Environmental Pollution Monitoring by Thin Metal Electrodes Prepared by Physical Vapor Deposition

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Abstract

This work is focused on environmental pollution monitoring utilizing thin metal electrodes on glassy/ceramic substrates prepared by physical vapour deposition. Besides others, 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 propose new system for environmental pollution monitoring based on application of extra-thin metal electrodes. The influence of morphology and chemical composition of pollutants on the surface resistance and conductivity of selected insulators is also discussed.

Keywords: *environmental pollution, metal electrodes, physical vapor deposition, electrical conductivity, insulators*

Introduction

Several activities forming modern society requires still higher consumption of electrical energy. 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]. In this context, European and national activities in this area are aimed at supporting the transition to reliable, sustainable and competitive energy systems. Contamination of high-voltage insulators is determined by the sources of pollution as well as meteorological factors in the locality and can vary during year [4]. Air pollution is recognized as environmental burden with negative great influence on environment as well as on different branches of industry. However, as electricity consumption increase, the electric energy consumption requires better quality of transmission networks. 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 results 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. For these purposes, ultra-thin metal electrodes prepared by physical vapor deposition present alternative method to monitor electrical conductivity between them, and thus to follow insulating properties of insulators. This paper deals with preparation and testing of thin metal electrodes introduced for environmental pollution monitoring.

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 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 connected to the electrodes was generated by wave signal generator Agilent 33220A. Amplitude of the testing voltage with sinusoi-

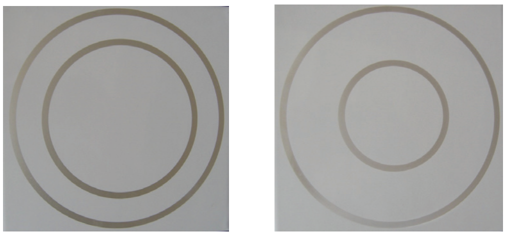

Fig. 1. Silver electrodes on glazed ceramic surface with 20 mm (left) and 40 mm (right) gap between them
Rys. 1. Srebrne elektrody na szkliwionej powierzchni ceramicznej z odstępem 20 mm (po lewej) i 40 mm (po prawej)

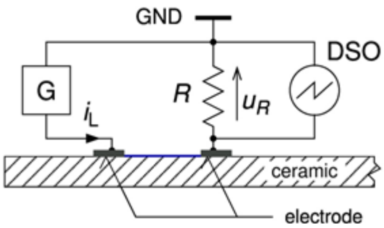

Fig. 2. Schematic diagram of the measuring circuit (G – wave signal generator, R – sensing resistor, i_L – leakage current, u_R – voltage, DSO – digital storage oscilloscope, GND – signal ground)
Rys. 2. Schemat obwodu pomiarowego (G – generator sygnału falowego, R – rezystor pomiarowy, i_L –prąd upływu, u_R – napięcie, DSO – cyfrowy oscyloskop magazynowy, GND – masa sygnału)

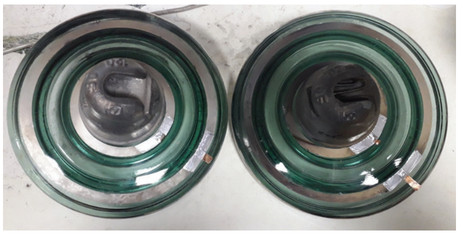

Fig. 3. Ultrathin aluminium-based metal electrodes deposited on high-voltage insulators
Rys. 3. Ultracienkie elektrody metalowe na bazie aluminium osadzone na izolatorach wysokiego napięcia

dal shape was set from 1 V to 7 V and the frequencies ranges from 1 Hz to 10 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 class) under dry and wet conditions.

Thin metal electrodes prepared by physical vapor deposition

Thin metal electrodes were prepared on the surface of the high-voltage insulators by physical vapor deposition (PVD) of aluminium. Figure 3 shows examples of thin metal electrodes deposited.

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 4. 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 Figure 5. 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. It can be seen that leakage current has lower values for dry surface in comparison 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. 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

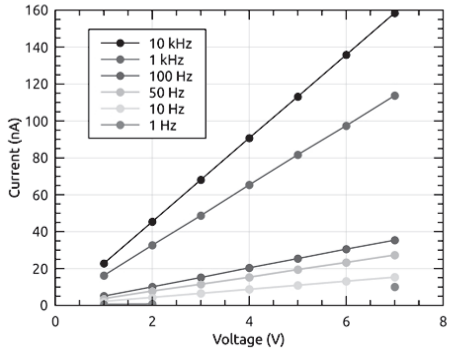

Fig. 4. Current vs. voltage at different frequencies recorded between silver electrodes on dry uncontaminated surface of glazed ceramic

