Detection of Partial Discharges in Power Transformers using UHF PD Measurements and Acoustic Measurements

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Abstract: For examination and diagnostics of the insulation quality of high voltage devices the measurement of partial discharge (PD) is accomplished. The conventional PD measurement according to IEC60270 is in some situations not sensitive enough because of the high interference level in field. The development of an unconventional measuring method using electromagnetic probes is presented. These probes are inserted in the transformer tank during full operation via an oil valve normally used for oil filling. Due to the shielding characteristics of the transformer tank external electromagnetic disturbances are minimized and enable measurements with high signal-to-noise ratio. New experiences made in measurements in laboratory and in field lead to modified UHF PD probes. The newly developed probes have to be tested on their mechanical and electrical properties. For the functional test of UHF probes the Performance Check is presented. Taking a further step from the Performance Check to a Sensitivity Check - which may in future allow an approximation of the PD quantity comparable to the apparent charge - is discussed. Experiences with the UHF PD Measurement in the field are presented. Furthermore the method of PD localisation by combining UHF measurements with acoustic measurements are shown.

1 INTRODUCTION

Examining the existing insulation quality of oil/paper-isolated transformers during full operation or at least in field gets more and more important because of the increasing number of transformers reaching their technical life expectancy. Important judging parameters are given with the measurement of PD. PD under oil are very fast electrical processes and radiate electromagnetic waves with frequencies up to the ultrahigh range (UHF: 300 – 3000 MHz). The electromagnetic waves are detectable with UHF probes, for example as in Fig. 1.

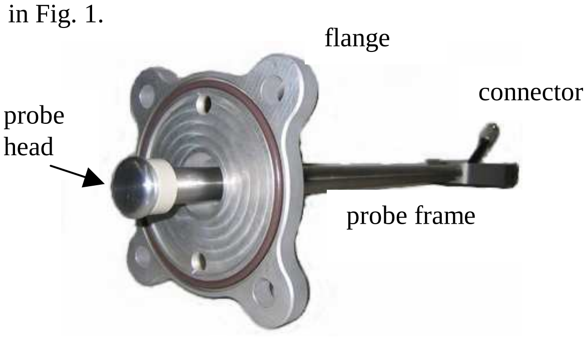

Fig. 1: UHF PD probe for standard oil valve

The probes can be inserted into the transformer during full operation using the oil filling valve. As a result of the 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. Precondition is the moderately attenuated propagation of UHF waves inside the transformer tank of the insulation materials and structures [1] commonly used in transformers. Because of a missing calibration possibility of the UHF measuring method it is necessary to examine the installed probes for its function with a Performance Check. Two general methods are conceivable and are a part of this work. Furthermore an investigation focussing on the sensitivity verification of the UHF measuring method is presented. Experiences with UHF measurements in field lead to identification of narrowband disturbances. For a full risk analyse the determination of the localisation of PD is discussed.

2 UHF PD PROBE DESIGN

An essential component for the detection of PD originated electromagnetic waves travelling through transformer tanks are the decoupling devices called UHF probes. New experiences made permanently during measurements in field and in laboratory lead to newly developed probes. Focus of investigation is to improve the measuring performance as well as the mechanical properties. Therefore standardised tests have to be performed. In the following the mechanical properties of the UHF PD Probe regarding the possible temperature and the pressure ranges of the surrounding transformer oil are shown. Furthermore the electrical properties are examined to determine the transmission ratio of the UHF probe.

2.1 Mechanical Development

Oil flanges of power transformers may be located at the top of the transformer tank. According to the IEC60354 “Loading Guide” [2], the maximum oil temperature at the top of the transformer tank may reach 115 °C regarding local hotspots with a temperature of maximum 160 °C. In addition to the resulting thermal stress the inserted UHF probe has to withstand mechanical stresses caused by the oil pressure. Most transformers do not get above the height of about 10 m (or the conservator respectively), consequently the oil pressure occurring in power transformers will be below 1 bar (also due to the fact that the density of insulation oil is lower than that of water). For a leakage test a safety factor of 5 might be sufficient. Summarizing these kinds of mechanical stresses, a type test for the UHF probe is performed with a pressure of 5 bar at a temperature of 120° C. The UHF probe developed at the Institute of Power Transmission and High Voltage Technology (IEH) is intended for the installation at oil valves with a normalized flange, as mentioned above. For the examination of the oil tightness a test vessel was designed that corresponds to a standard oil valve flange. The probe mounted at the appropriate flange side of the test vessel can be seen in Fig. 2 on the left side.

