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Influence of the Shape of Composite Insulators Housing on their Aging Resistance in presence of High DC Voltage and Clean Fog

***Abstract**. The increased interest in transmission of electricity by using high DC voltage forced the need to examine the ageing resistance of silicone rubber insulators exposed to high DC voltage. Under operating conditions, in the presence of a high DC voltage due to electrostatic phenomena is observed even a fourfold increase in the accumulation of contaminants on the surface of the insulator compared to the high AC voltage. Lack of crossing zero values by current and voltage curves favors to the maintenance of surface discharges concentrated especially in the presence of water. In the paper tests results of the model composite insulators with different inclination of upper surface sheds in the clean fog chamber under high DC voltage is described. The aim of the research is to recognition of degradation ageing process of composite insulators electric properties and the phenomena of leakage current development. Laboratory test results allow to inference about the influence of the shape and design parameters of sheds on the behavior of the silicone composite insulators in operation. ().*

Streszczenie.** W artykule przedstawiono wyniki rozkładów napięcia na połączonych w łańcuch izolatorach: kompozytowym na 110 kV i pojedynczym izolatorze kołpakowym pokrytym warstwą silikonu RTV. Zasymulowano zmianę właściwości powierzchniowych izolatorów w czasie eksploatacji. Stwierdzono, że dołączenie do izolatora kompozytowego niewielkiego izolatora ceramicznego, powleczonego silikonem RTV, w istotny sposób łagodzi występującą na izolatorze kompozytowym nierównomierność rozkładu napięcia. **Wpływ kształtu osłon izolatorów kompozytowych na ich odporność starzeniową w obecności wysokiego napięcia stałego i czystej mgły

Keywords: composite insulator, high DC voltage, fog chamber, aging, leakage current.
Słowa kluczowe: izolatory kompozytowy, wysokie napięcie stałe, starzenie, prąd upływu

Introduction

The implementation of composite insulators with silicone rubber sheds was to solve problems with so-called pollution flashovers that often led to failures of high voltage transmission and distribution networks. Due to the hydrophobic surface and the ability to hydrophobize the accumulated contamination, the insulators are known for their considerable resistance that limits the leakage current and the energy of surface electric discharge [1-5]. Although the polymers show the ability to restore their hydrophobic properties that were temporarily lost, they have poorer ageing resistance in comparison to the ceramics and glass [6,7]. Therefore, the optimum use of those properties that help actively limit the leakage current requires that the shape of the sheds be optimized because at present the shed design of classical ceramic and glass insulators is used.

During normal exploitation, the ageing process of the shed surface takes place unevenly [8,9]. Those areas that are exposed to more intense rainfalls and contamination deteriorate more quickly than the areas protected against direct contact with them [10]. The size and shape of those protected areas depends on the profile of sheds [11] and their inclination towards the direction of the exposure [8].

The exposure to rainfalls and fog poses a major ageing risk to composite insulators. The impact of water and high voltage results in deteriorating the hydrophobic properties of the insulator and accelerating the ageing process. A prolonged exposure may lead to the ignition of arcing concentrated on the insulator's rod, which at first results in the erosion of the composite cover and then the erosion of the fiberglass rod and the deterioration of the insulator's mechanical performance [12,13].

A growing interest in electrical energy transmission using high DC voltage lines forced researchers to test the ageing performance of insulating systems subjected to high DC voltage [14-16]. During exploitation in the presence of high DC voltage, the accumulation of contamination on insulators as a result of electrostatic phenomena is even four times greater in comparison to high AC voltage [15]. When the leakage current flows through the contaminated surface, no zero-crossing on the voltage and current curves facilitates the retention of concentrated surface discharges.

The research aims were as follows: recognize of aging process of composite insulators electrical properties,

obtaining empirical data that could help make conclusions on the effect of the sheds inclination on the behavior of silicone composite insulators. To that end, the comparative analyses of model insulators were carried out.

