ONSITE EXPERIENCES WITH MULTI-TERMINAL IEC PD MEASUREMENTS AND UHF PD MEASUREMENTS

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Abstract: The reliability of electrical energy networks depends on the quality and availability of electrical equipment like power transformers. Local failures inside their insulation may lead to catastrophic breakdowns and can cause high outage and penalty costs. To prevent these destroying events power transformers are e.g. tested on partial discharge (PD) activity before commissioning and currently also during service. This paper introduces the multi-terminal electric PD measurement set-up of on-site transformer measurements and shows some visualization with a star diagram. In contrast the UHF-Method with a bandwidth from 300 MHz up to 3 GHz is based on the fact, that PD inside oil filled transformer emit electromagnetic waves measurable with oil valve sensors inside the transformer tank. To compare the two different measurement methods under real conditions on-site measurements on two different power transformers were made. For comparison the results, the UHF and the multi-terminal measurements were made simultaneously.

1. INTRODUCTION

The reliability of electrical energy networks depends on the quality and availability of electrical equipment like power transformers. Defects in transformer insulation cause partial discharges (PD), which can progressively degrade the insulating material and can possibly lead to electrical breakdown. Therefore, early detection of partial discharges is important. PD measurements can also provide information about the ageing condition of transformers and thus enable conclusions about their lifetime.

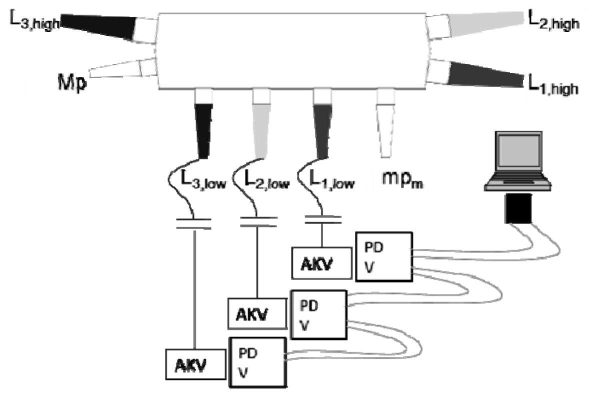

Figure 1: Multi-terminal PD measuring set-up for on-site transformer measurements

The basic PD measurement circuit is in common use in high voltage labs according to IEC 60270 [1] and specific phase-related representations (PRPD pattern) of the electrical measurements can assist to identify the fault type and a more precise localization of the fault. Due to the existing coupling of the three phases inside a transformer, single partial discharge pulses in one certain phase can be measured as voltage signals in all phases. PD cross-talk makes identification difficult. Evaluation of multi-terminal PD measurements, see Figure 1, establishes a straight forward approach to remove external disturbances and, furthermore, to clearly distinguish between multiple PD sources [2]. The PD pattern of a multi-terminal measurement is illustrated in a STAR diagram.

The so called UHF PD measuring method (UHF: Ultra High Frequency) base on the facts that PD under oil are very fast electrical processes and radiate electromagnetic waves with frequencies up to the ultrahigh range (UHF: 300 – 3000 MHz). Due to the moderately attenuated propagation of UHF waves inside the transformer tank [3], the electromagnetic waves are sensitively detectable with UHF probes, e. g. seen in Figure 2. The probes can be inserted into the transformer during full operation using the oil filling valve.

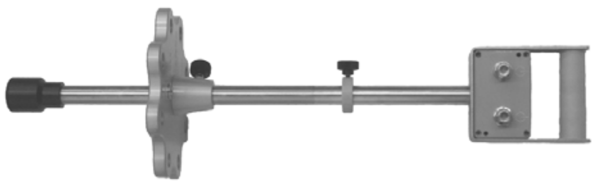

Figure 2: UHF Probe for standard oil filling valve

As a result of shielding characteristics of the transformer tank against external electromagnetic waves, normally a clear decision can be made concerning the PD activity of the test object.

