Identification of Partial Discharge Defects in Transformer Oil

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Abstract: Partial discharges in (power) transformers are often a predecessor of a serious fault. For this reason partial discharge measurements are an important diagnostic tool to monitor the insulation condition of a transformer. For on-line measurements, a detection method based on the high-frequency (UHF) signals emitted by the discharging source is used and can be detected. Moreover, the UHF technique offers the possibility to locate and identify the PD source.
To investigate the ability to accurately identify and discriminate between different sources, a research with modeled defects has been recently started. Up to now, three different partial discharge sources using three different defect models were tested in transformer oil: HV corona, floating part and surface discharge. Simultaneous measurements on these defects have been performed using 1) an detection circuit based on the IEC 60270 recommendations and 2) wide-band UHF system. With the IEC 60270 based measuring system the PD magnitude and phase resolved PD pattern is acquired. With the UHF system measurements are performed in frequency domain and in time domain. By using the spectrum analyzer as a band pass filter, a phase resolved PD pattern can be obtained as well. The results of the two measurement systems are compared with each other and conclusions are drawn.

Introduction

Partial discharges in (power) transformers are often a predecessor of a serious fault [1]. For this reason partial discharge measurements are an important diagnostic tool to monitor the insulation condition of a transformer. For on-line measurements, a detection method based on the high-frequency (UHF) signals emitted by the discharging source is used and can be detected. Moreover, the UHF technique offers the possibility to locate [2] and identify the PD source.
Partial discharges are detected by means of the electromagnetic waves radiated by the discharge source with a frequency range which can go up to 3 GHz [3]. With the UHF technique sensors are mounted on the transformer tank to measure these waves. Because the transformer tank is made from metal electromagnetic waves can not propagate outside the tank. Therefore openings are created in the tank to measure a PD signal. This is done on the always-present hatch covers. The openings are covered with dielectric windows, Figure 1. The sensors are connected with a coaxial N-type cable to an amplifier. A spectrum analyzer measures the frequency content of the amplified signal, with an fast oscilloscope the signal in time domain is measured. The obtained data can be stored and post-processing of the data is possible to obtain for example a phase-resolved PD pattern.

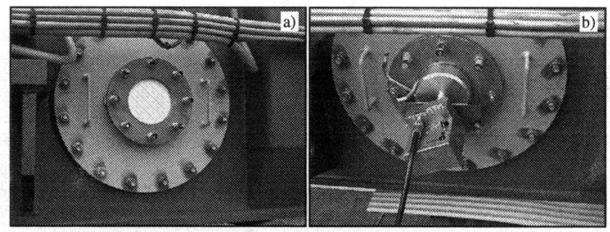


Figure 1. a) Dielectric window on a hatch cover of a transformer, b) A UHF sensor with an amplifier mounted on a dielectric window of the transformer

A great advantage of the UHF technique is the high signal-to-noise ratio. When the signal generated by a PD source is measured with a spectrum analyzer it can be very good distinguished from the noise.

The spectrum analyzer can be used to record the frequency content of the measured signal. The spectrum analyzer sweeps through the frequency spectrum with a certain sweep time. The amplitude of the frequency content is recorded during each sweep. With post-processing the average amplitude, as well as the maximum (max-hold) amplitude of multiple recorded sweeps can be acquired.
The spectrum analyzer can also be used to get a phase-resolved PD pattern [4]. The spectrum analyzer is then used as a tunable narrow band filter, with a bandwidth of 3 MHz. The frequency of the spectrum analyzer is fixed to a certain center frequency. This is done by setting the center frequency to the required measuring frequency. This is the frequency where the highest amplitude of the PD signal is measured, so were a peak in the spectrum plot can be seen.
The measuring span of the spectrum analyzer is set to zero. This can be done by the zero span option of the spectrum analyzer. The sweep time is set to 20 ms, the duration of one period of the 50 Hz sine wave. And the sweep time of the spectrum analyzer is synchronized with the frequency of the applied voltage, by means of a trigger pulse. With this technique a PD pattern related to

the 50 Hz sine wave is obtained, comparable with the PD pattern acquired with the classic IEC 60270 based measurement.

