A SENSOR SYSTEM FOR PARTIAL DISCHARGE DETECTION AND LOCALISATION ON DRY TYPE TRANSFORMERS

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ABSTRACT
In this contribution improvements of a partial discharge (PD) detection and localisation technique for dry type transformers are presented, focussed on the usability for measurements under realistic conditions. The described method uses a multi sensor system for a simultaneous electrical decoupling of PD-signals at different points, thus a comparison of the measured signals enables a localisation of the PD-origin with a resolution of one winding package. Investigations on a dry-type transformer model in the laboratory are introduced, leading to a detailed description how PD-sources can be localised.

INTRODUCTION
For the electrical energy distribution up to a voltage level of 36 kV and a power of 24 MVA in spite of liquid immersed paper insulated transformers dry type transformers can be used, which are usually insulated by epoxy resin. The main advantage of this category of transformer concerns the fact that they do not require any environmental precautions and are almost maintenance-free, wherefore they are occasionally assigned instead of paper-oil insulated transformers. However, due to the absence of self healing effects dry type transformers are extremely sensitive to PD-activities, which may cause serious damages often leading to breakdowns or even fire hazards combined with expenditures usually higher than the transformer cost price. The reason for this sensitivity is a chain reaction, which is initiated once partial discharges appear, because they impair the insulation leading to a reduction of the electrical strength and therefore to an increasing PD-activity [1]. In the final state, when the insulation is partially destroyed, turn to turn short circuits can be formed resulting in rising temperatures and ultimately in the worst case to blazes. Nevertheless, an online PD-monitoring has not been realised up to now due to the fact that such a system would top the transformer cost price in the majority of cases and could consequently not operate profitably. Therefore online protection systems have been developed [2 / 3], which are rather inexpensive and warn before fire hazards or expanded shorted turns appear, thus maintenance in time like the replacement of single coils becomes possible and can prevent both costs and serious destruction. However, due to the known partial discharge sensitiveness manufactures have to prove that their dry type transformers do not have any partial discharges with apparent charges above 20 pC after their production, which is presently defined as an uncritical limit according to the standard IEC-60726 [4]. For this purpose usually narrow-band electrical PD-measurements according to IEC-60270 [5] are performed, which do usually not allow an efficient localisation of the PD-origin. Other techniques like acoustic or ultrasonic measurements also fail in this case, because due to the damping characteristics of the solid insulation PD-signals can only be poorly detected by such sensors. Nonetheless, a PD-localisation is strictly required if a measured PD-activity is caused for instance due to design failures, because in this case a precise detection of the PD-origin enables an improvement of the dry type transformer design or respectively of a prototype and in some cases a repair of the failure. Therefore a new method has been developed whose functional principle is shortly explained in the following before measurements on a dry type transformer model in the laboratory are presented and discussed.

FUNCTIONAL DESCRIPTION
The functional principle of the patented method [6] is based on the simultaneous detection of the electromagnetic radiation that is influenced by the PD-signal on a multi sensor system, which is mounted on the surface of the transformer coil in such a way that at each winding package one sensor is placed. As shown in Figure 1 a localisation of the PD-source can be performed by comparing the sensor signals, because the closer a sensor is located to the PD-source the higher is its output signal.

Figure 1: Scheme of the functional principle

Previous investigations have shown that calibration impulses can be localised on-site a transformer, whereby in a shielded environment a sensitivity of 1 pC is attainable if the signals are amplified versus a reference potential [7]. However, up to now this method has not been tested.
on transformers in operation, because it was at first necessary to prove whether the sensors do not influence the electrical field in such a way that they can cause corona or even enforce PD-inception inside the insulation. These investigations can of course not be performed on a transformer in operation, thus it was necessary to carry out adequate experiments on a transformer model in the laboratory which are described in the following.

EXPERIMENTAL INVESTIGATIONS

On a single high voltage coil of a dry type transformer, in whose centre a grounded metallic tube has been positioned in order to simulate the transformer core, 7 sensors have been placed, i.e. one on each winding package. At the upper clamp of the coil high voltage has been applied, whereas at the lower clamp at first a test vessel containing a needle-plane electrode arrangement inside an epoxy resin block, which has been embedded in silicone liquid to avoid surface flashovers, has been connected for the generation of PD-signals. In a second experiment a grounded needle has been used instead of the test vessel for creating PD-pulses, which is depicted in Figure 2.

![Figure 2: Measurement setup](image)

The signals of the sensors have been amplified with a battery powered differential amplifier versus a reference potential, which is grounded via an 1 GΩ resistor. Ground can not be used as reference potential, because in this case the voltage difference between ground and the sensors, which have a floating potential close to the applied high voltage, would destroy the inputs of the amplifier, thus finally the sensors itself are connected to the ground and modify the electrical field surrounding the coil significantly. The amplified signal is transmitted via a fibre optic line and an optic receiver to a multiplexer, whose second input is coupled to a quadripole, which is in series to a capacitor of 6000 pF for a conventional decoupling of the PD-signals. The multiplexer is inside a wide-band PD-instrument using a frequency range between 100 kHz and 250 kHz, which is in accordance to the IEC-60270.

Using this measurement setup the PD-signals at the sensor and at the quadripole can not be determined simultaneously, thus a comparison of the PD-patterns of subsequent measurements has to be performed for localising the PD-source. The major advantage of this method is the reduction of the measurement equipment and consequently of the costs, because a simultaneous recording of 8 channels or even more for larger coils requires special instruments, which are usually quite expensive.