Research methodology

The study covered model composite insulators with HTV silicone rubber sheds dedicated for operation at 24 kV, with a different inclination of the upper surface of sheds (Fig.1).

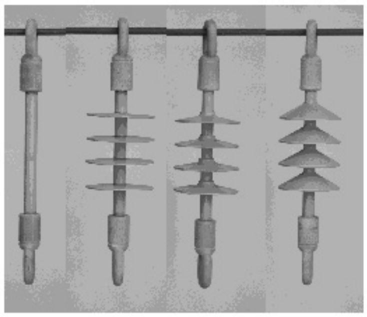


Fig.1. Test object.

Table 1. Design parameters of insulators

Insulator type	n	d	s	α	L_f	L_l
		mm	mm	deg	mm	mm
4k0	4	140	50	0	275	665
4k10	4	135	50	10	280	655
4k30	4	130	50	30	275	650

The following abbreviations are assumed in Table 1:
n – number of sheds, α – slope angle of the upper plane of sheds,
d – diameter of sheds, s – shed spacing,
L_l – leakage distance, L_f – flashover distance.

The flashover distance and leakage distance were similar for all insulators, due to the fact that the basic classification criteria for composite insulators were taken into account in relation to electrical requirements as specified in the norm IEC 61466-2. For comparison, a model without the sheds was also analyzed (Fig.1). The dimensions of models with sheds are given in Table 1.

The ageing performance tests in salt fog chambers are required for the purposes of designer's tests of composite insulators as specified in the norm IEC 61109; they are also recommended by CIGRE for material tests [17]. The usefulness of those tests is confirmed in numerous papers [11,18,19]. Due to considerable salinity, water is highly conductive. This high conductivity of water correspond to conditions which meet mainly at the sea costal. The exposure to salt fog in laboratory ageing performance tests is much higher in comparison to the land exposure. For this reason, it is also beneficial to subject composite insulators in pure fog chambers.

The analysis was conducted in a high voltage fog chamber. The fog chamber was equipped with a normalized system of nozzles located in opposite corners of the chamber. The insulators under investigation were exposed to high DC voltage and repeated cycles of artificial rainfalls. The day cycle consisted of consecutive one-hour ageing cycles. In the fog chamber 15-minute periods of fog were followed by 15-minute periods without generating fog. The test parameters are presented in Table 2. The diagram of the fog chamber is demonstrated in Figure 2.

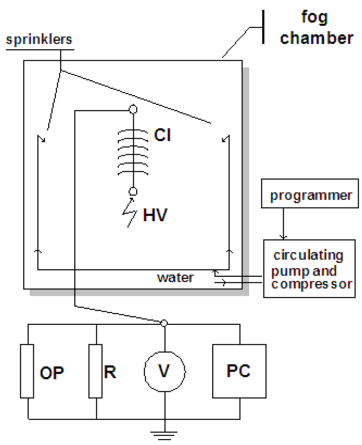


Fig.2. Diagram of the fog chamber.
CI – composite insulator, OP – overvoltage protection device, V – voltmeter, PC – personal computer.

Table 2. Test parameters.

	Parameters of ageing tests in the fog chambers
Test voltage	40 kV, DC
Water conductance	200 μS/cm
Fog intensity	0.6 $dm^3/(m^3 \cdot h)$
Day cycle: exposure time/pause time	7 h/17 h

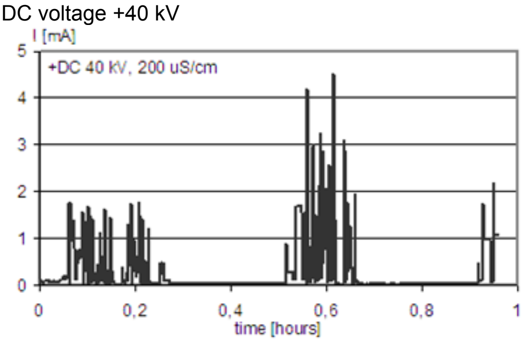
Every day, before the tests are started, the water conductance in the container was measured and if it was necessary than the distilled water was added to obtain the required conductance value.

