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Study of UV radiation emitted by partial discharge on the surface of a composite insulator

Streszczenie. *Artykuł zawiera wyniki pomiarów i analiz WNZ generowanych na powierzchni izolatora kompozytowego. WNZ rejestrowano za pomocą specjalistycznej kamery jako liczbę zliczeń emisji fotonów w zakresie UV. W badaniach poddano analizie porównawczej liczbę zliczeń fotonów emitowanych przez WNZ na powierzchniach mokrych, suchych, czystych i zanieczyszczonych różnej wielkości stężeniami roztworu solnego i kaolinu. (**Badanie promieniowania UV emitowanego przez wyładowania niezupełne na powierzchni izolatora kompozytowego**).*

Abstract. *The article contains the results of measurements and analysis of partial discharges (PD) generated on the surface of a composite insulator. PDs were recorded with a specialized camera as the number of photon emission counts in the UV range. The study comparatively analyzed the number of photon counts emitted by PD on wet, dry, clean, and contaminated surfaces with different concentrations of salt solution and kaolin.*

Słowa kluczowe: wyładowania niezupełne, kamera UV, zanieczyszczenia środowiskowe, diagnostyka.
Keywords: partial discharge, UV camera, environmental contamination, diagnostics.

Introduction

Currently, extensive research is being carried out on the development of non-invasive and non-destructive diagnostic methods for insulating systems of power equipment concerning the diagnosis of partial discharges [1-5]. There are several such methods, and one of them is the optical method, which involves recording and analyzing electromagnetic radiation in the ultraviolet range, which is emitted during the generation of partial discharges [6-8].

During operation, insulators are subject to various external factors, which include electrical, mechanical, thermal, and atmospheric exposures [9]. Electrical exposures come from operating voltage and lightning and switching surges. Under normal operating conditions, in a three-phase power system, the insulator is under the action of phase voltage. The threat of insulators as a function of rated voltage depends on their design. For lower voltages, lightning discharges are assumed to be decisive.

As the line voltage increases, the proportion of storm disturbances decreases while the proportion of dirt disturbances increases. As the voltage increases, the risk from switching surges increases. Manufactured insulators should withstand most switching and short-circuit overvoltage without surface discharge and breakdown. Lightning and arcing protection measures are used to protect from lightning surges. Contamination exposures are a separate issue since the potential emergency hazard exists all the time and is only revealed under certain circumstances. Such exposure consists of the fact that the insulator is affected by dirt and moisture simultaneously. Contamination hazard depends on the intensity and electrical conductivity properties of falling debris and the content of certain gases in the environment of overhead insulators. The value of the surface conductivity of a given insulator is used as a measure of contamination exposure. Since this value depends on the length of the leakage path, this path, together with the value of the highest operating voltage of the device, is taken as a criterion for contamination selection. Another criterion used is the contamination characteristics of the insulator, concerning the dependence of the fifty percent fouling discharge or breakdown voltage on the surface conductivity (PN-79/E-06303 standard). In the current standards (PN-81/E-05001, PN-79/E-06303), electrical exposures have been considered by assigning test voltage values depending on the rated voltages that an insulating system must withstand.

Mechanical exposures of insulators are divided by source of origin into electrodynamic loads and loads of non-electrical nature. Mechanical loads result from static, shock, and vibration forces. According to PN-88/E-06313, mechanical loads occurring in overhead lines are divided into external (wind, ice, ice-wind), continuous (coming from the tension of the wires and the weight of the line elements), and special (installation and disturbance loads).

Electrodynamic loads are greatest at high short-circuit currents and cause loads of a bending or torsional nature, hence are important for insulators in distribution stations. Loads of a tensile nature (e.g., conductor tension) determine the selection of line insulators. Another type of hazard is the effect of heat generated during an electric arc. For example, an arc current of 2.5 kA and a duration of 3.5 seconds causes permanent damage in the form of cracks or melting of porcelain. Sudden changes in insulator surface temperature caused by solar heating, cooling by hail, or cold rain can cause insulator cracking. Bushing insulators are exposed to heat generated in their inner part due to dielectric losses [10-11].

