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Detection of partial discharges occurring on HV cylindrical insulator made of porcelain using the spectrophotometry method

Abstract. *The paper presents results of measurements of optical signals emitted by partial discharges occurring on the surface of cylindrical insulator made of porcelain. The optical signals were recorded using a spectrophotometer type HR4000, from Ocean Optics. This device was applies for measurement of electromagnetic waves in the ultraviolet (UV) and visible light range. The measurement system and elements of the laboratory setup, used in research works, are presented in the paper.*
In the study the effect of supply voltage value on the intensity of the recorded signals was investigated. As a result of the performed analysis characteristics of optical signals emitted on the considered type of HV insulator were determined. In particular, the lengths and intensities of the emitted signals, and the dependency of the supply voltage on the optical emission were illustrated. The gathered wavelength spectra were subjected to a regression analysis where a mathematical model consisting of a set of Gauss functions was used in the aim of determining the intensities of wavelengths included in the registered radiation.

Streszczenie. *W pracy przedstawiono wyniki pomiarów sygnałów optycznych emitowanych przez wyładowania niezupełnewystępujące na powierzchni cylindrycznego izolatora wytworzonego z porcelany. Sygnały optyczne zostały zapisane za pomocą spektrofotometru HR4000 firmy Ocean Optics. Urządzenie to zostało wykorzystane do pomiaru fal elektromagnetycznych w zakresie ultrafioletowym (UV) oraz zakresie światła widzialnego. Układ pomiarowy i elementy instalacji laboratoryjnej, stosowanych w pracach badawczych, zostały przedstawione w artykule.*
*Wpływ wartości napięcia zasilania na natężenie sygnałów zarejestrowanych został zbadany. W wyniku przeprowadzonej analizy zostały określone charakterystyki sygnałów optycznych emitowanych przy użyciu badanego typu HV izolatora. W szczególności zostały przedstawione długości oraz natężenia emitowanych sygnałów i zależność napięcia zasilania od optycznej emisji. Zgromadzone widma długości fal zostały poddane regresywnej analizie, gdzie model matematyczny składa się ze zbioru funkcji Gaussa, który został wykorzystany w celu określenia natężenia fal, wynikającego z zarejestrowanego promieniowania. (**Detekcja wyładowań niezupełnych występujących w HV cylindrycznych izolatorach wytworzonych z porcelany stosując metodę spektrofotometrii**).*

Keywords: cylindrical insulator, spectrophotometry method, partial discharges.
Słowa kluczowe: cylindryczny izolator, metoda spektrofotometrii, wyładowania niezupełne.

Introduction

Technical condition estimation and diagnosis of the insulation elements, which are important parts of every high voltage (HV) equipment are crucial, since their improper operation may lead to breakdown in the power supply. Especially outdoor insulators are exposed to faster worsening of the insulating properties due to e.g. pollution and atmospheric conditions [1]. A high level of humidity by simultaneous occurrences of contaminants causes formation of conductive paths, which are the source of surface partial discharges (SPD) and corona discharges. The SPD, next to the natural aging process, cause further deterioration of the insulating properties of an insulation system. Therefore, a rapid development of various techniques for monitoring of PD is observed in recent years [2-20].

In their research works authors concentrate their effort on the improvement of nondestructive methods and in particular ondetermination of the feasibility and indication of the application scope of the optical spectrophotometryin the diagnosis of non-organic HV insulators.

This paper considers studies related to application of the optical spectrophotometry for detection of SPD occurring on a cylindrical insulator made of porcelain. The research works regarded to determination of the intensities of optical emission in the range from 200 nm to 1200 nm and to investigation of the influence of the supply voltage value on these intensities. The achieved wavelength spectra were subjected to a regression analysis where a mathematical model in form of a superposition of eight Gauss functions was applied in order to determine its specific characteristics.

