APPLICATION OF PD-LOCALIZATION SYSTEMS DURING PRODUCT RESEARCH TESTS

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Abstract: Electrical power transformers are the hub of electrical power transmission and distribution systems. This important task requires high reliability over a long period of time (up to 30 and more years) which can be achieved only by using components of the highest possible quality.
As is well known, manufacturing of transformers is a very costly and time consuming process and to optimize it most companies nowadays try to outsource production of labour intensive parts such as tanks, insulation components etc. It allows significant increase of the production capacity because of the shorter throughput times.
WEIDMANN as a company who is in transformer insulation business for over 100 years has been doing significant R&D work since many years. Before any new insulation components are offered for sale, extensive mechanical, chemical and/or electrical tests are performed in order to guarantee the high reliability of the product over many years.
In this paper a field report on an acoustic PD-localization system as an enhancement of a traditional electrical PD measurement system is given. This kind of system is used by WEIDMANN to test prototype products (e.g. Lead exits) in the high-voltage lab at Graz University of Technology (Austria). It allows precise localisation of the PD source within a test vessel caused either by the applied AC or DC voltage stress.

Key words: Transformers, insulation components, PD-localization systems, acoustic PD-localisation

1 INTRODUCTION

Electrical power is essential for the industrial world. In almost all areas of the everyday life a reliable supply with electrical energy is a mandatory requirement. Thus components of electrical power generation, transmission and distribution have become more and more important. For the distribution system level (0.4÷30kV) the large quantity and the regional limited influence lead to an optimisation considering replaceability versus reliability. For generation (≤30kV) and transmission level the main focus is more on reliability as these devices are mostly of individual, specific construction. Besides transportation from factory to the installation site is a non negligible challenge, which involves many factors and has a direct impact on the design of the device.

Power transformers are indispensable elements of the electrical power transmission and distribution. Because of their key role in the delivery of electrical energy they must have a high reliability which in turn depends on factors like design, used materials, quality of manufacture, operating method, maintenance and many more.

Manufacturing of power transformers is a very complex, time consuming process which binds high financial resources. The overall costs in general consist of two parts: labour and material. To curtail them transformer manufacturers these days try to outsource all labour intensive processes as making of metallic parts (e.g. tanks, radiators etc.) or insulating components (e.g. lead exits, shield rings etc.) to external companies - in this case there is no need to have own workshops - throughput times can be reduced and profit increased. The only important requirement is that these external suppliers must be able to deliver the products of required quality on the appointed time.

For suppliers the only way to fulfil this requirement is to do serious R&D work. Mechanical, chemical and/or electrical tests must be performed under realistic and severe conditions to guarantee the high reliability of the end product. One of the quality parameters during the electrical testing of insulating components is the partial discharge (PD) behaviour [1]. The knowledge about the PD inception voltage provides the design engineer an important tool to design a transformer and later to evaluate its safety margins.

Electrical test laboratories usually use air insulated high voltage supply terminals to achieve a high flexibility for different supply generators and setups. For testing purposes under oil an air-oil bushing and a vessel are needed. In most cases an appropriate test bushing which is higher utilised than a standard bushing or a special indoor bushing is used. In the case of UHV testing a pressboard barrier package for the bushing oil side is additionally necessary to energise the device under test. In combination with the mandatory required space for the whole (inner and outer) test setup a multitude of potential disturbing sources is given.

Housekeeping in the laboratory is essential to avoid outer PD. Especially at DC-tests the combination of humidity and dust on the superficial area and the long testing periods leads to unavoidable and in most cases unknown disturbance sources. One solution for this situation is the localization of the PD source.

Standard PD measurement systems according to IEC 60270 allow measurement of the apparent PD-charge of the whole test setup [2]. On the other hand this technique gives little to no information about the type and the location of the fault. The recorded electrical PD signal is maybe not even located inside the test vessel and so an accurate conclusion about the device under test cannot be given. Last but not least, the error sources might be located at the bushing or the barrier package or the supply generator thus causing a time-consuming and expensive outage or demolition of the whole test setup, in the worst case. Using a PD-localization system in parallel to electrical one allows the test team to localise the fault source with high certainty and precision.

2 PD-LOCALIZATION

The localisation of PD with a setup according to IEC 60270 consisting of coupling capacitor and quadrupole is only at very simple and well known arrangements possible [3]. At complex arrangements and at DC-tests this technique will fail. Therefore other methods were developed [4]:

2.1 Assessment of PD-level

The method uses damping effects of the high frequency part of PD on the transmission path. Therefore the PD level must be measured (preferably simultaneously) at several locations [3]. This technique is successfully used at GIS with UHF-sensors and at power transformers where signals coming from the HV and LV bushings are analysed. This method is not applicable in a HV-laboratory because of the simplicity of the test setups – there is no sufficient damping (either it is not possible to place different couplers (only a few laboratories have several UHV-couplers and the necessary power of the generator and space to operate them) or achieving the damping).

