

Evaluation of partial discharge impulses with optical and conventional detection systems

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Abstract: The dielectric condition of the insulation of high voltage equipment can be derived from partial discharge (PD) measurements. The aim is the detection of destruction in the electrical insulation. In the working field of the technical diagnostics are looked for alternatives to the conventional partial discharge measuring techniques for detection and localization.

In a research project a special fibre-optic cable is used as a receiver unit which collects the emitted optical radiation caused by partial discharges. An optical system for PD detection consisting of a fluorescent fibre-optic cable, a photomultiplier and an amplifier unit is developed. By the signal processing unit the measured signal is digitized and sent to a data processing unit. Simultaneous a conventional measurement of the partial discharge activity is applied with the aim to compare the electrical and optical impulses.

The special attention of this paper is to evaluate the different signal response (amplitude and pulse shape) of both detection systems. The conventional measuring equipment is bandwidth limited and so an information loss is present when the impulse frequency is higher than the upper band limit. With the help of a fast optical system a wide band detection system is possible.

Key Words: Partial discharge; optical signal, fibre-optic; photomultiplier; PD impulse characteristics

INTRODUCTION

For the economic use of the high voltage operational equipment it is important to know about the condition of the insulation of high voltage components and equipment. So monitoring-, analysing- or diagnose systems become a fixed part in power generating, transmission and distribution systems. In this area the partial discharge measurement is an important diagnostic tool to characterize the quality of an electrical insulation system.

The discharges are small arcs occurring within the insulation system, therefore deteriorating the insulation and can result in eventual complete insulation failure. The demand in a short time is not so important as the influences during a long time, which shows a destructive effect specially on organic insulation systems.

Partial discharge theory involves also an analysis of materials, impulse propagation and attenuation, electric

fields, arcing characteristics, pulse wave, different sensor sensitivity, frequency response and calibration, noise and data interpretation [1]. That's the reason why different techniques of partial discharges measurement procedures are suitable as important diagnostic tools for detection and location (cables, capacitors, transformer, rotating machines ...).

Partial discharge measurements will be used as non-destructive tests for the insulation of high-voltage equipment during quality tests in the factory and for equipment being in service. A multiplicity of different partial discharge sources and their appearances show different physical characteristics. For the measuring, physical effects, such like optical, electrical and acoustical appearances, can be used.

The partial discharge measuring technique as a part of the insulation diagnose is an object of investigations at the Institute of High Voltage Engineering and System Management in Graz. One scientific research project deals with the comparison between the conventional electrical partial discharge measuring method and the optical detected partial discharge signal. The aim is to compare and analyze the electrical and optical measured partial discharge impulses at different voltage forms (AC, DC, impulse voltage); further investigation about the rise time and impulse time. Special attention is to evaluate the different signal response (amplitude and pulse shape) of the both detection systems.

BASICS

Partial discharges are small discharges in the insulating materials. Initial points are local enhancements of the electric field in the area of inhomogenities, either in gaseous, liquid or solid media. They generate locally confined impulse currents in nano- to microsecond range.

Two basic kinds of detection methods can be distinguished: electrical and non-electrical methods.

Some developed partial discharge sensors detect electric current, acoustic wave, or electromagnetic wave caused by discharge. With these methods it is difficult to distinguish the partial discharge signal from external noise.

The electrical methods depend on the electrical and electromagnetic effects of partial discharges. These methods use for their detection currents, voltages or existing electromagnetic fields.

Conventional Measurement of Partial Discharge

The test set up for the partial discharge measurement according to IEC 60270 consists of a high voltage source, a coupling capacitance and measurement impedance (quadrupoles). Each partial discharge causes a short high frequency signal which can be detected with the measuring impedance. Following measurement systems are used to analyzed the detected signal. The system can be build up as a narrow-, limited-wide- or a wide-band system.