The presented on-site measurements on power transformers were performed off-line [4] and an external PD free generator step-up unit (110 kVA) was used to minimize the influence of the external disturbances. The electrical PD measurement and the UHF method complement one another and both measurement techniques have their advantages. With common use the internal PD activity can be clarified because only internal PD failures cause measurement readings on both systems.

2. MEASUREMENT TECHNIQUES

The UHF and the multi-terminal PD measurement base on different physical principles. The frequency range for electrical PD measurements on transformers is typically below 2 MHz contrary to the UHF method. Therefore, the measurement techniques are unrelated to each other. However, naturally an increased reliability of diagnostic results is given when internal PD can be detected independently with both measurement methods.

2.1. The multi-terminal IEC PD measurement

The multi-terminal PD measurement bases on the standard measurement circuit of the IEC 60270. For PD measurement on power transformers a three phase measuring system is used. Figure 1 describes the set up consisting of three coupling capacitors (1200 pF), three coupling devices and three measurement devices.
The interpretation of PRPD pattern from on-site transformer measurements might be difficult because of external disturbances and cross-talk of the transformer windings. Evaluation of multi-terminal PD measurements establishes a straight forward approach to remove external disturbances and, furthermore, to clearly distinguish between multiple PD and noise sources.

On-site measurements on power transformers showed these phenomena and distorted the PRPD patterns of all three phases. With the help of a STAR diagram one PD source can be selected out of disturbances and the internal PD failures of the other phases. Though every PD source is differentiated from each other and pattern recognition is possible.

The multi-terminal measurement of power transformer is illustrated in a STAR diagram [2]. The STAR diagram is a two-dimensional plot with a 120° phase shift of the three phase axis. Figure 3 (right) shows the impulse signals on all phases. E.g. the PD source is located on phase L_1 and the PD signals of phase L_2 and L_3 occur because of the cross-talk of the windings. An addition of the signal amplitude vectors of a single PD activity (value in pC) of the three phases builds a point in the diagram. In this example the point is close to L_1 and though the PD source is located in phase L_1.

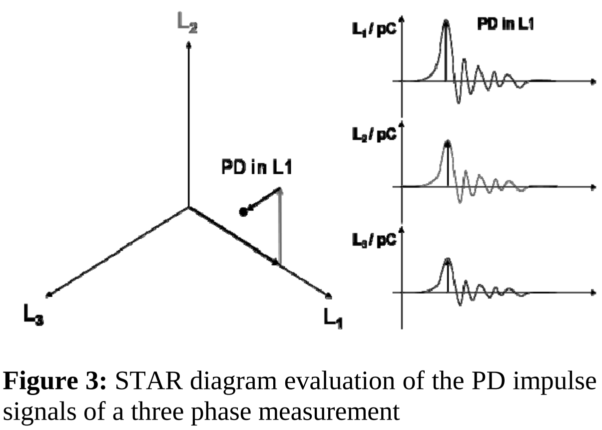

Figure 3: STAR diagram evaluation of the PD impulse signals of a three phase measurement

Assuming that each individual PD fault leads to a unique cluster, each cluster represents one specific fault location within the transformer.

External disturbances, like corona or noise, can be measured with the multi-terminal IEC circuit on all three phases. Measured external impulses often possess similarities of the shape and amplitude. Consequently the vector addition of those impulses leads to clusters located next to the point of origin. Therefore internal PD and external impulse sources can be differentiated from each other.

Retransformations of cluster of the STAR diagram into a PRPD pattern are possible. Therefore, a cluster can be extracted of the STAR diagram and can be illustrated in the well-known PRPD pattern. The selected cluster and the retransformation of a single PD sources enables pattern recognition.

2.2. UHF PD measurement

PD under oil are very fast electrical processes and radiate electromagnetic waves with frequencies up to the ultrahigh range. The electromagnetic waves are detectable in principal as could be seen in Figure 4. The UHF probe can be inserted into the transformer tank during full service because the probe has no galvanic contact to the high voltage circuit.

