System for measuring partial discharges in oil-paper insulated transformers and for localization of the sources

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Abstract This paper presents the procedure of partial discharge localization method with the help of sectional winding transfer function. Due to the use of a measuring system, which consist of sensor, amplifier and optical signal transmission an adoption to various kind of transformers is possible. The described method uses a multi sensor system for a simultaneous electrical decoupling and filtering of PD-signals, thus a comparison of the measured signals enables a localization of the PD-origin. Some investigation in the laboratory are introduced.

Key Words: Power Transformer; On-Line Monitoring; PD-Measurement; Frequency Response Analysis; Diagnosis; Sensor Technology

INTRODUCTION

Power transformers in electric distribution and transmission systems are mainly oil-paper insulated due to the requirements on the insulation and the cooling performance. They are one of the most important equipment within the components of the electric power system. The increase of load and the extension of the service time lead to an increase of the required information concerning the actual status of the insulation of the transformer. With increasing age of the insulation the failure risk increases too and therefore monitoring and diagnosis are very important. One of the sensitive parameter regarding the status of the insulation is the Partial Discharge (PD) activity, but not only the value of the PD level also the place of origin is of interest. Furthermore the detection should be preferably done on-line without switch-off of the transformer and the next step with localisation of the PD source can be done off-line.

THEORETICAL ANALYSES

The PD measuring system is based on the assumption that a PD signal travels through the transformer and can be measured at two specific point, e.g. at the neutral point and at the relevant bushing. A further assumption is the knowledge of the so called transfer function of the transformers which can be expressed by the following equations in time and frequency domain:

\[ x(t) = h(t) \cdot y(t) \]
\[ x(f) = H(f) \cdot Y(f) \]  

(1)

where x(t) and x(f) are the input signals in time and frequency domain, h(t) and h(f) the transfer functions and y(t) and y(f) the output signals\(^\text{[1]}\).

The transfer functions are typically for each transformers and they should be measured and calculated in advance. This is very often the main problem of the method, because for normal transformers only the complete transfer function between the two measuring points can be evaluated, but not the transfer function of the different windings sections. The so called Sectional Winding Transfer Function (SWTF) is necessary to calculate the change of the PD signals during travelling through the transformer windings. If the transfer function is known, the PD source can be located by calculating the PD signal at various virtual points within the winding using the two measurements at the neutral point and the bushing. Assuming a linear behaviour of the transformer windings the two calculated signals should have the same shape at the location of the PD. Fig. 1 shows the scheme of the localization principle.

![Fig. 1 Scheme of localization principle.](image-url)
where \( MB = \text{FFT} \{ \text{MB}(t) \} \), \( MA = \text{FFT} \{ \text{MA}(t) \} \), \( TE = \text{FFT} \{ \text{TE}(t) \} \) are functions in the frequency domain received by the Fast Fourier Transform (FFT) of the functions in the time domain.

For a correct signal analysis it is important to take into consideration besides the sectional winding transfer function also the transfer function of the sensor, transmissions system and recording device. This transfer function is represented by the functions \( \text{TF}_{(A \rightarrow MA)} \) and \( \text{TF}_{(B \rightarrow MB)} \) in Fig 1. They are influenced by the design of the bushing construction as well by the matching of the sensor and the amplifier parameters.

### PD MEASURING AND LOCALIZATION SYSTEM

The PD measuring system consists of sensors, quadripoles, amplifiers, transmission systems and recording devices. The developed sensors can be mounted easily at any transformer neutral point or bushing after a simple adaptation on the diameter of the bushing porcelain. All other components are independent on the type of transformer. The amplifier can be powered by a battery or solar cell and the transmission of the signal is performed with fibre optic technology\[^2\]. All amplifier parameters can be remote controlled from the ground station, such as amplification level and standby mode in order to get the maximum sensitivity and to safe energy during the measurement pauses. Furthermore a test pulse can be generated to check the performance of the transmission system.

Depending on the wishes of the customer the system can be used on-site as monitoring system in order to detect PD activities or at diagnosis system evaluating the PD activities and localize the PD source. The monitoring system can provide an alarm management at value which can also be defined by the customer. Depending on the storage capability the signals can be recorded over a long time and reasonable data management can control the large amount of data.

### EXPERIMENTAL RESULTS

Practical experiments were done under laboratory conditions and under manufacturing condition in their test laboratory.

#### Laboratory conditions

On a prepared distribution transformer without vessel (10kV/380V, 200kVA) the SWTF of the windings were measured with two methods, the pulse response method and the network analyzer method. The results of the measurements concerning the amplitude and phase shift are shown Fig 2.

![Fig.2 Comparison between network analyzer and pulse response method](image)

The transfer functions in frequency domain measured with the two methods are in a good agreement, only at higher frequencies the damping and the poles has some differences.

The transfer function \( \text{TF}_{(A \rightarrow MA)} \) and \( \text{TF}_{(B \rightarrow MB)} \) shown in Fig 1 were also determined for this transformer and the results are displayed in Fig. 3. The transfer function includes the sensor, the amplifier, the transmission system and the recording device.

![Fig.3 Transfer functions of two bushings](image)

It can be clearly seen that the two signal ways have no identical transfer function and this confirms the statement, that not only the transfer behaviour of the different winding sections but also the transfer behaviour of the signal way from the sensor to the recording device should be taken into account using the transfer function method for localisation of PD.

