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# Characterization of surface type partial discharges using electrical, acoustic emission and UHF methods

**Abstract**

This paper presents research results related to measurements of partial discharges (PD), which may occur in oil insulation systems of electric power transformers. Three measuring methods were considered: electrical (apparent charge - IEC60270), acoustic emission (AE) and ultra-high frequency (UHF) method. Research works have been proceeded under laboratory condition. PD were generated using special apparatus and spark gap configuration for surface PD modeling. Measurements were performed simultaneously for each of the regarded methods and were repeated for selected supply voltage levels. The electrical and UHF methods measurements were made using MPD measuring system from Omicron. The AE method measurements were made using a piezoelectric transducer, which was installed on the outer transformer tank wall. Comparative analysis of signals gathered during research works was made. Possibilities of application of the three considered PD detection methods for electric power systems with oil insulation were proposed in the paper.

**Keywords**: partial discharges, PD measurements, UHF method, AE method, IEC60270, transformer fault diagnosis.

## 1. Introduction

Providing continuous electrical energy supply is nowadays one of the primary aims for distributors as well as for costumers of electrical energy. Primary equipment's faults (e.g. faults of electric power transformers) may cause that the energy supply system is operating far away from the optimal state, which can lead to serious damages of apparatus or even to catastrophic events such as explosions of power transformers. Therefore technical condition parameters of such devices are permanently monitored. The main task for contemporary power apparatus' monitoring systems is adequately early detection and identification of potential faults. In this paper we consider PD as a common cause of insulation systems failure operation. PD diagnosis is one of the most effective and widespread techniques of insulation fault detection in electrical equipment [2].There exist many different methods of PD detection, identification and localization. The most common used are: electrical method (apparent charge), acoustic emission method and radio frequency method (in UHF band). Each of these methods corresponds to different physical phenomena, which are connected to PD occurrence, i.e. the current pulse is considered by the electrical method, the electromagnetic waves generated in the range from 300 MHz to 3 GHz is measured by the UHF method and the acoustic emission waves, which are in the ultrasonic range (20 kHz – 1.5 MHz) are regarded by the AE method [4]. The electrical method (classical method) is well known and used for many years [5]. The methodology, measurement rules and procedures, are standardized by the norm IEC 60270 [9]. The IEC method is characterized by high sensitivity, what can cause a high sensibility to background noise. Thus on-site diagnosis within this method can be impeded. According to the fact that the electrical method is a direct, which requires to proceed measurements under high voltage supply, it can potentially bring on some hazard and danger to the testing team. Measurement of radio signals in the UHF is another well known method, applied widely for PD diagnosis [7], especially for gas insulated systems (GIS) [10]. Unlike the IEC method, detection of PD events using the UHF is much less prone to external interferences [4]. The UHF method provides also high sensitivity level, gives the ability of PD source's localization [7] and wide analysis capability of PD activity using a phase resolved pattern [5]. The UHF method advantages have made a rise of interest of that method according to attempts of applying it to PD diagnosis of oil insulation systems, e.g. power transformers [1]. One of the main limitations of the UHF method is that the sensor needs to be placed inside the transformerhousing, usually via oil filling valves. The number of valves is usually limited to three [3]. Mostly noninvasive is the acoustic emission method. The measurement procedure allows for placing the sensors on the outer wall of the tested apparatus [6]. AE signals are registered by piezoelectric transducers, which are prone to external (acoustic) interferences: windings and core vibrations and other noise and vibrations propagated by the support structure elements of the device. In the case of industrial applications, there is a need to apply large amount of transducers and often their repositioning, thus the AE method is seldom used for continuous on-line and remote PD activity monitoring. The main fields of AE method application include PD detection and localization of its source, e.g. by using the triangular method. According to the fact that methods described above have their own closely determined advantages, it therefore seems essential to apply them simultaneously, in order to gather a holistic view of the device condition. In this paper authors have focused on comparison of the PD activity based on measurement results achieved using all three methods and have particularly considered a information about PD phenomena delivered by each method.

## 2. Measuring setup description

PD have been generated by surface type electrode configuration immersed in transformer insulation oil. Steel tank has been filled with oil and the electrode has been placed inside. The oil was a brand new mineral oil type Taurus, from Nynas, which is used for research tasks. The voltage applied to the HV electrode has been delivered by the test transformer with the ratio 220/100000. HV level has been adjusted in the range from 18 kV to 30 kV, using the automatic voltage control unit, connected to the primary winding of the test transformer (Fig. 1).