For diagnostic work on the assessment of the technical condition of power equipment and high-voltage transmission lines, among other things, specialized cameras are used that allow the detection and localization of corona, surface, and arc PD, and in particular the registration of the number of photons emitted by them in the UV frequency band.

The [12, 13, 14] papers present the results of research on diagnostics of overhead insulators by optical methods. The purpose of this work was to determine diagnostic criteria for UV camera applications for PD detection. The authors studied electromagnetic radiation in the ultraviolet range generated on the surfaces of ceramic and glass insulators under laboratory conditions. In contrast, the present study takes up the challenge of subjecting insulators to environmental conditions. Preliminary results were also published in [15].

The main objective of the presented research is to determine diagnostic criteria for UV camera applications for the detection and localization of partial discharges under varying environmental conditions. An additional goal is to gain knowledge with representative data that will enable the recognition of the type and source of the partial discharge. In particular, we want to investigate the hypothesis of whether the insulator defect that causes the partial discharge originated from mechanical damage or whether it is the result of environmental contaminants that are easier to remove.

Measurement system and methodology of testing

Figure 1 presents a photo of the insulator (FCI SML 70 kN composite insulator), for which test results will be presented in this paper. This is an overhead insulator made of composite. The experimental device was powered by a measuring system generating high AC voltage, which consisted of a control panel and a power transformer. The power source was the mains voltage, which was transferred to an autotransformer that allowed voltage regulation. A test transformer with 220/60000 V voltage ratio was used in the experiments. A DayCor Superb UV camera was used to measure the optical radiation emitted by the PD generated on the insulator surface. It is manufactured by OFIL Systems and is designed for monitoring medium-, high- and extra-high-voltage power grids.

The DayCor Superb specialized UV camera features the following basic technical parameters:

- spectral range: 250 - 280 nm,
- matrix: 640x480 pixels,
- UV sensitivity: $3 \cdot 10^{-18}$ W/cm^2.

Its measurement capabilities are:

- VIS and UV spectrum operation,
- measurement of PD intensity,
- operation in daylight.

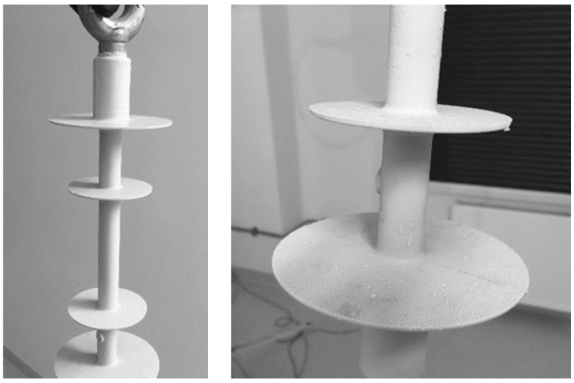

Fig.1. Photo of the considered composite insulator dry (left) and wetted with clean water (right). Source: own

The method used involves counting the number of photons that have reached the detector within a defined window where photons vibrating at a frequency that corresponds to a wavelength of 250 to 280 nm are counted. The camera also captures an image in visible light, which allows the researcher to identify the discharge and the size of the defect at the same time. Environmental conditions such as temperature, humidity, and atmospheric pressure were recorded with a digital meter. Outside the measurement room, they were kept constant: 23-24.5°C, humidity 37-52%, atmospheric pressure 1000.3-1004.7 hPa. Insulator tests were performed under laboratory conditions in a room that was a Faraday cage and sized to accommodate the power transformer and the considered object. The temperature inside the room was regulated using an air conditioner to cool it down and a heater to raise the temperature. In addition, an air humidifier was used to regulate the humidity of the air.

