Partial Discharge Measurement and Evaluation Techniques for Transformers

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Abstract: For an efficient power transmission and distribution with high reliability it is imperative that the used high voltage equipment such as transformers operate confidently at their maximum load without sustaining any malfunctions. For this purpose a diagnostic of the components is very important. Today the partial discharge (PD) measurement is a very important tool for the diagnosis and determination of the insulation condition of transformers. In this contribution some aspects of PD measurements on transformers are presented with a special focus on the problems arising under noisy conditions, which are typical for measurements on-site. A new PD monitoring system is introduced enabling not only the detection of the discharges but also the localization of the PD-origin.

1. Introduction

On the distribution level close to the consumer and especially in residential areas dry type transformers have become increasingly popular due to their reduced maintenance expenditures and improved environmental compatibility. A disadvantage of these also as epoxy resin insulated known transformers is their sensitivity against partial discharges (PD). Opposite to liquid insulation there are no self healing effects in solid insulation materials, thus PD activities may cause serious damages inside the insulation leading to interturn short circuits of single windings leading to larger short circuits.

PD measurement techniques like ultrasonic measurements are not applicable for dry type transformers due to the high acoustic damping of the solid material. Also chemical analyses like DGA (Dissolved Gas Analysis), as they are frequently used for oil filled transformers, can not be used. For these reasons only electrical PD measurements, which can be subdivided in wide- and narrow-band techniques, are applicable for dry type transformers [1,2].

Nowadays used PD measurement techniques on oil filled power transformers can be subdivided in chemical, acoustical and electrical measurements. Chemical methods are based on the analysis of dissolved gas generated inside the transformer due to PD activity. The integral characteristic of these regularly performed analyses allows indications on the long term behavior of the PD activity and therefore on the insulation condition. For information on the actual PD occurrence acoustic and electric PD measurements are preferable. The focus of acoustic or ultrasonic measurements is based on a PD location, whereas the electric measurements are orientated to a precise determination of the apparent charge, although investigations have shown, that sometimes a PD location is possible but complicated [3].

Narrow band electrical PD measurements are carried out offline, thus an enormous effort concerning the required equipment is unavoidable. Beside the measurement apparatus an external generator generally with a higher voltage frequency than the normally used one is necessary in order to discriminate noise generated by power frequency from phase correlated PD signals and to avoid saturation of the core, if test voltages at higher than the nominal voltage are required. Consequently up to now no efficient online PD analysis techniques are available, thus new methods have to be explored.

A new method for the evaluation of electric measured partial discharges has been developed. This method uses the transfer functions of a transformer for a PD location [4] and enables additional possibilities.

2. PD measurement on try type transformers

Often it is not possible to find a frequency range, in which the noise signals can be suppressed efficiently, thus a sensitive PD measurement can not be performed, although this is necessary especially for dry type transformers, because apparent charges above 20 pC have to be determined, according to the limit defined in the IEC 60726 [1]. Furthermore with the actually used electric PD measurements a localization of the PD source can only be achieved in seldom cases. Therefore a prototype of a new PD detection system has been developed, which allows beside the determination of the apparent charge also a localization of the PD origin.

Figure 1: Functional principle of new PD detection system
The principle of this patented system is quite simple [5]; by mounting a couple of sensors on the surface of the transformer coils the electromagnetic radiation caused by the partial discharges can be detected. A localization becomes possible, because on sensors, which are close to the PD source a higher signal can be decoupled than on sensors, which are placed far away, as clarified in Figure 1.

On a coil of a dry type transformer 7 sensors have been placed, one on each winding package. Into the lowest clamp calibration signals with an apparent charge of 20 pC have been injected, which close to ground via a 50 Ω resistor at the upper clamp. The signals decoupled at the sensors were band-pass filtered, thus only frequencies between 10 kHz and 1 MHz are amplified and recorded. The digitized signals are illustrated in Figure 2 making it obvious, that the amplitude of the recorded signals decrease with increasing distance between sensor and the PD source or respectively the calibration impulse generator. Thus in this case the signal from sensor 7 has the highest amplitude, because it is closest to the PD origin.