2.2 PD-Spectrum

The method uses the spectrum of the partial discharge to determine the sources [5]. The measured spectrum of a discharge in air differs significantly from discharges in oil because of a nonlinear damping of the transmission path. On the other hand, the behaviour of the PD must be known in detail and therefore a shielded laboratory with wideband measuring equipment is necessary. Especially at UHV a cavity resonator can be formed by the shielding and normally the walls are reflecting and not damping which limits the utilizable band width.

2.3 Additional UHF sensor

This method makes use of the fact that the bushing damps ultra high frequency (UHF) signals. By placing an UHF sensor inside the test vessel a yes/no decision is possible [6]. It helps at transformer investigations to make a fast decision about presence of PD. There are UHF sensors available which can be easily placed in drain valves even at operating transformers. In case of AC this method helps the operator to make his decision but for DC application the authors were not able to receive any signal. Either the PD-spectrum at AC is totally different from the one at DC and hence the used sensor was in the wrong frequency range or the used build-in signal processing hardware did not tolerate a DC (offset) field.

2.4 Triangulation

This method uses time differences of several sensors. The sensors can be on UHF or acoustic basis. The difference between the two technologies is the propagation velocity. The UHF sensor receives signal on electro-magnetic base which propagates with about 2/3 of light speed ($\sim 2 \cdot 10^8$m/s). The acoustic propagation of the mechanical signal of PD is in the range of $1.3 \div 1.4 \cdot 10^3$m/s depending on the oil temperature. The principle in both cases is the same though performing measurements with acoustic sensors is much simpler than with UHF sensors. The further discussion of this paper is focused on the acoustic technique.

The analysis of the PD location can be divided into two groups: with electrical trigger and without [7]. Due to the fact that electrical signals propagate more than 100 000 times faster than the acoustic ones an electrically linked (coupling capacitor and quadrupole or UHF) sensor can be used to determine the chronological origin of the PD. Using the delay time between the electrical and acoustic signal and knowing the sensor position and propagation velocity the most likely source of the PD can be evaluated. For spatial (3D) identifications at least three sensors are necessary. Without an electrical trigger, a virtual origin has to be found, which requires more sensors and more computation [8,9].

So far so good, but if there are materials with different acoustic properties the problem becomes more difficult [3,10]. Not only the absorbing effect of insulator barriers but also deflecting effects and anisotropy of the propagation will lead to deviations or pseudo sources. Especially for large transformers the localisation is tricky and needs a lot of experience. For a simple test setup however it will be manageable.

3 SETUP

Due to the limits of own test lab, WEIDMANN since several decades perform tests at Nicola Tesla Laboratory at Graz University of Technology which is one of the largest hermetically shielded labs in science in Central Europe. To test insulation systems and components a 30m³ steel tank (vessel) is in use.

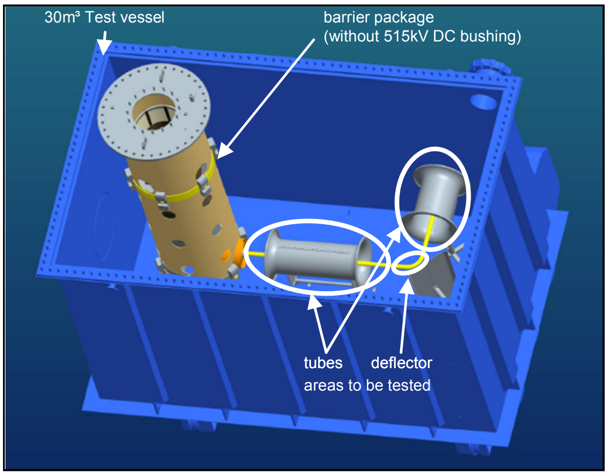

Figure 1: 3D visualisation of a test setup (without insulation system, 2 tubes and 1 deflector, internal vessel dimension 4.3x2.6x2.6m)

For DC investigations a 515kV bushing with specially designed barrier package for voltage control are available. The test object can be connected to the bushing by a special plug-in adapter. The turrets of a transformer are simulated by metal tubes (with rounded entries) inside the vessel. Compared with a real transformer most of the vessel consists of oil and relatively little insulation material and metal.

