COMPARISON OF DIFFERENT PARTIAL DISCHARGE MEASUREMENT METHODS ON DRY TYPE TRANSFORMERS IN OPERATION

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ABSTRACT
In this contribution different partial discharge (PD) measurement techniques based on the electrical decoupling of PD signals are demonstrated on dry type transformers in operation. A comparison of these techniques leads to an optimized PD measurement procedure especially concerning the suppression of appearing noises on site and therefore to an increased sensitivity. The discussion of the advantages and disadvantages of the presented PD measurement techniques results in an a prototype of a new PD detection technique which is described finally.

INTRODUCTION
For an efficient power transmission and distribution it is imperative that the used high voltage equipment operate at their maximum load without sustaining any malfunctions. Especially transformers, which are needed at the junctions of energy supply systems, have an exposed importance due to the widespread negative consequences resulting out of a failure. This is beside the fact that they are one of the most expensive components of electric power networks the reason why it is imperative that they work dependable and efficient for decades.

On the distribution level close to the consumer and especially in residential areas dry type transformers have become increasingly popular due to their reduced maintenance expenditures and improved environmental compatibility in comparison to paper-oil insulated transformers. A disadvantage of these also as epoxy resin insulated known transformers is their sensitivity against defects inside the insulation system in which partial discharges (PD) may occur. Opposite to liquid insulations there are no self healing effects in solid insulation materials, thus PD activities may cause serious damages inside the insulation leading to interturn short circuits of single windings. These winding shorts enforce due to the rising temperature along the winding or respectively on the contact resistance the PD occurrence leading to larger short circuits. If this chain reaction is once initiated a breakdown of the whole system sometimes accompanied by fire hazards can not be excluded any more. Therefore a detection of insulation defects in time is essential to improve the operation reliability, thus consequently PD measurements ensure the dependability of a transformer or at least allow statements about the actual condition of the insulation.

However, the PD behavior of solid insulation systems obstructs singular short time PD measurements e. g. during annual maintenance, because the PD activity is not continuous but characterized by interrupt periods [1]. Inside the void, where the partial discharges appear, the gas pressure can increase due to destructed epoxy resin material. According to the law of Paschen the electrical strength is
thereby increased, thus the PD activity is reduced or even can be interrupted. With the slow diffusion of the compressed gas into the solid material the pressure decreases resulting in a renewed PD inception. Therefore singular measurements can only show one sample out of this oscillating PD behavior but are not representative for the whole condition of the insulating system.

Another problem concerning PD measurements on dry type transformers is the fact that PD measurement techniques like ultrasonic measurements are not applicable for dry type transformers due to the high acoustic damping of the solid material. Also chemical analyses like DGA (Dissolved Gas Analysis), as they are frequently used for oil filled transformers, can not be performed for these devices in order to obtain indications for the PD behavior. For these reasons only electrical PD measurements, which can be subdivided in wide- and narrow-band techniques, are applicable for dry type transformers. In contrast to wide-band PD measurements, which are quite large-scaled, narrow-band methods offer the advantage to suppress noises by choosing a convenient center frequency and frequency range. Thus sensitive PD measurements as they are requested in the standard IEC 60726 [2] are possible, although the frequency parameters especially under noisy conditions as they appear during measurements on transformers in operation have already not been sufficiently investigated, even if the standard IEC 60270 [3] defines limitations of the frequency ranges.

Therefore some recommendations for optimizing a PD measurement in an extremely disturbed environment as they result out of our experiences are presented in this contribution, thus offering some guidelines for further evaluations.

**PD MEASUREMENTS ON SITE**

On a three phase 10 kV / 400 V / 400 kVA dry type transformer various electrical PD measurements have been performed using the setup shown in Figure 1. As illustrated a coupling capacitor of 1200 pF has been connected to the upper clamp of the high voltage phase W, thus via a quadrupole the current caused by the PD can be transformed into a voltage signal which is filtered by a band-pass. The band-pass filter itself has been realized using different devices in order to optimize the measurement procedure and the sensitivity. For evaluating the PD signals using $\varphi$-q-n or $\varphi$-q patterns a second capacitor is connected as voltage divider in series to the 1200 pF capacitor for determining the high voltage phase relation, which is analyzed by the PD evaluation unit. Furthermore with an antenna external noise pulses can be suppressed using gating techniques, which interrupt the computation of the $\varphi$-q-n patterns if a noise pulse appears.

At first calibration measurements have been performed using an impulse generator, which has been connected in parallel to the PD detection circuit as depicted in Figure 1. Using a band-pass filter with a lower cut-off frequency of 40 kHz and an upper cut-off frequency of 800 kHz without enabling the gating the $\varphi$-q pattern shown in Figure 2 has been determined during a measurement time of 500 cycles.
It is obvious, that with this configuration a sensitive PD detection according to the IEC 60726 is not possible, because according to this standard all occurring partial discharges with an apparent charge above 20 pC have to be proven, but in this case not even the calibration impulses with a charge of 100 pC could be identified. A repetition of the above depicted measurement using a reduction of the frequency range between 100 kHz and 250 kHz, which is in accordance with the revision of the IEC 60270, allows a significant reduction of the noise signals, thus making the calibration pulses with an apparent charge of 100 pC visible as shown in Figure 3. With an additional masking of the external disturbances with the gating technique using the antenna the sensitivity of the measurement procedure can be increased again, as it is depicted in Figure 4 for a measuring time of 500 cycles. Nevertheless, there are still many noise signals, which are characterized by vertical lines in the shown diagram and can therefore be suspected as influences of thyristor power electronics due to the phase constant appearance of the disturbances. Thus an optimized adjustment of the measurement setup has already not been reached, especially because the minimum detectable apparent charge is still above the required 20 pC.