The values of leakage current were saved automatically every 5 seconds by the computer connected with a digital gauge. Changes in the hydrophobic properties of the shed surface were determined with STRI [20].

Research results

The ageing of composite insulators is related to a gradual loss of the hydrophobic properties on their surfaces on which a network of hydrophilic paths is created. Those paths make privileged ways for the leakage current flow. The values of the leakage current are an important parameter that reveals the condition of the surface of insulators under investigation. The analysis of the recorded current flows enables an assessment of the ageing resistance of a particular insulator design. The ageing tests of model composite insulators were planned as comparative tests.

a) DC voltage +40 kV



b) AC voltage 40 kV

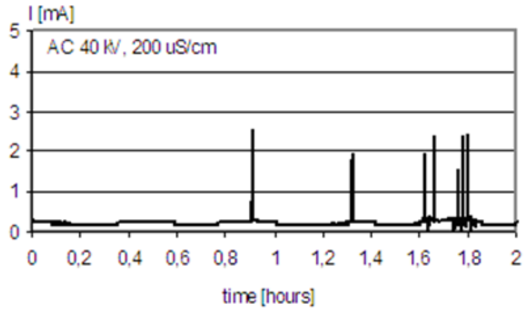


Fig.3. Leakage current for the insulators without sheds on the 6th day of the ageing process in the fog chamber: (a) insulators exposed to DC voltage with positive polarity, (b) insulators exposed to AC voltage.

Figure 3 shows a comparison of leakage current flows measured for two identical insulators without sheds, subjected to the ageing process in the fog chamber in a vertical position and exposed to both DC and AC voltage. The only difference in the testing conditions for the insulators was the kind of voltage. The effective value of the DC and AC voltage was the same; it was equal to 40 kV. In the case of the insulator exposed to DC voltage, the maximum value of the recorded current pulses was 4.5 mA, while in the case of the insulator exposed to AC voltage, the value was equal to 2.5 mA.

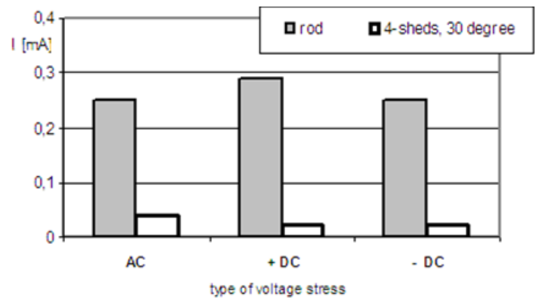
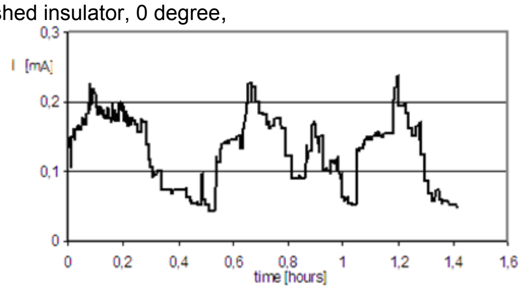


Fig.4. Average values of leakage currents recorded on 4-shed insulators with the inclination degree of upper surfaces of sheds equal to 30 degrees and on the insulator without sheds on the 7th day of ageing in the fog chamber at AC and DC voltage with both polarities.