All measurements were performed for adjustable voltage values, increasing them up to the breakdown voltage. First, the tests were performed for clean, dried surfaces of the considered object. Then the surface was covered with a salt solution of a preset concentration of salt or kaolin and measurements were taken. Methods for testing artificially soiled high voltage insulators are contained in the Polish Standard PN-EN 60507. In the study, the following solutions with salt concentrations were tested: 5, 20, and 80 kg/m^3. In particular, the following insulator surfaces were considered:

- dry clean,
- wet - sprinkled with clean water,
- wet - sprinkled with 5 kg/m^3 salt solution,
- wet - sprinkled with 20 kg/m^3 salt solution,
- wet - sprinkled with 80 kg/m^3 salt solution,
- dry soiled - dried after sprinkling with 80 kg/m^3 salt solution,
- soiled with kaolin solution 40 kg/m^3.

Results of measurements and comparative analysis

The result of the research and comparative analysis will be discussed below. In particular, the number of counts, which is denoted in the article as *LZ*, is considered. First, an example of the measurement results for a clean wetted insulator, operating at a temperature of about 13°C, is presented.

Figure 2 shows the insulator during testing, which was done with a UV camera. The image shows white spots, which visualize photons in the UV band. The advantage of the method lies in the ability to quickly localize the generated PD.

Fig.2. Example photo of an insulator during UV camera testing. Source: own study

Figure 3a shows an example of the measurement result showing box plots calculated for data recorded during voltage increase. Note that there is no linear scale on the OX axis. Below (Figure 3b), the trend of changes in the number of counts as a function of voltage is visualized. The trend line was approximated by a regression process using a first-order exponential type function (cross) and the recorded temperature values (circle).

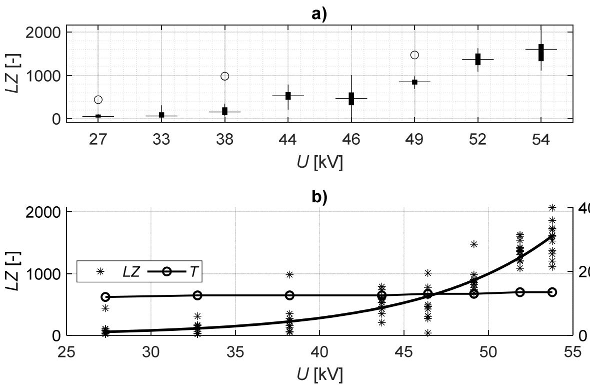

Fig.3. Results of *LZ* measurements (cross) carried out for a wetted clean composite insulator at an ambient temperature averaging 12.8°C (circle) (a) box plot, (b) dependence from the supply voltage. Source: own study

Figure 4 shows analogous example results for measurements at an average temperature of 35.2°C. Comparing Figures 3 and 4, the number of counts on the wetted surface of a clean insulator is lower at low temperatures (about 2000) and three times higher (about 6000) for high temperatures.

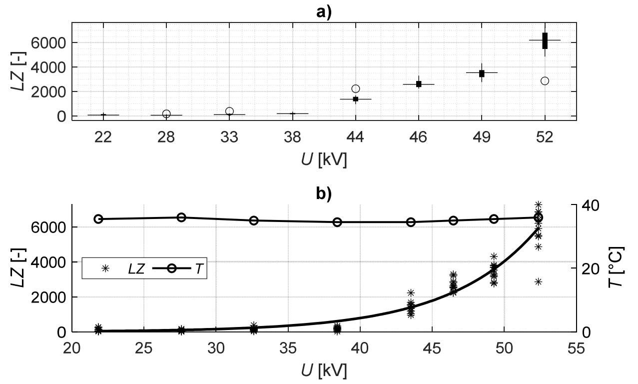

Fig.4. Results of *LZ* measurements (cross) carried out for a wetted clean composite insulator at an ambient temperature averaging 35.25°C (circle) (a) box plot, (b) dependence from the supply voltage. Source: own study

