Partial discharge behaviour of oil board arrangements by the installation of fibre-optic technology for monitoring

M. Muhr, R. Schwarz*
Institute of High Voltage Engineering and System Management
Graz University of Technology
Inffeldgasse 18, 8010 Graz, Austria
Schwarz@hspt.tu-graz.ac.at

Abstract: Insulation condition monitoring of high voltage equipment is of significant importance in maintaining a safe and reliable electricity supply system. New development in the area of the signal measuring and conditioning, data processing and analysing as well as environmental aspects make a more precise and detailed condition evaluation possible.
By detecting an electrical problem early, it is possible to locate and repair defects before they cause an unscheduled system breakdown or equipment damage - for example hot spots in transformers. Therefore different temperature measuring systems for diagnostics are possible. For surfaces thermography based technologies can be used. Measurements inside the equipment uses thermal sensors such as fibre-optic technologies.
Another important diagnostic method is the partial discharge measurement. It is a well known possibility to assess the quality of an insulation system of high voltage devices. Research results show the possibility of the optical detection of partial discharge inside of high voltage equipment by using applications of special fibre-optic cables.
By using fibre-optic technologies, it must be guarantee that the installation of fibre cables causes no additional disturbance inside the insulation system.
Basic studies and effects of the PD behaviour by usage of fibre-optic cables inside an oil-board model arrangement are examined in this paper.

1 INTRODUCTION

In high voltage networks, reliability and economical operation of the equipment are demand. Electrical, thermal and mechanical aging and high-voltage field strengths may affect the insulating medium of the equipment. Depending on the individual equipment, different monitoring and diagnostic systems are in use. With these systems significant parameters will be received and based on these recorded data (for example: temperatures, optical signals, electrical and mechanical measurement etc.) conclusions to the future behaviour of the device can be made. With advances in testing techniques and the employment of more appropriate monitoring systems the detection of early signs of deterioration in the insulation system is becoming possible to extend the life of certain units.

2 BASICS

By installing monitoring systems critical operating conditions can be recognized in time and failures can be avoided. Among other quantities the measurement of partial discharge and also the temperature within high voltage equipment are important.

2.1. Temperature measurement

Temperature measurement will identify potential problem areas (hot spots) that can lead to substantial equipment damage. Of great importance is the maximum temperature because according to a simple model for thermal aging, an “aging rate” can be defined. This aging rate doubles with approximately 6K temperature rise. By a transformer, the measuring of the oil temperature and the load current allows a indirect calculation of the hot spot. So the correlation between temperature, load and ambient conditions would allow the detection of abnormal condition and on the other side the optimal use of the equipment (load limit).

Several principles have been used for measuring the temperature. For example, temperature measurement using Pt 100 sensor or thermocouple devices, fibre optic systems for single point, fibre optic systems for distributed measurement and infrared temperature measurement. By the contact-afflicted temperature measurement the measuring sensor is brought in thermal contact with the measuring surface. Contact temperature sensors measure their own temperature, so the test object and the sensor must be in thermal equilibrium. For surfaces infrared thermography based technologies can be used. The spectrum and the intensity of infrared radiation from the object is a function of its temperature. Each body – whose surface temperature deviates from the absolute zero – emits electromagnetic waves and these emitted waves with their different wavelength and intensity spectra can be used for temperature measurement [1].

2.2. Partial discharge measurement

Partial discharges are small electrical sparks resulting from electrical breakdown of gas contained within a void or in a highly non-uniform electric field. The partial discharge (as breakdowns occurring in partial regions of the insulating system) measurement offer an important possibility to characterize the properties of defects in insulation materials and is an indicator for insulation degradation.

Irrespective of the material, partial discharges have a negative effect on their insulation properties. If partial discharge occur in organic liquid or solid, a stronger degradation (compared with inorganic materials) of the organic material results and may eventually cause the failure of the electrical insulation. While designing technical power apparatus, it is therefore particularly necessary to ensure that no PD arise at the working stresses. For the PD measurement the electrical, HF, UHF, acoustical, chemical and optical techniques are in use. For example the conventional partial discharge measurement a measuring circuit according to guidelines of IEC 60270 is used. In the simplest case a shunt resistor converts the PD impulse current to a voltage signal. The characteristic of the detector (quadrupole - RLC detection impedance) can be designed for integrating the PD signal to obtain the apparent charge of each discharge. The available measurement systems can detect the apparent charge and also the phase location according to the supply voltage. Furthermore the number of discharges over a given time interval will be recorded [2].

