EXPERIENCE WITH OPTICAL PARTIAL DISCHARGE DETECTION

Michael Muhr, Robert Schwarz
Institute of High Voltage Engineering and System Management;
Graz University of Technology,
Inffeldgasse 18, 8010 Graz, Austria, Europa

Partial discharge measurement is used to evaluate different electrical insulations of high voltage equipment as a quality control and to detect insulation deterioration. Improvements, new developments as well as the lower costs of sensors, electronics and processing units are some reasons for the increasing usage of PD diagnostic. This paper presents investigations in the area of optical partial discharge measurement technique. In an overview different PD measurement systems were presented, advantages and disadvantages of the optical method were discussed. An unconventional optical partial discharge detection system was developed and comparative measurements to an conventional electrical PD measurement system were accomplished. The system was tested in the laboratory by using a PD source in air or alternatively in oil to evaluate the sensitivity and the impulse behaviour in correlation to the conventional measurement technique.

Key words: Partial discharge, optical spectrum

1. INTRODUCTION

Partial discharges are local enhancements of the electric field in the area of inhomogenities, either in gaseous, liquid or solid media. The presence and the strength of partial discharges are criterions for the evaluation of the insulation quality of the electrical equipment. On one side partial discharges only have a small short time influence on the electrical firmness of electrical resources. On the other side, the long time influence shows a destructive effect predominantly on organic insulation systems, which degrade the electrical characteristics of the insulation or the insulation systems. This can lead to a breakdown and a failure of the concerning the electrical resource.

The partial discharge measurement is a sensitive, non-destructive method for testing and monitoring the insulation condition of high voltage equipment. Different techniques are used for detection and localisation. Apart from the conventional current pulse flowing in the circuit, partial discharge activity can also generated weak light, acoustic signal and local temperature rise etc. Different techniques have been explored to measure partial discharge activities in different apparatus. A multiplicity of different PD sources and PD features with characteristic properties as well as overlays of PD location high requirements against to the diagnostic system.

2. BASICS

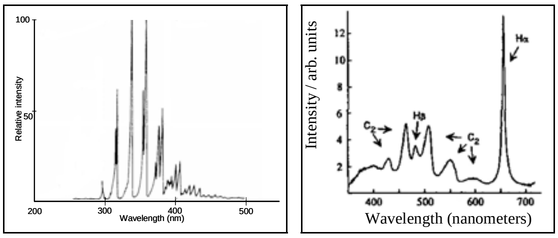
For the measurements, physical effects, such like optical, chemical, electrical and acoustical appearances, will be used.

1.1 OPTICAL PARTIAL DISCHARGE DETECTION

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. However, the optical spectrum of different types of discharge is not the same.

The amount of the emitted light and its wavelength depends on the insulation medium (gaseous, liquid or solid) and different factors (temperature, pressure …). So the spectrum of the light emitted by partial discharges depends on the surrounding medium and the intensity of the discharge. The optical spectrum reaches from the ultraviolet over the visible into the infrared range [1]. For example the wavelength of faint corona is less than 400nm. The main part falls in the ultraviolet region. The wavelength of a strong flash discharge is between 400nm and 700nm. The spectrum of surface discharges along the solid dielectric is more complex and influenced by many factors for example solid material, surface condition, including composition of gases etc. [2].

In gases with low pressure a very small fraction of the energy (1%) of the partial discharge may be emitted as light [3]. In liquids and solids this part is still smaller in the comparison to the total energy. In a rough approximation the light emitted by partial discharge is proportional to their charge. In air the nitrogen dominates the optical spectrum of discharges. 90% of the total energy of the emitted optical spectrum of PD is in the ultraviolet region. The corona discharge emits radiation in the 280nm-405nm spectral range, mostly in the ultraviolet (UV) (Fig. 1a). The main part of the emission is invisible to the human eye. A relatively weak emission at about 400 nm might be observed at night under conditions of absolute darkness.



a) b)

Fig. 1. a) Typical emission spectrum a) corona discharge and b) discharge in oil

Hydrogen gas however has its main spectrum in the visible and a smaller part in the infrared region. The spectrum of SF_6 is in the ultraviolet and in the blue-green region of the visible light.

Transformer oil exhibits a spectral region of 350 to 700 nm, depending on oil composition (Fig. 1b). The emission spectrum of oil is predominantly formed by hydrogen and hydrocarbons such as methane, ethane and ethyl.

1.2 CLASSIFICATION OF THE MEASUREMENT TECHNIQUE

Connected directly with the electrical discharge it comes to a radiation in:

- Ultraviolet
- Visible
- Infrared region.

Depending on these the different optical spectrum must be taken into account at the choice of the sensors respectively optical system:

- UV-corona scope
- Night vision
- Low-light enhancers
- Photodiode, photomultiplier

are used.

Three categories of optical PD detectors are available

- imaging
- quantitative non-imaging
- optical/electric detectors

Two different measuring techniques (applications) can be used. The techniques for the optical detection on the surface of the electrical equipment (A) and techniques to detect the optical signal inside of equipments in combination with fibre optic cable as sensor and as transport medium for the optical signal (B).

