Attenuation of UHF signals regarding the Sensitivity Verification for UHF PD Measurements on Power Transformers

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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 might 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.**

The current work deals with the electromagnetic PD detection method, also known as the UHF-Method. The disadvantage of the UHF-Method is still the missing possibility for a calibration or at least a verification of the sensitivity. The so-called Sensitivity Check might show in future a relation between unconventionally measured UHF quantities to the PD apparent charge level in pC. An import aspect is the attenuation of UHF signals within power transformers which is investigated in this paper.

***Index Terms*—Power Transformer, Partial Discharges, Ultra High Frequency, UHF Method, UHF Probe, Sensitivity Check, Unconventional Detection**

I. Introduction

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 might cause high outage and penalty costs. To prevent these destroying events power transformers are e.g. tested on PD activity before commissioning and currently also during service. The so called conventional PD-measurement according to IEC60270 might show certain drawbacks for online-measurements. The current work deals with the electromagnetic method, also known as the UHF-Method (Ultra High Frequency). The disadvantage of the UHF-Method is the missing possibility for a calibration or at least a verification of their sensitivity.

To analyze the relation between unconventionally measured UHF quantities to the PD apparent charge level in pC the following questions are important:

- Can UHF signals be measured everywhere inside the transformer tank with the same sensitivity? Are signal amplitude or signal energy strongly dependent on the measuring location? Assuming an attenuation of UHF signals inside and through the internal structure of the transformer: is there a constant attenuation factor and what is the range of the attenuation? When measuring inside another transformer with different tank size or internal structure: is the attenuation factor in a comparable range?

- Can an e.g. linear relation be found between measured UHF quantities like the signal amplitude to the PD apparent charge level in pC according to IEC60270? Is it possible to extract a relation for one single impulse or are only impulse repetition rates or phase correlation comparable? Is the relation constant for one transformer, or even for transformers of the same tank size or the same internal structure?

- Is it possible to perform a so called Sensitivity Check to verify the quantity of a PD in terms of apparent charge (?) by only measuring UHF signals? Is this strongly dependent on the location of PD inside the transformer, especially if there is a PD inside the winding?

The following chapters provide some answers to the questions above by outlining some experimental research work.

II. Attenuation of UHF signals in 220MVA Autotransformer

PD can only be measured and quantified within large power transformers with a UHF sensor [1], when electromagnetic waves emitted by a PD can be measured everywhere in the transformer without loss of signal power. There should then be no significant influence of the internal structure of the transformer on the propagation of UHF signals. For analyzing this characteristic of the UHF propagation inside power transformers two 220 MVA single-phase autotransformers of the same type intended for scrapping were prepared for some experiments. The transformers were oil free but with intact tank, which acted as a faraday cage for external disturbances. More important, the transformers included there complete active parts. Getting more different location for injecting and receiving electromagnetic waves through the transformer a lot of boreholes were drilled in the tank wall at various positions all around the transformer tank, e.g. seen in Fig. 1.

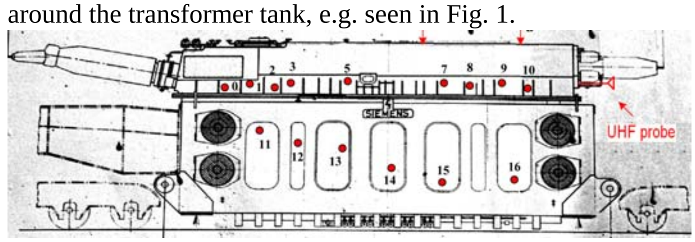

Fig. 1. Positions of boreholes into the front side of one transformer (other boreholes were at the back of the transformer, e.g. No. 17 – 27

At least two 10 cm long monopoles (see Fig. 2) can be shifted into the transformer through the boreholes. The attenuation of different propagation paths through the transformer can be investigated by feeding one of the monopoles by an UHF impulse generator and measuring at another monopole the received UHF waves. Additionally an UHF probe was installed for reverence measurements at an oil-filling valve. The feeding signal had an amplitude of 60 V with signal rise times of less than 100 ps and a corresponding frequency spectrum up to 2.5 GHz.

