Preliminary Partial Discharge Measurements with a Computer Aided Partial Discharge Detection System

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Abstract

Partial discharges (PDs) can be destructive to electrical insulation as they may degrade the material in time. Consequently, studies have been made to develop efficient systems for PD measurements and monitoring. Due to the complexity of PDs as well as factors that can affect PD characteristics, the research on PD measurement is still active. In this study a set off preliminary laboratory measurements of discharges, produced in laboratory environment with various test objects, were performed to evaluate understanding of the theory related to partial discharge and the relationship to early detection of insulation deterioration. Beside these, the common problems with recent computer aided partial discharge detection systems were tried to be identified such as detect level selection, exact PD inception voltage (PDIV) and PD extinction voltage (PDEV).

1. Introduction

Partial discharges (PD) are localized electric discharges that do not bridge the whole distance between electrodes, which can be classified in three different groups because of their different origins: (1) corona discharges, (2) internal discharges and (3) surface discharges [1-5]. There is no doubt that the recognition and evaluation of partial discharges (PD) is of great importance, because PD phenomena are regarded as the indication for ageing phenomena in electrical insulation.

Partial discharge monitoring is an effective on-line predictive maintenance test for high voltage and other electrical distribution equipment [6, 7]. The benefits of on-line testing allow for equipment analysis and diagnostics during normal operation. Corrective actions can be planned and implemented, resulting in reduced unscheduled downtime. An understanding of the relationship to early detection of insulation deterioration is required to properly evaluate the data obtained during such monitoring and testing purposes. This paper will present an implementation and measurement techniques that have evolved in the industry for partial discharge recognition systems via a computer aided partial discharge detection unit. A set of tests were performed at the National Metrology Institute (UME) High Voltage Laboratory as part of TÜBİTAK (Scientific and Technical Research Council of Turkey). During the tests computer aided PD measuring system Lemke Diagnostics GmbH (LDIC) LDS-6, designed for standardized PD measurements according to the international standard IEC Publication 270 [8], was utilized.

Throughout the simulation tests for partial discharges by using basic electrode configurations under high voltages, the apparent charge magnitude and the time of occurrence of each PD event was recorded and stored together with the instantaneous value of the test voltage. In this way, a continuous monitoring and phase resolved analysis of the PD events can be performed without data loss. Due to the computer technique the stored data can be post processed including statistical evaluation. Understanding the basic discharge characteristics such as corona, internal discharge etc. will be useful for the distinguishing the sources of the discharges from obtained data during the online or offline PD measurements.

Apart from the ability of creating discharges and successfully storing and evaluating them, common difficulties with computer aided partial detection system were identified

2. High Voltage Test Set-up and Computer Aided PD Measurement System

The common test set-up used during the tests is given in Fig. 1. The main components are a 400 kV High Voltage Test Transformer, 1 kV to 400 kV ($C_1 = 103.319$ pF, $C_2 = 16.004$ pF) Voltage Divider, Blocking Impedance (400 kV, 50 mH), Coupling Capacitor (1 kV-400 kV), computerized PD monitoring system (LDIC LDS-6) and a test object consisting of basic electrodes producing discharges at some specific voltage level.

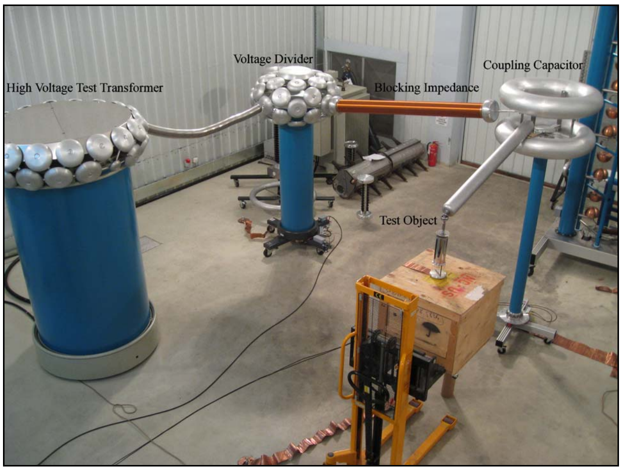

Fig. 1. Test set-up.