(A) Surface discharge outside the equipment

UV radiation emission measurements and observations with a night-vision device for detection of corona and other electrical discharges on surfaces are used. With the help of a daylight UV inspection camera corona and arc localization can be accomplished at high voltage transmission lines and in power stations.

The DayCor® corona camera (UV camera systems wavelength 240 – 280 nm) is a bi-spectral Solar Blind UV-Visible imager [4].

The UV channel works within the so-called sun blind range from 240 nm to 280 nm of the UV region. In this wavelength region the UV radiation of the sun is absorbed perfectly by the ozone layer before reaching the earth. Due to this particularly developed filter those UV rays can be produced by fires or electrical discharges also by day without influence by the sunlight.

The camera has two representation channels and contains an UV sensitive channel for the corona discharge and the second within the visible range for the admission of the environment. Both images are superposed and result in a video picture (see Fig. 2).

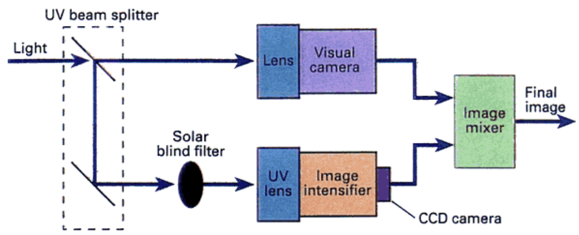


Fig. 2. Operation diagram camera DayCor II™ [4]

(B) Surface discharge "inside" the equipment

If the high voltage equipment is enclosed and light tight as transformer or GIS (environment light are totally enclosed) an optical detection under the use of fibre optical technology is possible. An optical fibre collects the light produced by partial discharge inside the equipment and transmit the signal outside to an detection unit. The optical characteristics of different fibre optic cable and optical detector materials (the relative spectral sensitivity as a function of the wavelength) must be considered.

1.3 OPTO-ACOUSTIC PARTIAL DISCHARGE MEASUREMENT

A modified form of optical detection is to influence an optical signal within a fibre-optic cable by the acoustic wave (pressure) produced by the partial discharge.

During a partial discharge in gas or oil an acoustic wave in the sonic and ultrasonic range is generated. If a PD in the surrounding medium arises, the pressure wave results in a deformation of an optical fibre and its optical transmission characteristic is changed. 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. This fact is used by the optoacoustical sensor principle. So the optical fibre methods involve optical phase modulation by the pressure. Interferometry is used and based on optical fibre intrinsic interferometers.

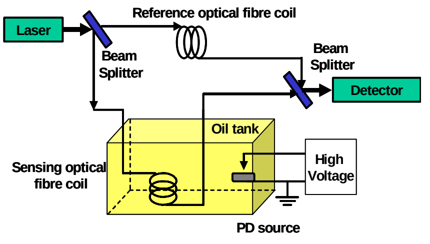


Fig. 3. Experimental setup of the optical interferometric detection of PD [5]

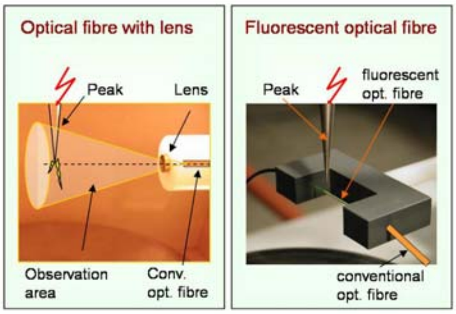
Fig. 3 shows the schematic of the Mach-Zehnder interferometer configuration with optical fibres in the reference and sensing arms. Both arms have the same length and are constructed with identical coils. The sensing optical fibre coil is in the oil tank and can be affected by the partial discharge signal (pressure), the other fibre is isolated from the impact of the acoustic wave and used as the reference arm for the optical path of the light. The interferometer is illuminated with a coherent light source. A beam splitter is used at the laser output to divide the light for the two fibre coils and also a mixer is used for the recombination of the two beams focused onto the optical detector [5].

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 deals with the economic possibilities of the optical detection of partial discharge with special fibre-optic cables and the acquisition of the impulse behaviour of PD in different isolating media.

3. INVESTIGATIONS

An optical system for PD detection for converting the light into electrical signals and a detection unit was developed.

The system consists of a lens or alternatively a special fluorescent fibre optic cable in front of a conventional fibre-optic cable, which is connected to a photodiode alternatively to a photomultiplier for the conversation of the light into an electric signal. Different procedures of the light linking into the fibre-optic cable, as well as different geometrical arrangements to the source of partial discharges were analysed. One method is to use a lens system in front of the optical fibre. Another method is using a fluorescent optical fibre, whereby the light penetrates over its surface into the fibre (Fig. 4). The light signal is coupled into the optical fibre and at the end of the fibre the signal is transmitted to the photodiode and/or photomultiplier and the amplifier circuit.



a) b)

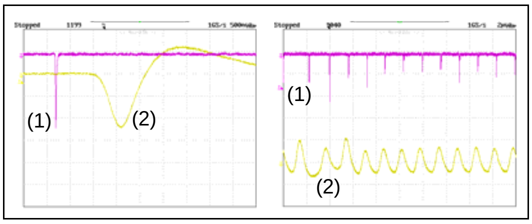
Fig. 4. optical fibre arrangement in front of an peak electrode
a) lens and conventional optical fibre
b) fluorescent and conventional optical fibre

A peak-plate arrangement as a test setup is used for the 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. The experimental setup is placed in a shielded and darkened high voltage laboratory in order to prevent influences from outside.

