Partial discharge measurement as a Diagnostic Tool for HV-Equipments

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

Abstract

Insulation monitoring and diagnostic are the base of condition maintenance and essential for an economic usage of high voltage equipment.
Electrical breakdowns in a small region of the insulating system are called partial discharge. The appearance and the intensity of these partial discharges are a quality criterion for an electrical equipment rating and therefore an estimation of the condition of the insulation system can be done. So the partial discharge measurement has become a fix part in industrial applications as a non destructive high voltage test. It uses the different physical effects in different insulating systems to detect significant parameters to give directly or indirectly information about the equipment condition. Not only high frequency electrical transient phenomena and especially currents are caused by partial discharges also optical, acoustical and chemical reactions and effects occur.
Different techniques are in use to observe relevant parameters and are supposed to provide an early warning. In the full paper an overview of partial discharge measurement techniques, particularly in the area of non conventional measurements, for diagnostics is given.

INTRODUCTION

For a condition based maintenance special insulation monitoring and diagnostic systems are necessary. With the use of technical diagnostic systems significant variables can be recorded. With these measured quantities (optical, electrical etc.), conclusions of the future behaviour of the equipment can be made.
The partial discharge (PD) measurement is a sensitive method for evaluation of the insulation condition of high voltage equipment. It is an effective way to detect the beginning destruction in the electrical insulation or insulation failures as a result of electrical stress. That is the reason, why PD measurement of electrical components or whole electrical systems is more and more important. Lower cost of sensors, improvements in the capabilities are also reasons for increased popularity of PD diagnostics. Due to the multiplicity of different PD sources and the characteristic properties of PD a high level diagnostic system is required.
Likewise the development in the range of the computer technology makes an ever more efficient data processing and automated pattern recognition technique possible. New noise suppressor systems permit the increasing use of ultra wide band detection systems. This is also an aspect why on-site and on-line PD testing have been increasing.
A so-called "expert diagnostic system" should make, after the recognition of a disturbance, an automatic case identification of the disturbances source. The reliability of the connection between this indication and the derived pattern is important for the usefulness of the assigned diagnostic procedure. Different methods, which acquire the multiplicity of physical dimensions e.g. temperature, conductivity and radiation into a database for the diagnosing, are used.

BASICS

The partial discharges are small electrical pulse from the electrical breakdown in a void or in a highly stressed electric field of the insulation, e.g. a dielectric surface in a solid or liquid insulation system. PDs cause a degradation process of the insulating material by the change of electric field energy into kinetic energy of electric charges. PDs have only a small short time influence on the electrical firmness of electrical resources. On the other side, the long time influence shows a destructive effect. If the void is in an organic solid or liquid, the PD will degrade the organic material and the insulation of the equipment can failure [1].
For the PD measuring, macroscopic, physical effects like pressure wave (sound), light, chemical reactions, high frequency wave will be used.
Different measuring methods depending on the electrical equipment are used for the PD behaviour analysis.
Possibilities of partial discharge detection:

- Conventional electrical measurement
  - Integration at frequency domain
    - Narrow - band, Wide - band
  - Integration at time domain
- Electrical measurement with high frequencies
  - HF / VHF method (20 MHz to 300 MHz)
  - UHF method (300 MHz to 3 GHz)
- Acoustic measurement (10 Hz to 300 kHz)
- Optical measurement
- Chemical measurement

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According to the elementary communication theory, the measured signal energy increases linear with the bandwidth. For the PD measurement could be recognized that the signal is constant over the measured frequency spectrum.
For on site measurements in electromagnetic disturbed environment of different high voltage equipment modern methods in conbination with digital technology (digital filters as well as suitable algorithms) of interference suppression shall be developed.