The optical partial discharge detection is based on the detection of the light produced as a result of various ionization, excitation and recombination processes during the discharge. The amount of the emitted light and the wavelength depends on the insulation medium (gaseous, liquid or solid) and by different parameters (temperature, pressure …). The optical spectrum of the emitted light of partial discharges reaches from the ultraviolet to the infrared range.

3 FIBRE-OPTIC TECHNOLOGIES FOR TEMPERATURE AND PARTIAL DISCHARGE MEASUREMENT

Various combinations of fibre-optic technology are in use in different applications (temperature measurement, active sensing element or data transport) and offer solutions for a variety of tasks. In the environment of high field strengths, the usage of optical sensors or fibre-optic technologies offer the possibility to observe important measurands without any influence by interferences (EMI). Also the galvanic separation is an advantage [3], [4].

3.1. Temperature

Alternative temperature measuring systems for measurements inside the equipment use thermal sensors such as fibre-optic technologies. This complex method consists of fibre-optic temperature sensors installed in the apparatus. Different types of sensors and functional principle are in use [5].

A possibility is to measure the temperature in one point of the fibre (Fig. 1). For example, the temperature measurement principle is based on an optical fibre sensing probe. In such a probe, a little part of the fibre cladding was removed and replaced by a suitable "reference" liquid, whose refractive index versus temperature characteristic is known [6]. Other techniques consists of an optical fibre with a temperature sensitive phosphor tip at the end. After excitation with blue-violet light the phosphor fluoresces with red light. The intensity of this light decays exponentially with time. The decay time is measured (the time constant of decay is inversely proportional to the sensor temperature) and correlated to the tip temperature [9].

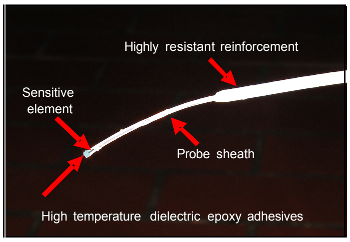

Fig. 1: Picture of a fibre optic temperature probe [10]

An other possibility is to measure the temperature distributions along the length of the fibre-optic cable under the utilization of thermo optical effects. The light impulse injected into the fibre is subjected to scattering as it travels and the back scattered light impulse is returned to the detector. Among the returned light pulse, the intensity of Raman Scattering is closely related to the temperature of the position of the scattering. So the temperature along the fibre can be measured by the intensity of Raman Scattering [7].

3.2. Partial discharge (PD)

By the optical method for the detection of partial discharge inside the equipment, a special fibre-optic cable (Fig. 2) is used as a receiver unit which collects the emitted optical radiation of the PD at the place of its origin and guides the signal to the optical receiver.

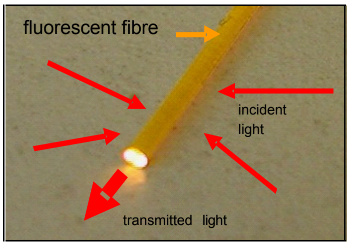

Fig. 2: Fluorescent fibre optic cable [8]

By using a fluorescent fibre-cable the fluor in the core material, can be illuminated by rays, coming from any incident angle even through the side of the fibre.

To establish fibre-optic monitoring systems in high voltage equipment investigations to prove the stability of the material (long-term stability of the fibre) and to test the influence of optical fibre on the dielectric strength within the apparatus must be carried out. An optical fibre represents an impurity in an electric stressed dielectric, which can lead to a weak-point of the dielectric (Fig. 4). It could be the reason for PD. So by using fibre-optic technologies it must be guarantee that the installation of fibre cables causes no additional disturbance inside the insulation system such as chemical reaction or field inhomogeneous causing PDs.

The partial discharge measuring technique as a part of the insulation diagnose is object of investigations at the Institute of High Voltage Engineering and System Management at the University of Technology in Graz. A scientific project examines the economic possibilities of the optical detection of partial discharge with fibre optic and/or fluorescent fibre-optic cables [10].

4 INVESTIGATIONS

On the basis of a plate-electrode arrangement in oil as experimental setup different types of board electrode barriers were used. At the same time the influence of the electrical behaviour by the placement of different fibre-optic cables within the board arrangement during variable voltage stress are evaluated (Voltage supply 5 – 50kV). Two different arrangements with fibre-optic cables were used (Fig. 3).

