The Application of the Spectrophotometry Method for the Measurements of Electrical Discharges

Tomasz BOCZAR, Marcin LORENC, Opole University of Technolgy, Opole, Poland

Abstract. The subject matter of this paper is connected with determining the application possibilities of the optical spectrophotometry method in diagnostics of insulation systems of apparatuses and electrical appliances operating in an electrical power system. The paper will present the measurements and analysis results of optical signals generated in spark-gaps modeling basic electrical discharge forms, which can occur during a regular operation of power appliances. There will be also determined the influence of metrological factors, such as the value of discharge generation voltage, burning time of the arc, location place of the spectrophotometer measuring sensor in relation to the source of electrical discharges, which can influence the measurement and analysis results obtained and, in consequence, decide on the evaluation accuracy of the insulation measured. In Summing-up there will be characterized advantages, disadvantages, limitations and a potential range of the application of the optical measurement method of electrical discharges in diagnostics of high-voltage insulation systems.

1. Introduction

The occurrence and development of electrical discharge in insulation systems are accompanied by various physical phenomena. The most important, from a power appliance diagnostics point of view, are: chemical changes of insulation, the occurrence of the current pulse and emission of an electromagnetic wave, and a percussive elastic strain with an acoustic wave generation that accompanies it. Based on these phenomena various methods of detection, measurement and electric discharge analysis have been developed, out of which of practical importance are: electric, gas chromatography, of the return voltage measurement, of light measurement, of pressure and heat change occurring during electrical discharge generation, and that of the acoustic emission. The current development of diagnostic methods of insulation systems results from the necessity to improve operational reliability of power appliances and extend the time of their operation, which, in consequence, can bring measurable economic profits. It refers especially to high power transformers, the investment cost of which in relation to the total value of the appliances used for transmission, division and distribution of power energy is about 20%. Moreover, the estimated cost value of a transformer failure may, in extreme cases, exceed the cost of its construction even five times. It justifies undertaking a broad diagnostic research, the range of which should be correlated with technical and economic significance of a power appliance measured [1-7].

Each measurement method of partial discharges has its own instruments. Within a definite measurement method various systems of receiving, processing and interpreting signals can be used. They depend on metrological conditions and the selection of the quantity measured. In recent years non-destructive methods, which can be used in industrial conditions during a regular operation of an appliance, have become of more significant. To such method belong the optical spectral diagnostics basing on the measurement and analysis of electromagnetic radiation for the waves of the lengths in the range from 10 nm to 30 mm

The research work carried out by the authors of his paper aim at determining the range and indicating recognition possibilities of basic electrical discharge forms that can occur in insulation systems of power appliances, based on the analysis results of their optical spectra.

The paper will present the results of measurements and spectral analysis of optical radiation generated in spark-gaps modeling discharges of the point-point and creeping surface in air types. Moreover, the influence of a series of metrological parameters on the obtained results of the optical spectrum analysis will be determined.

2. Characteristics of the system used for generation of electrical discharge and measurement of the optical spectrum emitted

Fig. 1 shows the photographs of the spark-gaps in which electrical discharges of the point-point (a) and creeping surface (b) in air types were modeled. Detailed presentation of supplying system spark gap, geometric dimensions of the fixing constructions have been presented, among others, in the works [2, 3].

a) b)