DETECTION SYSTEMS

Conventional Measurement of Partial Discharges

The high frequency PD impulses are superposed with the supply voltage and must be coupled out of the test circuits. The test set up consists of a high voltage source, a coupling capacitance and measurement impedance (quadrupoles). The PD impulse from the specimen appears on the measuring impedance via the coupling capacitor. Each PD causes a short high frequency signal, which can be detected with the impedance. The following measurement system can analyze the detected signal. Different systems can be used, which diverge by their bandwidth. They can be built as a narrow- or a wide-band system. Narrow band PD measuring systems have a small bandwidth (9kHz) and a centre frequency, which can be varied over a wide frequency range. The response of this system to a PD impulse is a transient oscillation with positive and negative peak values. Wide band PD measuring systems have a bandwidth of a few 100kHz, so the response of a PD impulse of such a wide band system is well-damped oscillation. So the apparent charge and the polarity of the PD signal can be determined [2]. The used measurement systems detect the apparent charge, the phase position to the test voltage and the number of discharges over a given gate time interval. Further parameters can be calculated by usage of stored data.

UHF Measurement of Partial Discharges

In the last years the ultra high frequency (UHF) method was established as usual PD measuring procedure in GIS systems (increasingly also applications by transformers).
The ultra high frequency PD detection is based on the detection of the high frequency signals generated in the event of discharges. PD impulses of very short duration (< ns), produce electromagnetic waves, whose spectrum reaches up to the GHz range.
Capacitive sensors, as like antennas, have been developed, which can detect transient waves.

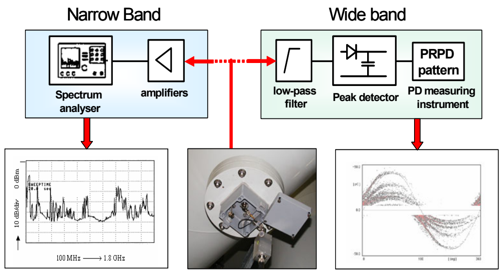

Fig. 1: UHF PD measurement

Two types of PD measurement can be recognized. These are the narrow band technique with a measurement bandwidth of only a few MHz, and the broadband method, whereby the PD signal is detected in the time domain, over a frequency range typically up to 2 GHz (Fig. 1).
The measuring sensitivity is comparable or rather higher than a conventional PD measurement. It has to be considered that no direct correlation between the PD intensity detected in the UHF-band and the apparent charge exists. A detection of partial discharges with the UHF-method is possible, but there is no measurement of the apparent charge according to IEC 60270.

HF Measurement of Partial Discharges

This method is based on the frequency characteristics of a discharge pulse. PDs, for example in polymeric insulations, show a duration of several nanoseconds at the point of origin. A transformation of the time signals in frequency domain shows a PD frequency spectrum up to the range of 100 MHz.
For the measurement of PD inductive and capacitive sensors are used. Considering as example of a inductive PD measurement a time variable magnetic field is inductive collected with a toroid coil surrounding a conductor (Fig. 2). Beneficial for this method is the galvanic isolated survey of the PD current, as well as the exact failure location by moving the coil.

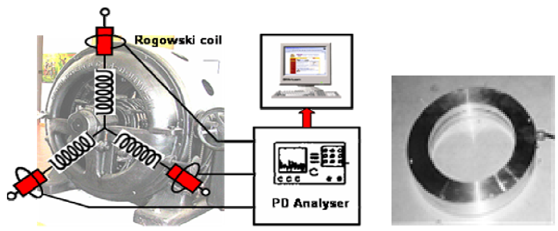

Fig. 2: Measuring for HF PD detection on machines, VHF PD coupler, split ring Rogowski coil [3]

Acoustic Measurement of Partial Discharges

The main field of application of the acoustic detection of partial discharge is the location of discharge sources alternative defective areas of equipment.

The principle of the acoustic PD detection is the detection of the pressure waves generated by the discharge within the insulation. The discharge appears as a small "explosion", which excites a mechanical wave, and propagates through the insulation. The propagation speed of the acoustic wave depends on the surrounding medium. Likewise, reflection and refraction, geometrical spreading of the wave and absorption in the materials lead to changes of sound propagation, which must be considered during detection and interpretation.