Due to the sinusoidal shape of AC voltage, each change in the voltage value resulted in suppressing the developing electrical discharge that was not naturally sustained as in the case of DC voltage. It might be inferred that the dynamics of the ageing process of the insulator surface will be greater in the presence of the DC voltage. The average values of leakage currents recorded on the 7th day of ageing on the surface of the insulator's rod were about 10 times greater in comparison to models with steep sheds (Fig.4).

a) 4-shed insulator, 0 degree,



b) 4-shed insulator, 30 degrees,

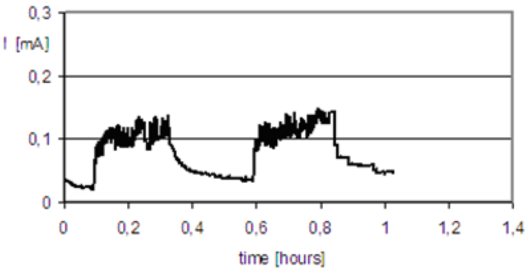


Fig.5.Leakage currents of 4-shed insulators with the inclination of the upper surfaces of 0 and 30 degrees on the 26th day of ageing in the fog chamber at DC voltage with positive polarity.

The comparison presented in Figure 4 shows that for designs with steep sheds, the average values of leakage current were on the same level for both polarities of the high ageing voltage and twice as low in comparison to results obtained for high AC voltage.

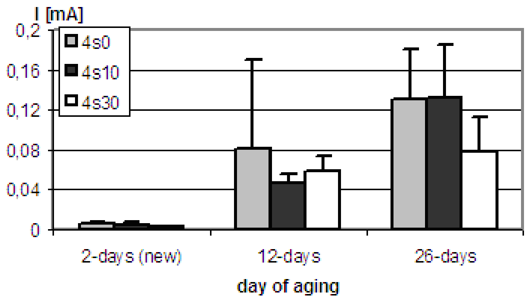


Fig.6. Comparison of daily average values of leakage currents measured on the second, twelfth and twenty-sixth day of ageing in the fog chamber.

Greater leakage current value recorded at high AC voltage may result from the presence of a polarization and capacitance components. Figure 5 demonstrates the leakage current flows for 4-shed insulators with the inclination of 0 and 30 degrees on the 26th day of ageing.

The maximum value of the current pulses was considerably greater for the design with flat sheds; it equaled 0.24 mA, while for the design with steep sheds it did not exceed 0.15 mA. Similarly, the daily average value of leakage current on the 26th day of ageing was about 40% greater for models with flat sheds (Fig.6).

The comparative study of identical models of composite insulators (4-sheds insulators, 10 degrees of inclination of upper sheds) in the fog chamber under similar testing conditions (the only difference is the kind of ageing voltage) reveals a considerably greater dynamics of ageing in the presence of high DC voltage (Fig.7). The daily average values of leakage current were about 20% higher in the case of high DC voltage.

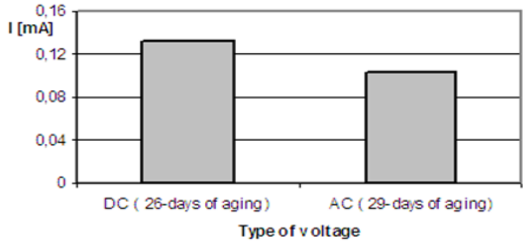
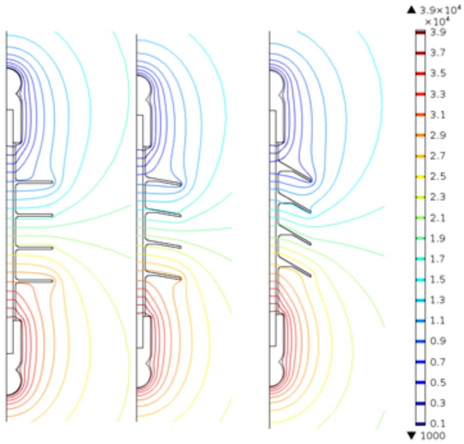
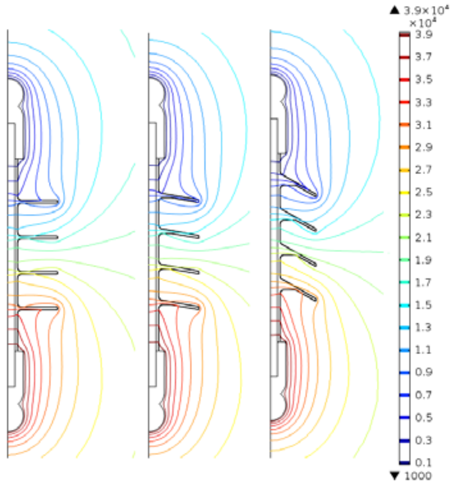