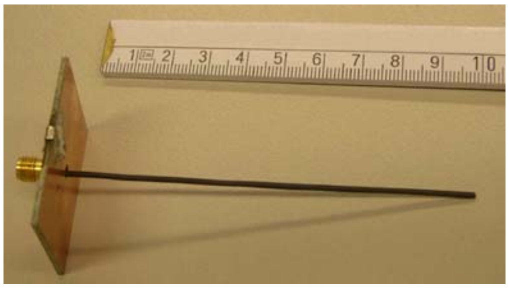

Fig. 2. Monopole for emitting and receiving electromagnetic waves

With the impulse generator repetition rate of 100 Hz, many non-amplified single signals could be received and analyzed independently. Fig. 3 shows e.g. the maximum amplitude of the received UHF signals at different positions characterized by the number of the borehole, see Fig. 1. The UHF signal source (the emitting monopole) was held on constant location, e.g. here at a borehole on top of the transformer tank.

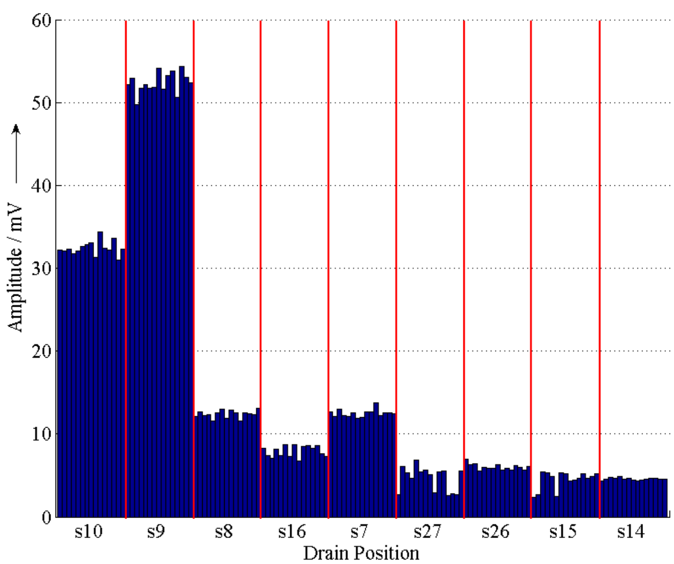

Fig. 3. Maximum amplitude of received UHF waves depending on the drain position (source position constant)

Immediately recognizable is the clear difference of signal amplitude depending on the position of the receiving antenna. Regarding the drain position 9 as a reverence, the damping factors to the other drain locations could be calculated. Fig. 4. summarizes an example of one fix UHF source location and different drain locations by plotting the calculated attenuation factors in dB, see left axis. By knowing the transformer tank dimensions, the corresponding drain source distances are calculated and included in the diagram. This results in general attenuation factors of the UHF signals inside the transformer with the unit dB/m, see right axis in Fig. 4.

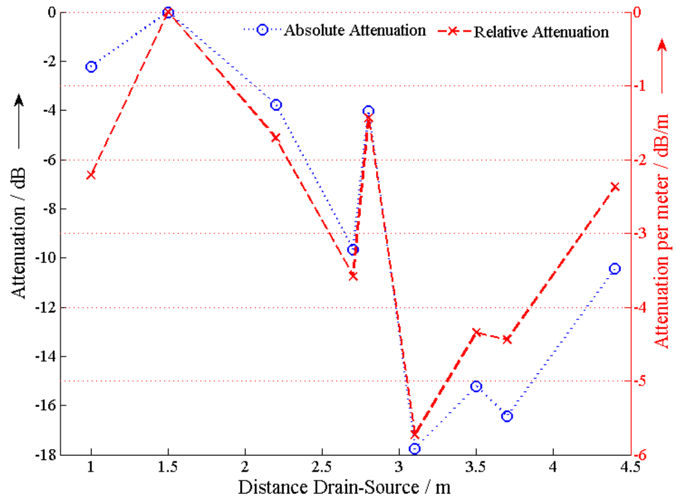

Fig. 4. Attenuation of UHF signals measured in time domain

The attenuation of UHF signals relating to the distance is not linear increasing with increasing distance. Depending on the internal structure of the transformer, some drain locations might be better for receiving the UHF signals than other locations. The showed way of analyzing the attenuation was done for many different measurements with different drain and source locations. Summarizing, the attenuation of UHF signals within the transformer varies between 5 and 13 dB/m, depending on the location and therewith the traveling path of the UHF signals.