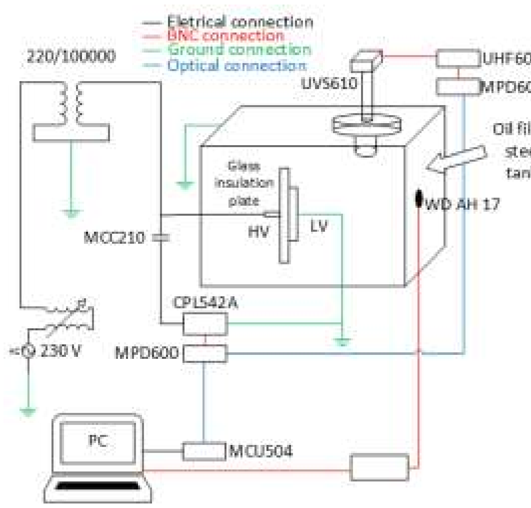


Fig. 1. Layout of the setup used for measurements

The electrical and UHF method measurements have been performed using the MPD600 system from Omicron. The IEC method measuring setup have consisted of coupling capacitor MCC210 with 1 nF of capacity, quadripole CPL542A with 30 µF of capacity (used for measuring impedance also) and MPD600 module (Fig. 2). The highest range of voltage for applied system has amounted 110 kV.

Fig. 2. MPD600 module and CPL542A quadripole

The UHF measurements have been performed with UVS610 sensor, UHF608 converter and another one MPD600 module (Fig. 3). Frequency range for UHF sensor has amounted from 150 to 1000 MHz and for UHF608 converter has amounted from 220 to 850 MHz. UHF sensor has been immersed directly in oil by the LV side via measuring valve. Additional measuring equipment high voltage separation has been provided with fiber optical connections and battery power supply for all MPD system devices. All units have been controlled by the PC via MCU504 module.

AE signals have been captured by the PC equipped with supported measuring interface CH-3160 from Acquitec. The interface has been fed by an amplified signal generated by the wide range piezoelectric transducer WD AH 17 installed on the outer oil tank wall (Fig.4). Frequency range for WD AH17 transducer has amounted from 100 to 1000 kHz (±10 dB), sensitivity has amounted 55 dB ± 1.5 dB. Additional external distortion reduction has been achieved by differential output, applied in AE sensor. In order to amplify an AE signal an model amplifier has been used. The amplifier gain has been adjusted in the range from 0 to 40 dB in 10 dB steps. In order to diminution the analyzed frequency range, just for a band that contains essential information for research, supplementary filtering has been applied: 100 kHz hi-pass and 500 kHz lo-pass.

## 3. Measurements methodology

The starting issue for measurements was to evaluate the applied electrode's ignition and breakdown voltage. Knowing those values has allowed to determinate the voltage levels appropriate for performing further measurements. Electrode ignition and breakdown voltages have been defined experimentally after sequence of 8 measurements and the values of them have amounted 18 and 42 kV, respectively. According to the relevant measurements, voltage levels have been chosen in the range from 18 to 30 kV in 2 kV steps.

AE, UHF and electrical signals have been captured simultaneously for every appointed voltage levels. Every single measurement has lasted 1 minute and has been repeated 10 times for every appointed voltage levels.

Research using the electrical method has been performed according to the IEC60270 standard in the frequency range from 100 to 400 kHz and after 100 pC charge calibration (using CAL542 by Omicron). Supplementary dynamic hi-pass charge filtering has been applied in order to background noise's influence reduction and diminution of measurement data that have not contain any essential information. The filtering has been adjusted simultaneously with voltage level adjustment. The triggering (source clock) for all measurement devices applied in the electrical and UHF methods was given by the MPD600 module.

Fig. 3. UHF PD sensor UVS610, UHF608 converter and MPD600 module

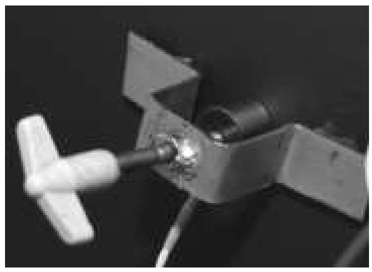

Fig. 4. Piezoelectric AE transducer WD AH17 installed on the tank wall

UHF measurements have been performed for three middle frequencies of the bands: 385, 485 and 570 MHz. Research UHF bands have been chosen experimentally on the basis of survey UHF measurements performed for appointed voltage levels. Survey results have been compared to UHF background level, and the highest UHF activity bands have been chosen. Integration window (for PD in UHF events counting) of MPD software has been set to 1.5 MHz for every selected frequency. As with IEC method, dynamic hi-pass charge filtering, adjusted simultaneously with voltage level adjustment, has been applied for UHF method.

AE signals have been captured in the frequency range from 100 to 500 kHz limited by hi-pass and lo-pass filters respectively. AE measuring path gain has been set to 20 dB and it was constant during all research works. The selected gain level has allowed avoiding overloading of the measuring equipment even for the highest expected AE levels. Sample frequency rate of the Aquitec interface has been set to 1 MHz, window has been set to 20 ms (20480 samples), which is as long as one whole 50 Hz power cycle period. 50 AE signals have been captured for every appointed voltage levels.

