Environmental Pollution Monitoring on High-Voltage Insulators

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Abstract

This work is focused on environmental pollution monitoring on selected high-voltage insulators. It is well known that environmental pollution on electrical insulation is one of the problems faced by distribution utilities and electricity transmission system. Due to this reason there is a need to deal with monitoring of environmental pollution as it strongly influences their capability to withstand the high-voltage stress without the breakdown. It is the aim of present work to explain influence of morphology and chemical composition of pollutants on the surface resistance and conductivity of selected insulators.

Keywords: high-voltage insulators, environmental pollution, leakage current, electrical conductivity, in-situ monitoring

Introduction

Electrical energy has major impact on the number of activities forming modern society including gross domestic product, science and research, education, social sphere, security, etc. Production and consumption of electrical energy are expressed in the regular calls of the European Commission's in the Framework Programme for Research and Innovation: Secure, clean and efficient energy [1–3]. Thus both European and national activities in this area are aimed at supporting the transition to reliable, sustainable and competitive energy systems. The level and nature of contamination of high-voltage insulators is determined by the sources of pollution as well as meteorological factors in the locality. One can even observe that certain types of weather affect the more significant accumulation of contamination on the surface of the insulator. In these cases it is common to observe the course of the minimum and maximum pollution levels during year [4].

Air pollution is recognized as environmental burden with negative great influence on environment as well as on different branches of industry. Increase of electric energy consumption requires better quality of transmission networks. For distribution of higher electrical power the transfer of electrical energy at high electrical voltage (110 kV, 400 kV and higher) is needed while the cross-section of electric wires must be preserved. Those facts requires also higher demand on insulator system − high-voltage line holders due to the energy losses voltage outlets, i.e. short circuits. Pollution of the surface of the insulator increases its electrical conductivity and is therefore an unfavorable situation because it increases the risk of destruction of the insulator, mechanical damage to surrounding components as well as possible outages in the damaged part of the transmission or distribution network. It is known that during foggy weather, drizzle or dew form, contaminants are partially dissolved to form on the surface of the isolation the conductive regions, or the conductive layers and result in increase of electrical conductivity.

Active monitoring of electric conductivity of contaminated parts of ceramic, glassy or polymer-based insulators allows early regulation (decrease of energy losses). In situ monitoring of conductivity of insulator surfaces can be used for control of environmental pollution caused by industrial activity. The aim of present paper is preparation of testing electrodes and measurement of electrical conductivity variation on dry and wet surface.

Materials and methods

Preparation of silver electrodes on glazed ceramic surface

Colloid silver was used as a starting material for preparation of silver electrodes. A proper amount of colloid silver was mixed with solvent to form homogeneous paste. To obtain proper geometry of electrodes silver paste was applied on surface of glazed ceramic screen printing. Such prepared ceramic substrate was dried and annealed at 700°C for 30 min in air atmosphere. As-prepared electrodes with different geometries are shown in Figure 1.

Electrical conductivity testing

Before all measurement the glazed ceramic sample was carefully cleaned in order to remove all traces of dirt and grease. The surface of the glazed ceramic sample is deemed to be sufficient clean and free from

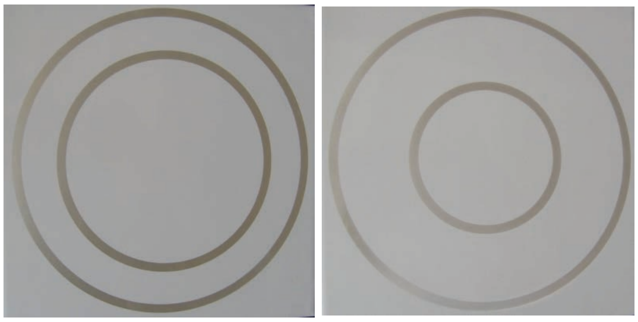

Fig. 1. Silver electrodes on glazed ceramic surface with 20 mm (left) and 40 mm (right) gap between them.