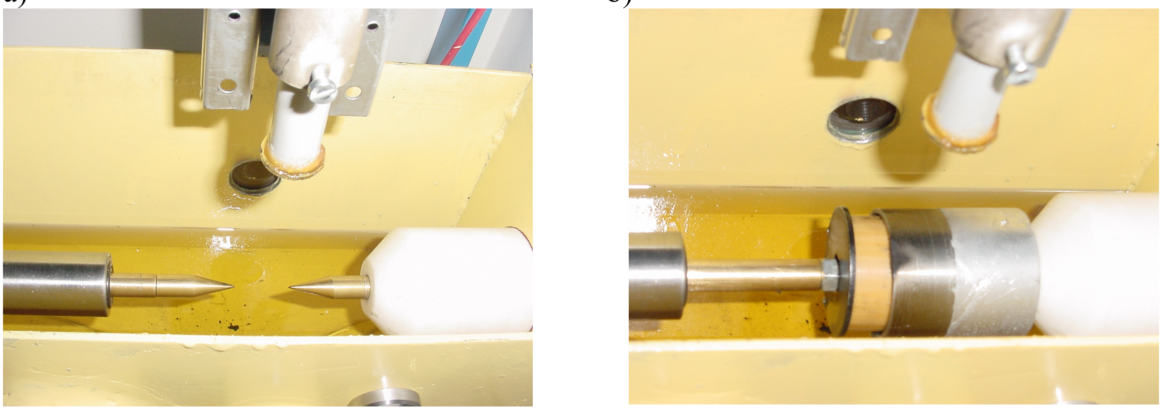

Figure 1. Photographs of the spark-gaps modeling electrical discharges in air of the: a) point-point type, b) creeping surface type

To measure a light radiation spectrum emitted by electrical discharges and generated in model spark gaps a spectrophotometer was used the optical transducer of which was placed in a specially profiled ebonite pipe with its opening placed right over the discharges generation area and which was tightly closed with a quartz glass.

An AVS-USB2000 spectrometer by the firm AVANTES was used for measurements, the main element of which is a multistage diffraction grating which enables the analysis of the spectrum in the range (270-1600) nm with the resolution of about 0.5 nm. A signal is delivered to the grating by a light pipe. After splitting the radiation falls on the CCD matrix (SonyILX511). The integration time can be changed in the range from 3 ms to 60 seconds.The measurement in the particular element of the CCD matrix (2048 elements sized 12.5 x 200 micrometers) is based on the photon counting in a time unit. One counting corresponds with the activation by 86 photons, which is the equivalent of the sensitivity of $2.9\ 10^{-17}$ J/pulse. The relative sensitivity depends of the length of the wave analyzed. The dependency of the relative sensitivity on the wave length is shown in Figure 2. The root-mean-square value of the dark current is from 2.5 to 4 countings.

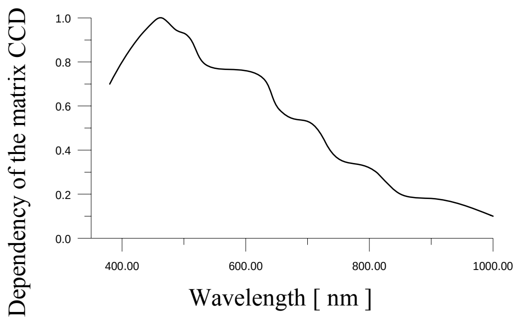

Figure 2. Dependency of the spectrometer matrix sensitivity on the radiation wave length

3. Results of analysis of light pulses generated in spark gap modeling electrical discharge of the point – point type in air

Figs 3 and 4 present the runs of the light radiation spectra emitted by partial discharges generated in the system modeling discharges of the point-point type in air at the supplying voltage equal to 0.5 (Figure 3) and 0.8 (Figure 4) of the breakdown voltage (U_b) of the spark gaps under study.

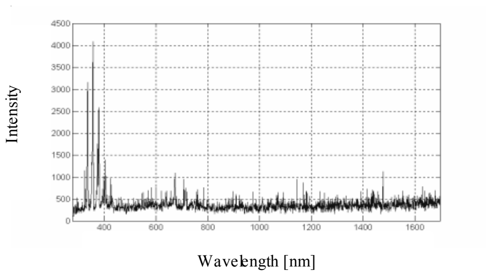

Figure 3. Optical spectrum of partial discharges generated in the point – point system in air, at the voltage of 0.5U_b

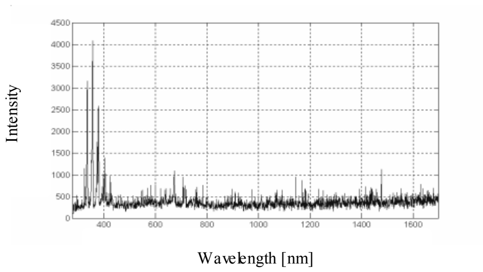

Figure 4. Optical spectrum of partial discharges generated in the point – point system in air, at the voltage of 0.8 U_b

The characteristics presented in Figure 5 shows the influence of the voltage value of the partial discharge generation in the system modeling surface discharges in oil in the range from 0.5 to 0.8 U_b.