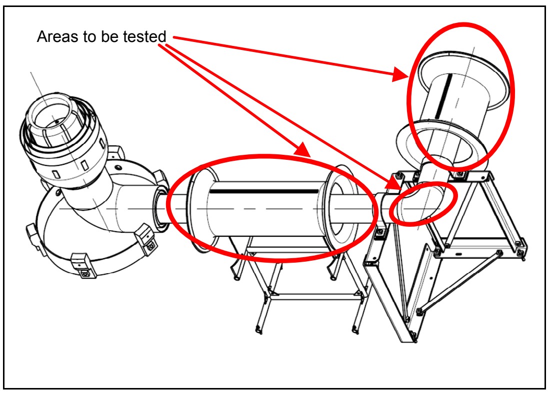

Figure 2: 3D visualisation of the inner part of the test vessel with insulation system (without deflector)

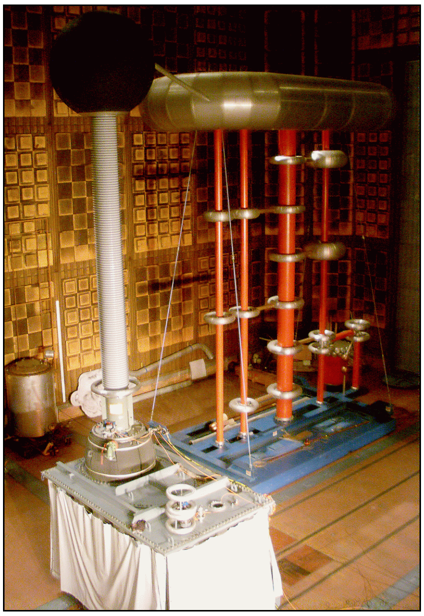

Figure 3: Test vessel and bushing with shielding sphere (diameter 2m), in the background 1500kV DC-generator

3.1 Measurement devices

For conventional PD measurement a standard wideband analogue/digital instrument is available. The test tap of the bushing is used for PD-coupling. Additionally an acoustic measurement setup is installed. It consists of up to five ultrasonic microphones with preamplifiers, a power supply with adjustable gain and a transient recorder for recording. The transient recorder is equipped with four 1MS/16bit inputs which are used for acoustic signals and two 10MS/12bit inputs – one of them is used for electrical triggering. The system is on purpose modularly configured for different applications of the transient recorder and upgrading of acoustic channels.

3.2 Measurement examples

The additional acoustic PD localisation system is an auxiliary device to support the operator during the test. It was not the target to prove or investigate the measurement system and so the occurrence and the further localisation of PD depend on the construction and the test level of the test sample.

In Figure 4 the position of the acoustic sensor can be seen. The vessel was divided into two areas: the “Go area” of the test sample (green) and the “No-Go area” of the bushing and the barrier package (red) as it can be seen in Figure 5.

With this setup several tests were done. Figure 6 shows an investigation with AC voltage. The electrical triggering was achieved by a UHF valve sensor and five acoustic sensors were used. The PD-level was unexpected high (about 13nC, only a few PD impulses could be observed before the breakdown occurred).

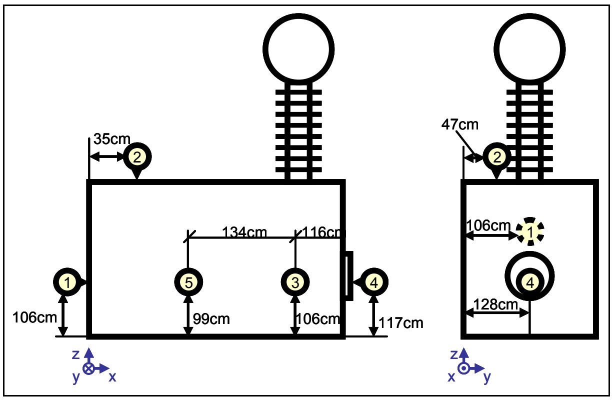

Figure 4: Positions of acoustic sensors (1÷5)

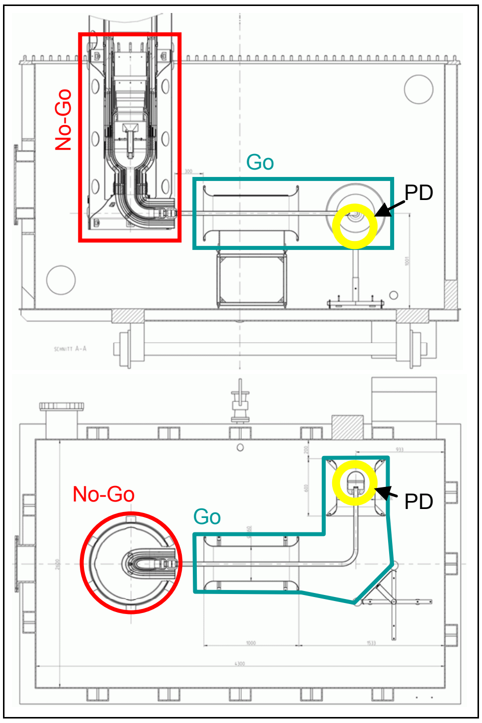

Figure 5: "Go" (green) and "No-Go" areas (red) for PD and located PD (yellow)

