PD by Megger®
Power Diagnostix Systems

PD MEASUREMENTS WITH POWER DIAGNOSTIX'S ICM*system* MAKE REPAIRS PREDICTABLE AND IMPROVE THE SECURITY OF SUPPLY

Manufacturers of distribution transformers and power transformers have been using partial discharge measurement (PD measurement) to analyse the condition of the insulation system for many years now. It is part of routine maintenance testing and a mandatory part of plant acceptance testing. In addition, reinsurance companies include PD measurements as a requirement for proof in their contractual clauses. Since the 1980s, this technology has been continuously developed by the German company Power DiagnostiX from Aachen, which has been part of the Megger Group since 2019.

The internal structure of large distribution transformers and power transformers is complex and almost completely closed to external access. After production, the cores, windings, insulation, and all the other components, such as the on-load tap-changer, are barely accessible for inspection and repair. Any attempt to open and repair a faulty transformer is time-consuming and costly. PD diagnostics are usually used in acceptance tests. However, they are also becoming increasingly important in the systematic and regular maintenance of power transformers, as the nature, risk and location of PD can be determined very precisely.

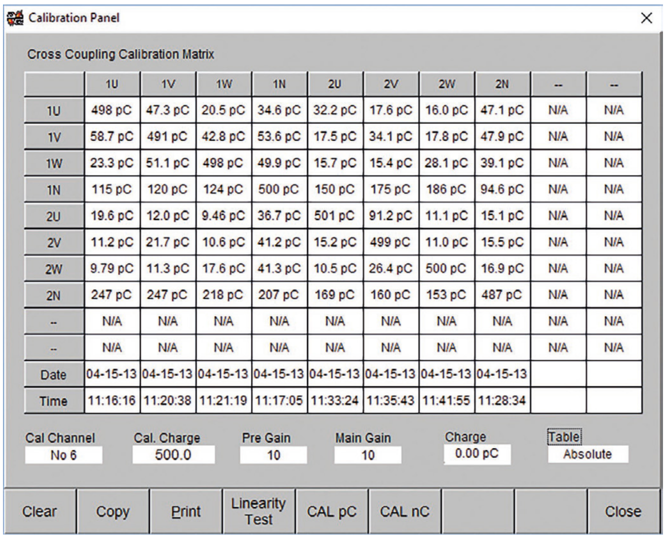
Figure 1: The ICMsystem is a universal locating and analysing device for service and acceptance tests to detect partial discharges on power transformers and on other components of the grid infrastructure.

Analysing dissolved gases during maintenance

Maintenance on the transformer usually begins with a systematic analysis of the insulation oil using a gas chromatograph – dissolved gas analysis (DGA). There is now a wealth of experience in linking the gases dissolved in the transformer oil due to errors such as overheating, paper ageing and arcing with the occurrence of PD activities. This preliminary gas analysis of the insulating oil focuses mainly on hydrocarbons and carbon oxides such as H_2, CH_4, C_2H_2, C_2H_4, C_2H_6, CO and CO_2. It provides important preliminary information about the fundamental existence of PD – and also about the danger posed by PD activity. Nevertheless, up to this point there is hardly any useful information about the actual location of the PD activities inside the transformer. Identifying this requires steps for pre-locating and pin-pointing.

Pre-locating PD activities in the transformer

As part of plant acceptance testing, the existing test taps of the power transformer's high-voltage bushings are used for the PD measurement in order to de-couple the high-frequency partial discharge signals by means of measuring impedances and then transfer them to the measuring system. The principle of impedance conversion developed by Power DiagnostiX, together with an early signal amplification, enables the measurement impedances to be interpreted for a high input impedance of 10 kOhm. Compared to other measuring systems typically designed for 50 ohm of input impedance, this approach is significantly less susceptible to failure, thereby eliminating the need for expensive optical transmission paths for optimisation of susceptibility.