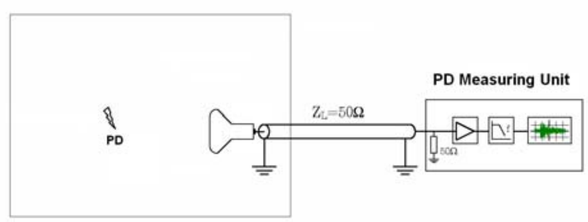

Figure 4: UHF PD Measurement on power transformers

According to recent research results [3, 5] the calibration of UHF measuring method in terms of apparent charge seems to be impossible up to now. Hence the method does not offer any quantity values in pC. But due to the transformer tank, acting as a shielding faraday cage, very sensitive measurement even in noisy surroundings can be performed. By frequency analysis broad banded UHF signals differ from narrow banded disturbances and have their origin normally in internal PD. Additionally PRPD´s of UHF signals result in typical PD pattern. Because of relatively low installation efforts UHF PD measurements can easily support onsite IEC PD measurements or be used to geometrically locate PD.

3. RESULTS OF THE MEASUREMENTS

On-site measurements on two different power transformers were made to compare the UHF method with the multi-terminal IEC measurement under real conditions. For comparison the results, the UHF and the multi-terminal measurements were made simultaneously. The UHF measurements were performed with the UHF-PD probe from LDIC [6] and the multi-terminal measurements with PD Smart from LDIC [6] and mpd540 from Omicron [7].

3.1. 210 MVA Grid-Coupling Transformer

The first measurements were carried out on a 110/220 kV, 210 MVA grid-coupling transformer, see Figure 5. The presented on-site measurements were performed off-line and an external PD free generator step-up unit (110 kVA) was used to excite the transformer over the tertiary side to the operating voltage.

Figure 5: 210 MVA Grid-Coupling Transformer

The advantages of on-site off-line measurements are less noises because of the disconnection of the electric network. This explicitly helps the electrical PD testing. The testing voltage can be varied to determine e.g. the PD inception voltage. The separate excitation on the tertiary side is also advantageous for more tests and experiments.

3.1.1 Multi-terminal PD measurement

Prior to the electrical measurement a calibration is required [1]. Therefore, a calibrator with a defined impulse charge is applied separately to all three measurement devices and therefore the level of the PD impulse is defined.

The results of the onsite measurements showed PD activity at operating voltage in the transformer. The measurements were done on the 110 kV and the 220 kV side. Exemplarily the results of the 110 kV side are shown.

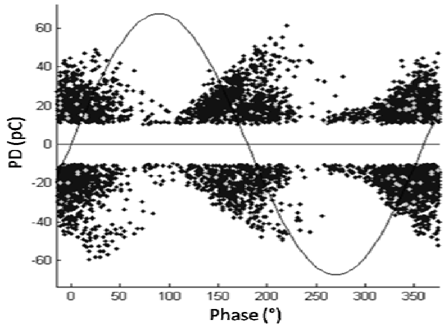

Figure 6: PD activity of the 210 MVA grid-coupling transformer on phase $L_{2,110}$

Figure 6 shows an internal PD on phase $L_{2,110}$ of the transformer. For phase $L_{3,110}$ and $L_{1,110}$ PD sources could not be detected and no cross-coupling from the active phase $L_{2,110}$ was visible in the PRPD pattern.

For demonstrating purpose a copper wire was fastened to the conductor of the bushing on phase $L_{3,110}$, see Figure 7, simulating an external disturbance source to show differences between the UHF and the electric IEC measurement method.

