Condition Assessment of Power Transformers using Enhanced Partial Discharge Measurement Techniques

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Abstract
In this contribution enhanced partial discharge (PD) measurement and evaluation techniques used for an improved condition assessment on power transformers are introduced and discussed. The PD measurement system itself is based on a wide-band electrical decoupling of the PD signals using special sensors and a superior signal transmission technology, thus the influences of disturbing noise can be significantly reduced during the online measurement. Remaining noises and pulses from outside the transformer are afterwards suppressed using improved digital signal processing tools, thus finally all PD pulses can be extracted and evaluated in such a manner that the apparent charge and the location of the impulses can be determined.

The single steps concerning the signal acquisition, denoising and analysis are explained exemplarily on different online measurements leading to the introduction of a new PD monitoring system.

1. Introduction

Transformers are one of the most important and cost-intensive components of the electrical energy supply networks, thus it is of special interest to prolong their life duration while reducing their maintenance expenditures. A view of the age structure of the transformers in service for different German 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.

Furthermore, the liberalization of the energy market in some countries forces the power supply companies to take extraordinary steps for optimizing their profitability, which is done, among other measures, by a so called life-risk management.

Therefore detailed information about the operation conditions of transformers is required, which can be gathered from monitoring systems. On this basis preventive maintenance in time can be initiated, which finally reduces failures and breakdowns, leading to an optimized power delivery and to a maximum profit.

Usually abnormalities are shown by such online operating monitoring systems, thus further measures like a DGA (Dissolved Gas Analysis) can be performed in order to check whether there is a serious problem or not. Using DGA techniques usually two different kind of failures can be distinguished: electrical and thermal faults. In case of indication for an electrical failure often PD measurements are used as an approved and practical tool for diagnosing the actual condition of the insulation, especially if the measurement can be performed online, because only in this case the electrical and thermal strains of the insulation are realistic, thus leading to a more precise evaluation of PD phenomena.

However, there are mainly four different used state of the art PD detection systems: Narrow- and wide-band electrical PD detection techniques and acoustic or ultrasonic measurements. The last mentioned methods often enable a rough PD localization, which is indispensable for initiating an adequate maintenance if necessary, but they do not allow a determination of the apparent charge, because a calibration is not possible. For narrow-band electrical measurements it is vice versa, that means a determination of the apparent charge is possible but they usually fail on a localization. The advantages of these methods are combined by wide-band electrical methods, because they allow, similar to narrow-band PD measurements, a precise determination of the charge and furthermore a localization is possible by evaluating the shape of the gathered PD signals, which has been subject of many investigations [1]. Nevertheless, wide-band PD detection techniques, which use a bandwidth of a few MHz, are more than other methods influenced by surrounding noise due to the higher bandwidth, although also for other techniques this problem still exists. Therefore it is necessary to have special digital signal processing tools in order to separate PD from noise pulses before an evaluation of the PD impulses can be performed, thus for an automated detection and interpretation of PD signatures an modular structured PD monitoring system is necessary, which can be adapted to various environments like the system which is introduced in more details consecutively.

2. PD Monitoring System

The structure of the developed PD monitoring and evaluating system is shown in Figure 1, where it becomes obvious that the system mainly consists of two modules: the online data acquisition and the offline data
analysis. For the data acquisition a new, patented detection sensor has been developed, which consists of a metal plate with defined dimensions and is mounted on 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.

After the signal digitalization 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 [2]. Afterwards periodically appearing noise pulses can be eliminated using cross correlation methods, whereas stochastically occurring pulse shaped noises like corona discharges are separated using a new developed two stage filtering technique. In the first stage the signal detection characteristics of the mounted sensors are used in order to separate large corona discharges from PD signals coming from inside the transformer, because if there is a significant corona activity at a certain phase the neighbour sensors will detect these signals too, due to a kind of antenna effect. The second stage is based on the localization principle [3], which uses the transfer function of the transformer coils in order to determine their origin: if a signal can be measured at the bushing and at the neutral, the measured signal at the neutral has to be almost identical with the signal measured at the bushing convoluted with the measured impulse response of the whole coil if the signal comes from outside the transformer, thus a separation of inner and outer discharges is possible.