Next, the results obtained are presented comparatively. The LZ as a function of voltage recorded during PD emission on the surface of a clean composite insulator wetted and dried, for lower and higher temperatures are shown in Figure 5. Figure 5a shows trends for the clean insulator in the wet state, while Figure 5b shows trends for the dry state. Circles mark the results for higher temperatures, around 35°C, and crosses for lower temperatures around 10-12°C. It should be noted that for the insulator wetted with clean water there are visually apparent differences in the values of counted ultraviolet emissions, while for clean and dry, no such effect was observed, or at least these differences are not statistically significant. Furthermore, it was found that the effect of temperature causes significant differences when the wetted insulator operates at voltages exceeding 40 kV.

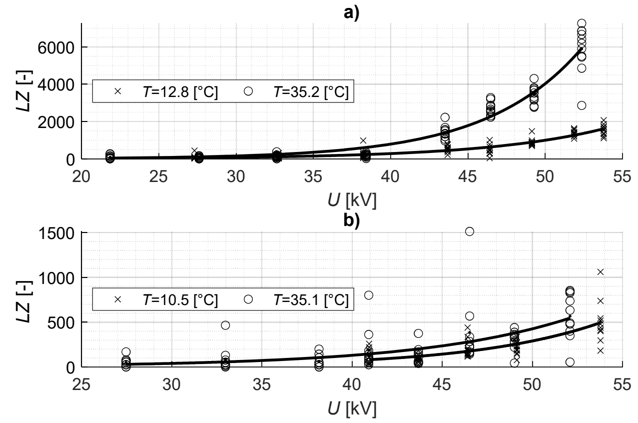

Fig.5. Comparative results of *LZ* measurements carried out for composite insulator wetted (a) and dried (b), at two extreme ambient temperatures averaging below 13°C (cross), and above 35°C (circle). Source: own study

Figure 6 comparatively shows the number of photon counts emitted by PD on the surface of dried insulators covered with the salt solution of different concentrations. Observation of the visualized results, allows us to find significant differences in the number of *LZ* for higher and lower temperatures, specifically 13-14°C versus 31-37°C. In this case, the opposite trend occurs, for the clean insulator, i.e., on the surface of the clean wetted insulator there is more PD when it is warmer, while on the surface of the salt-contaminated insulator, more PDs occur when it is cold.

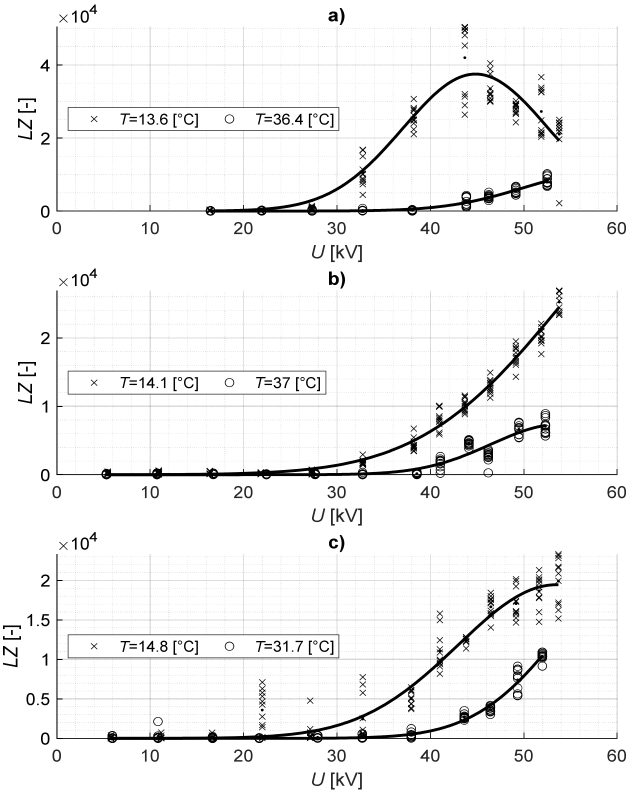

Fig.6. Comparative results of *LZ* recorded for a dried composite insulator covered with a 20% (a), 40% (b), 80% (c) salt solution, at two extreme ambient temperatures averaging below 15°C (cross), and above 35°C (circle). Source: own study

This kind of visualization allows a good comparison of the obtained test results. Only for the lowest of the considered temperatures and the highest of the considered voltages the highest photon counts in the UV range were registered.