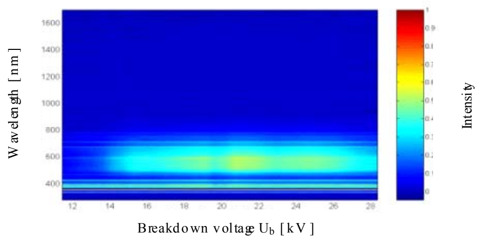

Figure 5. The influence of the supplying voltage value in the point-point spark gap in air on the length of the light wave emitted

Figure 6 shows the dependence of the average light radiation intensity during the burning time of the electric arc accompanying disruptive discharges in the point-point spark gap on its ignition to extinction, at the constant value of the supplying voltage and at the increasing distance between the electrodes.

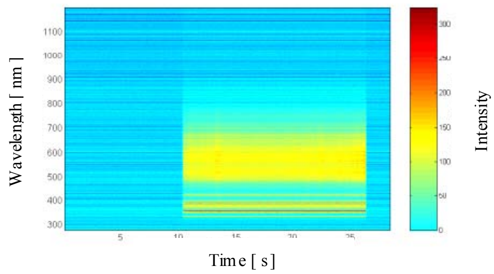

Figure 6. Changes of the optical spectrum during the arc burning time of the disruptive discharge in the point-point spark gap in air

Figs 7 and 8 show distributions of an optical spectrum in the inter-electrode space for a point-point spark-gap placed in air.

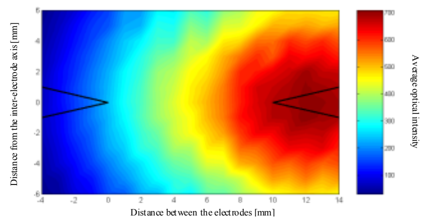

Figure 7. Optical spectrum distribution in a point tangent to the surface of the spark-gap points for discharges of the point-point type in air

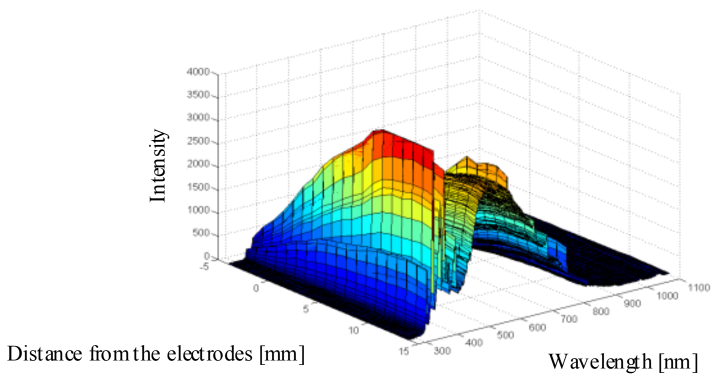

Figure 8. Optical spectrum distribution on the inter-electrode axis for a point-point spark-gap in air

Fig. 9 shows the optical spectrum of disruptive discharges generated in the spark-gap modeling discharges of the point-point type in air. The spectrum run is characteristic of both a linear area in the range of ultraviolet and a continuous area in the range of a visible light VIS.

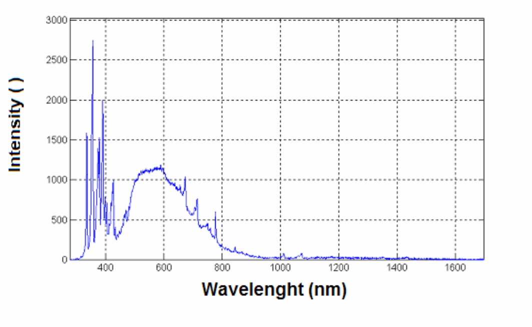

Figure 9. Optical spectrum of disruptive discharges in the point-point system in the wavelength range 270-1700 nm