## 4. Results

Example result showing phase-resolved PD pattern (PHPD) for 28 kV captured within 1 minute using the electrical method is shown in Fig. 5.

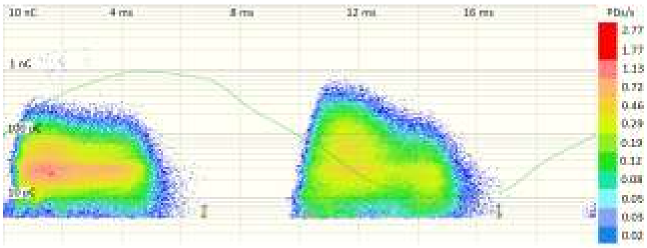


Fig. 5. IEC 60270 PRPD measurement for 28 kV

The captured PD events have been synchronized with power supply voltage. Higher intensity of PD events can be seen in the first, positive half of the power cycle period, but an average PD charge level is much higher in the second, negative half of the power cycle period. Similar situation has been observed for every other appointed voltage level. Statistical analysis of PD events for 28 kV, described as a number of events in a function of charge level is shown in Fig.6.

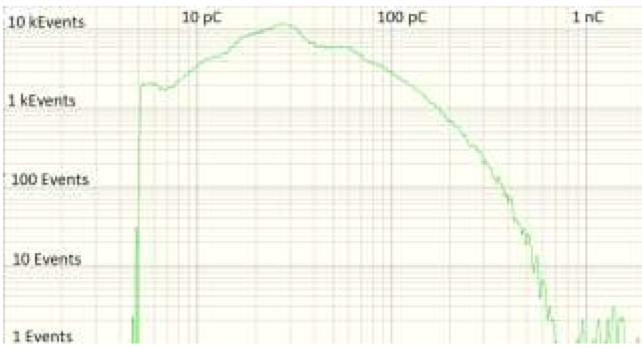


Fig. 6. Number of PD events as a function of charge level for 28 kV

The largest number of PD events can be noticed by the charge level equal to 28 pC. The intensity of the 28 pC PD occurrence equals 10 000 events, registered during 1 minute of measurement. The average charge value during the 28 kV measurements have been equal to 420 pC, the maximum charge level has not exceed 2.5 nC and the average frequency of all PD events appearance during the 1 minute measurement has been equal to about 11 000/s.

UHF analysis has been performed for three middle frequencies in the following frequency bands: 385 MHz, 485 MHz and 570 MHz. Frequency spectra of UHF in the range from 250 to 850 MHz for electrode powered with 28 kV are shown in Fig. 7. Analysis of UHF spectra obviously shows three main bands, where PD activity is the highest. Middle frequencies of those bands have been appointed as the measuring points for the UHF method. The UHF method was used for measuring the phase-resolved PD patterns (PHPD) by 28 kV and for all three appointed frequencies captured within 1 minute, examples of which are shown in Fig. 8.

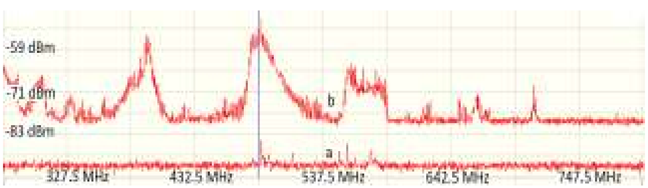


Fig. 7. Spectra of UHF band for 28 kV: (a) background; (b) PD spectra

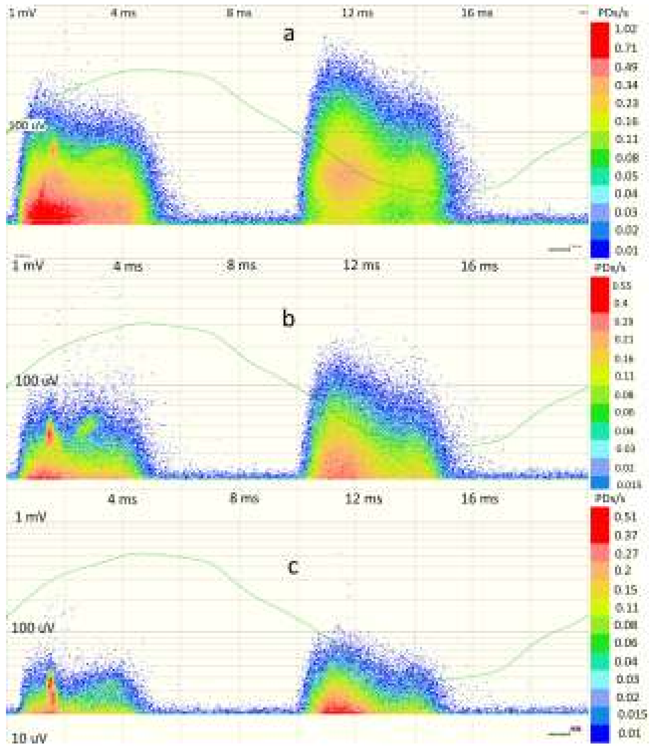


Fig. 8. UHF PRPD measurement for 28 kV for selected frequencies: a) 485 MHz; b) 385 MHz; c) 570 MHz