The UHF PD detection technique together with a classical PD measuring system based on IEC 60270 recommendations is used to do measurements on typical PD defects in transformer oil. The results of two measurement systems can be compared with each other.

Typical PD defects

In a laboratory environment a test set-up is made. PD defect models are placed in a glass tank filled with transformer oil. Three different defect types are considered here: High Voltage corona, floating part and surface discharge. The models are shown in see Figure 2.

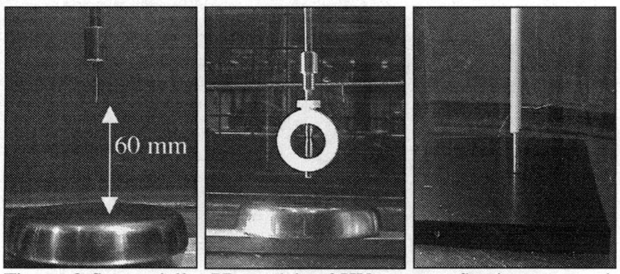


Figure 2 Sequentially: PD models of HV corona-, floating part- and surface discharge

HV corona discharge

Sharp points inside the construction of the transformer, especially on the high voltage side, can produce discharges, which are known as corona. Corona can pollute the oil, which results in small conductive particles. This can cause a decrease in breakdown stress. In transformers the point to plane configuration is often present in the shape of a conducting particle. The particle can be coming from the manufacturing process or can be developed during operation of the transformer, for example due to mechanical distortion. The particle can be stuck at a barrier or freely moving in the bulk oil. To generate streamers and eventually breakdown it is not necessary that the particle is in direct contact with the electrode [5].
To simulate a high voltage corona in oil discharge a point-plane configuration is used as shown in Figure 2. The point diameter is approximately 300 µm and the distance between the point and the ground plane is 60 mm.
The inception voltage of the corona in oil was 40 kV for this configuration. At this voltage only little discharge activity is present. To generate more discharge pulses the applied voltage was raised to 60 kV.
The discharge repetition rate was low. Pulses appeared randomly with different time intervals between the pulses. The PD patterns are recorded with the two measuring techniques and showed in Figure 3.
From the figure it can be seen that the PD patterns show great resemblance with each other. Because the applied voltage is above the inception voltage, PD pulses are present on both the positive and the negative peak of the sine-wave.

In Table 1 the average- and the max-hold frequency plots are shown. This means that with post-processing the average of the frequency content over all the recorded sweeps is calculated, as well the maximum amplitude in the frequency spectrum over all the sweeps. The frequency plots show great difference with each other. This can be explained due the fact that the only few discharge pulses are present. In the average frequency spectrum these pulses hardly influences the average spectrum and the average signal is comparable with the noise signal. When only the maximum amplitude is taken, the pulses are very well visible. The large difference in the frequency plots tells something about the repetition rate of the discharge defect.

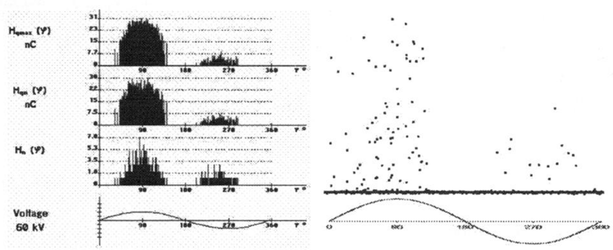


Figure 3 PD pattern of a HV corona discharge acquired with a classic PD detection system and with the UHF technique

Floating part discharge

Badly earthed or floating parts can be present in a transformer. These parts do not have a defined potential and this can result in discharges. These discharges occur in the gap between two conducting parts with a difference in potential as a result of capacitive coupling. In Figure 2 a model is shown to simulate a floating discharge. A piece of metal is on floating potential in the oil. The metal is kept in place with an epoxy ring, so the distance between high voltage and the floating part is constant. In this set-up the distance is 0.5 mm
Also in this case the PD patterns obtained with the two measurement systems show great resemblance, as can be seen in Figure 4.

The average and max-hold frequency spectra of the floating part discharge, shown in Table 1, show great resemblance with each other. Because a lot discharge pulses are present continuously, these pulses have a great contribution in the average amplitude of the frequency spectrum. From this it can be concluded that the discharge defect has an high repetition rate.