Calibration of the channels used for partial discharge detection has a significant effect on measurement results. For the calibration of the PD monitoring system the calibrating pulses were generated by means of a 100 pF capacitor subjected to a voltage step of well known magnitude. Under this condition a voltage step of 10 mV corresponds to an apparent charge of 1 pC. The rise time of the applied voltage step was less than 50 ns, causing a charge injection duration also less than 50 ns. The main characteristics of the monitoring system are given below [9].

- Minimum detectable apparent charge: < 1 pC
- Maximum detectable apparent charge: 100 000 pC
- Upper cut-off frequency of the wide-band preamplifier: 30 MHz
- Selectable input attenuation 0 ... 93 dB, 3-dB-steps
- Frequency range of the PD signal evaluation 100 - 500 kHz
- Bandwidth of the PD-processing unit: 400 kHz
- Resolution of the digital signal acquisition: 12 bit

LDC-5 is a calibration unit used to calibrate the monitoring system. Calibrating charges are 5, 20, 100, 500 pC and error of the rated values is less than 0.5%.

During the tests, in order to investigate different sources of partial discharges in high voltage apparatus, various electrode configurations such as sharp edge-sharp edge, sharp edge-plane, rod-semi-sphere were used including coaxial electrode system with wire electrodes (simulating corona discharges). The above mentioned electrodes and housings are shown in Figure 2 from a to e.

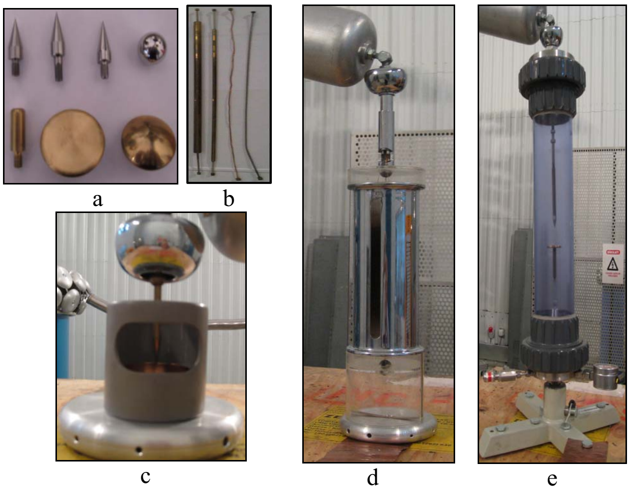

Fig. 2. Different electrode types and housings used during the tests: a) basic electrodes, b) wire electrodes, c) rod-semi-sphere electrode system, d) coaxial arrangement for wire electrodes, e) closed housing for basic electrodes.

Figure 3 below gives the dimensional and material based characteristics of wire electrodes used in coaxial arrangement. In this electrode configuration the wire was energized with high voltage whereas the housing was grounded.

During the measurement in order to get the real applied voltage waveform a PC Oscilloscope which has 200 MHz bandwidth, 200 Ms/s single shot sampling rate, 50 ppm time base accuracy, and ±100 mV to ± 20 V voltage range, was utilized and connected to the high voltage side via a voltage divider with a ratio of 1/ 1111.

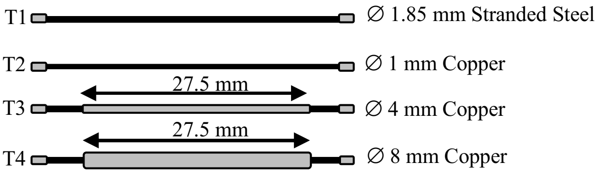

Fig. 3. Stranded steel and copper wires for coaxial electrode arrangement.

At the beginning of the test the room temperature of 22 °C, relative humidity of 32% and 995 mbar pressure had been noted and 22 °C temperature was kept constant throughout the measurements.

3. Measurements and Results

Before beginning the tests partial discharge detection system was calibrated with LDC-5 calibrator for 5 pC charge value. The first electrode arrangement was wire and coaxial cylinder arrangement which represents the corona discharges. For that purpose different wires given in Fig. 2 are used in coaxial electrode system (∅ 100 mm) shown in Fig. 2-d.

After placing the test objects, that is, different electrode arrangements, which produce discharges at a definite AC voltage level, high voltages with increments of approximately 2 kV/s were applied to wire electrodes whereas the coaxial cylinder was grounded and all necessary data for the evaluation were recorded for usually 20 to 30 seconds, meaning about a duration of 1500 periods.

