Diagnosing the Insulation Condition of Dry Type Transformers using a Multiple Sensor Partial Discharge Localization Technique

Peter Werle, Hossein Borsi, Ernst Gockenbach
University of Hannover, Institute of Electric Power Systems
Division of High Voltage Engineering, Schering - Institute
Callinstrasse 25 A, D-30167 Hannover, Germany
Werle@mbox.si.uni-hannover.de

Abstract: In this contribution an electrical partial discharge (PD) measurement technique for dry type transformer is presented. The method has been tested in the laboratory as well as on a transformer in the test bay using an automated partial discharge evaluation based on the comparison of quasi simultaneously detected PD patterns at different decoupling points. Therefore a multiple sensor system is placed on the surface of the transformer coil, thus PD signals can be measured at various sites along the winding before they are processed and compared. The described technique enables beside a localization of the PD source a determination of the apparent charge, which can be more accurate than conventional narrowband PD measurements via a quadripole in parallel. A discussion of the results leads therefore to a proposal about improvements concerning the calibration for actual PD routine tests on dry type transformers.

INTRODUCTION

Since the use of PCB contaminated transformers is restricted and the production of PCB is prohibited many distribution transformers for power levels up to 24 MVA and voltages up to 36 kV have been replaced by dry type transformers usually insulated by epoxy resin. Dry type transformers are due to the absence of self healing effects especially sensitive to partial discharge (PD) phenomena as a result of local field strength extensions in non-homogenous areas of the insulation, which may lead to serious damages over a long time period if they appear once. Therefore PD measurements are recommended with the aim to localize critical points inside the solid insulation, thus a repair of the failure or an improvement in the design of the transformer becomes possible.

However, state of the art PD detection techniques, like acoustic or ultrasonic PD localization methods, are often unsuccessful concerning a precise localization of the PD origin. Using these kinds of measurements the PD signals can in general only be acquired inaccurately, due to the high attenuation of the solid insulation, thus a correlation of the gathered signals does not lead to the required results. Furthermore a determination of the apparent charge is not possible by acoustic and ultrasonic measurements, because a calibration can not be performed. This is the reason why usually electrical PD measurements are used during routine tests on dry type transformers after their manufacture, because they allow the determination of the apparent charge but fail on a localization. Therefore a new PD measuring and evaluation method has been developed, which has been investigated on a test setup in the laboratory as well as on a 400 kVA dry type transformer in the test bay. The results show that beside a localization of the PD origin also a more precise determination of the apparent charge can be possible in comparison to recently applied methods, because the PD signal is decoupled more close to the PD origin, thus damping or distortion as they usually appear during conventional parallel decoupling via a quadripole can not falsify the evaluation. Beyond this background it is discussed if the allowed charge limit of 20 pC at dry type transformers [1] can be detected more accurately if another calibration technique than those defined in the standard [2] may lead to more precise results and finally to a better quality assurance.

FUNCTIONAL PRINCIPLE AND BASIC MEASUREMENTS

The functional principle of the patented method [3] is quite simple and based on the simultaneous detection of the electromagnetic radiation that is influenced by the PD signal on a multi sensor system, which is mounted on the surface of the transformer coil in such a way that at each winding package one sensor is placed as shown in Figure 1.