Fig.7. Comparison of daily average values of leakage current measured on the insulators subjected to the ageing process in the fog chamber at high DC and AC voltage.



a) at the beginning of the test



b) at the end of the test

Fig.8. Distribution of field lines along the surface of the insulators at the beginning and at the end of the test.

On the basis of the daily average values of leakage currents a simulation of field line distribution at the beginning and at the end of the test was carried out (Fig.8)

The loss of hydrophobic properties led to an increase in the value of the leakage current under moist conditions as well as to an amplification of the electric field strength at the lower fitting near the lower shed. The comparison of field lines at the beginning and the end of the test demonstrates that the greatest disturbances occurred for the model with steep sheds. This effect was also visible for models with flat sheds and sheds inclined at an angle of 10 degrees. These simulation results are compatible with those presented in the paper [18].

In the case of the insulator equipped with steep sheds, the measurements of temperature distribution made by means of an infrared camera demonstrated a significant increase in temperature on the rod below the lower shed

(Fig.9) in an area with a considerable concentration of field lines.

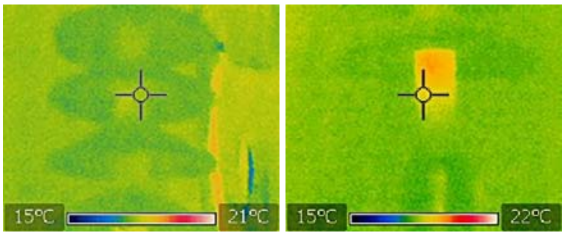


Fig.9. Temperature distribution along the surface of the insulator with sheds inclined at 30 degrees – 26 day of the experiment.

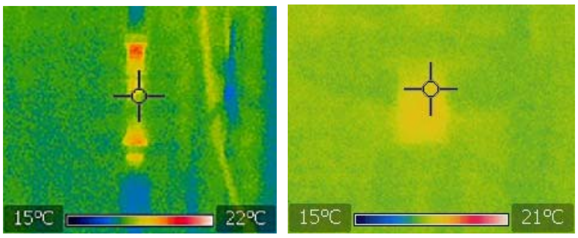


Fig.10. Temperature distribution along the surface of the insulator with sheds inclined at 0 degrees – 26 day of the experiment.

The increase in temperature may result from surface partial discharges. In the case of insulators with flat sheds, the penetration by fog droplets into the areas between the sheds is far greater. Measurements of temperature distribution indicate the presence of discharges on the rod between the sheds (Fig.10).

Conclusions

The set criterion for the completion of the test was the occurrence of distinct differences in measured leakage currents. This target was considered to have been reached after 26 days of experiment.

The results of comparative tests reveal the dependence of ageing dynamics on the angle of sheds: an increase in the shed inclination resulted in an increase in the insulator resistance to fog. The impact of the shed inclination on the ageing resistance was also established in tests in the salt fog chamber [14, 18] and in the rain chamber [21]. In the models with steep sheds, water is not accumulated on their upper surfaces and the protected areas under the sheds are larger. A greater inclination angle also prevents bounced droplets from moistening the lower shed surfaces. These factors inhibit the development of leakage currents under moist conditions. The usage of sheds with a great inclination angle has a negative impact: an uneven distribution of electric field lines and stresses along the insulator's rod in the place it is connected to the shed [11,18].

Furthermore, it was also established that the dynamics of ageing the composite sheds in the presence of high DC voltage is greater in comparison to the ageing process at high AC voltage.

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