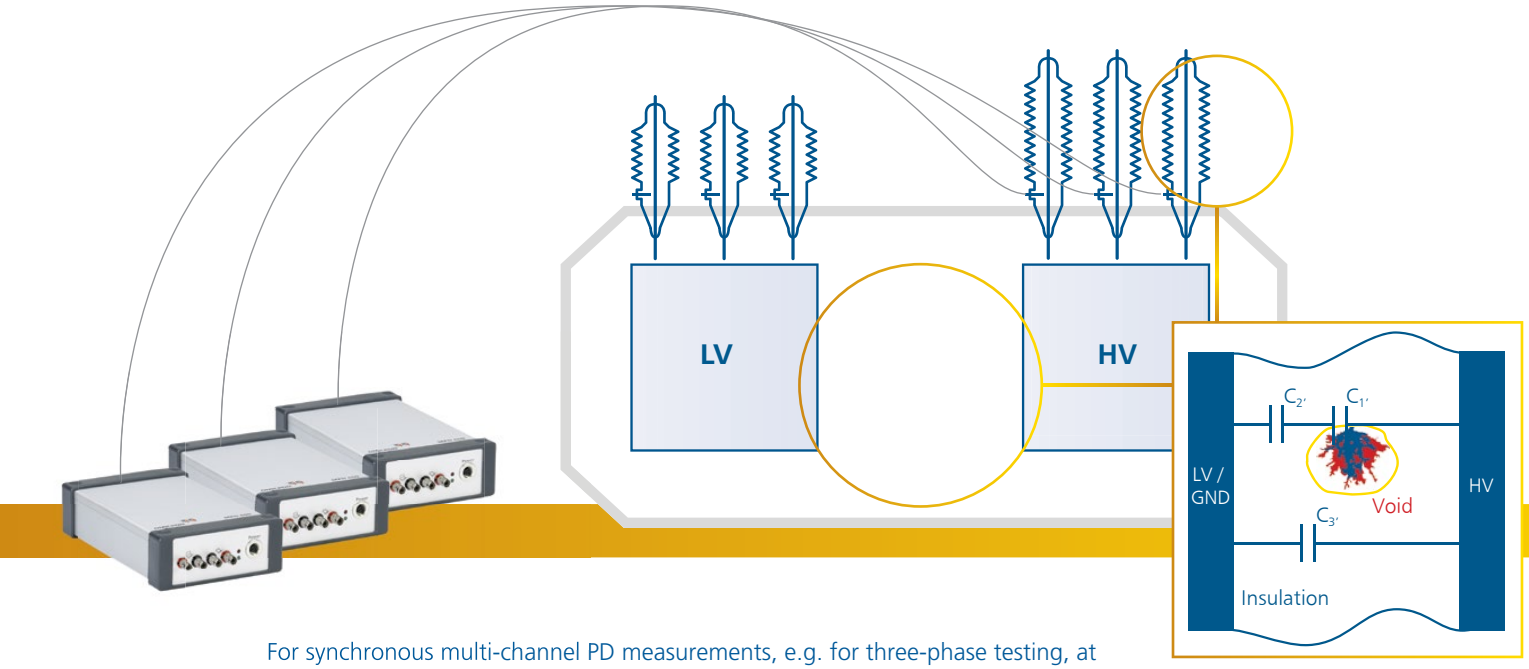
PD measurement is recommended during the development, production, and service life of power transformers.

PD measurement provides test engineers with very sensitive information to help them to effectively detect even the smallest weak points in the insulation system.

According to the IEC 60270 standard, partial discharges are "localized electrical discharges that only partially bridge the insulation between conductors and which can or cannot occur adjacent to a conductor." Partial discharges are in general a consequence of local electrical stress concentrations in the insulation or on the surface of the insulation.

Partial discharges are observed in power transformer bushings and windings if the insulation material between different voltage potentials is aged, contaminated or faulty. It can be initiated by voids, cracks, or inclusions within a solid dielectric, at interfaces within solid or liquid dielectrics, in bubbles within liquid dielectrics, or along the boundary of different insulation materials. PD can progressively damages insulation materials in power transformer bushings and windings, leading to their eventual failure and costly outages. Therefore it is important to recognize the PD source, find it, and eliminate it if necessary.

PD measurement is a reliable and non-intrusive method that can be used anytime to diagnose the insulation condition of power transformers. It can either be performed off-line, by energizing each phase successively with a high-voltage source, or on-line during regular service operation. With additional PD acquisition devices, three-phase measurements can be performed to save time when identifying phase-to-phase activity.



For synchronous multi-channel PD measurements, e.g. for three-phase testing, at least three MPD 600 acquisition units are needed for connection to the HV bushings.