A localization of the PD source can be performed by comparing the sensor signals, because the closer a sensor is located to the PD source the higher is its output signal [4].
Due to the fact that usually several sensors are necessary the simultaneous detection is replaced by a quasi simultaneous decoupling using a multiplexer to record subsequently the PD activity at the sensor and at a quadripole in parallel to the test object. This procedure reduces the measurement efforts drastically, because otherwise a PD instrument with a lot of input channels would be necessary to log the sensor signals cointstantaneous. Nevertheless, this proceeding does not influence the results significantly, because during the short measurement time the PD activity usually does not change considerably. The signals of the sensors are amplified with a special differential amplifier, which is battery supplied and amplifies the signals against its own reference potential before the signals are transmitted via a fiber optic cable to the PD meter using a frequency range between 100 kHz and 250 kHz. As depicted in Figure 1 at a dry type transformer coil, in whose center a grounded metallic tube has been positioned in order to simulate the transformer core, high voltage has been applied for 120 s during a measurement session. Throughout each session PD signals on two channels have been recorded alternately in such a way that each channel has been active for in total 60 s, but a switching of the channels takes place every 10 s. On channel 1 always the pattern from the quadripole has been determined whereas at channel 2 successively all sensors have been connected, thus leading to the results shown in Figure 2, where the absolute value of the apparent charge versus the phase angle is displayed for the signals gathered from the sensors and from the quadripole during two different tests. During the tests A (upper two diagrams) and B (lower two maps) it is obvious from the measurements at the quadripoles that the PD activities have been more or less constant during each cycle. However, for test A the signals at the sensors increase sensor by sensor leading to a maximum signal at sensor 7. This indicates that the PD source has to be closest to sensor 7, which indeed has been the case, because for this test a needle plane arrangement inside an epoxy resin block has been connected to the lower clamp of the coil, which is nearby sensor 7. The PD signals generated inside the epoxy resin block close via the coil and the coupling capacitor to ground and causes therefore at the sensors 7 to 1 decreasing signals, due to the damping, distortion and deformation of the PD signals on their propagation through the coil.

Regarding the results of test B the signals at the sensors increase from sensor 1 to 4 but remain more or less equal from sensor 4 to 7. In this case the PD origin has to be at sensor 4, because the generated PD current at this point flows via the upper coil and the coupling capacitor to ground and causes therefore a voltage drop between the sensors 4 to 1. Because of the fact that almost no PD current flows through the lower part of the coil the sensors 4 to 7 are on the same potential, thus the acquired signals have similar amplitudes. For the described test a grounded needle has been mounted on the surface of the coil close to sensor 4, thus again the PD source has been localized correctly.

Figure 2: - PD measurement results for the test setup
PD DETECTION ON A TRANSFORMER IN THE TEST BAY

For the measurements on a 10 kV / 400 V / 400 kVA dry type transformer the setup depicted in Figure 3 has been used, in which only phase W of the transformer has been supplied with a high voltage of approximately 10 kV, whereas all other coils have been grounded, which is in accordance with the actual standard [2]. The high voltage coils of this transformer consist of 12 winding disks, thus in total 12 sensors have been mounted along phase W.

Figure 3: - PD measurement on a 400 kVA transformer

After verifying that the circuit without the specimen is free of discharges a calibration of the sensors has been performed. In contrast to the calibration of the PD detection via quadripole for which a PD pulse has to be injected in parallel to the specimen [2], the calibration impulse has been applied into the lower clamp of phase W, which is close to the sensor 12. Therefore it is possible to calibrate sensor 12, but assuming that all other sensors are uniformly positioned to their according winding package this calibration is valid for all sensors. The apparent charges measured at all sensors and via the quadripole during this calibration are shown in Figure 4, where a charge of 20 pC has been used and the frequency range of the PD analyzer has been adjusted to the span between 40 kHz and 800 kHz.

Figure 4: - Calibration of sensors

From Figure 4 it is obvious that at sensor 12 the correct apparent charge can be measured and that at sensors which are more distant from the PD source the measured apparent charge decreases, what corresponds to the functional principle of the localization. Furthermore it can be seen that at the quadripole only an apparent charge of about 7.3 pC has been measured, although a calibration impulse of 20 pC has been injected, thus only 36.6 % of the original charge has been detected. As mentioned before the reason therefore is that the PD pulse is damped and distorted on the way from its source to the decoupling point as shown in Figure 5, thus the measurement at the quadripole can not assumed to be precise in any case. It has to be pointed out that the closer the PD source is located at the end or respectively lower clamp of the coil the more inaccurate a measurement via the quadripole becomes.

As example for the signal deformation an injected calibration pulse of 20 pC as well as its response at the upper clamp of the coil has been recorded simultaneously as depicted in Figure 5.