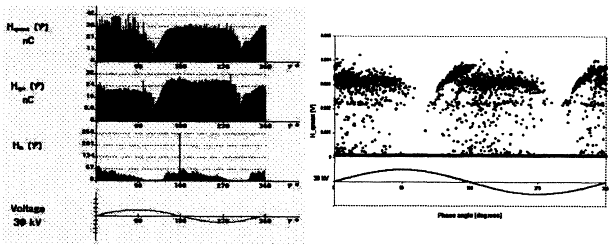


Figure 4 PD pattern of a floating part discharge acquired with a classic PD detection system and with the UHF technique

Surface discharge

On surfaces between different materials discharges can take place. This happens when there is a high field component parallel to the dielectric surface. As a result of these discharges the dielectric material deteriorates and this can lead to erosion of the dielectric surface, which eventually leads to breakdown. In transformers surface discharge can occur due to bubbles on the insulation surface or delaminating of the different layers of the pressboard.

To model a surface discharge, a 20 mm thick piece of pertinax is used as insulation material between the HV supply cable and the ground electrode, see Figure 2. Pertinax is an isolating material made of hard-paper with resin.

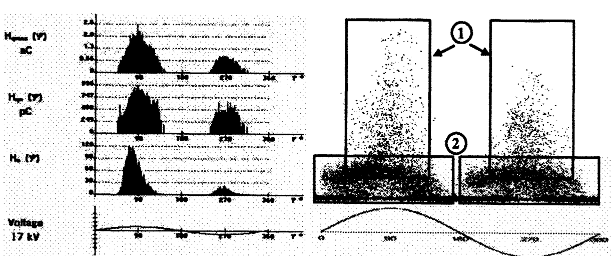


Figure 5 PD pattern of a surface discharge acquired with a classic PD detection system and with the UHF technique

The PD pattern obtained with the UHF technique show the appearance of two different partial discharges. One type shows a PD pattern with discharges mainly present around the voltage peaks, marked as region 1 in Figure 5. This discharge pattern can be subscribed to the surface discharge.

There are also small discharges present which follows the shape of the sine wave. These discharges are marked as region 2 in Figure 5. This pattern is generated due to another PD source. The discharges are probably coming from bubble discharges in the oil, due to little air bubbles. Pattern 2 shows great similarity with the air bubbles in oil discharge pattern in Krivda [6].

The PD pattern of region 1, obtained with the UHF technique, shows a difference in magnitude between the discharges on the positive half cycle and the negative half cycle. However, this difference of the amplitudes of the positive- and negative half cycle are much larger in the PD pattern obtained with the classic measuring system. An explanation for this difference can be found in the different pulse shapes of the PD signals. Very short current pulses are detected as strong PD signals with the UHF technique, but the with the IEC 60270 PD system these pulses are recorded with low values. This is due to the small integrated charge content of the pulses. On the other hand when the duration of the current pulses is longer, the UHF technique records lower values, while the IEC 60270 system detects large PD pulses. This is because of the higher charge content of the longer current pulses. [7].