The active part of transformers has a strong influence to UHF signals and the caused attenuation seems not linear to the distance. More experiments like the mentioned above with different transformers will show, if the attenuation is within same range or even predictable for identical transformer types.

Because of the showed attenuation, it might be impossible to examine the quantity of an PD originated UHF source (in terms of apparent charge) without knowing its location and therewith the possible span of the experienced attenuation of the UHF waves on the traveling path to the UHF probe.

III. Correlation between UHF – IEC60270

The so-called Sensitivity Check for UHF measurements on power transformers might be comparable to the procedure suggested for the UHF method at gas isolated switchgear (GIS) [2,3]. An approximation of the measured UHF PD quantity comparable to the quantity of the apparent charge in pico Coulomb (pC), determined with the measurement according to IEC60270 (IEC), should be achieved.

First step is an investigation about the correlation between the apparent charge pC and the measured UHF signals. Therefore the IEC measuring method was done simultaneous with the UHF measurement method, see measuring set up in Fig. 5. The UHF signal and the voltage signal of the IEC measuring impedance were recorded at the same time.

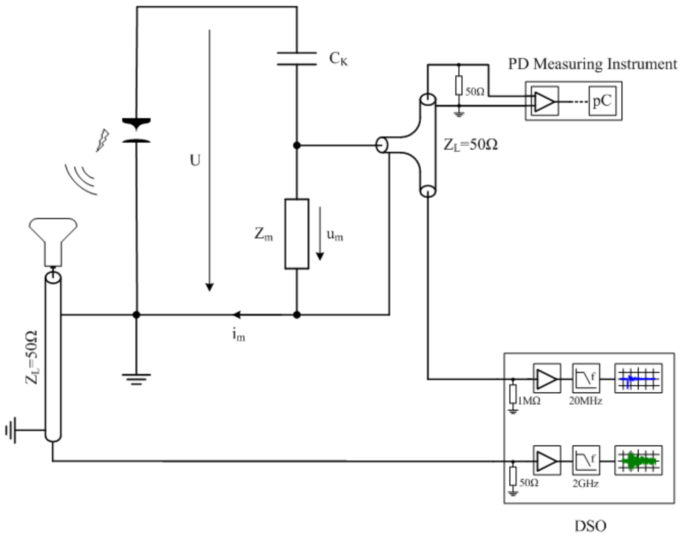

Fig. 5. Combination of UHF and IEC60270 measurement

Additionally over a PD measuring system the apparent charge level Q_{IEC} was measured directly, which served as a reference measurement and for voltage measurements. After calibrating the IEC measuring method, the scope measures the apparent charge and the UHF effects of one and the same PD pulse. While recording more than 30 signals the natural deviation of PD defects helps to find a relation between UHF signal amplitude and apparent charge.

Two different sources of PD are shown in Fig. 6. The first source of PD consists of a glass ampoule with an air cavity between a rod-plane PD source under oil. The second PD source consists of another rod-plane arrangement which uses the same oil volume as the transformer. The high voltage was applied by a coaxial cable (RG214), which is PD-free up to a voltage of approximately 12kV. PD inception voltage of the sources was about 5-10kV.

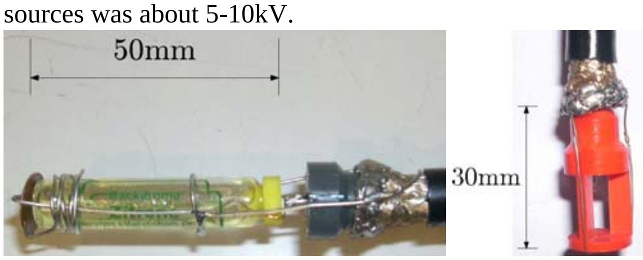

Fig. 6. PD sources, 50-300 pC, 5-10 kV

The presented PD sources were brought into a 10 kV/380 V 200 kVA distribution transformer. Over an available oil filling valve an UHF probe was slid into the transformer, receiving the emitted UHF waves from inside the transformer tank. Because of the not completely closed top cover, the location of the PD sources, mounted on a stick, can be changed to 20 different positions, see Fig. 7. During the measurements the transformer with the included active part was oil-filled and an aluminium foil closed the cover to simulate a closed tank.