PD pulses are of short duration and have rise times in the nanosecond range. The most important criteria for evaluating PD are:

> Charge level, measured in either picocoulombs (pc) or nanocoulombs (nC)

> Phase position relating to the applied voltage

> Pulse repetition rate

An increase in any of these criteria indicates the presence of localized weak spots in the insulation, which can lead to further damage and eventual failure. Advanced noise suppression techniques can be deployed in high-voltage laboratories and in the field to minimize irrelevant data and simplify analysis.

Last check during commissioning

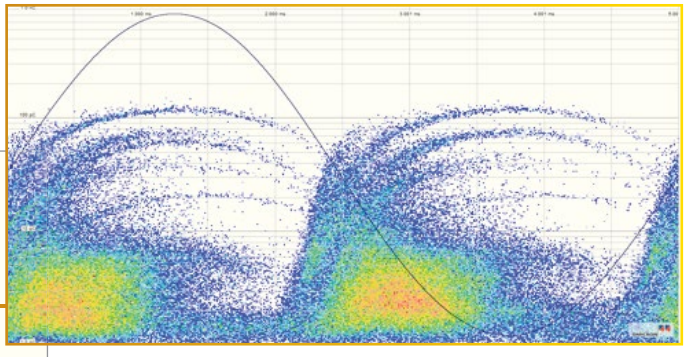
It is important to check functional and dielectric integrity after transport, especially for large transformers. The most common methods are the Frequency Response Analysis (see information box, page 4) and PD measurement.

Improper handling during transport and installation can lead to internal mechanical damage and can be detected through comparison with the reference measurements from the factory.

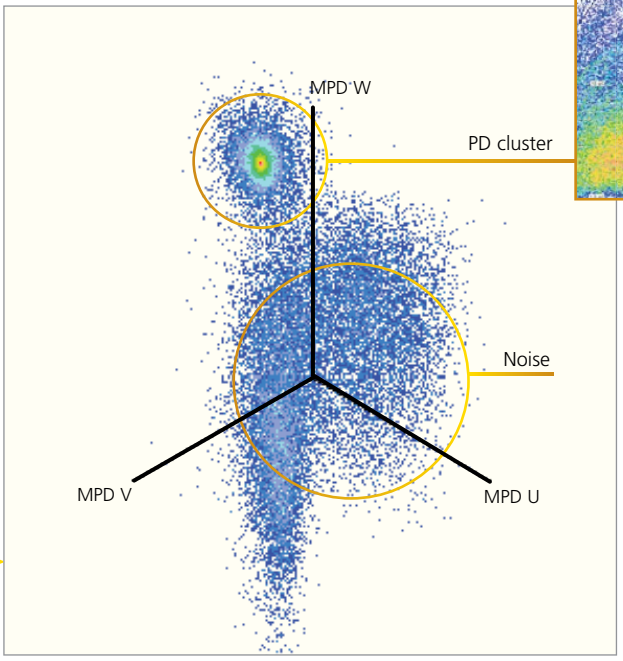
When a PD measurement is performed during commissioning, possible transport influences on the dielectric can be detected. It also enables a quality control of all high-voltage components, such as bushings, installed on site.

Ensuring safe and reliable operation

If a piece of equipment has successfully passed all the tests during commissioning, it can be put into operation, and the second stage of the quality assurance begins. With advancing age, power transformers require regular checks of their operating condition in the field. Strategic decisions about further maintenance and monitoring must be made to ensure a reliable service life.



The detected PD cluster can be visualized in detail by using the PRPD histogram.



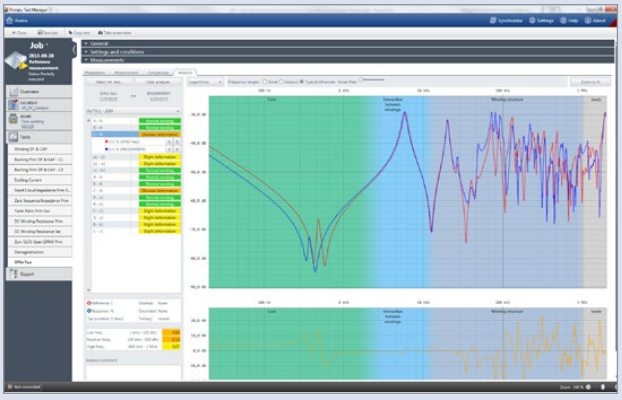
A 3PARD (3-Phase Amplitude Relation Diagram) separates PD sources from noise.

Frequency Response Analysis (FRA)

Frequency Response Analysis (FRA) is performed to check the electric and mechanical integrity of the active components (windings, core, connections, and leads). FRA is a recommended diagnostic method for checking mechanical integrity. More and more power supply companies are using FRA in routine tests because it allows numerous faults to be detected in a completely non-invasive manner.