Fig. 2: Picture of leakage test; left) UHF PD probe attached to a test vessel, right) Measured temperature and pressure

The bleeder screws existing at the probe are used for the subsequent oil filling. At room ambient temperature oil is pumped into the test vessel with an appropriate oil pump. Existing air in the vessel is released over the second bleeder screw. Finally, the oil filled test vessel with the attached UHF probe is brought into a furnace.

With the help of the attached pump a pressure of 5 bar is generated and held. The following heating lead to an expansion of the oil and the pressure equalization is reached manually with an expansion container. The furnace reached after short time the necessary temperature of 120 °C and heated up the test container with the oil inside. With closed valves the heating caused a constantly increasing pressure. With manual opening of the valve to the expansion container, the pressure can be kept constant at approximately 5 bar. The necessary monitoring of the pressure allows a check of the completely heated oil volume with a constant pressure and the detection for an arising leakage by a sudden decrease of pressure. After heating the oil volume the pressure remained apparently constant during the tests. The optical control of the whole UHF probe during the pressure and heat tests resulted in no evidence of a leakage.

The developed UHF PD probe might be installed at every located oil valve and will withstand every occurring thermal and pressure caused stresses.

2.2 Electrical Improvements

Using a UHF probe with solely receiver capability is a limitation of its possible functionality considering a performance verification of the mounted UHF probe. Therefore the new design of the UHF probe includes an insulated monopole (Fig. 3).

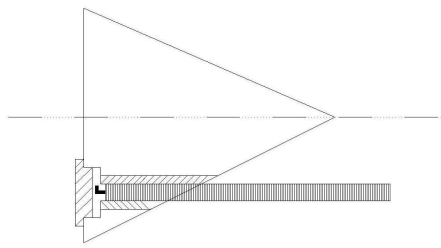

Fig. 3: Schematic of the conical probe head with integrated insulated monopole

That additional monopole offers the possibility to inject an artificial UHF impulse insulated from the receiving path. The capacitive coupling to the receiving path extends the functionality to the so-called Performance Check, described in chapter 3.

Using a network analyser the electrical properties of the whole UHF probe, especially of the integrated monopole, are investigated. For high frequency signals every change of the wave impedance through the travelling path causes reflections and decreases the performance of signal transmission. Fig. 4 shows a moderate attenuation of 15 dB in average for the transmission of signals from the integrated monopole to the receiving path of the probe.

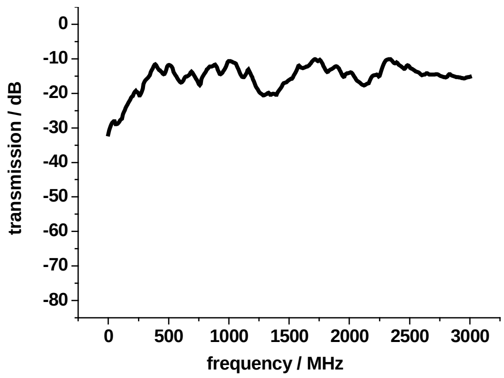

Fig. 4: Transmission from monopole to conical probe head

That measurement refers only to the conducted high frequency signals within the measuring lines. The propagation path of the signals include the connectors to the measuring lines and the lines themselves. It includes the capacitive coupling between the monopole and the probe head and proofs the successful transformation of the wave impedance of the probe head, by the conical shape, to the 50 Ohm impedance of the measuring line.

Further investigations will focus on the gain of the probe head as measure for the transformation of the electromagnetic waves (far field conditions assumed) inside the oil filled transformer tank to the conducted UHF signals. Therefore a set up using a giga hertz transverse electromagnetic (GTEM) cell might be necessary offering defined electromagnetic waves and standardised analyses for high frequency antennas.

3 PERFORMANCE CHECK

For detection of PD in power transformers UHF probes as in Fig. 1 can be installed during operation which measure UHF signals from inside the transformer tank. Using this so-called UHF method a calibration comparable to the measurement according to the IEC60270 standard is not possible yet. Up to now it is impossible to check the functionality of the mounted and inserted UHF probes. Therefore two different ways of a so-called Performance Check were investigated. During the Performance Check the verification of the whole signal path including the UHF probe, the measuring lines and the PD acquisition unit is essential.