In the exemplary results shown in this paper, the UHF probe was installed at the upper oil filling valve and the PD source with the glass ampoule was used. The applied voltage was adapted so that PD with an intensity of 50 to 150 pC occurred.

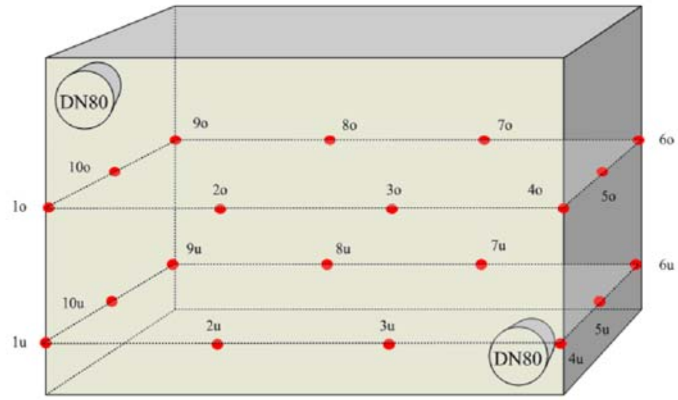

Fig. 7. Measuring positions in transformer tank

For each measured UHF signal, the amplitude and the apparent charge of the corresponding PD were determined. In Fig. 8 the measured UHF amplitude over the apparent charge Q_{IEC} is shown.

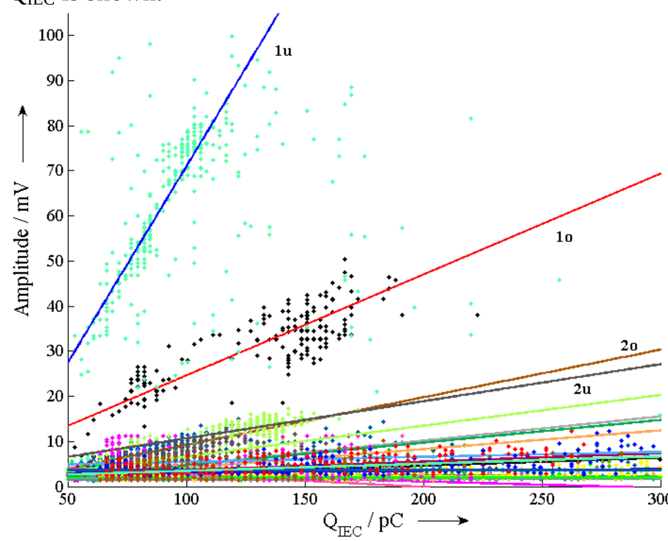

Fig. 8. Relation between UHF amplitude and apparent charge Q_{IEC}

All measurements (points) of the 20 locations are coded with a clear color. Different clusters of points with the same color are remarkable. These points show a linear relation between the apparent charge and the measured amplitude of the UHF signal. In order to examine this relation quantitatively, for the measured values regression lines were computed according to the method of the smallest error squares, see Fig. 8.

The following observations can be made:

- The regression analysis shows a linear correlation between the apparent charge and the measured UHF signal amplitude.
- The relation is constant for a fixed position of PD source. The relation depends on the position of PD source and thus of the distance between PD source and UHF probe.
- The signal-noise ratio increases with the distance between PD source and UHF probe. Finding a relation between the UHF signal and the apparent charge is getting more and more difficult then.
- The PD sources show - even with constant apparent charge level - a large dispersion regarding the UHF signal

amplitude. From this it can be stated that different kinds of PD have likewise different characteristics concerning the relation between measured apparent charge and emitted electromagnetic waves.