Using OMICRON's FRANEO 800, a current measurement is compared to a reference measurement (fingerprint) performed at an earlier time. If no fingerprint is available, another phase or an identically constructed power transformer can be used for the comparison.

www.omicronenergy.com/FRANEO800



OMICRON's Primary Test Manager™ software offers automatic result assessment and comparison, also typical influences for deviations can be visualized.

As part of fleet management, for increasing availability and planning security, but also for value conservation, regular maintenance is the state of the art for large transformers and other high-voltage equipment. However, the diagnostic options normally applied are limited to a small selection from the range of dielectric diagnostic options.

Dielectric response measurements (see information box, page 5) can be used to evaluate the water content in oil-paper insulation and is therefore a helpful tool for making an assessment of the ageing of the cellulose. The analysis of the gas-in-oil (DGA) is a well-proven method of analysis but must be complemented by efforts to verify any faults indicated by excess hydrocarbon gases in the oil. This way, important maintenance can be performed in time to avoid a sudden total failure. Fault detection can be successfully performed using modern type test equipment for resistance, winding ratio, short circuit impedance, C, tan delta, FRA and PD measurements.

Best indication of insulation deterioration

Because PD activity is often present well in advance of insulation failure, it provides the most evident indication of defects and deterioration. Asset managers can evaluate PD activity over time and make informed strategic decisions regarding the timely repair or replacement of the equipment before an unexpected outage occurs.

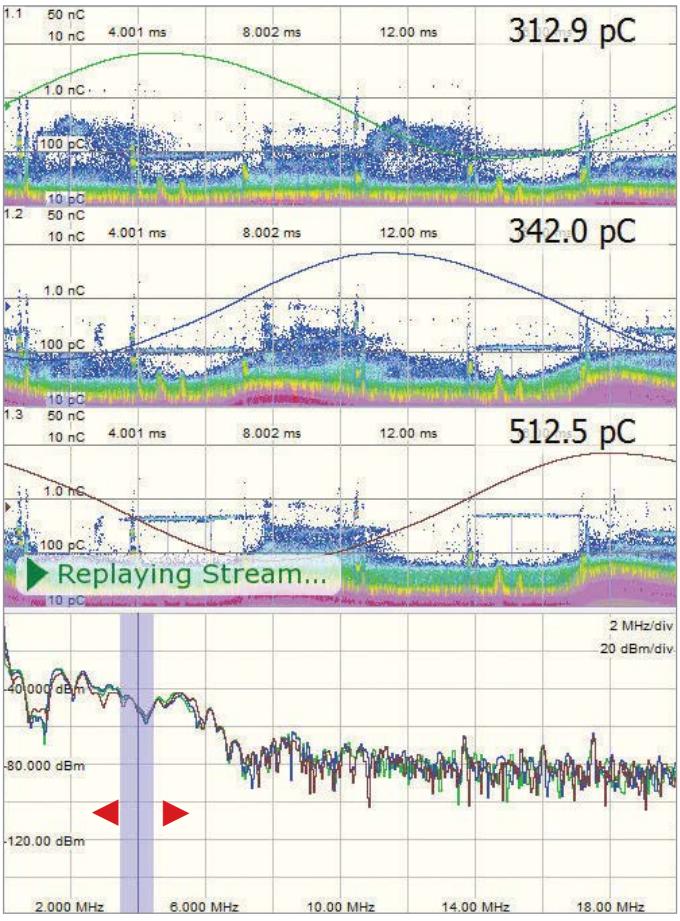
When measuring and analyzing PD activity in power transformers in the field, the particular tests and test set-ups are determined by the type of transformer and to which standard the measurements are performed. Depending on the type of bushings used, the PD analysis system is connected either to the capacitive tap of the bushings or to an external coupling capacitor for standard electrical PD measurements on power transformers.

Minimizing the effect of noise in the field

Outside screened laboratories PD signals are very often superposed by noise pulses, a fact that makes a PD data analysis more difficult for both experts and software systems. Therefore the proper minimization of disturbances is one of the main tasks when measuring PD in the field.

OMICRON's MPD 600 PD measurement and analysis system allows very high sensitivity detection and measurement, using several methods of electrical noise suppression. With freely-selectable filtering options, the center frequency and bandwidth can be adjusted to achieve a high signal-to-noise ratio and low background noise level for reliable PD measurement and analysis.

When using three or more acquisition units with the MPD 600 system, a fully digital, synchronous multi-channel PD



Adjustable center frequency and bandwidth

measurement is ensured. This not only minimizes the time for which high voltage has to be applied during off-line testing and speeds up measurement time, it also enables unique separation tools, such as 3PARD (3-Phase Amplitude Relation Diagram) to be applied. PD signals originating from various sources or location appear in different parts of the 3PARD and can be analyzed separately. This enables an effective de-noising as well as an easy separation of overlapping PD signals in the corresponding PRPD (Phase-Resolved Partial Discharge) pattern.