Rys. 4. Zależność napięcia od prądu przy różnych częstotliwościach rejestrowane między elektrodami srebrnymi na suchej niezanieczyszczonej powierzchni szkliwionej ceramiki

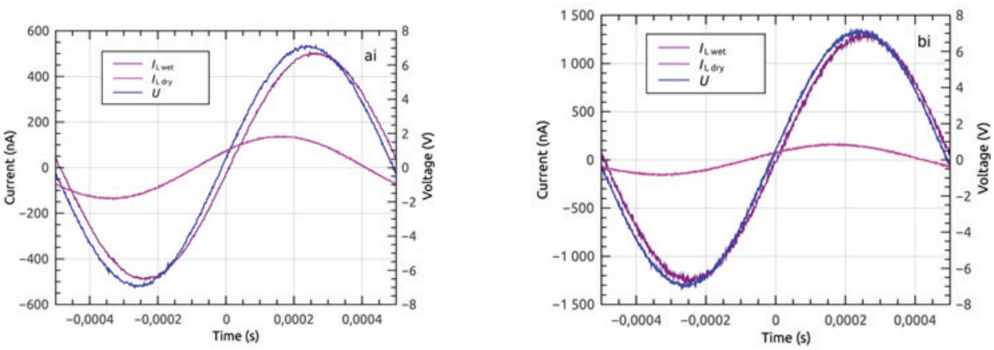

Fig. 5. Comparison of surface leakage current in measuring circuit supplied with sinusoidal voltage: left) dry and wet surface of glazed ceramic surface without contamination; right) dry and wet surface after contamination with solution class I

Rys. 5. Porównanie prądu upływu powierzchniowego w obwodzie pomiarowym zasilanym napięciem sinusoidalnym: po lewej – sucha i mokra powierzchnia oszklonej powierzchni ceramicznej bez zanieczyszczeń; po prawej – sucha i mokra powierzchnia po zanieczyszczeniu roztworem klasy I

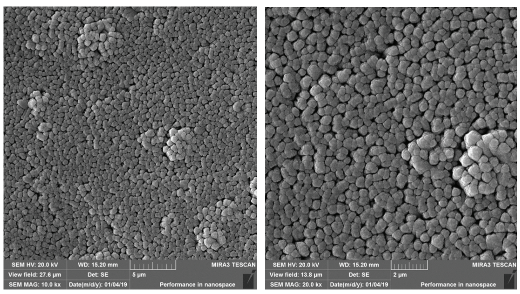

Fig. 6. SEM micrographs of surface of aluminium based metal electrodes with different magnifications

Rys. 6. Mikrografy SEM powierzchni elektrod metalowych na bazie aluminium o różnych powiększeniach

properties of high-voltage insulators and thus prediction of electrical losses.

For real applications, real metal electrodes replacing expensive silver should be proposed. In this manner we have prepared ultra-thin aluminium-based metal electrodes by PVD. Figure 6 shows SEM micrographs of their surface. Based on the electrical conductivity studies, performed on the silver electrodes, it is the plan of future work to test electrical conductivity of novel aluminium electrodes prepared by PVD on the surface of high-voltage insulators.

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. PVD was used for preparation of aluminum-based electrodes. Improvement of their porosity and testing of their electrical properties is the aim of our future work.

Acknowledgements

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Monitorowanie zanieczyszczenia środowiska za pomocą cienkich elektrod metalowych przygotowanych przez fizyczne osadzanie z fazy gazowej

Artykuł dotyczy monitorowania zanieczyszczenia środowiska za pomocą cienkich elektrod metalowych na szklanych/ceramicznych podłożach przygotowanych przez fizyczne osadzanie z fazy gazowej. Widomym jest, że zanieczyszczenie środowiska odpadami izolacji elektrycznej jest jednym z problemów, przed którymi stoją firmy dystrybucyjne i system przesyłu energii elektrycznej. Z tego powodu istnieje potrzeba monitorowania zanieczyszczenia środowiska, ponieważ ma to duży wpływ niezawodność sieci wysokiego napięcia i jej awaryjność. Celem przedstawionych prac jest zaproponowanie nowego systemu monitorowania zanieczyszczenia środowiska w oparciu o zastosowanie bardzo cienkich elektrod metalowych. Omówiono także wpływ morfologii i składu chemicznego zanieczyszczeń na rezystancję powierzchniową i przewodnictwo wybranych izolatorów.

Słowa kluczowe: *zanieczyszczenie środowiska, elektrody metalowe, fizyczne osadzanie par, przewodnictwo elektryczne, izolatory*