Transfer Function as Tool for Noise Suppression and Localization of Partial Discharges in Transformers during On-site Measurements

E. Gockenbach, H. Borsi
Leibniz Universität Hannover, Schering-Institut
Callinstr. 25A, 30167 Hannover, Germany
*E-mail: gockenbach@si.uni-hannover.de

Abstract — Partial discharge (PD) measurements are one the most important non destructive test methods to evaluate the integrity of the insulation system of power transformers. PD measurements on site are strongly influenced by noise and besides the level of the PD activity the location of the PD source is of importance. Using the well known transfer function from transformer impulse tests the variation of the PD signal travelling through the transformer winding are the basis for the separation between noise and PD signals and also for the localization of the PD source. Laboratory tests show very good results. With a simple capacitive coupler and signal transmission via fibre optic cable the system can also be used satisfactorily on site.

Index Terms — High voltage technique, Partial Discharge measurement, Noise suppression, Localization

I. INTRODUCTION

Partial discharges are used as measure during non destructive tests and are also helpful for the diagnosis of insulation systems, because they appear at a very early stage of the failure. Partial discharges activities can be detected also by gas-in-oil analysis, but not only the detection also the localization of the partial discharge source is important. Furthermore the partial discharge online measurement allows also the consideration of other parameters like temperature, temperature changes and of all information within the signal of the partial discharge like apparent charge, phase angle etc.

II. MEASURING METHOD

The transfer function is well known in the signal transmission field and also in the high voltage test and measuring business. The details of the theory are reported in former publications and [1]. The main idea of introduction the transfer function in the high voltage test technique was the impulse test of transformers.

The experience with the transfer function shows the reliability and the advantages during transformer impulse tests and also the possibility to use the transfer function as diagnosis tool [2-4]. The principle of the transfer function will also be used to detect partial discharges (PD) in transformers and more over to localize the PD origin and to calculate more accurate the true charge amount. Figure 1 shows the principle diagram of the developed method.

The coil of a transformer is divided in numerous winding sections. The PD at an unknown origin generates a signal which travels through the winding sections to the high voltage bushing and to e.g. the neutral or star point. The bushing as well as the neutral point are accessible points for PD measurements and the signals can be recorded. Assuming the transfer function of the transformer coil is known by the sectional transfer functions of the winding sections the change of the signal from the origin point to the measuring point can be calculated.

Fig. 1. Basic principle of the transfer function for partial discharge detection
This procedure can be used to calculate the shape of the signal at any point within the coil using the measured signal and the section winding transfer function. This can be done for both signals measured at the bushing and at the neutral point and calculated at each winding section within the transformer. The point where the two calculated signals are identical is the true origin PD origin.

III. NOISE SUPPRESSION

Then same principle could be used to separate between PD signals and noise. The noise signals have to travel through the complete winding and the calculation of the transfer function of such a signal should be theoretically equal to the measured transfer function of the transformer. Furthermore, the amplitude of such a signal should be more attenuated as a PD discharge signal generated within the transformer, because the travelling way is much shorter. These both criteria could be used to separate noise signals from PD signals. Fig. 2 shows the signal magnitude as function of the frequency for several measurements. It shows clearly that a signal, which has passed the complete transformer, has much lower amplitude. But this criterion is not sufficient. If a calculation of the transfer function of a signal measured at the two points shows that this transfer function is identical with the transfer function of the complete transformer, this signal should be definitely generated outside the transformer winding. Unfortunately this criterion requires a computation and can not be shown in a simple diagram.

IV. PD LOCALIZATION IN LABORATORY TESTS

On a specially prepared distribution transformer (10 kV / 380 V, 200 kVA), which has been pulled out of its vessel, 7 clamps have been mounted along phase V with equidistant spaces comprising 2 winding packages. Into each clamp 150 PD-pulses have been injected spread equal to three different PD-types generated by a needle-plane arrangement in air, oil and pressboard, in order to simulate different failures. Thus in total 1050 PD-pulses have been digitized at the bushing and at the neutral via a 50 Ω resistor using a sampling rate of 100 MHz and a low-pass filter with a 20 MHz cut-off frequency.