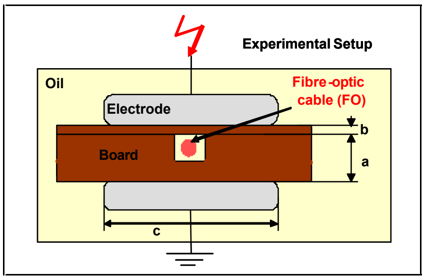

Fig. 3 : Schematic of the arrangement I and II

Arrangement I:
- Electrode diameter c=75mm,
- Transformer board 200x200mm with thickness a=4mm, b=1mm, slot 3x3mm
- fluorescent plastic fibre-optic cable (PM MA) (∅ 1mm)

Arrangement II:
- Electrode diameter c=50mm,
- Transformer board 250x250mm with thickness a=5mm, b=1mm, slot 3,5x3,5mm
- fluorescent plastic fibre-optic cable (∅ 1mm) alternatively
- Neoptix fibre-optic cable (casing ∅ 3,1mm)

Figure 4 show the simulated field characteristics of the arrangement with the fluorescent plastic fibre cable (PMMA).

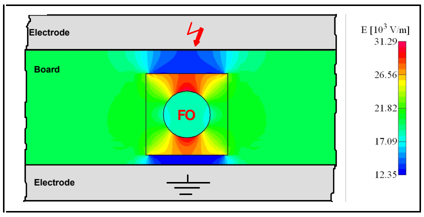

Fig. 4 : Simulate field characteristic of the arrangement with an PMMA fibre.

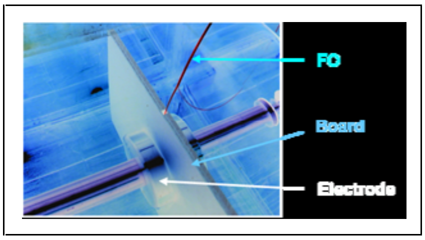

Fig. 5 : Oil - board - fibre-optic cable arrangement I

For the conventional partial discharge measurement a digital PD measuring system is used. The test setup is shown in Fig. 6 and Fig. 7.

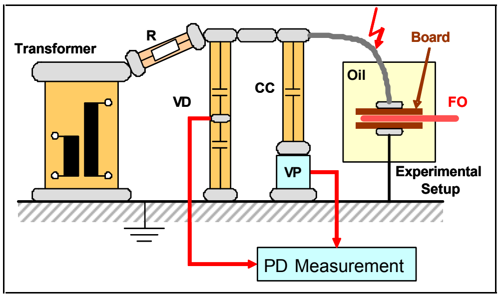

Fig. 6 : Schematic of the test setup:

R - damping resistor,	VD - voltage divider,
CC - coupling capacitor,	VP - measuring impedance,
FO - fibre-optic cable,	PD - con. PD measuring system

Fig. 7: Test setup in the laboratory - PD measurement according IEC 60270

The two different types of fibre-optic cable were used and also different positioning of the fibre-optic cable within the board arrangement. Setup 1 - the fibre-optic cable is completely in the board (Fig. 8 a) and Setup 2 - the end of the fibre-optic cable is within the electrodes – board arrangement (Fig. 8 b)

a) b)

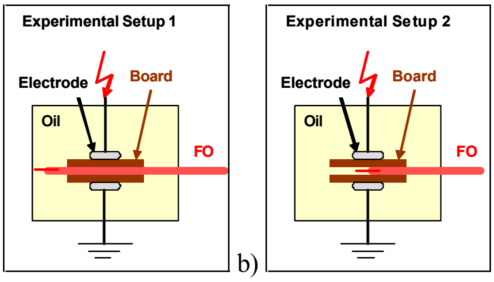

Fig. 8: a) Setup 1 - fibre-optic cable is completely in the board b) Setup 2 - the fibre-optic cable ends within the board arrangement.

The fluorescent plastic fibre-optic cable in the experimental setup is also used as sensor for the optical detection of the partial discharge with an at the institute developed optical PD detection system. The system consists of this fluorescent fibre-optic cable, an conventional fibre-optic cable for the transport of the optical signal to an photomultiplier and an amplifier for the electrical PD signal from the photomultiplier [8].