In a single port Performance Check artificial UHF impulses are injected insulated from the receiving path while the injected impulses are detected with the receiving path of one and the same probe. A dual port Performance Check uses a second UHF probe to inject the artificial UHF impulses to demonstrate the functionality of the first UHF probe. Therefore a second port, e.g. a second oil valve is needed. The main difference between both ways is the fact that in case of the dual port Performance Check electromagnetic waves have to be transmitted through the transformer tank. It is sufficient for the single port Performance Check to use a capacitive coupling of high frequency signals, realized by the UHF PD probe mentioned in chapter 2. For the same signal to noise ratio, the dual port Performance Check needs a signal generator with higher output power because of the necessary wave emission but may be expanded to a Sensitivity Check as will be discussed in chapter 4.

For the following investigation of the Performance Check the artificial UHF impulse is injected with an UHF signal generator, see Fig. 5.

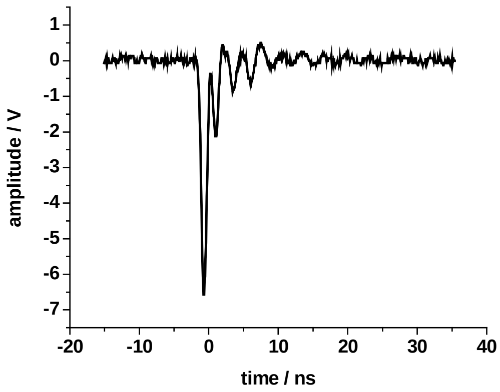

Fig. 5: Time signal of a UHF signal generator

The related frequency spectrum is comparable to an original PD source. The signal generator features signal rise times shorter than 300 ps with a pulse bandwidth of less than 450 ps at a 50 Ohm impedance. The corresponding frequency spectrum includes components up to 1.25 GHz.

3.1 Single Port Performance Check

Inside the UHF-probe an insulated monopole was integrated, as described in chapter 2.2. The injection of the presented UHF-impulse caused a coupling of the UHF signal to the probe head and allowed the following Performance Check. Therefore two parallel lines inside the probe frame for transmitting and receiving are necessary. Precondition of a correct Performance Check is the prevention of direct cross-coupling of signals from the transmitting to the receiving line. The line lengths are used for an approximation of the signal propagation time of 6 ns in case of solely coupling from the integrated monopole to the probe head. The theoretically estimated propagation time was proofed in a separate laboratory test, e.g. there is no direct cross-coupling of signals.

Another precondition for a successful Performance Check is the recognition of an inaccurate probe application. One fault might be the galvanic contact of the probe head within the transformer tank due to incorrect mounting and the resulting grounding. In that case, no high frequency signals may be detectable. During a reference measurement the completely installed UHF probe with integrated monopole laying on a wooden table is punctually grounded. The detectable signal has a frequency spectrum without significant high frequency fractions. (see Fig. 6, grounded probe).

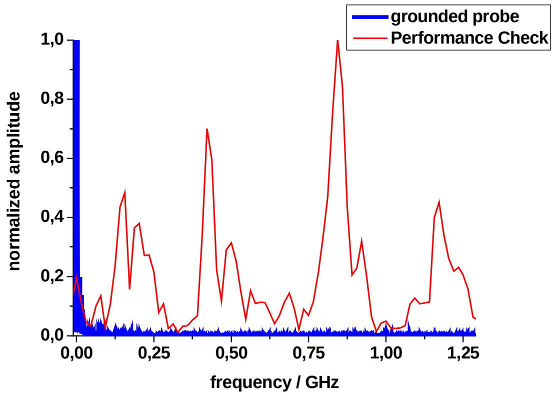

Fig. 6: Spectrum of the grounded probe (thick blue line) in the comparison to the error free probe in the transformer tank (thin red line) using same injected signal

The method of the Performance Check is investigated finally on a test transformer tank inside the laboratory. The described signal generator is used and a transient recorder with the analogue bandwidth of 2 GHz. After injecting the artificial UHF-impulse the signal with the corresponding frequency spectrum (see Fig. 6, thin red line) was detectable. High frequency components up to 1.25 GHz are clearly recognizable. Hence it could be obviously measured that the complete receiving path from the UHF probe to the PD acquisition unit is correctly installed, e. g. that the Performance Check fulfils its task.