A further improvement of the noise suppression could be achieved by another reduction of the measurement bandwidth down to 9 kHz with a center frequency of 2.4 MHz which seemed to be the most convenient frequency below 5 MHz, although this center frequency is out of the limits defined in the IEC 60270. As depicted in Figure 5 the vertical lines previously representing disturbances, are suppressed during the measurement time of 500 cycles, while a separation between positive and negative apparent charges is not possible any more, due to the characteristics of the preprocessing system behind used band-pass filter. Due to the reason that also with this setup the

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**Figure 2:** Calibration measurement (apparent charge 100 pC, frequency range 40 kHz – 800 kHz)

**Figure 3:** Calibration measurement (marked apparent charge 100 pC, frequency range 100 kHz to 250 kHz)

**Figure 4:** Calibration measurement equivalent to the measurement shown in Figure 3 but with reduction of external noises by gating

**Figure 5:** Calibration measurement (marked apparent charge 100 pC, bandwidth 9 kHz, center frequency 2.4 MHz, gating enabled)
noise level is still in a range of about 35 pC and therefore above the required 20 pC, a further band-pass filter realized by a spectrum analyzer has been applied. Using the spectrum analyzer at a center frequency of 14.6 MHz calibration impulses with an apparent charge of 20 pC could be detected without doubt, as it is depicted in Figure 6. Also during this measurement, which lasted 500 cycles, a separation between positive and negative calibration impulses was not possible due to the preprocessing properties of the spectrum analyzer.

The performed calibration measurements show, that especially the PD evaluation with the help of the spectrum analyzer at a center frequency of 14.6 MHz is favorable due to its superior noise suppression capability. A major disadvantage of this procedure is beside the fact that the apparent charge of a detected PD can not be assigned correctly due to the decreasing PD spectrum at higher frequencies, that only partial discharges characterized by a wide frequency spectrum are detectable. Therefore additional investigations in the laboratory have been performed in order to prove if partial discharges in epoxy resin have the necessary frequency spectrum. The used measurement setup for these experimental investigations is similar to the setup shown in Figure 1, only the specimen has been changed, i.e. instead of the transformer an epoxy resin block with a needle plane electrode configuration inside has been used, on which high voltage is applied to the needle [4]. The result of the measurement using the setup with the spectrum analyzer is illustrated in Figure 7, where two clusters of occurring partial discharges can be seen. This represents a typical \( \varphi-q \) pattern for PD activities inside voids of solid insulation materials. The performed experiments lead to the conclusion, that partial discharges in the regarded solid insulation material have indeed parts in the high frequency range, thus the described measurement technique using high center frequencies is applicable for offering statements concerning the PD activity on dry type transformers. However, the PD signals are subjected to a distortion during their run from the source through the coil to the decoupling point, thus also the frequency spectrum of the partial discharges is modified. Nevertheless, this is less important for the high frequencies of the spectrum, because these parts were mainly transmitted via the winding capacities, so that the damping of these frequencies is rather small.

Therefore with the described method further measurements during transformer normally operation have been performed, lasting for about 15000 cycles. The recorded data is illustrated in Figure 8, in which the original shape of the applied high voltage is displayed, whereas the preceding diagrams containing the calibration measurements, i.e. excluding Figure 7, show only symbolic sine waves for reference purposes.

As shown in Figure 8 during the PD measurement only signals at the end of the period have been detected, which may represent partial discharges. However, in this case these
signals can be identified as noise pulses due to two different reasons. The first one is the fact, that the PD cluster is twice interrupted, thus being an indication for an active gating and therefore for the occurrence of noise pulses at this time. Furthermore the same PD cluster can be observed during a subsequent calibration measurement similar to the measurement shown in Figure 6, but during the time of peak-load power when the noise level extends, which is depicted in Figure 9. In this diagram the shown reference sine wave is in correlation with the measured high voltage sine shape displayed in Figure 8, thus it becomes obvious that the position of the noticed PD cluster is the same in both measurements and can therefore be indubitable identified as noise pulses.

Summarizing it can be stated from the presented measurements, that the monitored transformer showed no PD activity. However, although this measurement technique can be applied successful in this case it has some disadvantages which are partly mentioned above. A further inconvenience is beside the expendable adjustment of the measuring parameters the inability of a PD source location, which may enable preventive measures like the replacement of single coils. Therefore a prototype of a new PD detection device has been developed, which is briefly described in the following chapter.

**PROTOTYPE OF A NEW PD DETECTION TECHNIQUE**

The main idea of the new PD detection technique is the measurement of the electromagnetic radiation originating from the partial discharges with sensors mounted directly on the surface of the transformer coil [5], which is shown in Figure 10.
CONCLUSION

For power levels up to 24 MVA with a maximum voltage up to 36 kV beside paper-oil insulated transformers so called dry type transformers usually insulated by epoxy resin are used. These transformers are especially sensitive to partial discharges (PD), which are usually accompanied by irreversible degradation and destruction of the insulation that may finally lead to a breakdown of the whole system. In order to prevent such failures it is necessary to monitor the transformers regularly during operation, which can be performed using PD measurement techniques preferable based on the electrical decoupling of the PD signals. Applying this method the selection of a convenient frequency range in which the PD pulses are detectable can optimize the sensitivity of the measurement due to the suppression of noise pulses as they appear on-site. This is demonstrated on a 400 kVA dry type transformer in operation under extremely noisy conditions leading to guidelines and recommendations for an adequate measurement procedure using high frequency ranges above 10 MHz. Furthermore, based on these investigations and experiences a prototype of a new PD detection system is introduced, which can be effortlessly applied and enables beside the determination of the apparent charges a localization of the PD source, thus maintenance procedures can be initiated in time for ensuring a uninterruptible power supply.

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1 Original in German language, title translated

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