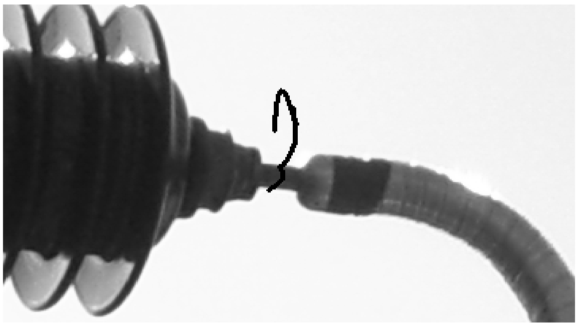

Figure 7: Copper wire on phase $L_{3,110}$ with bushing and connector between conductor and coupling capacitor

While the corona discharge of the attached wire is not measurable with the UHF method, see Figure 11 and Figure 12, the IEC method showed a typical PRPD corona pattern which corrupts the measurement. The STAR diagram in Figure 8 confirms the results of the two PD sources. One cluster is close to phase $L_{2,110}$ (rectangle) which is the internal measured PD and the corona discharge on $L_{3,110}$ (ellipse).

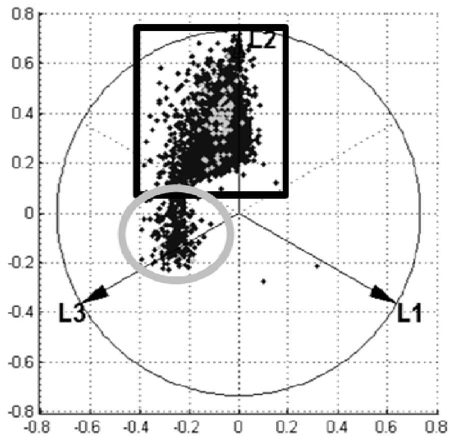

Figure 8: STAR diagram of the PD activity of the 210 MVA grid-coupling transformer (rectangle showing internal PD and ellipse showing corona discharge at attached wire)

The pattern of $L_{2,110}$ after the retransformation do not differ from the pattern of Figure 6 because the PD level of the coupling from phase $L_{3,110}$ to $L_{2,110}$ and vice versa is equal or smaller than the noise level and not visible in the recorded PD pattern.

In Figure 9 the PRPD pattern of the corona discharge after the retransformation is shown.

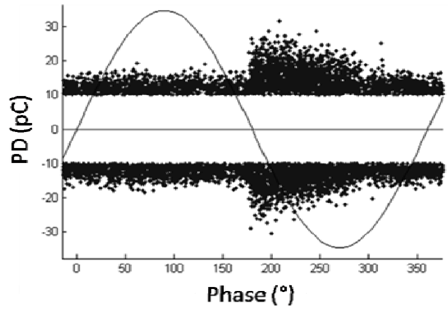

Figure 9: Corona discharge on phase $L_{3,\ 110}$ after retransformation

3.1.2. UHF PD Measurement

Because of missing a calibration procedure in terms of apparent charge for UHF measurements, the so called Performance Check [5] was. Artificial UHF impulses proofed that the UHF PD measuring set-up is measuring sensitively.

At nominal voltage inside the transformer some PD defects occur and UHF signals were recorded. Figure 10 shows an exemplary time signal and the calculated frequency spectrum. The signal, with a signal to noise ratio of 5:1, was recorded without amplification with an oscilloscope with an analogue bandwidth of 3 GHz.

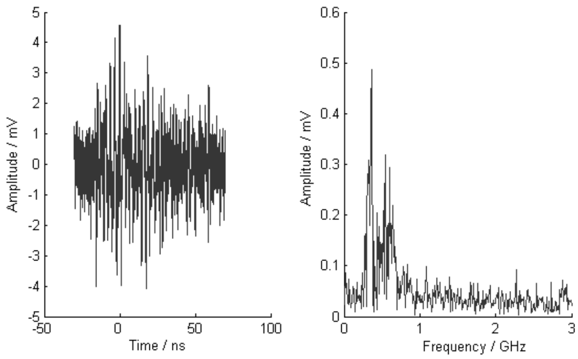

Figure 10: UHF signal at nominal voltage

This signal features frequency portions up to 1 GHz which is normally emitted by a broad band emitter of UHF waves like an internal PD in oil. External noise would have been narrow banded, e.g. at around 500 MHz for digital video broadcasting or around 900 MHz for global communication systems. For further proof that the signals correlate to a PD, PRPD´s of the signals were recorded. Similar to the IEC PD measurements typical pattern according to theory for internal PD are visible, see Figure 11.