Because of the short duration of the PD impulses, the resulting compression wave has frequencies in the ultrasonic region. The frequency range is between 10 Hz and 300 kHz.

In air and gases, microphones are usually employed as sensors. Microphones produce a voltage proportional to the pressure of the sonic wave (Fig. 3). Piezo ceramic transducers as acoustic emission sensors or accelerometers offer the best sensitivity for detection of ultrasonic waves in the enclosure [4].

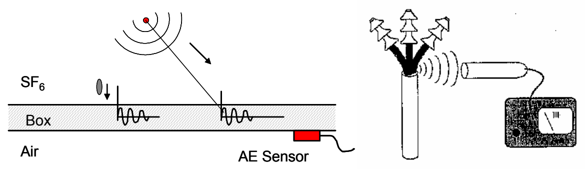

Fig. 3: Principle schematic to the acoustic PD detection

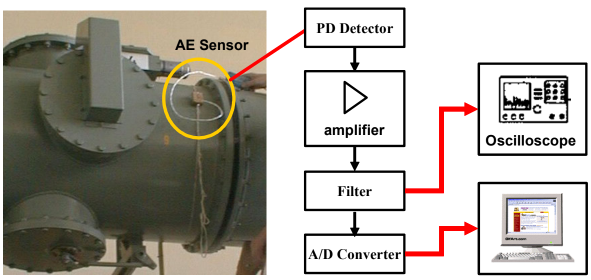

Fig. 4: Acoustic PD detection system

Chemical Verification of Partial Discharges

Partial discharge activity results in changes to the chemical composition of the particular phases. These changes have been exploited in the detection of PD activity.

In insulating liquids usually gaseous compound are developed, which can be determined with the help of the Gas-in-Oil analysis. Thereby the developed fission gases depend on the power density as well as the insulation materials. If PDs occur in air, the chemical reactions between the components of air accumulate NOX and ozone. The determination of ozone concentration makes conclusions concerning the PD activity possible, for example air-cooled machines. However, a disadvantage of the chemical procedures is the integrative character, which does not allow statements about the current operating condition. It is not possible to indicate nature, intensity, extent or location of a single PD.

Opto-Acoustic Partial Discharge Measurement

During a partial discharge in gas or oil an acoustic wave into the sonic and ultrasonic range are generated. If a PD in the surrounding medium arises, the pressure wave result in a deformation of an optical fibre and its optical transmission characteristic is changed. This fact is used by the opto-acoustical sensor principle. It comes to a mechanical stress and a stretch of the fibre and an influence of the used polarized light by this fibre too. The result is a change of the optical distance as well as the polarization condition (Fig. 5). The advantage of such system is the immunity to electromagnetic field, high flexible, high sensitive and large bandwidth [5].

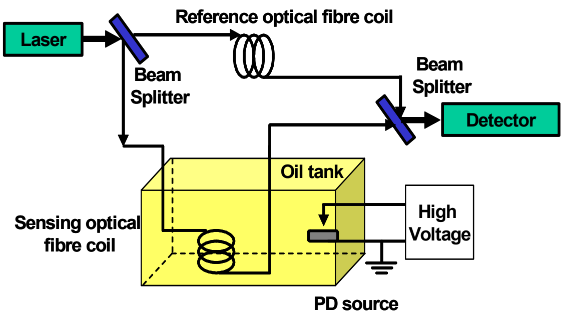

Fig. 5: Experimental setup of the optical interferometric detection of PD [5]

Optical Partial Discharge Detection

Each partial discharge produces a light emission as a result of various ionization, excitation and recombination processes during the discharge. This emission transports information about the energy level of the discharge. Depending on the surrounding isolating medium (its chemical components - air, SF6, oil) and different factors (temperature, pressure …) the optical spectrum is between the UV range and the infrared range (Fig. 6).