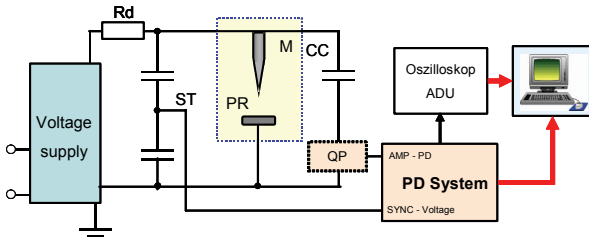


Fig. 1 conventional PD measurement (IEC 60270)
Rd - filter, ST - capacitive divider, PR - test object (peak – plate), CC - coupling capacity, QP – quadripole
M – medium (air – oil)

Optical Detection of Partial Discharge

An alternative measurement possibility is to detect the light emission produced by partial discharges. This emission transports information about the energy level of the discharges. In connection with the electrical discharge a radiation in the ultraviolet-, visible and infrared area could be recognized. The emission spectrum of the radiate light depends on the surrounding medium (air, SF₆, oil) and must be considered by the selection of the optical detection system [2]. One advantage of the light detecting method is, that no influences from electrical or acoustical noise are given.

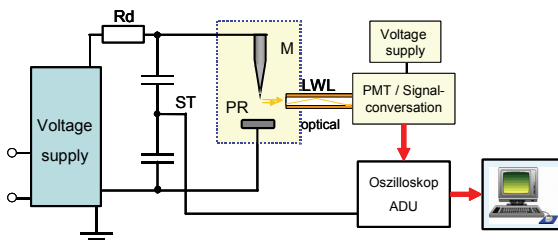


Fig. 2 optical PD measurement, Rd - Filter, ST - capacitive divider, PR - test object (peak – plate), LWL – fiber optic, PMT - photomultiplier
M – medium (air – oil)

INVESTIGATIONS

In an investigation, optical techniques have been developed to supplement current measurements. These consist of fiber optic cable, a photomultiplier and a processing unit.

A photomultiplier converts light into an electric signal. It consists of a photocathode (photons are converted into electrons - photoelectric effect, process of secondary emission), a multiplier chain - called dynodes and an anode, which collects the resulting current.

Because of secondary-emission multiplication, photomultiplier tubes provide extremely high sensitivity, allowing the measurement of very low levels of light. A further advantage is the very fast rise time (response characteristic) to register the discharges and a very low dark current. Photomultiplier has high bandwidth and noise-free gain on the order of a million. This wide dynamic range makes it ideal for the detection of extremely low light or short pulses of light.

Photomultipliers can be used to detect photons from 150nm to 1600nm wave length. The gain is adjustable by varying the power supply. If using a constant voltage power supply the anode current is proportional to the incident light.

The receiver unit for the optical PD signal forms a lens system or optionally a fluorescent fibre optic in front of a conventional fibre-optic cable [2]. This is used to collect the light emission and transmission of the optical signal to the photomultiplier.

After a second amplifier circuit the electrical signals are digitized and sent to a data processing unit for analysis, storage and result presentation [3].

As test setup a simple peak-plate arrangement is used for producing reproducibly partial discharge activity at the same location.

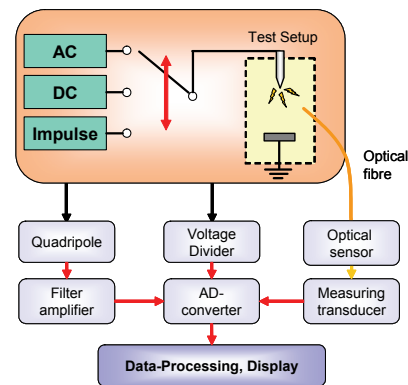


Fig. 3 concept of the conventional and optical PD measurement

The distance between the peak and the plate can be changed in a range from 1 to 20 cm, and the voltage supply from 0 – 100 kV. As isolating medium air or oil (transformer oil) under normal pressure conditions, is used (Fig. 3).

The experimental setup is placed in a shielded and darkening high voltage laboratory in order to prevent influences from outside.

A conventional partial discharge measuring system according to IEC 60270 is simultaneous used.

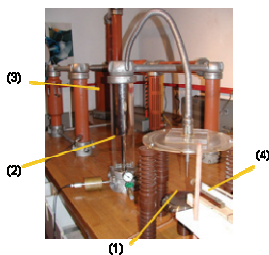


Fig. 4 experimental test setup (1) peak – plate, (2) voltage divider, (3) high voltage supply, (4) optical fibre

TEST RESULTS

After investigations for the determination of the characteristics of the developed optical system preliminary investigations under the use of a peak-plate arrangement and different voltage supplies source (AC, DC, impulse) have been taken.

PD Impulses under AC in air

In the following pictures PD impulses in air are shown, which were measured by a conventional and the optical measurement system.