4. Results of analysis of light pulses generated in spark gap modeling electrical discharge of the surface creeping type in air

Fig. 10 shows the optical spectrum of the creeping surface discharges at a selected moment in which an intensive generation of radiation took place. The runs of the spectrum derivative used for the automatic detection of local extrema of the optical spectrum are marked red. This spectrum is characteristic of a continuous area and two main components in the visible band. Local extrema in the UV range are not observed

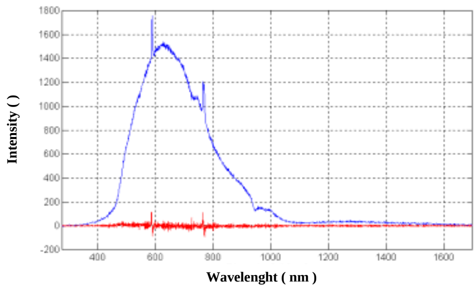

Figure 10. Optical spectrum of creeping discharges in air in the range from 270 to 1700 nm

The analysis of the distribution of the creeping discharges in air in the plane parallel to the plane containing the axis between the electrodes and perpendicular to the optical sensor has been carried out. The measurement time was about 2 min. due to the necessity of moving the optical waveguide along and across the plane analyzed. In the tests the distance between the electrodes was constant and was equal to 15 mm. The height of the optical waveguide in relation to the electrode axis was 90 mm.

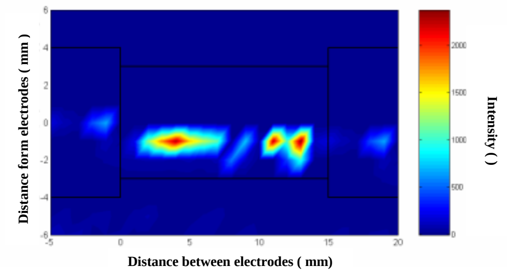

Figure 11. Distribution of the average optical intensity in the interelectrode space in the band 270-1700 nm

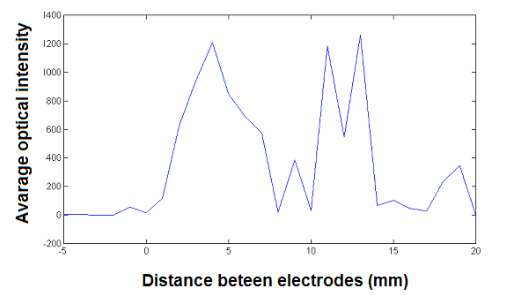

Figure 12. Dependence of the average optical intensity on the distance between the electrodes in the band 270-1700 nm.

The result of the measurements is shown in Fig. 11. The diagram shows the radiation generation in line, along which the development of creeping discharges took place. The run of the averaged intensity in the whole wavelength band analyzed is shown in Fig. 12. The diagram shows a fluctuating character of radiation, but the evaluation of the special changes is of no metrological significance due to a too long measurement duration time in relation to time changes of the phenomenon generated.

5. Summing-up

In a non-uniform field in air, optical spectra of electrical partial discharges are in the range from 320 to 430 nm and the optical spectra of electrical disruptive discharges are in the range from 330 to 850 nm. During electrical creeping surface discharges on porcelain in air the optical spectrum generated is contained in the range from 400 to 1000 nm. The varied optical spectra for the types of partial discharges under study can be used for recognizing their forms. Similarly, the optical spectrum runs, which differ considerably, for the partial and disruptive discharges for a non-uniform system, can be used for evaluating the hazard to paper-oil insulation caused by electrical discharges. No differences in the optical spectrum runs were observed at the changes of the supplying voltage in the range from 0.4 to 0.8 U_p.

The results presented in this paper proved to be useful in the spectral analysis method, which as non-destructive method can constitute a valuable supplement of classical measurement methods of electrical discharges used during a regular operation of power appliances. The results obtained can contribute to the development of knowledge on the mechanism of the occurrence and development of electrical discharges in air insulation systems and they can find their physical implementation in diagnostics of power appliance insulation.

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