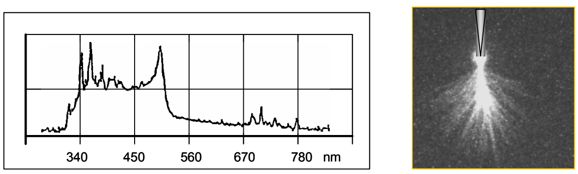

Fig. 6: Spectrum from breakdown arc in SF6 and photo of a discharge [6].

If the HV equipment is enclosed and light tight as transformer or GIS (environment light are totally enclosed – Fig. 7) an optical detection is possible. The advantage of this method is the immunity to EMC, the insensitivity to electromagnetic and acoustic interference sources.

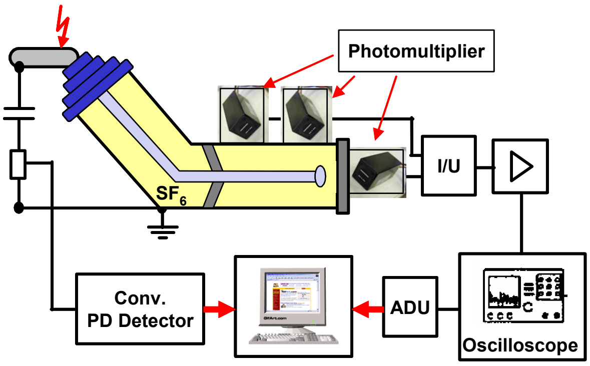

Fig. 7: Test arrangement for optical PD measurement

The optical measurement is a very sensitive method in comparison to the conventional electrical or acoustic techniques especially by on-site measurements.

PD PATTERN RECOGNITION

PD pattern recognition is the ability to recognize and distinguish between different types of PD within the electrical insulating systems.
The phase resolved Partial discharge (PRPD) analysis or PD pattern is a significant method to present and interpret the PD measuring results (Fig. 8). Different PD sources (external or internal PD) and different locations can be recognized by this pattern.

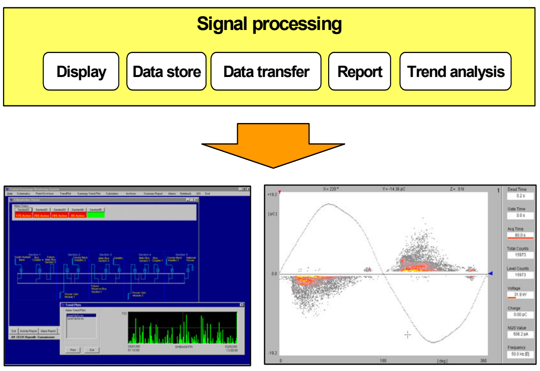

Fig. 8: Example for signal processing

Computerized techniques with statistical parameters take into consideration the stochastic nature of the PD process, and technique, which require no statistical precondition of the data, for example neural networks, may be employed [1], [7].
Developments are accomplished in the following areas:
- Statistical Analysis
- Neural Networks
- Fuzzy Logic
- Wavelet Transformation
- Fractal Analysis
- Time vs. Frequency clustering.

CONCLUSION

The uses of new technologies make possible an early recognition of changes in the insulation system. However, the knowledge of the insulating material of the different equipment and systems is very important for diagnosis. New developments on the sector of the sensor technology, cheaper electronics, memory and powerful software tools make the employment of ultra wide-band detection systems with interference suppression possible.
For example a powerful technique for the location of PD activity is the acoustic or the optical detection. Also the chemical techniques will increase, if the correlation between detectable molecular species and the appearance of the PD activity can be obtained.
The data acquisition, monitoring system, the data transfer and the storage according to accomplished analysis and trend evaluation become a fixed part of the equipment of reliable diagnostic systems.

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