The voltage at which PD first appears is called the PD inception voltage (PDIV). Once this occurs, the voltage must be usually reduced below the PDIV level before the PD activity stops. The voltage level at which PD stops is called PD extinction voltage (PDEV). PDIV is often greater than PDEV due to the following factors: Statistical time lag (availability of an initial electron), Residue voltage, Oxidation (consumption of oxygen). For the stranded wire (T1) the inception voltage level for discharges was 12 kV, on the other hand, extinction voltage level was 8.5 kV, which is quite usual.

The noise created from the detection circuit as well as outer noise sources always affect the measurements results and depending on the Signal to Noise Ratio (SNR) it may results in wrong PD evaluations. For that purpose detect level adjusting the desired minimum detectable PD level was utilized during the measurements. This threshold level is useful for rejection of background noises. The control element contains an input data field together with a level cursor on the bar graph, where the desired value can be selected. As an example, for the tests performed for stranded wire (T1), when the detect level was selected as 33 pC the inception voltage level was 12 kV, whereas for the 4 pC it was 11.9 kV. This example shows the dependency of test results to the selected threshold level. Therefore this dependency makes it necessary to use different evaluation methods to define the exact inception-extinction voltage levels, apparent charges, wave shapes etc. For that purpose recording the raw data with noise and processing it with strong signal processing methods such as use of wavelet transform can be more reliable.

Although the tests were repeated for all wire electrodes explained earlier (Fig. 3), apparent charge vs. applied voltage for the copper ∅ 4 mm wire (T3) electrode in coaxial cylinder arrangement is shown in Fig. 4. The lower part of it shows voltage-time function, which can be displayed after opening the data file for evaluation. It displays the AC test voltage versus the measuring time. In this test, the voltage level was first increased from 0 kV to 23 kV then reduced back to zero level gradually in 30 seconds. In this duration first remarkable discharge value was obtained at 21.5 kV, which is the inception voltage level. When reducing the voltage back to zero level, 21 kV voltage level was recorded as extinction level.

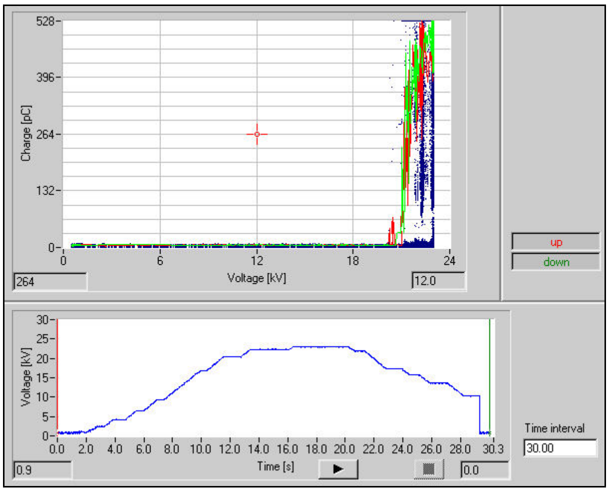

Fig. 3. Apparent charge vs. voltage and voltage vs. time graphs for the ∅ 4 mm copper wire (T3) electrode in coaxial cylinder arrangement.

Fig.4 indicates the charge versus phase angle graph (detect level 9 pC) at 21.5 kV for the energized T3 electrode in coaxial cylinder arrangement when the cylinder outside is grounded. In this figure the horizontal axis is scaled by the phase angle of the power frequency test voltage. The PD magnitude can be displayed versus the measuring time or versus the test voltage, depending of the selected evaluation function. The appearing points indicate PD events versus the phase angle of the AC test voltage. Each recorded point represents the apparent charge magnitude of a single PD pulse. During the tests detect level was adjusted to 19 pC. This element adjusts the desired minimum detectable PD level.

As it can nearly be seen from Fig. 4, during the duration of measurement time whole apparent discharges occur around either 90 degree or 270 degree phase angle. On the other hand, charge distribution over time (7 seconds) and for the same configuration is given in Fig. 5. There is one important thing here to mention is that the apparent discharge values (unit pC) are remarkably higher than usual since they have been created for data collection purpose.

Fig. 6 indicates apparent charge, phase and pulse number plot at 21.5 kV for the ∅ 4 mm copper wire (T3) electrode in coaxial cylinder arrangement (t = 10 s). Discharge pulses are mostly accumulated at around 270 degree phase angle.