Measurement and Analysis Methodology

The measurements were performed under laboratory conditions using a spectrophotometer type HR4000, from Ocean Optics (Fig. 1a). The object under studywas an insulating cylinder made of porcelain (Fig.1b).

a)

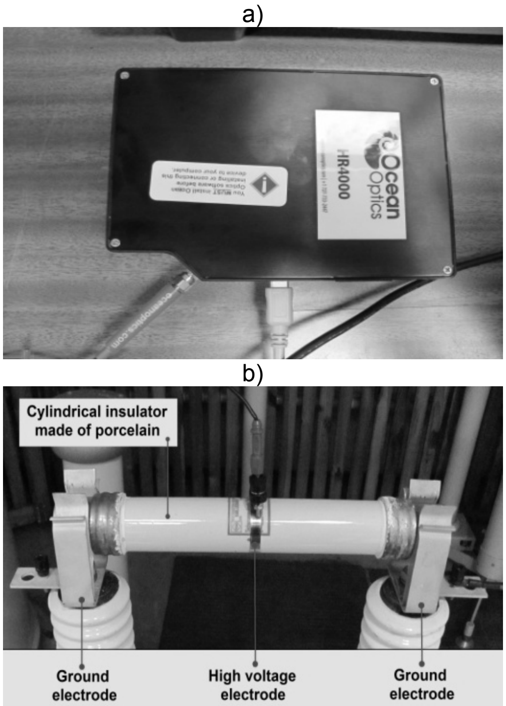

Fig. 1. a) – the applied spectrophotometer; b) – the object under study, a cylindrical insulator made of porcelain

The two ends of the cylinder were mounted in holders, acting as ground electrodes, the high voltage electrode was mounted in the middle of the cylinder at a distance equal 3 cm to one of the ground electrodes. The ground electrodes were installed on special brackets as shown in Fig 1.

The power supply system consisted of a control panel and a testing transformer. The voltage value was regulated by an autotransformer and then it was forwarded to the primary winding of the single phase testing transformer, rated with 220/110000 V/V. From transformers secondary winding, through a water resistor, which was used for limiting the short-circuit current, the tested insulator was powered. The measuring setup is presented in Fig. 2.

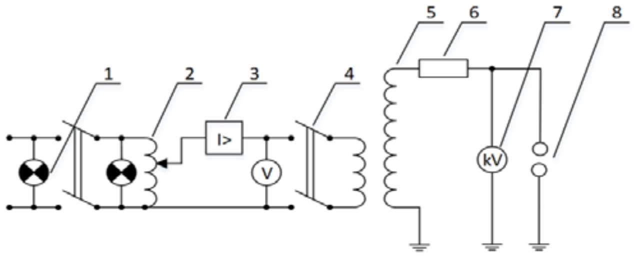

Fig. 2. Schematic of the HV power supply used in the experiments. 1 – control lamp, 2 – voltage regulator, 3 – overcurrent protection, 4 – switch, 5 – transformer, 6 – water resistor, 7 – voltmeter, 8 – the object under study

A series of measurements was performed for various voltage values in the range from 0 to 100 kV. At each trail the emitted optical radiation was registered by the measuring device and recorded on a personal computer (PC). Five trails were gathered for each voltage value, thus the result may be assumed to be statistically important.

In the regression process eq. (1) was applied. It constitutes a superposition of Gauss functions, where each component has its own amplitude A, shape C and location B.

$$Model(\lambda) = \sum_{i=1}^{8} A_i e^{-\left(\frac{\lambda - B_i}{C_i}\right)^2} \quad (1)$$

where: λ – wavelength, A_i,B_i,C_i – model parameters

Eg. (1) was applied for all gathered signals and the parameters were estimated. As goodness indicator R-square value, eq. 2, was evaluated.

After the regression process the estimated parameters were subjected to analysis, which aim was to determine the characteristic wavelengths included in the radiated signals and their intensities.

$$R^2 = \frac{\sum_{\forall\lambda}\left(\tilde{y}_\lambda - \bar{y}\right)^2}{\sum_{\forall\lambda}\left(y_\lambda - \bar{y}\right)^2} = 1 - \frac{\sum_{\forall\lambda}\left(y_\lambda - \tilde{y}_\lambda\right)^2}{\sum_{\forall\lambda}\left(y_\lambda - \bar{y}\right)^2} \quad (2)$$

where: R^2 – R-square value, $\tilde{y}_\lambda$ – value estimated for a given wavelength λ, $\bar{y}$ – mean over the measured data, y_λ – data measured for given wavelength λ.