Former investigations have showed that SWTF for all part of the winding have significant similarities up to frequency of about 1 MHz\[^3\]. However for higher frequencies above 1 MHz the dissimilarities were used for the determination of the sectional winding transfer.
In order to check the procedure of PD localisation a PD signal generated by needle-plane electrode configuration in oil was injected at point 4 of the transformers, just in the middle of the windings. The diagram a) of Fig. 4 shows the measurement of the injected PD at the end and the beginning of the winding, named as point 0 and 8. With these information the SWTF were calculated for the complete transformer assuming that the transformer was divided into 7 sections with in total 8 measuring or calculation points. The diagram b) of Fig. 4 shows two calculated signals, one starting from point 0 and one starting from point 8, both using the relevant SWTF. The diagram c) shows the same calculation for point 4, which was the true PD location, and diagram d) the calculation at point 6.

![Fig. 4 Example of calculations](image)

A comparison of the calculated curves shows only at point 4 a good agreement of the two curves in amplitude. It should be noted here, that the scale of the y-axis in diagram c) of Fig. 4 is 5 times higher than in diagram b) and d). The difference in the calculated signal at point 4 is caused by the fact, that the calculation of the SWTF was not good enough. During the investigations it was also recognised that errors in the transfer function at low frequencies have large influence on the amplitude of the calculated signals, but errors at high frequencies have much less influence.

In order to get very fast a rough idea about the location of the PD source and to automate the complete procedure some calculations have been done. The identification of PD source is based on a parameter which depends mainly on the difference in amplitude and integral of the two calculated signals. As smaller the difference of the calculated signals with the starting points at the two ends of the winding, as better is the localisation of the true PD source. The jitter in the calculated parameters would give also some information about the limits of the procedure at the present status and would point out the necessary improvement of the method.

<table>
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<tr>
<th>Calculation</th>
<th>PD signal injected in winding No. (true PD location)</th>
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<tbody>
<tr>
<td>1</td>
<td>0.009 0.073 0.191 0.404 0.820 1.645 3.292</td>
</tr>
<tr>
<td>2</td>
<td>0.005 0.038 0.090 0.187 0.377 0.756 1.513</td>
</tr>
<tr>
<td>3</td>
<td>0.023 0.006 0.039 0.090 0.187 0.376 0.754</td>
</tr>
<tr>
<td>4</td>
<td>0.300 0.142 0.054 0.007 0.071 0.170 0.354</td>
</tr>
<tr>
<td>5</td>
<td>0.502 0.246 0.113 0.036 0.024 0.095 0.214</td>
</tr>
<tr>
<td>6</td>
<td>1.531 0.766 0.385 0.195 0.103 0.063 0.054</td>
</tr>
<tr>
<td>7</td>
<td>3.098 1.547 0.768 0.374 0.167 0.044 0.058</td>
</tr>
</tbody>
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The dark grey areas represents the are with the smallest values of the parameter and identifies the PD location. However it can also be seen, that not in all cases a clear determination of the PD location is possible. The light grey represents the neighbouring areas which may be also a location of PD. There are some reasons for the jitter in the results, the difference between the real transfer function and the in the calculation used transfer function and the noise in the signal. Anyhow this simple method can be used for on-line monitoring system, where only fast and easy indication of the PD source is required.

**Test field conditions**

In order to prove the system under real high voltage test filed conditions some others measurement were done on a single phase auto-transformer 230 kV/115 kV/13.2 kV with a power of 133.3 MVA. The measurement set-up of the sensor and amplifier is shown in Fig .6.
The measured signals will always influenced by noise and therefore it is necessary to process the data and to filter the recorded signals. In Fig 7 the original signal and the in two steps filtered signal are displayed.

The lower trace of Fig. 7 shows clearly some pulses and the next step in the procedure is to identify these pulses as true PD within the transformer or as noise coming from outside and travelling through the complete winding. According to the theory a signal travelling through the complete winding should lead to a transfer function which is identical with the already calculated and known transfer function of the complete transformer.

A signal generated as PD signal inside the transformer should lead to a transfer function which is at least different from the transfer function of the complete winding. With this simple comparison of the frequency spectra quotient between the signals measured at the two bushings a separation between PD signals and noise can be done[4]. However it is very important for this calculation to take into consideration also the transfer function of all components of the measuring system as sensor, amplifier, optical transmission system and recorder.

All signals in Fig. 7 could be identified as PD signals inside the transformer. A check with another independent PD measuring system gave the same result. The sensitivity of the measurement can be evaluated by the fact, that the highest pulse in Fig. 7 represents an apparent charge of about 1900 pC. The smallest detectable pulse is in the range of about 100 pC. An increase in the amplification of the signal would lead to an additional increase of the sensitivity, because the signal in the lower trace of Fig. 7 shows extremely low noise and even small impulse can be recognised.

**CONCLUSIONS**

On-line monitoring of power transformers opens the possibility for extending the operating time and reducing the risk of expensive failures.

The most important features of this monitoring system are the flexibility in software and hardware. Presently this method is prepared to be tested online with the cooperation of a transformer manufacturer.

The presented method shows good results for PD located near the central part of winding. However further improvement in modelling of the transformer will lead to higher accuracy also for the PD located near the ends of the winding.

The charge measurement shows a good agreement with another standard methods (e.g. narrow band electrical PD measurement). With the knowledge of the current shape a calculation of the “true” charge of the PD will be possible.

Future investigations on other types of transformer will lead to an additional improvement of the proposed method.

**REFERENCES**