Afterwards all sub or respectively sectional transfer functions from each clamp or respectively origin to the bushing and to the neutral including in both cases the termination resistor of 50 Ω have been determined using a network analyzer. The transfer functions have been recorded with 1601 equidistant points between 10 kHz and 5 MHz, thus only this frequency range has been considered when the measured signals were transformed via the FFT. A network analyzer with a dynamic range of about 90 dB is needed for a frequency range up to 5 MHz, while for frequencies up to 1 MHz a dynamic range of approximately 60 dB is sufficient, which can be used to reduce the efforts for the measurement equipment.

![Fig. 2. Measured amplitude of partial discharges and noise](image.png)

![Fig. 3. Measured and calculated PD in air](image.png)
one clamp using the needle-plane electrode configuration in air. On the top diagram in Fig. 3 the signals measured at the bushing and at the neutral are displayed, while the other diagrams show the signals at the 7 origins calculated back from the measured data. The recalculated signals from the bushing and from the neutral are almost identical at origin 3, thus indicating that there is the actual origin of the measured PD-pulses. The small discrepancies between the signals at the actual origin can be traced back to measurement inaccuracies.

Another question is what happens if a partial discharge occurs at an origin from which the transfer function to the bushing and to the neutral is unknown.

To simulate this problem a partial discharge produced by the needle-plane arrangement in oil has been injected right into the middle of a winding package between two clamps. The result of this experiment is shown in Fig. 4, where similar to Fig. 3 the signals measured at the bushing and at the neutral as well as the calculated signals at all origins are displayed. At origin 4 and 5 the calculated signals have the most significant identicalness, thus indicating that the actual origin has to be between these origins, which is indeed the case. Further evidence therefore is that the signal calculated at the bushing lags the signal calculated from the neutral at origin 4, but lead at origin 5.

In all cases the conformity of the calculated signals at the actual origin is so evident, that all measured PD-signals can be localized with reasonable uncertainty.

V. PD LOCALIZATION ON-SITE

The PD measurement on site is much more influenced by noise compared to laboratory measurement and the transfer function of the transformer is very often calculated based on a single step response measurement and a modeling of the transformer [5].

In order to suppress the sinusoidal spurious signals during the measurement, with the presented wide-band measuring method, optical transducers are used, which convert the PD signal directly after its decoupling into an optical signal, which will then transfer via fibre-optic cable to the test van. Thus a launching is so efficiently suppressed by spurious signals that in particular continuous sinusoidal noises are nearly no longer present, so that a digital filtering of the remainder disturbances is possibly problem-free. However the diode-rushes in the measuring is small relative to the PD signal and thus can efficiently be suppressed by digital filters, which are based on the Wavelet transformation.

Fig. 5 and 6 give an overview of the measurement set-up on site, as well as the digital detection equipment of the measuring signals.
channels at the same time. Three signals for the three phases and one for the neutral. The first aim is to recognize if there is PD activity inside the transformer. The second aim is the recognition of the faulty phase or phases with PD signals. The results are presented in Fig. 6 which shows the screen of the digital oscilloscope presenting the signals picked up from Phases U,V,W and the neutral (MP) respectively. The left column has a time scale of 200 ms, the right column of 10 μs.

As is seen in the picture there is some stronger PD signals for phase V (second signal from the top) which are coherent with the pulses at the MP channel (signal at the bottom). Therefore phase V can be simply recognized as the faulty phase which has PD. The PD signals of V phase are picked up at the bushing as well as at the neutral and are saved for further investigations.

The further evaluation of the measured signals leads to first to an oscillogram showing all signals, noise and PD, for one phase together with the applied AC voltage. Fig. 7 shows an example.

A reasonable filtering with suppression of sinusoidal noise and stochastic noise by the above mentioned method leads to a further oscillogram which shows only the PD signals as function of the phase of the AC supply voltage. Fig. 8 gives an impression of the noise reduction. With these information the calculation of the PD location could start using the signals measured at two points (high voltage bushing of one phase and neutral point) and using the transfer function of sections of the winding.

VI. CONCLUSIONS

- Partial discharge measurements on-site are strongly influenced by noise.
- With the help of the transfer function a separation between noise signals and PD signals is possible and can be used during on-site PD measurements.
- The transfer function can be used to localize the PD source within the winding.
- The quality of the localization depends strongly on the accuracy of the transfer function of the winding sections.
- For existing transformers the uncertainty in the PD source localization is limited due to the mostly unknown transfer function.
- For new transformers with known transfer function of the winding sections the localization uncertainty is acceptable.

VII. REFERENCES