3.1 Dual Port Performance Check

With an existing second oil valve a dual port Performance Check is feasible. In an exemplary laboratory test a monopole oil valve probe was installed into a second oil valve of the test tank. The UHF signal from the described UHF signal generator could be received with the presented UHF probe. The corresponding spectrum can be seen in Fig. 7.

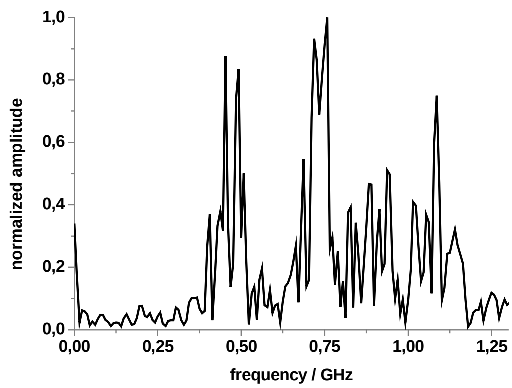

Fig. 7: Spectrum of the dual port Performance Check

The coupling of electromagnetic signals via electromagnetic wave transmitting through the transformer seems to work as well like the capacitive coupling inside the UHF PD Probe.

The dual port Performance Check fulfils the same task as the single port solution but may be not applicable in case of no present second oil valve.

4 SENSITIVITY VERIFICATION

A so-called Sensitivity Check for the UHF measuring method on power transformers might be comparable to the procedure suggested for the UHF measuring method at gas isolated switchgear (GIS) [3]. An approximation of the measured PD quantity comparable to the quantity of the apparent charge in pico Coulomb (pC) which is determined with the measurement according to IEC60270 should be achieved. Due to the fact that PD emit electromagnetic waves inside the transformer tank, the dual port Performance Check emitting electromagnetic waves in the transformer will be expanded to a Sensitivity Check. Therefore a well known real PD has to be placed into a transformer tank in a laboratory. The same probe reading from the measured real PD will be simulated in a second step with an UHF signal generator with variable output. This will lead to a ratio, for example 5 mV probe reading quantity relates to a 100 pC PD, measured with the method according to IEC60270. This will be simulated with a second transmitting probe at a second oil valve with a excitation voltage of for example 40 V. Installing the whole measuring system at a transformer with two oil filling valves may then allow a sensitivity verification for 100 pC with the excitation voltage of 40 V in identical transformers (assuming a linear relation between the used mV and pC quantities). The UHF probe may have a quantity reading of e.g. 2.5 mV, which will be the calibration for 100 pC. In case of an internal PD inside this calibrated transformer a quantity reading of for example 5 mV will lead to an approximation of the apparent charge of 200 pC.

A newly developed UHF signal generator offers the possibility to eject a voltage step with variable amplitude between 0 V and 60 V. Its signal rise time is shorter than 100 ps which results in a corresponding frequency spectrum up to 2.5 GHz. The optional synchronisation to the applied voltage via a photodiode can be seen in the phase resolved Partial Discharge pattern (PRPD), see Fig. 8.

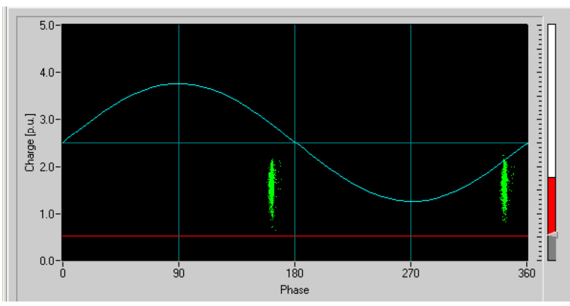

Fig. 8: Phase Resolved Partial Discharge pattern (PRPD) of the new UHF signal generator

For signal propagation times of UHF PD signals in the range of nanoseconds compared to the cycle duration of 20 miliseconds, e.g. for 50 Hz, the measurement of Phase Resolved Partial Discharge

(PRPD) patterns is useful since UHF PD patterns will remain essentially unchanged to electrically recorded PD patterns.

4.1 Measurements in laboratory

A completely closed test tank is filled with oil. Two oil valves are installed approximately two meters away from each other, see Fig. 9

Fig. 9: Test tank with two oil valves and two flange mounted UHF probes

An electromagnetic coupling between the two probes has to be a wave based coupling because of wavelengths smaller than 0.75 m for frequencies higher than 300 MHz. For the investigation of the sensitivity verification the new UHF signal generator feds one probe with variable output voltage. The quantitative Fast Fourier Analyses (FFT) of the measured signals from the receiving probe are shown in Fig. 10.