	1U	1V	1W	1N	2U	2V	2W	2N	--	--
1U	498 pC	47.3 pC	20.5 pC	34.6 pC	32.2 pC	17.6 pC	16.0 pC	47.1 pC	N/A	N/A
1V	58.7 pC	491 pC	42.8 pC	53.6 pC	17.5 pC	34.1 pC	17.8 pC	47.9 pC	N/A	N/A
1W	23.3 pC	51.1 pC	498 pC	49.9 pC	15.7 pC	15.4 pC	28.1 pC	39.1 pC	N/A	N/A
1N	115 pC	120 pC	124 pC	500 pC	150 pC	175 pC	186 pC	94.6 pC	N/A	N/A
2U	19.6 pC	12.0 pC	9.46 pC	36.7 pC	501 pC	91.2 pC	11.1 pC	15.1 pC	N/A	N/A
2V	11.2 pC	21.7 pC	10.6 pC	41.2 pC	15.2 pC	499 pC	11.0 pC	15.5 pC	N/A	N/A
2W	9.79 pC	11.3 pC	17.6 pC	41.3 pC	10.5 pC	26.4 pC	500 pC	16.9 pC	N/A	N/A
2N	247 pC	247 pC	218 pC	207 pC	169 pC	160 pC	153 pC	487 pC	N/A	N/A
--	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
--	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Date	04-15-13	04-15-13	04-15-13	04-15-13	04-15-13	04-15-13	04-15-13	04-15-13		
Time	11:16:16	11:20:38	11:21:19	11:17:05	11:33:24	11:35:43	11:41:55	11:28:34		

Figure 2: Cross-coupling matrix during calibration

Each measuring tap on the power transformer is assigned a channel on the measuring device. The ICM*system* offers up to ten measuring channels to enable the primary, secondary and tertiary side and (if present) the star point to be measured simultaneously. Having installed the entire measuring chain, the measuring setup must then be calibrated. For this purpose, an artificial charge pulse with a known charge is fed into PicoCoulomb (PC) for each measured phase and the system is calibrated. During the calibration process, the ICM*system* software automatically generates the cross-coupling matrix (Figure 2), which provides information about the over-coupling of high-frequency signals between the individual measuring points.
Comparing the crosstalk during calibration and the crosstalk of the real partial discharge gives an initial indication of the location of the PD in the transformer.

Pin-pointing the activities in the transformer

Further measures can be taken to locate PD signals precisely. There are several ways to do this:

Variation of the excitation modes

The PD inception voltage and the phase position of internal PD activity depend on the mode of the excitation voltage. Varying this excitation mode provides valuable information about the location of the fault in the transformer. In the three-phase induced voltage test, all three phases of the transformer are supplied with high voltage with a 120-degree phase offset. This offset results in further phase shifts of a multiple of 30 ° between phases. This means that changing the phase position of the phase-resolved PD pattern (PRPD) between single-phase and three-phase induced voltages provides valuable information about the local electrical field of the fault location – and therefore its location in the transformer. If the phase position does not change between single-phase and three-phase measurements, the observed fault is in the phase-earth insulation system, but if the phase position changes, the insulation between two phases is faulty.

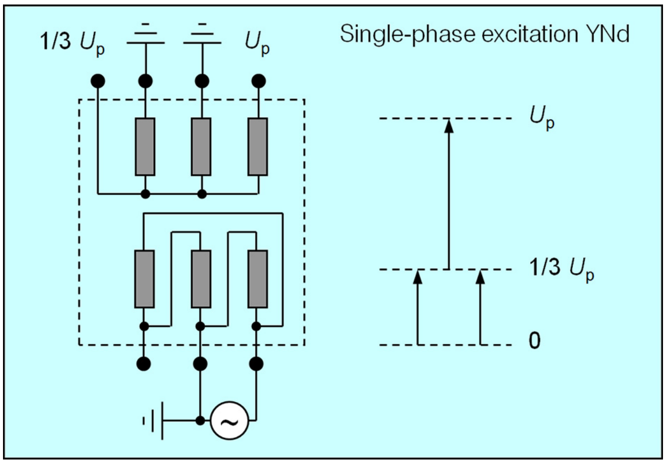


Figure 3: Single-phase excitation on a YNd transformer

Provided that the transformer to be tested permits this operating mode, single-phase excitation with an unearthed star point offers further diagnostic options. Compared to the regular, single-phase induced voltage measurement, the volt-age drop within the excited winding is reduced by 1/3 for excitation with an unearthed star point. Comparing the PD inception voltages between single-phase excitation with an earthed star point and single-phase excitation without an earthed star point therefore provides valuable information about the location of the PD fault within the respective winding.