As with IEC method, the highest number of PD events can be observed in the first, positive half of the power cycle period, but an average PD charge level is much higher in the second, negative half of the power cycle period. This tendency is rather noticeable for frequency 485 MHz and 570 MHz than for 385 MHz. Contrary to the direct electrical method, charge levels are not directly available in the UHF indirect method – information about PD's charge levels are delivered as the UHF voltage level expressed in µV. For the 480 MHz frequency band and by 28 kV, the average PD charge level was measured as UHF emission and has been equal to about 450 µV, and its maximum value has not exceed 800 µV.

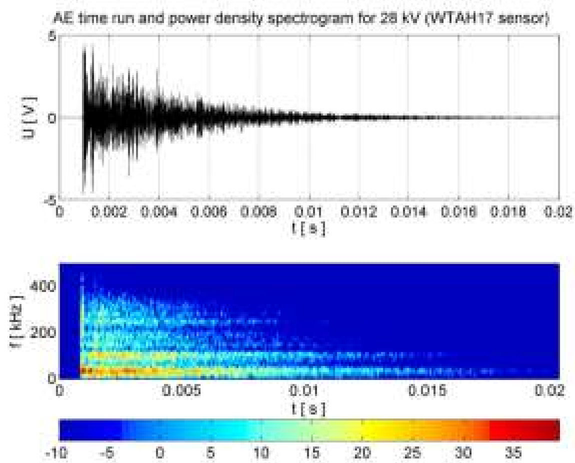


Fig. 9. Time run and two-dimensional power density spectrogram of AE signals generated by PD registered within 20 ms for 28 kV

All captured AE signals have depicted that applied surface type electrode configuration emits acoustic signals only in the first, positive half of the power cycle period. Typical example of a time run and two-dimensional power density spectrogram of AE signals, generated by PD registered within 20 ms (one 50 Hz power cycle period) for 28 kV in the frequency range from 0 to 500 kHz is shown in Fig. 9. Maximum amplitude of AE signals depends on the voltage supply level and rises proportionally with the voltage growth – from about 300 mV for 18 kV to over 4 V for 30 kV. The higher the voltage level, the higher the frequency of AE signal appearance. Harmonic content hardly depends on the voltage supply level and the most dominant are frequencies from the range from 20 to 350 kHz. Low frequency components (up to 100 kHz) show the highest amplitudes as well as the longest time run (up to 18 ms). High frequency component share of analyzed band is very minor and run times of those signals are much shorter, from about 5 ms for lover voltage supply levels and up to 8 ms for the highest voltages.

## 5. Conclusions

PD detection in oil insulation is presently one of the fundamental methods for providing save exploitation of such primary electrical power apparatus as power transformers. Reliable and continuous providing of electrical power supply is a priority for distributors as well as for consumers of energy. Nowadays many PD diagnosis methods are available and most of them might be also applied for on-line purposes. Every method is dedicated for different field of application and requires specific measurement conditions.

The aim of presented research was the comparison of different detection methods of PD occurring in oil insulation, with particular consideration of information about PD phenomena delivered by every method and potential possibility of captured data further analysis for PD source identification. According to the presented results it was shown that the most sensitive and effective method is the electrical, which also delivers the largest amount of information about PD phenomena. One needs to notice that the IEC measurement is a direct method, which requires a direct access to HV. It means that the electrical method might be quite awkward or even impossible for some on-site applications. Other presented methods are indirect methods and might be applied in much wider range of solutions. AE method seems to be a proper tool for survey measurements: on one hand it is quite simple in application but on the other hand it is quite prone for background noise and vibrations. Much less sensitive for external interferences is the UHF measurement, because the background noise elimination is much easier in that frequency range than in case of lower bands. However, the UHF sensor needs to be placed inside of the oil tank for providing an effective UHF measurement. This will not probably be a problem in the future, since some transformer manufactures started with installing UHF sensor valves in new apparatus nowadays.

Presented research works have been performed under laboratory conditions, complying with required standards and measurements methodology. As such, they provide a survey scope. Presented results also give a solid fundamental for further research works connected with correlation method of PD source detection and identification in oil insulation using all methods presented in the paper.

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