Rys. 1. Srebrne elektrody na szkliwionej ceramicznej powierzchni ze szczeliną 20 mm (po lewej) i 40 mm (po prawej)

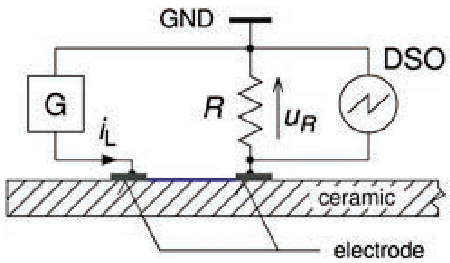

Fig. 2. Schematic diagram of the measuring circuit. (G – wave signal generator, R – sensing resistor, i_L – leakage current, u_R – voltage, DSO – digital storage oscilloscope, GND – signal ground)

Rys. 2. Schemat obwodu pomiarowego. (G – generator sygnałów falowych, R - rezystor pomiarowy, i_L – prąd upływu, napięcie u_R, DSO – oscyloskop cyfrowy, GND – uziemienie sygnału)

any grease if large continuous wet areas are observed. After cleaning, the insulating parts of the glazed ceramic sample were not touched by hand. Fairly uniform conducting electrolytic layer of a defined solid pollution, made from sodium chloride (NaCl) of commercial purity and tap water, was deposited on the dry sample surface representing the pollution layer in the service. The salinity of the prepared solution corresponds to four classes of pollution (I–IV) in accordance with [5, 6]. After drying of the deposited solution, uniformly distributed solid layer was formed.

The schematic diagram of the measuring circuit is shown in Figure 2. The applied voltage of sinusoidal shape or rectangular shape connected to the electrodes was generated by wave signal generator Agilent 33220A. Amplitude of the testing voltage with sinusoidal shape was set from 1 V to 7 V and the frequencies ranges from 1 Hz to 10 kHz. The amplitude of square wave was set to 5 Vp (peak) with frequencies 50 Hz and 1 kHz. The response of the electrode system to the applied voltage was measured with digital storage oscilloscope Agilent DSO 7104B. The amplitude of the leakage current on the surface of the sample was calculated according to the Ohm's law as the ratio of voltage and known resistance of resistor connected to one electrode. The resistance of sensing resistor is R = 3.3 MΩ.

At first, clean dry sample was measured. After measurement under dry conditions, the surface of the sample was wetted and the measurement was repeated. This procedure was then applied on sample with polluted layer (I–IV class) under dry and wet conditions.

Results and discussion

The values of leakage current flowing through the dry surface without contamination of the glazed ceramic surface between silver electrodes at different frequencies with sinusoidal shape is shown in Figure 3. As can be seen, the sensitivity of measurement increases with increasing frequency of the testing voltage. Furthermore, it can be seen that with increasing testing voltage, the leakage current increases linearly.

Low frequencies (from 1 Hz to 100 Hz) does not result in satisfied sensitivity due to the presence of electromagnetic interference. Based on achieved results, for further experiments 1 kHz frequency was used.

The time course of the testing voltage and the surface leakage current on the uncontaminated sample in the time interval of 1 ms (one period at frequency 1 kHz) is depicted in Fig. 4. Designation of individual lines is as follows: U represents the open circuit voltage applied to the silver electrodes, iL dry is the leakage current flowing between silver electrodes on glazed ceramic surface without contamination and iL wet is the leakage current flowing between silver electrodes on glazed ceramic surface with presence of humidity. From the Fig. 4ai and 4aii it can be seen that leakage current has lower values for dry surface in comparison

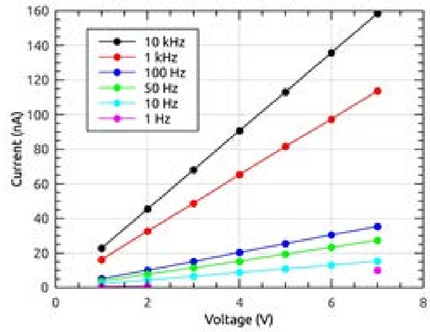

Fig. 3. Current vs. voltage at different frequencies recorded between silver electrodes on dry uncontaminated surface of glazed ceramic

Rys. 3. Natężenie a napięcie na różnych częstotliwościach zarejestrowanych pomiędzy srebrnymi elektrodami na suchej nieskażonej powierzchni szkliwionej ceramiki