The results show a nearly linear ratio between the magnitude of the excitation signal and the frequency components of the received signal. The linear relation seems to be valid over the whole frequency range up to 2 GHz. E.g. the frequency fraction around 1.75 GHz rises from 0.7 mVs up to 1.4 mVs if the feeding signal rises from 30 V to 60 V. Existing UHF PD acquisition units offer the possibility to measure signals within a small bandwidth (narrow-band equipment). Further investigations may show if the reading quantity of mV in a defined frequency range is useful for a sensitivity verification or check as mentioned above. Other reading quantities or post processed quantities as e.g. the signal power or energy may also be useful and should be focused in future.

For a proper sensitivity check relating to apparent charge measurements a real PD must be active in a transformer tank. With parallel measurements of the apparent charge in accordance with IEC60270 and the mentioned reading quantities for the UHF signals a relation of the electromagnetic effect of the real PD and the stimulated artificial impulses can be found. In general the sensitivity verification of the UHF measuring method on power transformers seems possible.

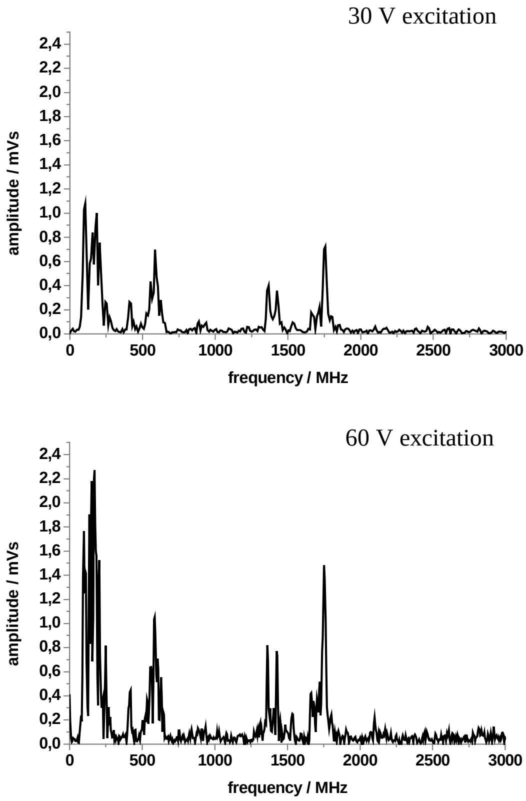

Fig. 10: Sensitivity verification with variable output voltage: Linear ratio between voltage of excitation signal and frequency components

5 UHF-MEASURING EXPERIENCE

An on-site test of the UHF measuring method was performed on a three phase 40 MVA transformer.

There were no indications for internal PD so the whole measuring equipment was tested regarding its performance online. An old disc shape probe and a prototype of the newly developed UHF PD probe were tested with and without amplification of 20 dB and with an high pass of 300 MHz respectively. The Performance Check with the new UHF PD Probe was carried out.

5.1 Probe application

The older disc shaped probe and the new UHF PD probe were installed several times during full operation of the transformer without any problems. First the blind flange at the oil valve has to be removed and the probe has to be mounted at the flange. During opening of the oil valve, the enclosed air can be vented through the bleeding screw. After complete opening of the oil filling valve the probe can be inserted through the oil valve up to a position maximum aligned with the tank wall. With the new developed UHF PD probe the Performance Check was performed. The frequency spectrum of the

Performance Check is shown in Fig. 11 using a high pass of 300 MHz.

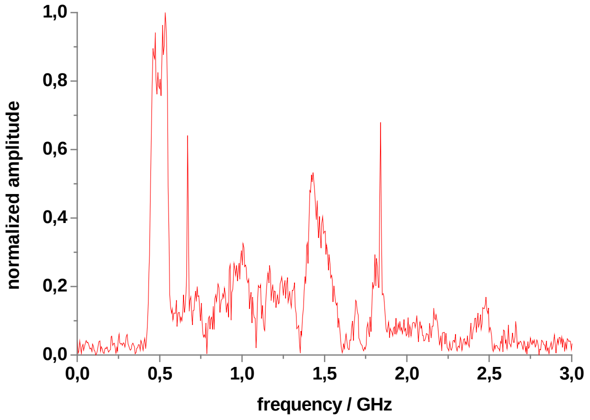

Fig. 11: Spectrum of online Performance Check at 40 MVA transformer using a 300 MHz high pass

The whole set up of the system takes less than 5 minutes.