CALIBRATION AND PREPARATION MEASUREMENTS

At first two calibrations have been performed: one for the decoupling via the quadripole and a second one for the sensors. Primarily calibration impulses with an apparent charge of 1 pC have been injected in parallel to the capacitor for adjusting the determination of the PD-signals through the quadripole. Afterwards impulses have been inducted into the lower clamp of the coil, thus sensor 7 could be calibrated, because this sensor is placed directly at the winding package containing this clamp. Assuming that all sensors are uniformly positioned to their according winding sections this calibration is valid for all sensors.

Thereafter the test vessel has been disconnected and high voltage has been applied to the upper clamp in order to prove that the whole setup does not show any PD-activity. From the phase-charge-histogram, as it is displayed in Figure 3, it becomes obvious that during the 60 s of continuous measurement no PD-signals above the background noise could be detected at the quadripole up to a voltage level of about 10 kV, which is equal to the normal operating voltage of this transformer coil.

![Figure 3: PD-detection on setup without test-vessel](image)
test vessel is reproducible for all measurements. Despite this comparability the patterns of the 7 sensors show remarkable dissimilarities concerning the measured apparent charges, which increase from sensor to sensor.

Figure 4: PD-patterns decoupled at different sensors

As mentioned above a maximum charge can be measured at the sensor closest to the PD-origin, that means in this case the PD-origin has to be close to sensor 6 or 7. The measured apparent charges at sensor 7 seem to be a little bit higher, but due to the small deviations it is not possible to judge undoubtful. Furthermore it must be considered, that the calibration was valid only for sensor 7, but can as pointed out also be used for the other sensors if a uniform placement is guaranteed. Usually there are small differences in the thickness of the solid insulation between winding package and sensor due to the production process, thus influencing the damping characteristic of the transmission of a PD-pulse to the sensor. Therefore correction factors should be determined in order to counterbalance these effects [7]. Although these influences are normally rather small it can not be stated unambiguously whether the difference between the charges are caused by different decoupling characteristics, by standard deviations of the apparent charges of subsequent measurements or by the nearness of the sensor to the PD-origin, thus it has been necessary to acquire simultaneously signals from sensor 6 and 7 using a digitiser. The result of this measurement is shown in Figure 5, whereat is has been previously assured that sensors 6 and 7 have an equal transfer characteristic.

Figure 5: PD decoupled simultaneously at sensor 6 and 7

From Figure 5 it becomes evident that a partial discharge generated in the test vessel causes a higher output signal on sensor 7 than on sensor 6, what can be traced back to the fact that the PD-origin is most close to sensor 7.

Beside the possibility of a localisation of the PD-origin this technique offers also a more precise determination of the apparent charge. Regarding Figure 4 a maximum charge of about 13 pC has been measured at sensor 7, whereas with the conventional PD-measurement technique using the quadripole a maximum apparent charge of about 8 pC has been determined, although both systems have been calibrated correctly. The reason therefore is that the PD-signal is subjected to distortion and reflection on its way from the source to the decoupling point, thus the signal is damped leading to a minor detectable charge at the decoupling points far away from the PD-source, which is as mentioned before the basic operating principle of the localisation.

PD-GENERATION USING THE GROUNDED NEEDLE

In the second experiment instead the test vessel a needle, which has been slightly impressed at the fourth winding package, was connected, thus at sensor 4 a maximum signal should be detected. The results of the performed measurements, which are similar to the last preceding ones with the exception that only a high voltage of approximately 2.5 kV has been applied to the upper clamp of the coil, are shown in Figure 6. Again from each subsequent measurement the PD-patterns achieved from the quadripole and from the sensors are displayed similar to Figure 4. The PD-patterns gathered by the
quadrupole are for each measurement session quite equal, thus implicating that the PD-behaviour has been uniformly during the different measurements.

**CONCLUSION**

Dry type transformers are due to the absence of self healing, effects especially sensitive to PD-phenomena, which may lead to serious damages. Therefore PD-measurements are performed with the aim to localise critical points of the solid insulation, thus a repair of the failure or an improvement in the design of the transformer becomes possible. However, state of the art PD-detection techniques do not offer a precise localisation of the PD-origin, wherefore a new method has been investigated.

PD-measurements on a dry type transformer coil in the test bay using the introduced multi sensor system show that winding packages in which PD-signals appear can be determined. Furthermore the method allows a precise determination of the apparent charge, because the PD-signal is decoupled close to the PD-origin, thus damping or distortion as they usually appear during conventional parallel decoupling via a quadrupole can not falsify the evaluation. Further investigation by a dry type transformer manufacturer will show whether additional improvements or adjustments are necessary for increasing the efficiency of the method.

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Figure 6: PD-patterns decoupled at different sensors

The apparent charges determined at the sensors increase noticeable up to sensor 4, whereas between the sensors 4 to 7 only small discrepancies can be observed. This phenomenon can be explained by the fact that the major part of the PD-current flows via the upper coil, the capacitance and the quadrupole to ground and causes therefore an alteration of the potentials at the sensors 4 to 1. Only a minor part of the PD-current closes to ground via the lower part of the coil and stray capacitances, thus at the sensors 4 to 7 more or less the same potential or respectively PD-pattern is measured. Consequently in this case it can be stated that the PD-origin has to be most closely to sensor 4, which is indeed the case.