3. Paper-oil filled transformers

Due to the different insulation media and the different construction for paper-oil insulated transformers other techniques than for dry type transformers have to be used, but also for these transformers PD activity and its consequences are most suitable to be considered. Therefore a new PD evaluation technique has been developed which is explained in the following.

PD localisation

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. The magnitude spectrum of all sectional transfer functions is displayed in Figure 3.

![Figure 2: Voltage signals of the sensors 1 to 7 (scale 1V/10µs)](image)

![Figure 3: Sectional winding transfer functions](image)
As expected it becomes obvious from Figure 3 that the damping generally increases with ascending numbers of winding sections between origin and decoupling point. Thus 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. Furthermore, it is noticeable that transfer functions from origin number \( n \) to the bushing have significant similarities up to a frequency of about 1 MHz to those from origin number \( 8-n \) to the neutral (compare e.g. origin 3 in Figure 3).

This fact can be explained by the comparable size of the winding sections these transfer functions include, thus resulting in a similar behavior for lower frequencies for which mainly the inductive signal transmission is responsible. For higher frequencies above 1 MHz the dissimilarities are primarily caused by differences in the stray capacitance as well as by the influences of the other coils. However, the similarities at lower frequencies could be used for the determination of the sectional winding transfer functions by computation and modeling of the tested transformer.

The results obtained with the transfer functions convoluted with the measured PD-signals are exemplarily shown in the Figures 4 and 5. In Figure 4 a discharge has been injected into one clamp using the needle-plane electrode configuration in air. On the top diagram in Figure 4 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 accuracy.

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 Figure 5, where similar to Figure 4 the measured signals measured at the bushing and the neutral and the calculated signals 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. A further evidence therefore is that the signal calculated at the bushing lag 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 doubtless localized with 100 % correctness independent on how the discharge has been generated or on where it has been injected. The evaluation of the calculated signals is also facilitated by the fact that signals far away from the actual origin have significant dissimilarities especially concerning their maximum amplitudes. This is why a certain voltage level at the bushing or at the neutral can be caused by a lower / higher input voltage at an origin closer / further from the decoupling point due to the lower / higher damping. Furthermore a signal coming from outside and travelling though the complete transformer winding can be easily recognized as noise by the evaluated sum on winding section transfer functions and its influence of the signal change. Measurements in the laboratory and on-site have shown the good performance of this method [7].

4. Conclusion

Dry-type transformers insulated by epoxy resin are especially sensitive to partial discharges, which are usually accompanied by irreversible degradation and destruction of the insulation that may finally lead to a breakdown of the whole system. In order to prevent such failures it is necessary to monitor the transformers regularly during operation, which can be performed using PD measurement techniques preferable based on the electrical decoupling of the PD signals. Furthermore, based on these investigations and experiences a prototype of a new PD detection system is introduced, which can be effortlessly applied and enables beside the determination of the apparent charges a localization of the PD source, thus maintenance procedures can be initiated in time for ensuring an uninterruptible power supply.

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 optimized energy supply.

Actually used PD-measurement techniques on transformers can not be performed efficiently online, thus an integration into monitoring systems is impossible wherefore other methods have to be investigated. The presented method has been tested in the laboratory and fulfills the most important requirements as • precise PD-localization • accurate determination of the apparent charge • determination of the PD-type by convoluting wide-band measured PD-signals decoupled at the bushing and at the neutral using the sectional winding transfer functions of the transformer coil. With this procedure the PD-signal becomes visible at its origin, which is not possible with any other known method, thus the convincing results encourage further investigations under online conditions. Although more experiences are needed for the determination of the required sectional transfer functions an integration of this technique into future monitoring system is imaginable.

5. References


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