As another electrode arrangement, rod-semi sphere electrode arrangement was put under the test (Fig. 1-c). In this configuration the copper rod electrode has a diameter of 6 mm and semi-sphere has a radius of 25 mm, while the distance between the edge of rod and sphere inner surface is again 25 mm (standard rod-semi sphere electrode).

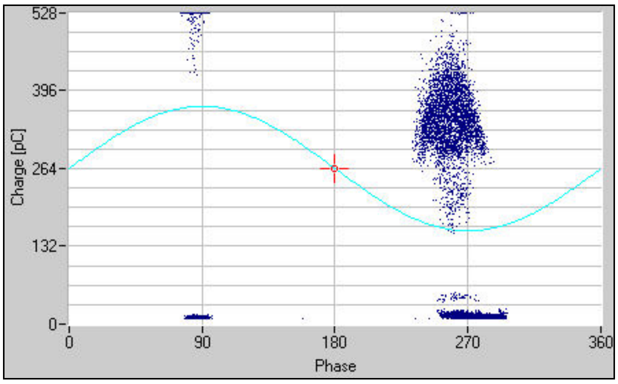

Fig. 4. Charge vs. phase angle graph at 21.5 kV for the ∅ 4 mm copper wire (T3) electrode in coaxial cylinder arrangement.

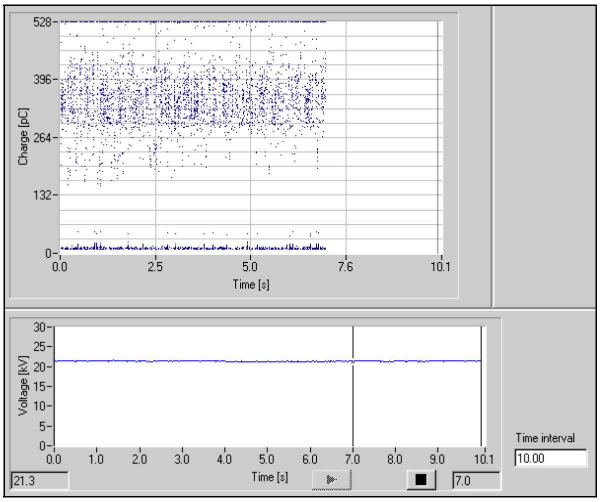

Fig. 5. Time vs. charge and angle time vs. applied voltage graph at 21.5 kV for the duration of 7 seconds (∅ 4 mm copper wire (T3) electrode in coaxial cylinder arrangement).

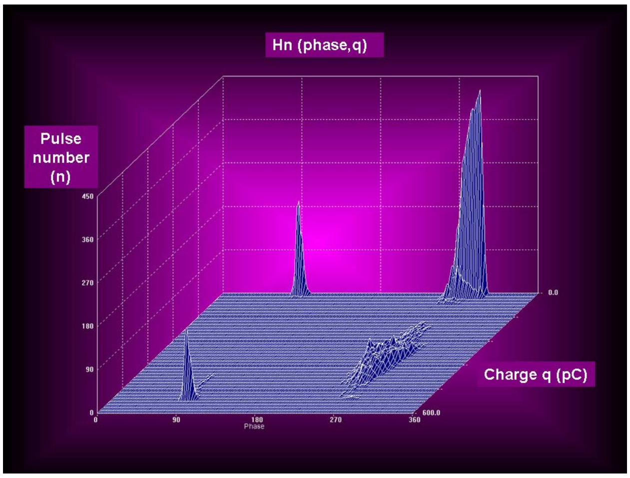

Fig. 6. Apparent charge, phase and pulse number plot at 21.5 kV for the ∅ 4 mm copper wire electrode in coaxial cylinder arrangement (t = 10 s).

As a first step voltage level was increased from 0 kV to 6 kV, and then reduced back gradually in 30 seconds, which revealed 3.4 kV for inception voltage level (Fig. 7).