Figure 7 comparatively visualizes the *LZ* values recorded during measurements in which the insulator surfaces were contaminated with kaolin solution after drying. A trend is evident: the lower the ambient temperature, the more PD is generated.

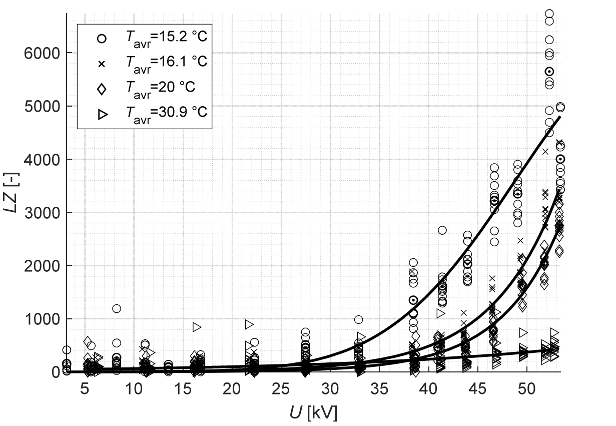

Fig.7. Comparative results of *LZ* recorded for dried, kaolin solution-stained composite insulator at different ambient temperatures averaging 15°C (circle), 16°C (cross) and 20°C (diamond), and 31°C (triangle)

Figure 8 presents the changes in LZ values as a function of temperature. They refer to PD recorded on the surface of dried clean (cross) and kaolin-stained (circle) insulator, for the same voltage of 53 kV.

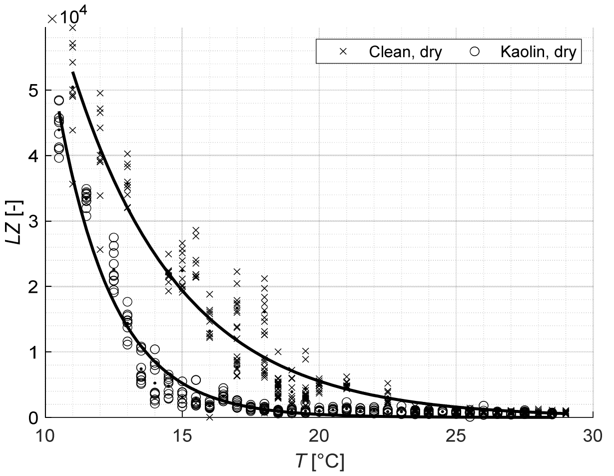

Fig.8. Comparative results of *LZ* recorded for dried clean (cross) and kaolin solution soiled (circle) composite insulator with dependence on temperature. Source: own study

Summary and future work

The results presented here show that the number of counts of partial discharges is affected by both temperature and surface moisture. When the insulator surface is dry, regardless of the degree of contamination, fewer partial discharges occur. In addition, it was noted that significantly more discharges appear on surfaces when the ambient temperature falls.

Summarizing the measurements performed, it should be emphasized that the temperature range that was achieved under laboratory conditions is not satisfactory, and in the future, it is planned to carry out tests in a thermally insulated room at temperatures below zero.

In addition, it was found that the number of results is too small to confirm the statistical significance of the relationships obtained.

In the future, it is also planned to perform research works for other types of insulators and to develop a knowledge base and, in further steps, a diagnostic support system for classifying the type and source of PD.

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