5.2 Identification of on-site disturbances

With a transient recorder with an analogue bandwidth of 3 GHz and with an external amplification of 20 dB, UHF signals were detectable. With removing the measuring line from the probe, the coupling could be originated at the probe itself. A post processing of the measured signal shows known narrowband disturbances. Disturbances around 0.5 GHz are caused by the digital video broadcasting service, at nearly 0.9 as well as 1.8 GHz are the mobile phone disturbances and at about 2.1 GHz UMTS signals are detectable (Fig. 12).

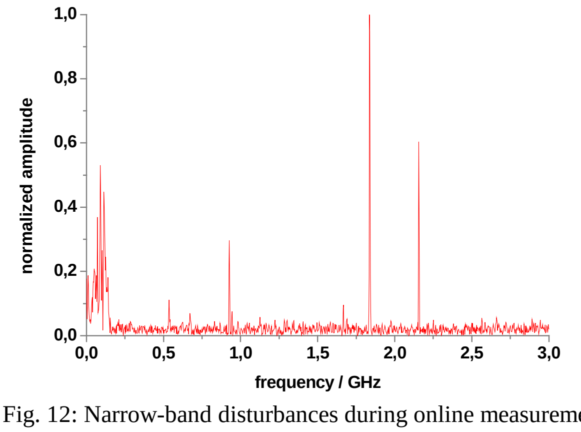

Fig. 12: Narrow-band disturbances during online measurement with 20 dB amplification

In fact, in vicinity of the transformer was a tower as a mobile phone station. This tower with installed communication systems might have been the origin of most of the narrow-band disturbances.

The shown identification has to be done after measuring and an online decision whether it is a disturbance or may be an internal PD source is only possible after the test when using a broad-band system. Therefore a PD acquisition unit that offers more measuring possibilities than a transient recorder is useful. Advantageous are narrow-band measurement systems allowing the same identification based on the frequency as well as the frequency sweep function, which is comparable to a FFT for repetitive signals. With narrow-band systems disturbances can be suppressed in the sense of simply measuring “next to them” in an unaffected frequency range. Another powerful tool in field are phase resolved UHF measurements as shown in Fig. 8. Internal PD have to produce phase stable UHF signals and with the PRPD patterns the disturbances were identified in field because of their non phase stable occurrence.

Fig. 12 in comparison to Fig. 11 shows a significant different spectrum which means that also in case of external disturbances the Performance Check allows a significant statement about the correctness of the probe installation and the proper performance of the whole measuring equipment.

Due to the missing second oil valve at the transformer no investigations referring a dual port Performance Check or a sensitivity verification were feasible.

6 LOCALISATION OF PD

Concerning PD measurements two main tasks are encountered. First is to provide evidence of PD (detection) as sensitive as possible in terms of a decision “PD-yes/no”. Second is the, in many respects important, determination of the PD location (localisation). The on-site resulting detection sensitivity for PD may be hampered in the conventional electric case while the mentioned unconventional methods – electromagnetic (UHF) and acoustic – do generally not suffer from external disturbances. Besides applying the two unconventional methods separately an advantageous combination of them is also reasonable for an optimised detection and localisation.

Regarding the PD localisation on the basis of acoustic arrival time, three different approaches for the system of non-linear observation equations could be distinguished. Depending on whether mixed-acoustic (i.e. electric or electromagnetic triggering) or all-acoustic (acoustic triggering) measurements are used, the equations have three (space coordinates (x, y, z) of the PD) or four unknowns (an additionally unknown temporal origin). A new approach within the acoustic signal processing works with pseudo-times, allowing the usage of robust direct GPS (Global Positioning System) solvers instead of the previously used iterative algorithms [4]. In the presence of inevitable measuring errors, sensitivity limits or wrongly assumed acoustic propagation velocities much more stable results were featured by the direct solver. Another important part of the localisation procedure is a correct objective arrival time determination. Here good experiences have been gathered with signal-energy based criteria.