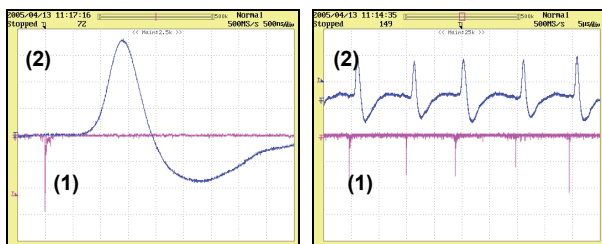


Fig.5 comparison conventional detected PD signal (2) and optical detected impulses (1)

Due to the signal processing of the used conventional system a time delay about 1 μ s results (fig 5.) occurs. The limited bandwidth of the system causes a signal extension (2,5 μ s). The rise time amounts to 400ns in the comparison to the optical system with a rise time of approx. 5ns and an impulse time of approx. 20ns

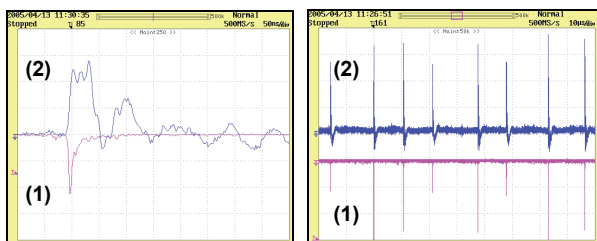


Fig. 6 comparison conventional detected PD signal (system with wide bandwidth) (2) and optical detected impulses (1).

By the use of a conventional system with a higher bandwidth the rise time increases (10ns) and the time delay is missing. The test shows a good correlation between the conventional measured PD level and the output signal from the optical system [2, 3].

PD Impulses under AC in oil

The detected discharges in oil (Fig. 7) are scattered in

amplitude and shape. It shows positive and negative streamer with their different transient behavior. Positive streamers are a superposition of fast pulses and the negative streamers are composed by a burst of fast pulses of growing intensity [4].

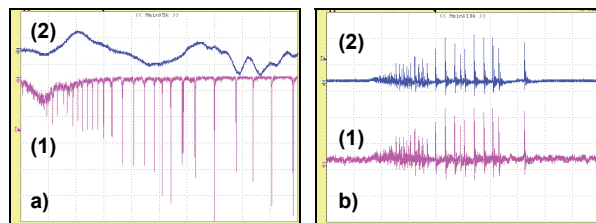


Fig. 7 comparison conventional detected PD signal (2) (– 7 b system with a higher bandwidth) and optical detected impulses (1)

In Fig. 7 a comparison of the conventional system and the optical system is presented. An exact view of the results of measurement shows, that the conventional PD system, with the limited bandwidth of the measuring technique the fast impulses in oil can not be correct represented. The optical system shows the single impulses but a relation between the results of the conventional PD measurement and the single impulses could not be found. In Fig. 7b there is a good correlation between the measured conventional signal (wide bandwidth) and the optical detected PD impulse.

PD Impulses under DC in air

In the following pictures PD impulses in air are shown at different polarity of the test voltage.

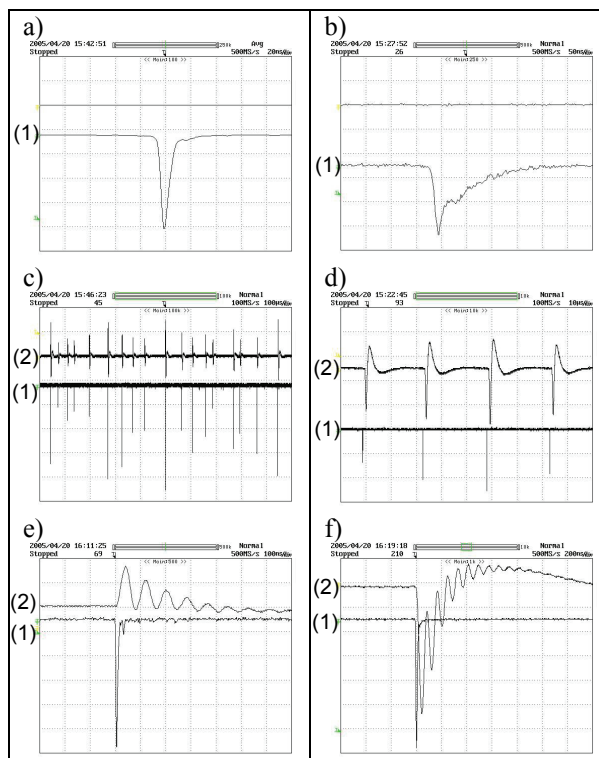


Fig. 8 comparison conventional detected PD signal (2) and optical detected impulses (1), (a, c, e – neg. polarity; b, d, f – positive polarity)