5 TEST RESULTS

The following pictures shows the max. PD level and the number of partial discharge during a measuring time of 30s of the conventional PD measuring system. The adjustment of the conventional PD measuring system took place in such a way that the basic noise level was widely gate out. Only a small horizontal line of acquired noise pulses in the display appears. The voltage supply was varied between 5 – 35kV.

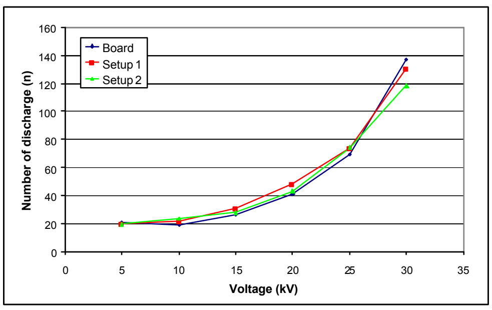

Fig. 9: The number of discharge in dependence of the voltage and the experimental setup, average value, arrangement I

Several series of measurements were accomplished in the arrangement I (Board – without an fibre-optic cable, and Setup 1 and Setup 2 with the - fluorescent plastic fibre-optic cable) and the average value from all measurement were formed, shown in Fig. 9 and 10.

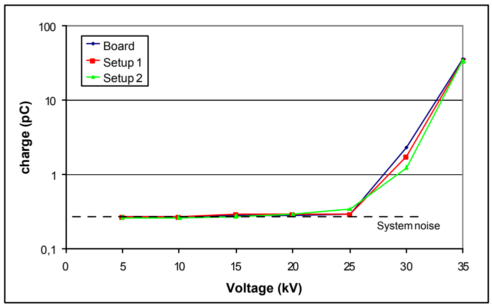

Fig. 10: The max. charge (PD level) in dependence of the voltage and the experimental setup, average value

In Figure 9 it can be seen, that the number of discharge is negligible increase in the case of the employment of the fibre-optic cable. Also there is not significant difference between the PD level of the board arrangement without fibre-optic cable, Setup 1 and Setup 2. Fig. 10 shows the max. PD level. Between 5kV and 20kV the PD activity is in the range of the basic noise level (System noise). Starting from 25kV a rise of the activity is to be determined. Figure 11 shows the scattering range of the individual measuring series.

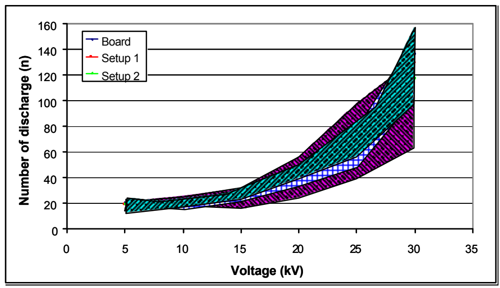

Fig. 11: Scattering ranges of the individual measurements

Figure 12 shows the measurement results of the arrangement II with the fluorescent plastic fibre-optic cable. The voltage supply was varied between 10 – 50kV.

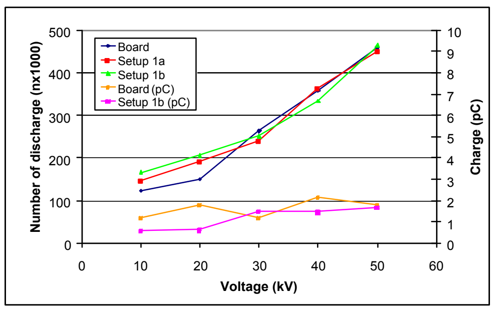

Fig. 12: The number and the max. level of the discharges in dependence of the voltage and the experimental Setup (using the fluorescent plastic fibre-optic cable), arrangement II

Between 10 and 20kV is the number of discharge is increasing by using the fibre, at 30kV their is approximate no different between the results.

In Fig. 13 four fingerprints of the measurement are shown. There is no significant different between board arrangement II without a fibre-optic cable and Setup 1.