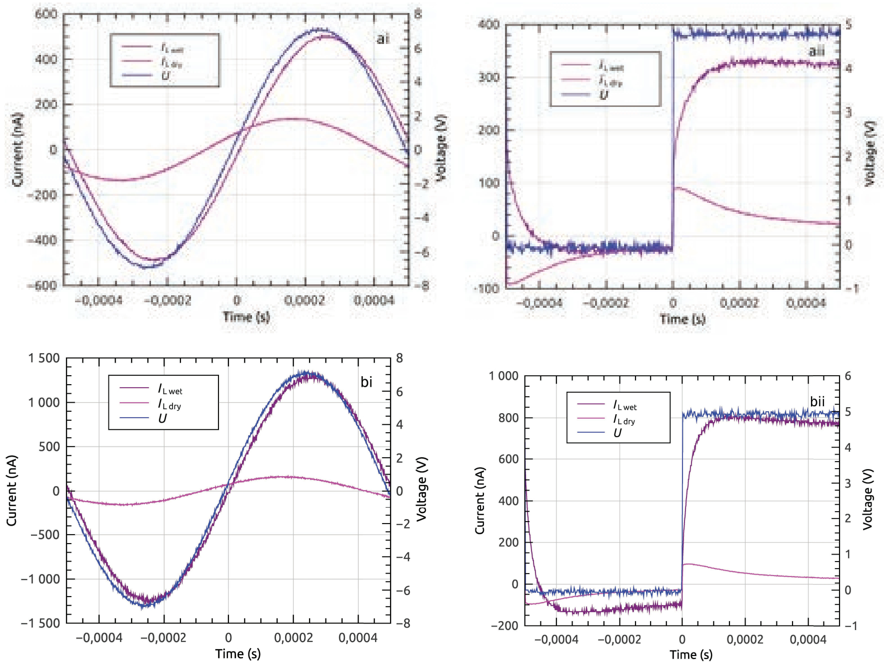

Fig. 4. Comparison of surface leakage current in measuring circuit supplied with sinusoidal and square testing voltage: a) dry and wet surface of glazed ceramic surface without contamination; b) dry and wet surface after contamination with solution class I

Rys. 4. Porównanie powierzchniowego prądu upływu w obwodzie pomiarowym zasilanym napięciem sinusoidalnym i kwadratowym: a) powierzchnia mokra i sucha na powierzchni szkliwionej ceramicznie bez zanieczyszczeń; b) sucha i mokra powierzchnia po kontaminacji roztworem klasy I

to surface after wetting. Thus it is shown that environment influences the conductivity between electrodes and measured voltage is higher in the case of humidity. Figures 4bi and 4bii compare leakage current measured on silver electrodes when glazed ceramic surface is contaminated by solution class I. From this figure it can be stated that the amplitude of the leakage current is very low in the case of dried samples. However, there is significant increase in leakage current measured when surface is wetted. It can be attributed to the better electric conductivity on the surface of glazed ceramic in the presence of humidity.

Based on achieved results it is clear that proposed methodology of environmental pollution monitoring is suitable and sensitive on in-situ study and monitoring of insulating properties of high-voltage insulators and thus prediction of electrical losses.

Conclusions

Pollution layer on the insulation of electrical equipment has a visible effect on service life and reliable operation of installed electrical equipment. The aim of the experiment was to determine the effect of pollutants on the outer isolation. From the measured data it is clear that environmental conditions have a great influence on the leakage current (surface resistivity) for pure and polluted insulation. The experimental results showed that the amplitude of the leakage current along the surface connected to testing voltage has increased on the polluted sample in wet conditions. The experimental results show that monitoring of leakage current along the surface of the external insulation is a useful indicator of the pollution of external insulation.

Acknowledgements

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Monitorowanie zanieczyszczenia środowiska na izolatorach wysokiego napięcia

W artykule przedstawiono wyniki prac dotyczących monitorowania zanieczyszczenia środowiska na wybranych izolatorach wysokonapięciowych. Powszechnie wiadomo, że zanieczyszczenie środowiska oddziałujące na izolację elektryczną jest jednym z problemów, z którymi borykają się przedsiębiorstwa dystrybucyjne i system przesyłu energii elektrycznej. Z tego powodu istnieje potrzeba monitorowania zanieczyszczenia środowiska które silnie wpływa na ich zdolność instalacji do pracy bez awarii. Celem niniejszego artykułu jest wyjaśnienie wpływu morfologii i składu chemicznego zanieczyszczeń na opor-ność powierzchni i przewodnictwo wybranych izolatorów.

Słowa kluczowe: izolatory wysokonapięciowe, zanieczyszczenie środowiska, prąd upływowy, prze-wodnictwo elektryczne, monitorowanie in-situ