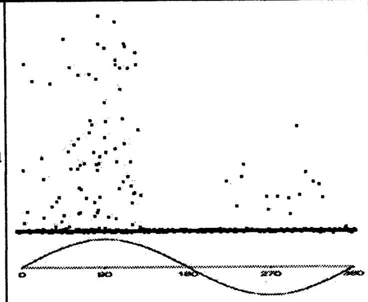
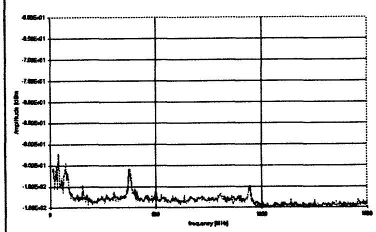
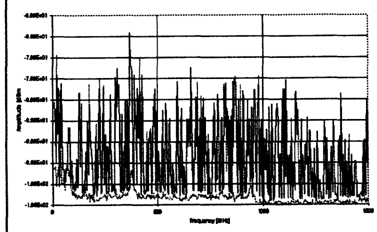
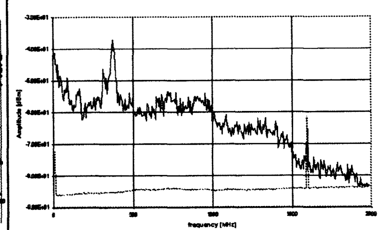
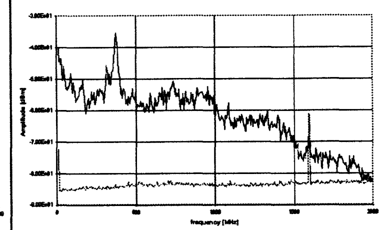
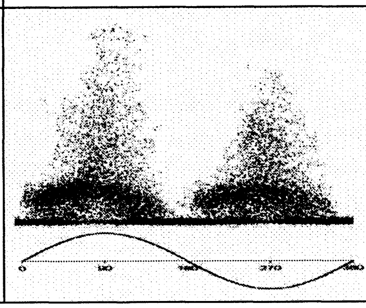
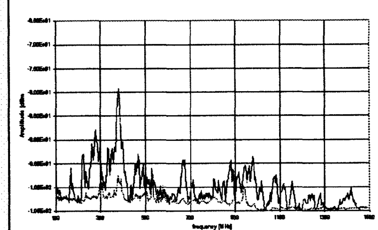
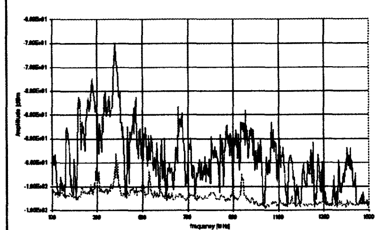
The average- and the max-hold frequency spectra of a surface discharge in Table 1, have a similar shape, but the amplitude is different. This can be explained due the fact that the discharge rate is high, but the discharges are not continuously present.

Conclusions

- The PD patterns acquired with the measurement system based on IEC 60270 recommendations show great resemblance with the phase resolved PD patterns obtained with the UHF technique.
- The PD patterns of the three defects differ from each other, which makes it possible to distinguish the different defects and gives information about the type of defect.
- The frequency spectra of the three defects differ from each other, in particular when the frequency spectra are post-processed using the average frequency spectrum and the max-hold frequency spectrum of the defects. This gives information about the repetition rate of the discharges.

In table 1 the pd pattern and the frequency spectra are presented. Differences between the different defects can be seen.

Table 1 Overview of the PD patterns and average- and max-hold frequency spectrum of the three defects obtained with the UHF technique. In the frequency plots, the grey line represents the noise spectrum and the black line represents the frequency spectrum of the discharge

Defect	PD pattern	S/N average	S/N max-hold
HV corona			
Floating part			
Surface discharge			

References

[1] V. Sokolov, Z. Berler, V. Rashkes, Effective Methods of Assessment of Insulation System Conditions in Power Transformers: a View Based on Practical Experience, Proceedings of the Electrical Insulation Conference and Electrical Manufacturing & Coil Winding Conference, pp. 659-667, 1999

[2] S. Meijer, R.A. Jongen, E. Gulski and J. J. Smit, "Location of Insulation Defects in Power Transformer Based on Energy Attenuation Analysis", Proceedings of the International Symposium on Electrical Insulating Materials, pp., Kitakyushu 2005

[3] M.D. Judd, B.M. Pryor, S.C. Kelly, B.F. Hampton, "Transformer monitoring using the UHF technique", Eleventh International Symposium on High Voltage Engineering, Volume: 5, pp. 362 – 365, august 1999

[4] S. Meijer, Partial Discharge Diagnosis of High-Voltage Gas-Insulated Systems, Optima Grafische Communicatie, 2001, Rotterdam.

[5] G. Berg, L.E. Lundgaard, "Discharges in Combined Transformer Oil/Paper Insulation", Proceedings of the 13th International Conference on Dielectric Liquids, Nara, Japan, pp. 144-147, 1999

[6] A. Krivda, Recognition of Discharges, Discrimination and classification, Delft University Press, 1995, Delft.

[7] M.D. Judd, G.P. Cleary, S. Meijer, "Testing UHF partial discharge detection on a laboratory based power transformer", Thirteenth International Symposium on High Voltage Engineering, pp. 1-4, Delft, 2003