Figure 5: - Voltage-time signal of injected PD pulse and its response

Another conspicuousness concerns the fact that the apparent charge measured at the quadripole is about as twice as high as detected on sensor 1. The reason therefore is that the equivalent circuit the PD pulse has to pass through operates in the regarded frequency range of 40 kHz to 800 kHz like a lowpass, which can also be seen in Figure 5, where higher frequencies (see especially steep front of the injected impulse) are much more damped than lower ones (compare with damping of the oscillation). In addition the transfer characteristic of the sensors itself can be approximated by a highpass, thus due to this two opposite tendencies the distorted signal is more accurately detected via the quadripole because of its better transfer properties compared with those of the sensors.

After this preparative measurements high voltage has been applied to the coil and the signals at the quadripole and at the sensors have been detected subsequently similar to the measurement described in Figure 2. The results of this test are shown in Figure 6, where the absolute values of the phase related apparent charges detected by the sensors are displayed. For the reason that during this investigation the PD activity detected at the quadripole has been again almost uniformly, these signals are not shown. It should only be mentioned that the maximum apparent charge measured at the quadripole has been around 15 pC, which is below the limit defined in the actual standard [1]. However, it becomes obvious from
Figure 6 that there is a slight increase of the signals gathered from sensor 1 to sensor 9, but between sensor 9 and 10 a significant raise of the apparent charges can be noticed, whereas from sensor 10 to 12 the signals remain nearly constant. This indicates that a PD source has to be close to sensor 10 or respectively in the winding package this sensor is placed on. The maximum apparent charges which have been measured at the sensors 10 to 12 are above 30 pC, which is notably above the defined limit, thus this transformer should fail the PD test but it would not if only a measurement via the quadripole would have been performed.

Figure 6: PD measurement results for a 400 kVA transformer

DISCUSSION

The investigations have shown that with the introduced multi sensor system PD activities can be localized on dry type transformer coils with a simple comparison of the phase related apparent charge diagrams of all sensor signals. The resolution of the localization is at least one winding package, but can be increased by additional techniques if required, although in this contribution this is not pointed out in details. Furthermore at the sensor closest to a PD source the determination of its apparent charge is possible with a higher exactness than with any other known method. Especially compared to the often used decoupling via a quadripole in parallel it has been proven that it might happen that the PD level measured via the quadripole is below the defined limit although it is above the limit at the PD origin, which can be clarified with the sensor system. This situation is not satisfying, thus it is proposed that in case of parallel PD decoupling during PD tests on dry type coils a second calibration is performed if any PD activity is detected during the test. For this calibration an impulse with an apparent charge of 20 pC should be injected into the lower clamp of the coil and the charge at the quadripole, which has been calibrated conventionally in advance, should be measured. If this charge is used as limit adapted to the specimen it can be guaranteed that the criteria of the actual standards are met. Although there is a special note in the annex of the actual standard [2] it would be reasonable if this problem is solved.

CONCLUSION

An improved partial discharge (PD) measurement and evaluation technique has been tested on different setups in the laboratory as well as on a 400 kVA dry type transformer. The PD measurements using the introduced multi sensor system have shown that winding packages in which PD signals appear can be determined efficiently. Furthermore the method allows in general a more precise determination of the apparent charge than conventional parallel decoupling via a quadripole, because the PD signal is decoupled close to the PD origin, thus damping or distortion can not falsify the evaluation. For conventional parallel decoupling methods on dry type transformers a modified calibration method should be considered, for which the calibration impulse is not only injected in parallel to the specimen but also in the end of its winding, thus improving not only the accuracy of the measurement but mainly the intention of quality assurance of PD tests after the production. Otherwise the results show that the larger the part of the coil a PD pulse has to pass the more inaccurate becomes the parallel decoupling technique. As it has been demonstrated this can lead to the problem that a dry type transformer has partial discharges above the allowed limit of 20 pC according to the actual standard, without noticing this dilemma during a conventional PD measurement.

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