IV. Sensitivity Check

The idea for the so-called Sensitivity Check for the UHF measuring method on power transformers is based on the procedure suggested for the UHF measuring method at gas isolated switchgear (GIS) [3]. 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 power using a second transmitting probe. With an excitation voltage of e.g. 10 V this will lead to a ratio of the feeding amplitude to the apparent charge of 0,1 V/pC. Installing the whole measuring system at an identical transformer with two oil filling valves may then allow a sensitivity verification for 100 pC, i.e. the UHF method is able to detect PD effects with at least 100 pC.

Aim of the following investigation is to find the above mentioned relation between the feeding signal and the according apparent charge.

Activating the PD source at position "7u'" (see Fig. 7) with an apparent charge of 100 pC the UHF sensor, installed in the upper DN 80-oil-filling valve, detects an UHF signal with an amplitude of 5 mV. The monopole antenna (Fig. 2) held at position "7u'" was fed by the UHF signal generator with an amplitude of 4 V for simulating the same measurable effects as the original PD. I.e. the relation of 0,04 V/pC can be used for the Sensitivity Check.

Comparing the relation of 0,04 V/pC to results in [4], which stated a relation between 0,2 V/pC and 1,5 V/pC, the big discrepancy might be explained by:

- different sensitivity of the UHF coupler or used amplification
- different transformer tank sizes
- different internal structures
- different types of PD

Investigations in future may allow comparable results when defining some standards for the Sensitivity Check procedure in laboratory first.

By using the regression line from Fig. 8, the PD can be quantified by only measuring the UHF signal. Important is, that this approximation of the apparent charge is only valid for this position “7u” and for only that transformer. For analyzing, if the artificial impulse of 4 V leads to the same quantitative result as in the chapter III, the transmitting antenna was located successively at the 20 different defined positions in the transformer and the UHF probe signal was recorded.

The following Fig. 9 compares the measured UHF amplitudes using the 4 V impulse with the UHF impulses caused by the original PD of 100 pC at each location. Position “7u” is the reference point of the Sensitivity Check where the UHF signal amplitude of the original 100 pC PD has the same value as from the artificial impulse of 4,0 V

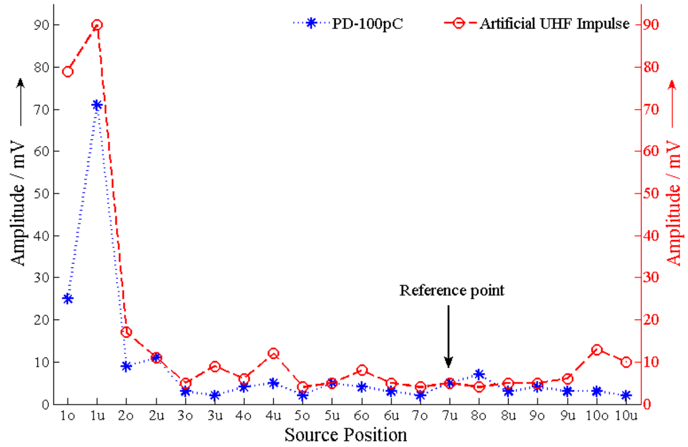

Fig. 9. Sensitivity Check

The other positions support the preliminary investigation results, that the attenuation of the UHF signals depends on the internal structure and the traveling path, because measured values of the same origin (100 pC PD and 4 V impulses) varies between 3 and 90 mV.

Generally the Sensitivity Check for UHF measurements does not afford an estimation of the apparent charge, because of not predictable UHF attenuations according to the location of the PD and the resulting traveling path of UHF signals. The procedure makes an evaluation possible whether a PD of certain intensity at the tested positions are detectable, i.e. it might only be a worst case estimation of the sensitivity. But defining a general procedure for the immense number of different types of transformers might be difficult.

V. Conclusion

The results of the presented research can be concluded as followed:

- UHF signals experienced significant attenuation dependent on the traveling path through the internal structure.
- For fixed traveling paths there is a linear relation between the UHF amplitude and the apparent charge pC of PD.
- The Sensitivity Check is not reasonable for verifying the intensity of an PD compared to IEC60270.

Future research will consist of the presented procedure in chapter III and IV of the Sensitivity Check at the transformers planned for scrapping to find some additional information.

VI. References

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