Increasing the signal/noise-ratio or in other words denoising signals with an averaging process (continuously form the mean value) has long been known and used. To be successful a stable trigger is required, signal and noise should be uncorrelated and the noise is supposed to be white (i.e. has a constant spectral density in the investigated frequency range). In terms of PD measurements and the goal to denoise acoustic signals e.g. to quantify their arrival times hidden in the noise, one needs to have a physical signal related to the PD with a significantly higher sensitivity than the acoustic one. Here, electromagnetic UHF PD signals have proven their applicability.

During the averaging process, the noise contained in the acoustic signal tends towards its statistic mean value, which is zero if white noise is assumed. The acoustic signal itself is superimposed constructively and the presence of an acoustic signal with stable relation to the UHF trigger can be verified with high sensitivity. The theoretically maximum signal/noise-ratio gain is N x 0.5, where N is the number of superposition. Fig. 13 shows a comparison of a single acoustic PD impulse of a 132 pC with no clearly observable information and an UHF-triggered averaged signal with 500 superimpositions of maximum 9 pC. There a clear impulse is visible (same experimental arrangement, same sensor position) [5].

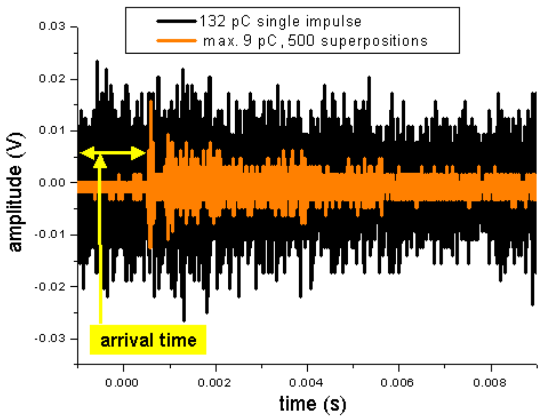

Fig. 13: Comparison of a 132 pC single impulse and an UHF-triggered averaging signal with 500 superposition of maximum 9 pC (same experimental arrangement and sensor position)

Another important aspect of UHF-acoustic coupled measurements lies within the increased plausibility of the decision for or against PD activity: Mechanical noise has typically no inner electromagnetic signal, while electromagnetic noise could not create mechanical signals with a stable phase relation needed to be existent for showing a signal after an averaging process.

6.1 Laboratory localisations of PD

The experimental configuration consists of a coil at high voltage surrounded by two pressboard cylinders immersed in an oil-filled transformer tank with a stimulated PD on the inner side of the coil. The applied UHF sensor was a monopole antenna inserted through a drain valve with no amplification for the signal. On the outside of the tank, four piezo-electric acoustic sensors and 60 dB amplifiers were attached to capture the acoustic PD signals. A comparison of acoustic PD signals of 575 pC (single impulse) and 9 pC (averaged signals with 500 superposition) concerning their amplitude, arrival time and the resulting location accuracy was drawn. The noise floor of the single impulse measurement (575 pC) was about 35 mV and could be diminished to about 2.5 mV in the averaged signal. With maximum impulse amplitude of approximately 12.5 mV of the superposed impulse, this averaged impulse is completely hidden in the noise floor of a single measurement. The resulting acoustic sensitivity gain due to the UHF triggering is conservatively estimated to a factor 10 in this experiment (PD around 100 pC might be visible on sensor positions not used). The computed PD localisations featured a spatial deviation from the PD origin of 1.6 cm (575 pC case) and 10.4 cm (9 pC case).

7 CONCLUSION

The detection of PD during full operation of power transformers is possible with the shown UHF PD probes. The probes withstand all occurring mechanical and thermal stresses and can be used as a permanently installed measuring device for online monitoring systems. Improvements of electrical properties of the UHF PD probes allow a significant functionality test of the probes and the whole measuring equipment including measuring lines and the PD acquisition unit.

The so-called Performance Check shows its capability even in case of external disturbances and is practicable in a single port way as well as in a dual port way with a second oil valve. It allows the clear statement, whether the installed measuring equipment is working properly, including the UHF PD probe, the measuring lines and the PD acquisition unit.

Main focus of future research will be the presented idea to develop a sensitivity verification of the UHF measuring method. Goal is the approximation of the quantity of a PD, comparable to the apparent charge in pC according to IEC60270. First steps as developing a UHF signal generator with variable output power and investigations with two probes at a transformer tank are already accomplished. The next step is implementing real PD sources inside the same transformer. Further investigation in this area will lead to a suitable instrument reading parameter.

