Partial Discharge Measurements on Power Transformers using Transfer Function for Detection and Localisation

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Abstract: In this contribution a system for the detection and evaluation of electrical broadband measured partial discharges (PD) on power transformers is introduced and discussed. The theoretical background for some features of the system like the PD localisation based on the use of sectional winding transfer functions (SWTF), are explained exemplarily, whereas the operation of the system is described for two different transformers. The performed measurements could be carried out on-line due to an enhanced sensor technology, superior signal transmission techniques and improved digital signal processing, which enables a significant reduction of disturbing noise.

INTRODUCTION

Transformers are one of the most important and cost-intensive components of electrical energy supply networks. A view on the age structure of the transformers in service for different utilities shows, that many of the transformers already have reached their design age. Thus a replacement of some transformers can hardly be postponed, but the deregulation forces the utilities to save costs. As a consequence the need and the interest in measures for the life span extension and load optimisation of the components of the electrical power supply strongly rose. For this purpose the knowledge about the operation condition of the component is of enormous importance, thus monitoring and diagnostic systems become more and more indispensable. However, monitoring systems have to consider the rate of recurrence and the importance of the errors at the different transformer components, for which a statistic is shown in Fig. 1.

Especially at the tap changer as well as at the coil and the core most failures appear, thus special monitoring systems are required therefore. For tap changers the manufactures offer extensive possibilities for determining the actual condition in contrast to the transformer coils, where additional off-line methods like PDC (Polarisation Depolarisation Current) or RVM (Recovery Voltage Method) have been developed in order to achieve more information about the insulation condition. However, PD measurements are known as an adequate and practical tool for diagnosing the actual condition of the insulation, thus often these methods are used for getting detailed information, although usually an intensive signal processing is necessary in order to evaluate the measured data and to suppress the noises which influence the measurement. Therefore a new system has been developed, which allows due to an enhanced signal acquisition, transmission and data processing an efficient evaluation of the measured signals, because beside the determination of the apparent charge also a localisation of the PD source becomes possible, which is described in the following.

FUNCTIONAL PRINCIPLE

The basis of the used PD detection and evaluation system is the electrical broadband decoupling of the PD signals on both sides of the transformer coils: the bushing and the neutral. At both decoupling points a characteristic distortion of the PD signal can be seen caused by the transmission of the signal from its origin to the measurement points. This characteristic distortion is defined by the transfer function of the transformer coil including the way from the PD source to the decoupling point. From this it follows that vice versa a measured PD signal can be calculated back to its origin if the sectional winding transfer function (SWTF) to its source is known. This idea represents the basis of the here described patented method for localising wide-band measured PD pulses [2].

Regarding a transformer coil as a black box as shown in Fig. 2, PD signals measured at the neutral and at the bushing can be calculated back to its origin if the sectional winding transfer function (SWTF) to its source is known. This idea represents the basis of the here described patented method for localising wide-band measured PD pulses [2].

Figure 1: Occurrence of failures in different parts of power transformers [1]
theory. Thus the PD origin is determined by comparing the calculated signals at the virtual origins, which has been proven in the laboratory [3].

**Figure 2:** Scheme of the functional principle

The SWTFs can be achieved by modelling techniques, while the transformer coil is simulated using a model consisting of R-L-C-M-units, which are adapted in an optimisation process until the measured step response matches with the simulated one [4]. After this optimisation process the transmission properties of the transformer coil are known, thus the SWTF between each point along the winding and the neutral or bushing respectively can be determined as shown in Fig. 3.

Based on the described localisation principle a PD diagnosis system has been developed with a modular structure, which is explained in more details consecutively.

**MODULES OF THE PD DIAGNOSIS SYSTEM**

The structure of the developed PD monitoring system is shown in Fig. 4, where it becomes obvious that the system mainly consists of two modules: the on-line data acquisition and the off-line data analysis.

**Figure 4:** Scheme of developed PD monitoring system

For the signal decoupling a new, patented sensor has been developed, which consists of a metal plate with defined dimensions and is mounted at the bottom of the bushing, thus a capacitive decoupling of the PD signals is possible. The mounting of the sensor is quite simple and can be used for any kind of transformer, thus measurement taps, which are not available especially on older transformers, are not necessary. As illustrated in Fig. 5 the signal transmission is performed via an enhanced fibre optic technology with a bandwidth of about 10 MHz, whereas the used quadripoles (QP) and the amplifier cut off frequencies below a few 10 kHz.