The suppression of the mentioned noise types is demonstrated on two different measurements in the following, thus the remaining signals represent PD pulses from inside the transformer, which can be finally evaluated in order to determine their apparent charge and their origin [3].

3. Measurements on-site

The introduced system has been applied during different measurements on transformers, thus as an example the measurement on a 110 kV / 35 kV / 40 MVA / Yy0 ONAN transformer in operation are presented in Figure 3. This figure shows the transformer (a) as well as the measurement setup concerning the signal decoupling (b) and the used equipment, which has been placed inside a vehicle (c) for an adequate shielding. The digitized results of a measurement are depicted in Figure 3d, where the signals from the sensors mounted on all three phases (U / V / W) and the neutral (N) of the upper voltage have been recorded simultaneously. For the three phases the same scales per division has been chosen, whereas for the neutral the setting has been more sensitive because of the smaller signal amplitudes. Figure 3d illustrates that even without a digital filtering a good signal to noise ratio (SNR) can be achieved using the new signal decoupling and transmission technique. Moreover, from a comparison of the recorded signals it becomes obvious that especially in the middle phase (V) a lot of impulses can be measured, of which some correspond to the data stream of the neutral, which is an indication for inner

![Figure 1: Scheme of developed PD monitoring system](image1)

As illustrated in Figure 2 the signal transmission is performed via an enhanced fiber optic technology with a bandwidth of about 10 MHz, whereas the used quadrupole (QP) and the amplifier inside the battery supplied unit cut off frequencies below a few 10 kHz using an amplification of 0 to 50 dB adjustable in 10 dB steps.

![Figure 2: Scheme of data acquisition](image2)
partial discharges, because signals from outside are often so much attenuated that they can not be detected properly at the neutral.

Consequently the introduced system can allow first statements about the PD activity during the online measurement, even if no digital filtering or data processing has been performed.

Figure 3: Measurement setup and data acquisition
a) 40 MVA transformer
b) Mounting of the sensors and signal transmission units
c) Used instruments inside a shielded vehicle
d) Simultaneous PD signal recording on 4 channels

Figure 4: Measurement on a 520 MVA/420 kV transformer
An example of the data processing after a PD measurement on a 520 MVA / 420 kV transformer shown in Figure 4, is demonstrated in Figure 5, which represents a screenshot of a special software package developed with MATLAB. On the top of this figure the measured data stream for one cycle can be seen, which is filtered by a low pass with a cut off frequency of 2.5 MHz and afterwards by a high pass using a cut off frequency of 10 kHz. Finally in the graph on the bottom of Figure 5 the signal after the suppression of sinusoidal and white noises is shown, using frequency rejection filters in frequency domain as well as wavelet filtering techniques.

Figure 5: Signal processing using self designed software
To any time during the data processing process impulses can be detected using a self developed algorithm, thus each pulse can be analyzed, as shown in Figure 6.
However, before the determination of the apparent charge of single impulses all pulses from outside have
to be suppressed by the two stage filtering algorithm, which have been explained in the previous section, resulting in graphs according to Figure 7.

Figure 6: Impulse detection

On the top of Figure 7 the recorded data stream from phase U for one cycle after the mentioned band-pass filtering is shown, whereas in the middle graph the data after the suppression of continuous noises is visualized. Finally in the bottom graph all corona signals have been rejected, thus almost no significant signals are remaining. Therefore, in this case no critical PD activity could be observed on the regarded phase, because almost all signals came from outside the transformer, thus further measures have not been necessary.

Figure 7: Suppression of noise and corona signals

Figure 8: Automated PD monitoring system

In the meantime a realization of the described PD system has been carried out, leading to a stand alone PD monitoring and evaluation unit for automated PD measurements as shown in Figure 8, in order to improve the condition assessment on power transformers based on a PD diagnosis.

4. CONCLUSIONS

The need for methods which enable a precise condition assessment of power transformers becomes more and more relevant, thus among others methods for the online monitoring of PD activities on transformers, which can offer information on the actual condition of their insulation leading to an estimation of their reliability, have to be improved. Therefore a new PD monitoring and diagnosing system has been developed, which has been approved during various online measurements as demonstrated, in order to enable maintenance in time if necessary, which may result in a life prolongation of these components and consequently in a technically and economically optimised energy supply.

5. REFERENCES

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