Figure 11 shows a PRPD pattern of UHF signals, amplified narrow banded with 30 dB. The PD events are phase stable and the measurement were synchronised at the generator step-up unit with phase $L_{2,110}$. All measurable UHF signals were recorded for a time period of three minutes.

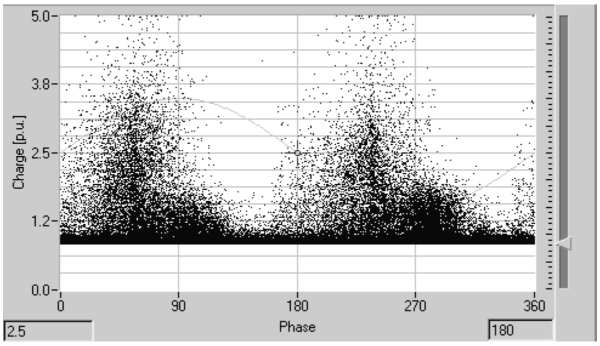

Figure 11: PRPD UHF – synchronised to L_2 – 3 min

In order to demonstrate the insensitivity of the measuring method against external disturbances, a copper wire was attached to the conductor of the bushing of the phase $L_{3,110}$. This wire represents a source of outside PD (corona), see Figure 7.

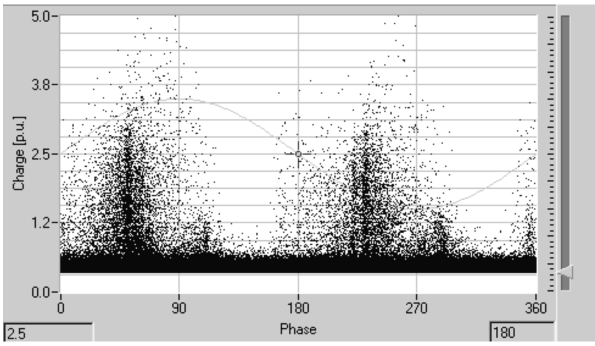

Figure 12: PRPD UHF – corona at L3 – 3 min

At the same voltage level little changes occur in Figure 12. Hence the tank wall and bushing shield the UHF sensor very well in relation to the corona.

3.2. 120 MVA Generator Step-up Transformer

The second onsite measurement were made on a generator step-up transformer 110/10 kV, 120 MVA, see Figure 13. Again the onsite measurements were performed offline and an external PD free generator unit (110 kVA) were used to minimize the influence of the external disturbances. The 10 kV windings were used for the excitation of the transformer.

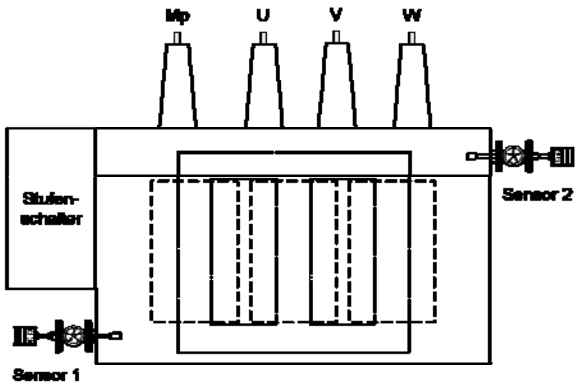

Figure 13: 120 MVA Generator Step-up Transformer

3.2.1 Multi-terminal PD measurement

The measurement set-up calibration in terms of apparent charge was also done separately for all three measurement devices with a defined calibrator impulse.

Results of the measurements at the 110 kV side are shown in Figure 14.