**Figure 5:** Scheme of data acquisition

Due to this new combination of decoupling and transmission technique as well as to the short distances between sensor and optical transmission the influences of noise can be significantly reduced, wherefore various parameters like the amplification factor or the dimensions of the sensor can be used to optimise the signal to noise ratio (SNR).
After the signal digitalisation the data processing is started with a digital filtering of continuous noise signals. Sinusoidal noise, caused by e.g. radio and communication services, is suppressed with new developed frequency rejection filters in frequency domain and white noise owing especially to the optical transmission is filtered with wavelet techniques [5]. Afterwards periodically appearing noise pulses can be eliminated using cross correlation methods, whereas stochastically occurring pulse shaped noises like corona discharges are separated using the new localisation technique: pulses from outside the transformer can not be calculated back to virtual origins along the coil, thus a comparison of the relation of frequency spectra of the impulses measured simultaneously at the neutral and at the bushing can be used in order to separate the data into groups, which is demonstrated on two different measurements.

**MEASUREMENTS USING THE PD SYSTEM**

The introduced system has been applied during different measurements on transformers, thus as an example the results of the PD evaluation on a 110 kV /35 kV / 40 MVA / Yy0 / ONAN transformer in operation (Fig. 6) as well as on a 220 kV /118 kV / 10 kV / 150 MVA / Yy0 / ONAF transformer (Fig. 7) are presented in the following. From both examples it is obvious that even without a digital filtering an adequate signal to noise ration (SNR) can be achieved (Fig. 6a and 7a), although an improvement using the mentioned filtering techniques is recommendable. After the suppression of sinusoidal and white noise (Fig. 6b and 7b) a rejection of all signals from outside the transformer, like corona discharges, can be performed (Fig. 6c and 7c). Therefore a separation between inner and outer impulses is carried out by comparing the frequency spectra quotient between the signals measured at the bushing and the neutral simultaneously, thus it is possible to divide the frequency spectra into groups as displayed in Fig. 8, where signals measured at the 40 MVA transformer are regarded.
As demonstrated by Fig. 8 the detected signals can be divided into two groups: PD signals and external noise pulses, which are much more damped due to the transmission through the whole coil, thus the spectra quotient has a significant higher attenuation, wherefore usually only a small signal can be measured at the bushing.

In a final step the PD signals, which remain in the data stream after the denoising and the pulse separation are analysed concerning their apparent charges as well as their origins. In this case the highest PD impulses have an apparent charge in the range of 1000 pC at the 40 MVA transformer, whereas on the 150 MVA transformer single impulses could be 10 times higher and as displayed in Fig. 6 and 7 much more PD pulses per cycle could be detected, which explains the releases of the Buchholz-relay at the 150 MVA transformer, which have been the reason for performing a PD measurement. Due to the fact that at the 150 MVA transformer all high voltage phases have shown such a high PD activity, while at the 40 MVA transformer only one phase has been noticeable, the owner of the 150 MVA transformer decided to replace the transformer, thus it was not necessary to determine the PD origin.

For the 40 MVA transformer the determination of the PD origin, which is based on the modelling of the transformer coil and explained comprehensively in [6], lead to the result that there is mainly one defect, which is located close to the beginning of the winding nearby the bushing. An additional PD localisation based on acoustic measurements performed by an other institution confirms this result.

CONCLUSIONS

The need for methods which enable a precise statement about the insulation condition of transformers becomes more and more relevant. The online monitoring of PD activities on power transformers can offer information on the actual condition of their insulation leading to an estimation of their reliability. Thus enabling maintenance in time if necessary, which may result in a life prolongation of these components and consequently to a technically and economically optimised energy supply, which is preferable considering the background of deregulation.

Actually used PD measurement techniques on transformers can not be performed efficiently on-line, thus an integration into monitoring systems is impossible, wherefore a new PD monitoring and diagnosis system has been developed. The introduced method allows

- an adequate noise suppression,
- a determination of the apparent charge and
- a localisation of the PD origin,

due to the use of enhanced signal acquisition techniques and new digital signal processing algorithms, which uses the sectional winding transfer functions (SWTF) of the transformer in order to determine the PD origin according to the convolution theorem.

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