UHF and acoustic PD measurements

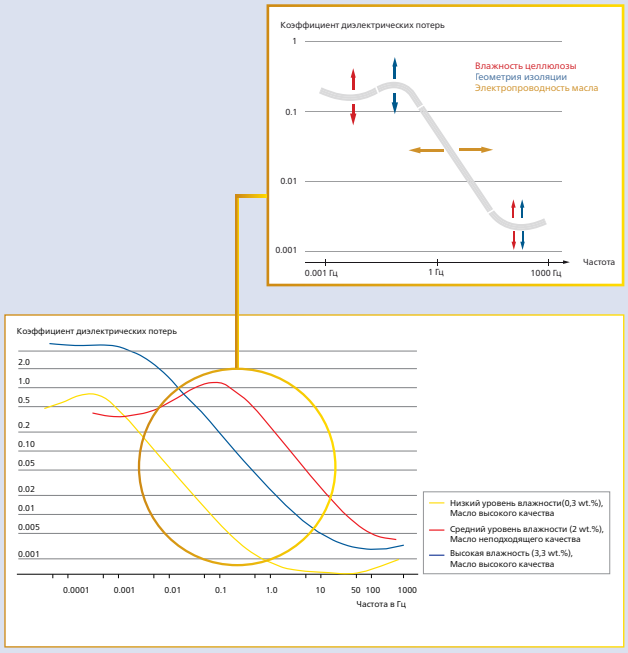
For liquid-insulated power transformers, UHF PD measurements can be used as an effective gating method in both HV labs or out in the field to verify the results of the electrical PD measurements. Using this method, PD is directly measured inside the transformer tank using ultra-high

Dielectric response measurement

If the dissipation factor of a power transformer is measured over a wide frequency range, conclusions about the condition of the insulation can be drawn on the basis of the dielectric response measurement. The analysis of the dielectric characteristics also allows the water content in the solid insulation (cellulose) to be evaluated and its condition to be monitored. Knowing the water content is important for determining the condition of the bushings and the active components of a power transformer.

OMICRON's DIRANA measures the dielectric response over a very wide frequency range (10 µHz – 5 kHz). It reduces test times through the combination of dielectric spectroscopy (FDS) for high frequencies with the time domain procedure (PDC) for low frequencies. The measured values also allow insulation diagnosis not only power transformers, but also generators, motors, converters and cables.

www.omicronenergy.com/DIRANA



The dielectric response curve allows conclusions to be drawn about the different factors that influence the measurement result.

frequency (UHF) sensors. PD pulses from an electrical measurement at the bushings are only accepted if a UHF pulse from the transformer tank is also present. Once PD activity is detected, acoustic PD measurements can be performed with a PD localization device and multiple UHF sensors attached to the outside of the transformer tank to accurately locate insulation defects.

Extending service life

Finally, at the end of the transformer's service life, the gathered data from previous PD and other diagnostic measurements can be used for effective fleet management. The information allows asset managers to anticipate continued service behavior under similar operating conditions. As a result of the condition-based data, continued timely maintenance and replacement of components can enable the extended operation of power transformers beyond their design service life.

Ulrike Broniecki studied electrical engineering with a focus on electrical power technology at the TU Berlin. She worked as a research assistant in the high-voltage technology group at the TU Berlin from 2008 to 2014. Her main focus was on acoustic partial discharge detection in power transformers. She has worked at OMICRON since 2014 as an application engineer in the partial discharge diagnostics and monitoring division. Her responsibilities range from technical customer service to the analysis of PD measurement data.

MPD 600

> IEC 60270-compliant partial discharge measurement

> Fiber optic data transmission for safe operation and improved signal-to-noise ratio

> Simultaneous and synchronous multi-channel PD measurement for more complete analysis

> Active noise suppression and gating methods for optimal accuracy despite high interference

> Powerful tools (3PARD and 3FREQ) for separating noise and multiple PD sources

> Recording and playback of measurements for convenient and detailed post-analysis

Hands-on PD training is available from OMICRON Academy, where you can learn how to use the MPD 600 PD measurement and analysis system on a variety of electrical assets.

www.omicronenergy.com/mpd600

OMICRON is an international company serving the electrical power industry with innovative testing and diagnostic solutions. The application of OMICRON products allows users to assess the condition of the primary and secondary equipment on their systems with complete confidence. Services offered in the area of consulting, commissioning, testing, diagnosis and training make the product range complete.

Customers in more than 150 countries rely on the company's ability to supply leading edge technology of excellent quality. Service centers on all continents provide a broad base of knowledge and extraordinary customer support. All of this together with our strong network of sales partners is what has made our company a market leader in the electrical power industry.

© OMICRON 2017