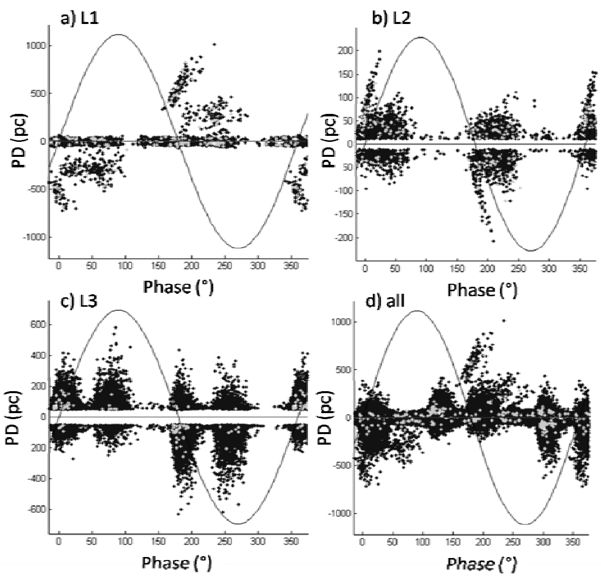

Figure 14: PRPD pattern of the generator step-up transformer on phase L_1, L_2, L_3 and the STAR point

On the upper left diagram the PRPD pattern of phase L_1 (a) and among L_3 (c) is shown, on the right side L_2 (b) and among the PRPD pattern from the STAR point (d). The measurement on the STAR point is a good method for comparing the UHF PRPD pattern with the multi-terminal PD pattern because all internal PD are shown in one diagram.

The STAR-diagram in Figure 15 shows four different PD sources, one in phase L_2, one in phase L_3 and two in phase L_1.

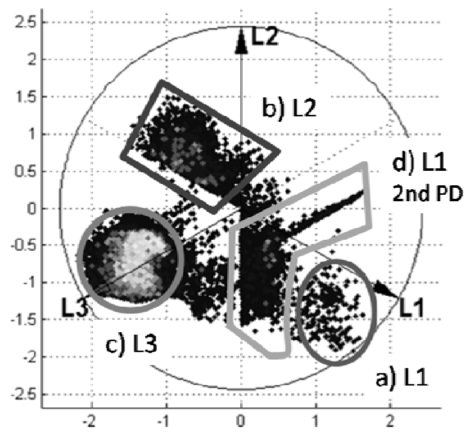

Figure 15 STAR-diagram of the generator step-up transformer on phase L_1, L_2 and L_3 with four clusters

The retransformations of each cluster confirm the four PD sources. The pictures in Figure 16 are the PD sources in L_1 (a, d), L_2 (b) and L_3 (c). The pattern of phase L_2 could be a void in oil. The PD source of L_1 with the maximum of 1000 pC was the highest detectable value and occurred after some minutes during the measurement. The PD source in L_3 was the first occurring signal at 40 kV. The level of the PD increased with higher voltage.

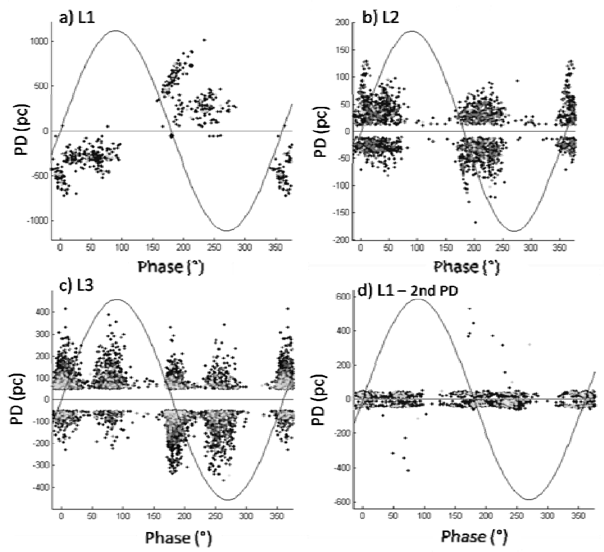

Figure 16: PRPD pattern of the unit generator transformer after retransformation of the cluster L_1, L_2, L_3 and L_1-PD2 in the STAR-diagram.