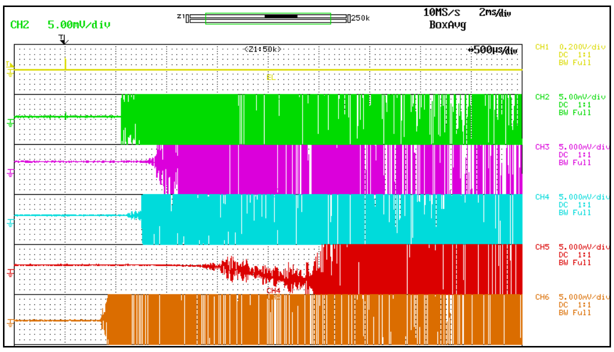

Figure 6: Signals of an intense PD event during an AC test (CH1 was the electrical trigger, CH2 to CH6 were the acoustic sensors 1 to 5, overriding of the inputs occurred)

A defined conclusion about the location could be done, which was at the weakest point of the small test tube (see Figure 5, yellow circle). During testing, the operator had to (roughly) evaluate the location of the discharge(s) and decide:

- whether the bushing and/or barrier package are involved ("No-Go area") and cancel the test immediately,
- whether the test object(s) shows PD ("Go Area") and keep on testing,
- whether the recorded PD are outside the vessel (which is of interest from side of the lab owner).

The difficulty of defining a clear and reproducible time delay of the acoustic signals are observable in Figure 5. CH4 and CH5 (fourth and fifth signal from top) show the issue of different propagation velocities. The shortest geometrical path is not the fastest for the acoustic wave. The combination of oil length and steel wall was faster than the direct path between source and sensor and so an uncertainty of the time delay occurred. A signal processing with filter or the energy consideration will help to improve the evaluation of the "exact" delay time of the arriving acoustic wave (see Figure 7, sensor position 3 (second from bottom - cyan) shows almost no utilisable signal).

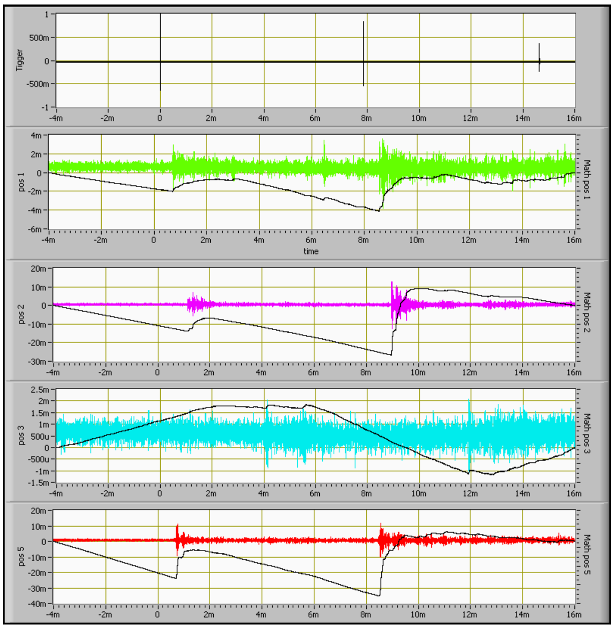

Figure 7: Measured signals and calculated energy consideration of a multiple PD event during a DC test (sensor positions according to Figure 4, sensor 4 was disconnected, triggering by conventional PD measurement system)

4 CONCLUSION

Partial discharge diagnostic is a powerful tool to assess the quality of an insulation system or a complete device. To perform a UHV-test with DC without disturbing PD is challenging even in well shielded laboratories due to dust and changing humidity which causes accumulation of surface charges. The classical PD measurement according to IEC 60270 allows only evaluating the whole entire setup and gives poor information about the type and the localisation of the fault. An additional PD localisation system gives the operator more information and helps him by making decision about proceeding or aborting of the test.

Therefore following aspects should be considered:

- sufficient number of sensors to cover the whole area (three or more)
- a high resolution for measurement and processing to achieve a wide dynamic range (the more, the merrier but sufficient band width for sampling)
- rugged housing, mounting and cables (especially for on-site tests)
- robust against discharges, breakdowns and short circuits
- simple and intuitive handling and evaluation (keep it simple)
- easy verifiability and exchangeability of parts
- ensured detection of each individual PD impulse especially at DC (no or minimal dead time of the system)

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