Investigations with an conventional detection systems according to IEC 60270 in comparison to the optical system were carried out. The PD pulses were observed simultaneously by the used systems. Further investigations about the PD impulse behaviour at AC and DC were made.

4. TEST RESULTS

In the following picture PD impulses in air are shown, which were measured by conventional and optical measurement systems.



a) b)

Fig. 5. Comparison conventional detected PD signal (2) and optical detected impulses (1) in air with a) fluorescent fibre and b) lens

The PD impulses (Fig. 5) measured with the optical system (1) shows a rise time approx. 5 ns and an impulse time of approx. 20 ns. Due to the signal processing of the used conventional system (2) a time delay of about 1µs and also an signal extension of about 2,5µs results. There is a good correlation between the conventional measured PD signal (in air) and the output signal from the optical system (Fig. 5 and Fig. 6).

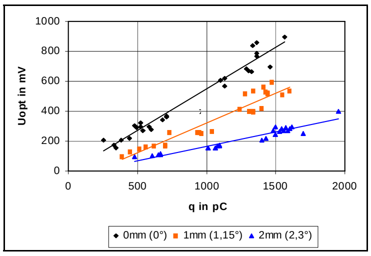


Fig. 6. Output voltage of the optical system as a function of the apparent charge during angle (0° - 2,3°) dependent light linking (air, lens)

By varying the angle to the PD source between the peak and the sensor (lens + optical fibre), a change in the peak value of the light pulse was observed as shown in figure 6.

In oil, the detected discharges are scattered in amplitude and shape. Positive streamers show a superposition of fast pulses and negative streamer are composed by a burst of fast pulses of growing intensity. The PD impulse amplitude and the repetition rates were randomly distributed within the acquisition period.

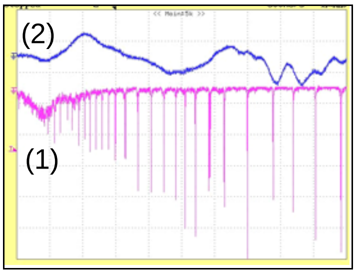


Fig. 7. Comparison conventional detected PD signal (2) and optical detected impulses (1) in oil

The result (Fig. 7) shows, that the conventional PD system (2), with the limited bandwidth of the measuring technique cannot represented the fast impulses in oil correctly. A relation between the detected single impulses of the optical system (1) and the result of the conventional PD measurement (2) could not be found (Exception: occasionally arising single pulses with larger pulse interval).

Both, the air and the oil gap conditions, were measured and the relationship between the electrical and optical signal is shown in figure 8.

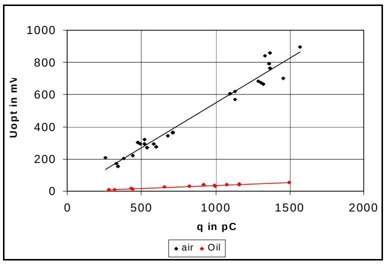


Fig. 8. The relationship between the optical signal and the discharge level in air and in oil at the same arrangement

It is to consider the circumstance that in air and in oil different discharge behaviours, another optical absorption, as well as different spectral regions of the radiated light are given. This also effects the characteristic of the optical system change, evidently caused by the large difference between the received output signals (Fig. 8).

5. CONCLUSION

The optical measurement is a sensitive method in comparison to the conventional electrical techniques especially by on-site measurements. Other advantages of this method are the immunity to EMC, the insensitivity to electromagnetic and acoustic interference sources. So the light detection is not affected by the environmental noise and the highly flexible and large bandwidth of the system. Furthermore the optical partial discharge detection can be simply used under impulse voltage condition.

Air and SF_6 are almost to 100% transparent, so the light can be detected from a lager distance. Adverse in liquids and solid insulations a section or the whole emitted light will be absorbed and no detection is possible. Also in comparison with the conventional measuring the optical detection of PD cannot be calibrated.

REFERENCES

[1] SCHWARZ R., „Optische Teilentladungsdiagnostik für Betriebsmittel der elektrischen Energietechnik“, Dissertation, TU Graz, 2002

[2] CHEN G., X. YANG, Y. MING, XIAOLONG C., CHANGRONG Q., “Comparison between Optical and electrical Methods for PD Measurement”, The 6th International Conference on Properties and Applications of dielectric Materials, June 2000, Xian

[3] FORSYTH K.W., “Optical partial discharge detection”, Iris Rotating machine Technical Conference, March 1998

[4] [http://www.daycor.com]

[5] MACIA-SANAHUJA C.; L-RIVERA H., “Wavelet Analysis of Partial Discharges Acoustic Waves obtained using an Optical Fibre Interferometric Sensor for Transformer Applications”, 0-7803-7912-8/03/ 2003 IEEE