Advanced locating methods

The analysis methods mentioned so far offer valuable information about the fault location within the transformer without in-depth knowledge of the physical background for the generation of partial discharge. The following advanced analysis methods can also be used to locate the exact fault location down to a few centimetres.

Partial discharge pattern analysis

The appearance of the phase-resolved partial discharge pattern is also determined by the physical properties of the surrounding insulation medium and the position in the insulation medium. There are some typical PD patterns that often occur on power transformers. This means that PD pattern analysis indirectly contributes to the localisation of the PD. For example, separations within paper layers have a very clear PD pattern. This allows the areas in question within the transformer to be narrowed down considerably.

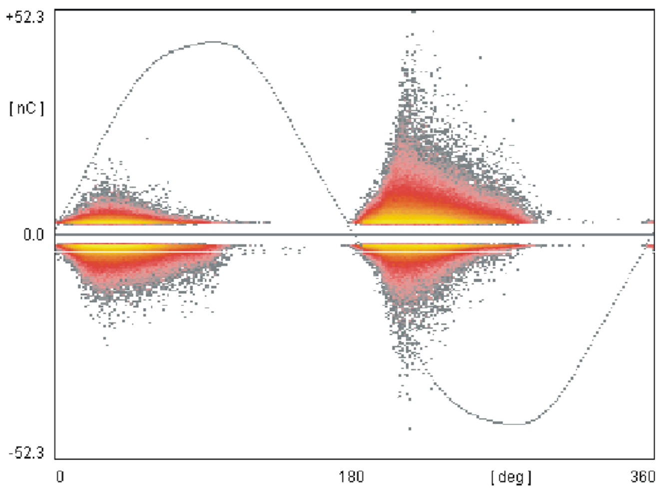


Figure 4: PD pattern of a paper separation

Time domain measurement

Partial discharge signals are high-frequency pulses with rise times in the 1 ns range (under nitrogen), resulting in frequency components up to 400 MHz. However, like all high-voltage equipment, power transformers have been developed to transmit high currents and voltages at frequencies of 50–60 Hz.

On the way through the transformer to be tested, the high-frequency PD signals are inevitably subjected to reflection and oscillation effects caused by impedance changes, attenuation and dispersion effects. Therefore, in addition to the previously mentioned methods, further important information about the location of the PD activity in the transformer can be drawn from comparing emitted and introduced signals using the multi-channel oscilloscope built into the ICM*system*.

Frequency range measurement

A spectrum analyser picks up an analogue input signal and scans the frequency range of the applied input signal in specified steps. The result of this sampling is a frequency spectrum that provides information about the frequency components of the applied signal. The composition of the frequency spectrum of a partial discharge signal allows conclusions to be drawn about the path the signal has travelled.

An example of such a frequency range measurement in the range from 100 kHz to 10 MHz can be seen in Figure 5. This shows, for example, the absence of a high-frequency component. As a result, the signal had to travel a longer distance inside the transformer before it was detected by the sensor on the feed-through tap. A relatively evenly distributed amplitude spectrum indicates a location that is similarly close to the feed-through tap or the measurement point used. In addition, the complex impedance of the feed through itself must also be taken into account. The feed pulse on the same feed through is now compared to the pulse recorded during the

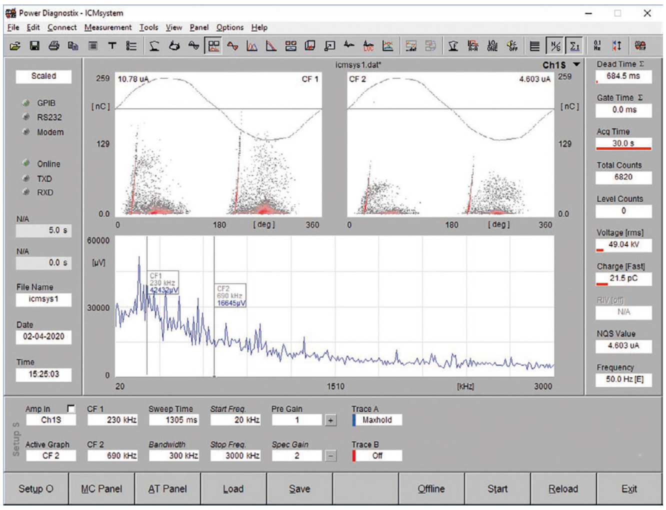


Figure 5: Frequency spectrum during acoustic fault location of PD activities

calibration before the transformer was switched on. The deviation now gives precise information about the location of the PD activity.