The curve progressions in Fig. 8 show the optical (1) and electrical (2) detected partial discharge impulses. In Fig. 8a) and b) the optical detected PD impulses are represented. Fig. 8a) show the impulse by neg. polarity with a rise time approx. 5ns and the impulse width approx. 20ns. Fig. 8b) show the impulse by pos. polarity with a rise time approx. 10ns and the impulse width approx. 150ns. Fig. 8 c) and d) are example for the impulse correlation between both systems. The wide-band conventional measuring system shows thereby strongly swinging impulse response (Fig. 8e,f).

PD Impulses under impulse voltage in air

In the following pictures PD impulses in air are shown at different polarity of the impulse voltage.

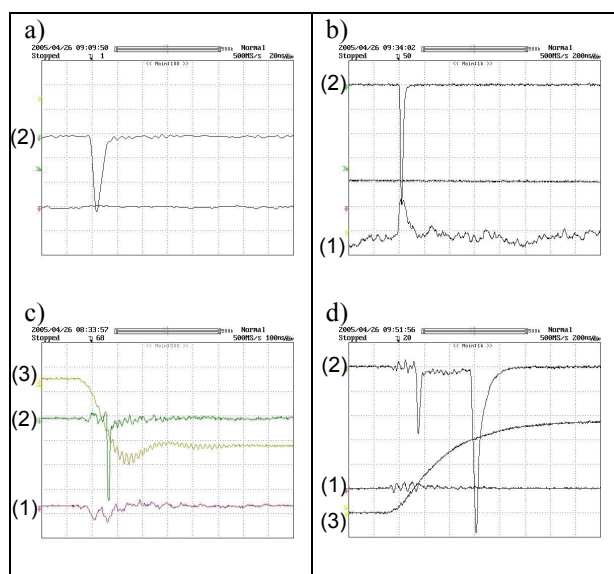


Fig.9 comparison conventional detected PD signal (2) and optical detected impulses (1), supply voltage (3),

(a, c, – negative polarity, b, d, – positive polarity)

During the accomplished measurements the rise time of the optical signals (2) (pos. und neg. Impulse) is thereby in the same order of magnitude (approx. 5ns) the pulse time varied however (20ns – 150ns). The electrical detected signal (1) is affected by strong disturbances and with the assigned measuring system a interpretation of the signal was not possible. Curve (3) shows the impulse voltage.

SUMMARY

- (1) The experiment results show that a good correlation between the results of the optical system and the conventional PD measurement - with higher bandwidth - at AC and DC is given.
- (2) It has been found that the intensity of the optical signal corresponds with the level of the partial discharge.
- (3) The phase affiliation (AC) between both systems is given.
- (4) The circumstance that fast partial discharge impulses with high repeating rate (e.g. in oil - brush discharges -

many discharges in very short temporal succession) the characteristics of the measuring system for a correct partial discharge measurements (impulse-dissolved) must be considered.

(5) During the impulse voltage a strong transient influence of the electrical signal is given, the optical system reacted however only to the partial discharge of the experimental setup.

(6) With the optical system by using a photomultiplier provides extremely high sensitivity and further fast time response and low noise.

CONCLUSIONS

This contribution gives the example of the possibility of the optical signal detection produced by partial discharge. The measurement system can be used to detect and locate the optical signal produced by partial discharge occurred in transparent dielectrics.

Based on a peak-plate arrangement some preliminary investigations have been done in air and oil as insulation media and different voltage forms. It has been found that the detection of very fast impulses (rise time about 5ns) is possible and the intensity of the optical signal corresponds with the level of the partial discharge.

Further investigations on the time performance (rise time) and impulse behavior of the partial discharge in different isolating media at different voltage sources and the consequence for the choice of the detection system are planned.

The detection of the optical signal produced by partial discharge seems to be a method for specific applications in the future and offers additional possibility in the area of the partial discharge diagnosis for measurement and discharge location also with the advantage of the immunity to EMV.

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