Measurement and Analysis Methodology

In Fig. 3 intensity of optical signals measured in the UV and visible light range as supplying the insulator with 18 kV is presented. The dots depict the measured data, while the solid line regards to the estimated model. In Fig. 3 it is clear to recognize that the particular wavelengths correspond to the locations of the Gauss components in the model (parameter Bi), and the amplitudes (parameter Ai), more or less, to the intensities registered at these wavelengths. The less intense wavelength bundle about the value 290 and 390-450, were not very well estimated in the regression process. Although, the most significant picks and the overall pattern were determined with a very good fitting, what was confirmed by a high value of the R-square parameter.

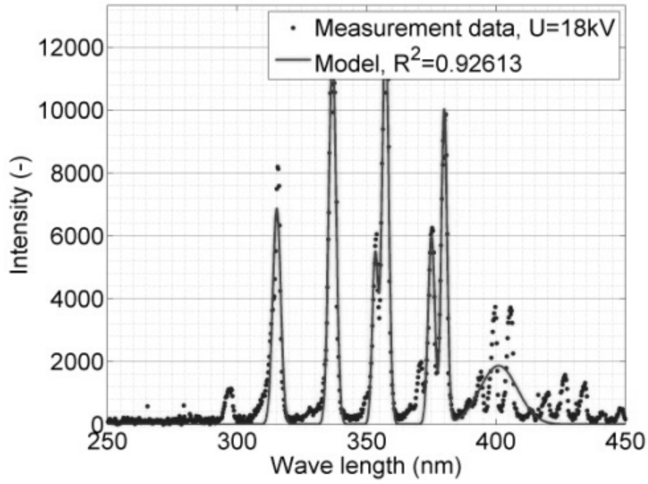

Fig. 3. Intensity of optical signals measured in the UV and visible light range

In Fig. 4left, R-square values calculated based on result of regression over all considered supply voltage values and trails are presented. One can recognize that apart from the lower voltage values, about 15 kV, all values are close to one. This is an indication that the chosen model fits well to the empirical data and the estimated parameters may be selected for further purposes.

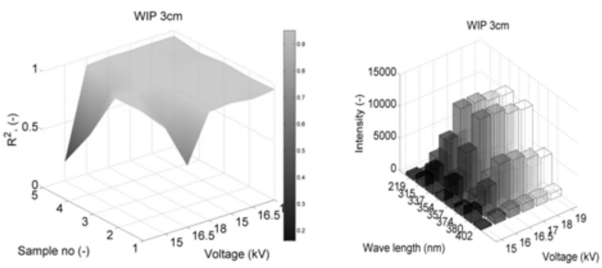

Fig. 4. Left: R-square values calculated for all considered supply voltage values and each of the five trails. Right: Model parameters A estimated through the regression process for all registered signals

In Fig. 4 right, the estimated through regression analysis model parameters Ai, which correspond to the intensities of the most significant spectra in the registered signals are presented. The depicted values constitute arithmetical means over the five data sets gathered for each voltage value. Based on these results it is possible to list the particular wavelengths and the corresponding intensities. The most intense components are: 380, 357 and 337 nm. It is to recognize that the rising voltage causes similar growth in the particular intensities. Further increase in voltage after achieving the value of 19kV caused a short cut.

Conclusions

Results of measurementand analysis of optical radiation emitted by SPD occurring on cylindrical insulator made of porcelain were presented in the paper. The influence of supply voltage value on the registered signals was determined and depicted. A mathematical regression was applied for to determine the intensities of most significant wavelengths contained in the recorded signals.

Based on the gathered results it was stated that:

- the measured signals are characterized by a wavelength components of various intensities;
- the characteristic wavelengths pattern may be approximated by a sum of eight Gauss functions with high goodness
- the model parameter Ai – amplitude of the i-th Gauss component, corresponds to the intensity, and the model parameter BI – location of the i-th Gauss component, corresponds to the wavelength of the empirical signal;
- the rising voltage causes corresponding growth of all wavelength intensities.

Results of investigations performed by authors will be applied in further studies aiming improvement of the optical spectroscopy method for diagnosis of non-organic HV insulators dedicated to monitoring of SPD.

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