Acoustic fault detection of PD activities

PD activities also cause sound waves and therefore an audible emission. Piezoelectric sensors on the transformer tank can measure these signals so that they can be used for pin-pointing. With the internal multi-channel oscilloscope, the ICM*system* can be used for acoustic fault detection by simply changing the pre-amplifiers. No additional expensive measuring devices are required.

Compared with electrical signals, acoustic signals are relatively slow and the speed depends on the material. In oil, an acoustic signal has a propagation speed of approx. 1400 m/s (temperature-dependent), while the propagation speed in steel is above 5000 m/s. By means of several acoustic sensors, it is now possible to narrow down the location of the fault within the transformer to a few centimetres by analysing the differences in the delay of the acoustic signals. The biggest problem with acoustic fault detection is determining the precise time of origin of the partial discharge pulse. To determine this, a large number of sensors are required for purely acoustic locating.

Technical Report
ICM*system*

The ICM*system* offers considerable time and cost benefits to the user

The ICM*system* elegantly bypasses this issue by using the electrically decoupled PD signal. This provides a precise reference point, so that three acoustic sensors are sufficient to determine the point of origin of the sound waves generated by the partial discharge during the measurement and to provide an immediate result. Due to the small number of sensors, the ICM*system* performs acoustic locating in the event of a PD fault relatively quickly and with little effort. This offers the user considerable time and cost advantages.

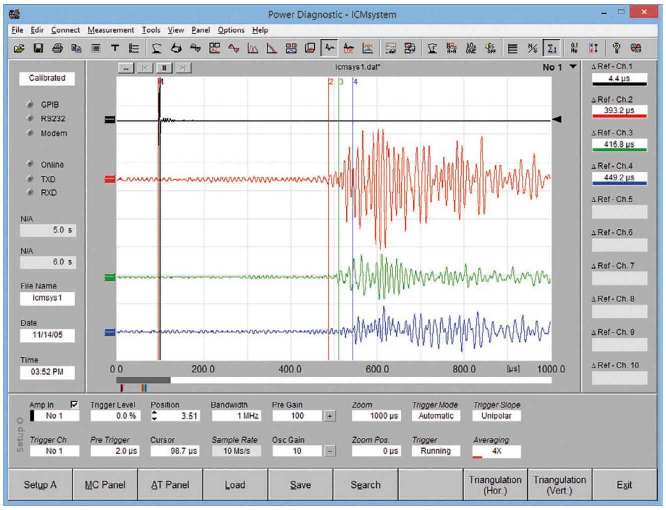


Figure 6: Differences in the delay between the electrical and acoustic signal

PD measurement makes repairs of the transformer predictable

Overall, it can therefore be noted that a vulnerability causing PD within the insulation system of a transformer can be localised with the ICM*system* to a level of precision that allows precise repair of the damaged area.

PD measurements in the field

In principle, most of the techniques described can also be carried out on location in the field. However, the special circumstances of an on-location measurement must be taken into account. While factory acceptance testing is carried out in specially shielded high-voltage laboratories, elevated basic interference levels prevent sensitive measurements in the measuring range below 1 MHz. The optional built-in spectrum analyser therefore not only offers the possibility of examining the frequency spectrum of the measured signal, but also the possibility of performing PD measurements with variable centre frequency within the 9 and 300 kHz bandwidth.

ICM*system* is suitable for both the maintenance and plant acceptance testing of power transformers. Combining traditional methods with modern PD measurement technology offers both manufacturers and also operators of large power transformers, a very accurate option to gain reliable information about the cur-rent state of the power transformer.

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Certified to
ISO 9001, ISO 14001
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