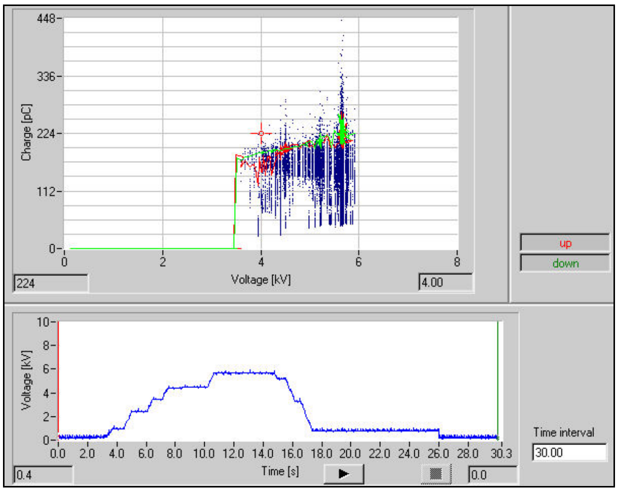

Fig. 7. Apparent charge vs. voltage and applied voltage vs. time graphs for the rod-semi sphere electrode arrangement.

Fig. 8 shows rod-semi sphere electrode arrangement discharge vs. phase angle with occurrence rate (H(n)) and applied voltage vs. time. Discharge pulses are mostly accumulated at around 270 degree phase angle, but it is not seen any apparent charge around 90 degrees, which is a remarkable difference between wire electrode and semi sphere configurations. Figure 9 indicates apparent charge, phase and pulse number plot for rod-semi sphere electrode arrangement (t = 10 s).

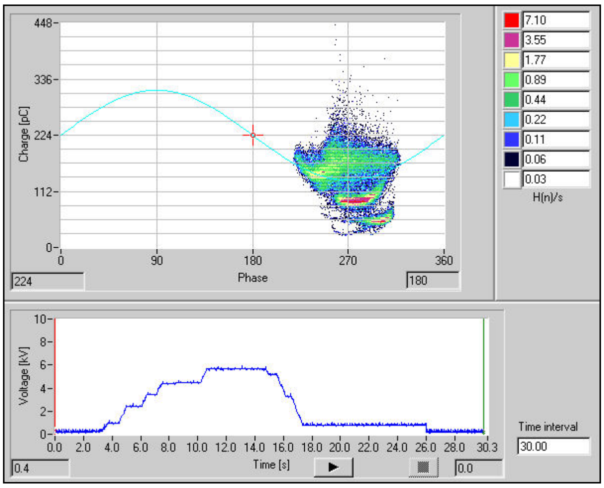

Fig. 8. Rod-semi sphere electrode arrangement apparent charge vs. phase angle with occurrence rate (H(n)) and applied voltage vs. time.

6. Conclusions

In order to evaluate understanding of the theory related to partial discharge and the relationship to early detection of insulation deterioration various preliminary partial discharge measurements have been successfully done in UME High Voltage Laboratory by using a computer aided discharge detection system.

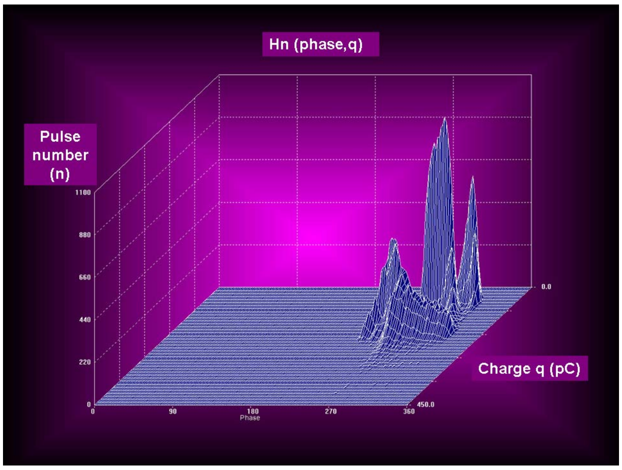

Fig. 9. Charge, phase and pulse number plot for rod-semi sphere electrode arrangement (t = 10 s).

Throughout the simulation tests for partial discharges by using basic electrode configurations under high voltages, the apparent charge magnitude and the time of occurrence of each PD event was recorded and stored together with the instantaneous value of the test voltage. Having different electrode configuration PD inception voltage (PDIV) and PD extinction voltage (PDEV) levels were defined.

It was realized during the tests that apparent charge values as well as discharge waveforms were strongly dependent to the selected threshold level. Therefore this dependency makes it necessary to use different evaluation methods to define the exact inception-extinction voltage levels, apparent charges, wave shapes etc. For that purpose recording the raw data with noise and processing it with strong signal processing methods such as use of wavelet transform manually can be more reliable.

The obtained data in these series of tests will be useful for the classification study of PD sources on offline or online attained PD data.

7. References

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