Amplified UHF measurements in field have shown narrowband disturbances which have been identified online by a narrowband measurement of UHF signals or with a phased resolved PD pattern. An offline post processing approach of identification using FFT led to the same results.

Generally the unconventional UHF measuring method offers many advantages on-site and supports the online monitoring of the insulation quality of high voltage devices.

Supporting acoustic measurements the UHF signals offer a stable trigger for denoising on-line measurable acoustic signals by the presented averaging process. Measurements in laboratory led to the estimation of a 10 times higher acoustic sensitivity. PD localisation on the basis of acoustic arrival times with moderate deviation seems possible.

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9 ZUSAMMENFASSUNG

Die vorgestellte UHF Messmethode ermöglicht die Detektion von Teilentladungen (TE) bei in Betrieb befindlichen Leistungstransformatoren. Die zu diesem Zwecke entwickelten Ölflanschsensoren wurden erfolgreich auf ihre mechanischen Eigenschaften untersucht und wiederstehen den auftretenden mechanischen Druckbelastungen bei gleichzeitiger thermischer Belastung. Somit sind sie als permanent installierte Messgeräte für online Monitoring Systeme zu gebrauchen.

Verbesserungen der elektrischen Eigenschaften der Sensoren erlauben erstmalig eine Funktionsüberprüfung der Sensoren sowie des gesamten angeschlossenen Messsystems. Für diese Funktionsüberprüfung wurde der Begriff des Performance Checks eingeführt. Die Leistungsfähigkeit dieser Funktionsüberprüfung wurde im Falle externer Störungen erfolgreich nachgewiesen. Durchführbar ist dieser Funktionstest sowohl bei lediglich einem vorhandenen Ölflansch als auch bei zwei vorhanden Ölflanschen.

Angestrebtes Ziel für die zukünftige Forschung ist die Realisierung einer Sensitivitätsabschätzung, die eine Abschätzung der Quantität einer TE erlauben soll. Eine geeignete Messgröße der empfangbaren UHF Signale soll in Relation zu der elektrisch, nach IEC60270, messbaren Einheit in pC gebracht werden. Die Sensitivitätsanalyse, engl. Sensitivity Check, soll angelehnt an das Verfahren in gasisolierten Schaltanlagen (GIS) entwickelt werden [3].

Im ersten Schritt erzeugt ein UHF Signalgenerator künstliche UHF Signale mit variabler Ausgangsspannung. Zwei gleichartige Sensoren wurden an einem Versuchskessel angebracht. Ein Sensor diente dabei als Sender von UHF Signalen, die vom anderen Sensor empfangen wurden. Ein lineares Verhältnis zwischen den auswertbaren Signalanteilen und der Ausgangsspannung des UHF Signalgenerators konnte ermittelt werden. In einem zukünftigen Schritt werden die künstlich erzeugten Signalanteile mit einer realen TE im gleichen Versuchskessel verglichen. Weitere Untersuchungen zur Auswahl geeigneter Parameter der messbaren UHF Signale, wie z.B. der breitbandig gemessenen Spannungsamplitude, schmalbandigen Frequenzanteilen oder der integrativen Signalenergie, werden folgen.

Erfahrungen mit der UHF Messmethode im Feld zeigen, das schmalbandige Störer bei einer Messung auftreten können, wenn die messbaren Signale mit einer Verstärkung von ca. 20 dB breitbandig verstärkt werden. Diese Störer können jedoch durch die vorgestellten Messmethoden erfolgreich erkannt werden. Schmalbandige Messungen, nachträgliche Frequenzanalysen oder phasenaufgelöste UHF Signale ermöglichen eine Zuordnung zu bekannten Störer des Mobilfunks sowie zu Radio- und Fernsehsignalen.

Zusammenfassend kann die unkonventionelle UHF Messmethode vorteilhaft für Messungen während des Betriebs verwendet werden und kann z.B. innerhalb eines online Monitoring System zur Isolationsüberwachung bei Hochspannungsgeräten eingesetzt werden.

Weiterhin kann die UHF Messmethode die Ortung von TE aufgrund akustisch messbarer Laufzeit-differenzen unterstützen. Sie liefert dabei einen definierten Startzeitpunkt einer TE und ermöglicht eine effiziente Rauschunterdrückung der akustischen Signale durch die vorgestellte Mittelwertbildung (Averaging).

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