3.2.2 UHF PD measurement

The transformer possesses two oil filling valves, see Figure 13 and Figure 17. The first valve is underneath the step changer housing on height of the lower core. The second valve is on the opposite side underneath the oil expansion tank in the cover of the transformer.

Figure 17: UHF probes installed at a 120 MVA transformer

The first measurement, a so-called dual port Performance Check [5], demonstrates the sensitivity of the measuring system. Wide-band signals of a signal generator are fed over the first UHF sensor into the transformer housing and measured with the second UHF sensor. Figure 18 represents the received time signal and its FFT. This measurement took place without high voltage.

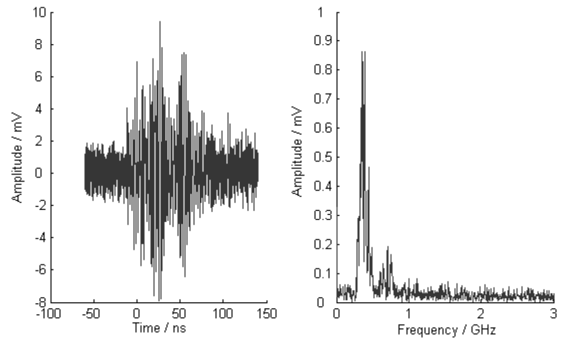

Figure 18: Dual port Performance Check

From the illustration it is evident that a wide-band signal (right, frequency portions up to 1 GHz) was travelling through the transformer and its active part. Likewise the signal-to-noise ratio is sufficient in the time signal (left). Therefore the sensors are correctly installed and attached to the measuring instruments. A sensitive UHF measurement is possible.

During the measurements UHF signals were measured with both probes. Run time differences might allow a localisation of the PD source with additional analysis [8].

The measurable UHF PD events were synchronised to the phase L_3 of the AC test voltage and stored for a period of three minutes, see Figure 19.

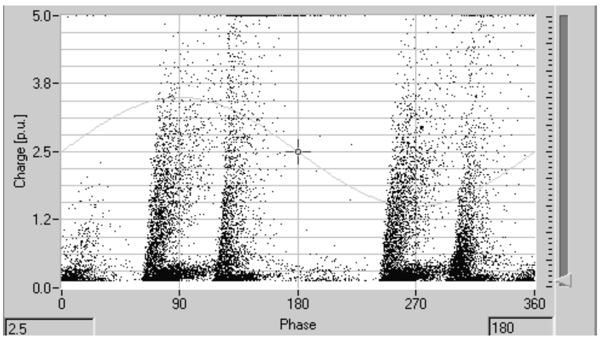

Figure 19: PRPD UHF 120 MVA Generator Step-up Transformer – 3 min

The resulting pattern shows a typical example, which refer to internal PD. A comparison of UHF PD data to the measuring data of the conventional measuring method showed comparable pattern, see Figure 14 d).

4. CONCLUSION

Both measurement techniques have their advantages and disadvantages. The conventional method enables the calibration of the PD measurement in terms of apparent charge and in contrast UHF pattern show only the internal PD activity of a transformer unaffected by external disturbances. The electrical PD-measurement on transformers might show certain disadvantages for on-site measurements for increased noise levels during on-line testing and the UHF misses the possibility for a calibration. Simultaneous use of the two measurement methods compensates the disadvantages. The results of these on-site measurements and the analysis of the results confirmed the good cooperation between the two approaches. Above this, the UHF signals can be used for geometric PD location, additionally with the help of acoustic sensors [9].

Both measurement methods showed PD inside the transformers and the UHF results bear resemblance to the IEC patterns.

The multi-terminal PD measurement is illustrated within STAR diagrams for clear discrimination between external noise clusters and internal PD sources. Different PD sources at different phases were found and the UHF method confirmed the results of multiple PD sources inside the transformer.

The UHF PD measuring method was proofed to be not affected by external corona discharge and is thus a powerful help for conventional PD measurements.

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