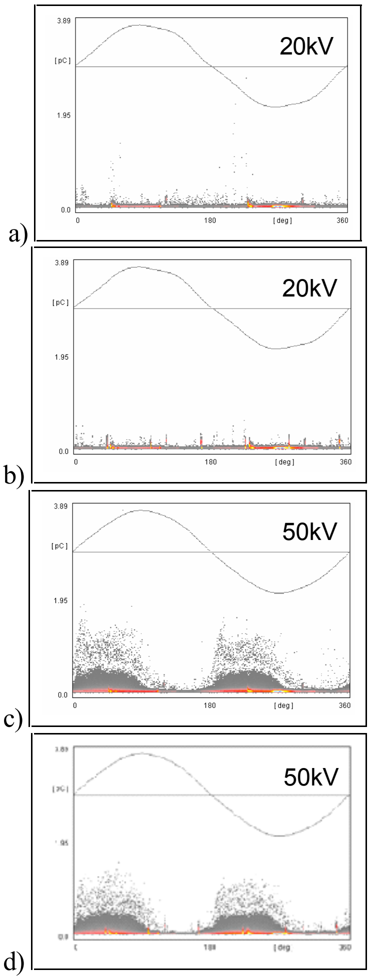

Fig 13: Fingerprint of the conventional PD measurement, Oil-board arrangement without the fibre-optic cable (a, c) and with the fluorescent plastic fibre-optic cable (b, d) in Setup 1, arrangement II

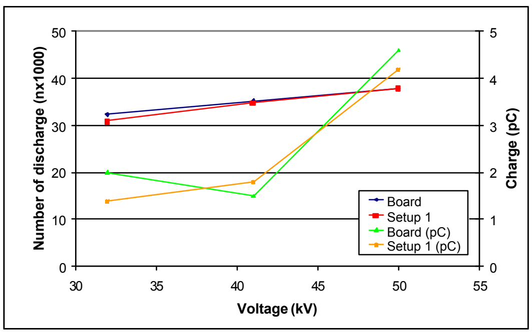

Fig. 14: The number and the max. level of the discharges in dependence of the voltage and the experimental setup using the Neoptix fibre-optic cable, arrangement II

First results with the Neoptix fibre-optic cable do not show significant differences between the number of discharge and max. PD level of the arrangement II with and without fibre-optic cable (Fig. 14).

The application of fluorescent fibre-optic cable offers the possibility for the detection and location of partial discharge inside an equipment. Test results of past investigations between the optical detection of partial discharge with an optical system using fibre-optic technology and the conventional PD measurements show a good correlation [8]. Fig. 15 shows the comparison of the optical (1) and electrical (2) measured PD signal.

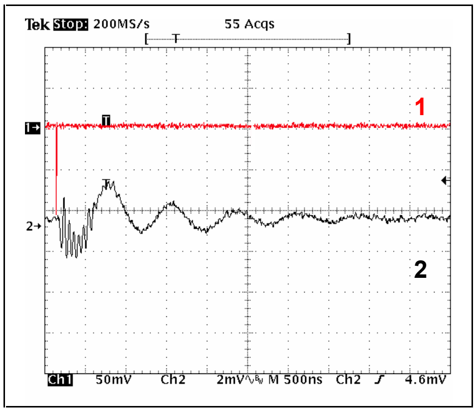

Fig 15: Comparison of one single PD impulse measured with the fluorescent fibre-optical cable with the optical system (1) and the conventional measured PD signal (2).

The optical PD signal (converted into an electrical signal) has a very short rise time (ns) and pulse time (high bandwidth of the measuring system) and no oscillation like the conventional detected PD signal (low bandwidth of the measuring system).

6 CONCLUSION

Continuous temperature monitoring of energized equipment provides additional information about the condition of the equipment. Loading capability of a power transformer is limited mainly by winding temperature, and makes the temperature measurement very important. Fibre optic sensors have improved that direct measurement of winding temperature is becoming the preferred method to measure this critical parameter.

An second important diagnostic tool is the PD measurement with the aim to detect beginning destruction in the electrical insulation as a result of electrical stress. For their measurements different physical effect will be used. Also the possibility of the optical detection under the use of fibre optic technologies seem to be an suitable method for specific applications.

First investigations with an oil-board-electrode arrangement shows that the influence of the optical fibre on the dielectric strength is not strongly recognizable. A small rise of the number of partial discharge was detectable, but it was approximately the same PD level.

Investigation in the area of the optical detection of PD shows a good correlation between the optical and electrical PD measurement. The possibility of the optical detection for specific application is to observe critical geometrical areas in the equipment with the advantage of discharge location and immunity to EMC. This seems to be an appropriate method for the future.

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