Effect of silicone rubber insulators' profiles on their ageing performance in rain conditions

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Abstract: Numerous studies have been conducted to understand the effect of insulator profiles on ceramic insulators. Whereas for polymer insulators this problem has not sufficiently examined. The research so far has concentrated on material composition. The new investigations into influence of the shape of composite insulators with silicone rubber housings have dealt only with ageing performance in fog conditions. Rains constitute a major ageing stress for composite insulators. They can wash out low molecular weight components from the surface of silicone rubber, which may lead to loss of hydrophobicity by the insulator surface, an increase in leakage currents, the development of surface discharges and in consequence, the development of ageing processes. This paper presents investigations into ageing processes of model composite insulators in high-voltage artificial rain chamber. The same housing material – silicone rubber (HTV) – was used to manufacture the model insulators. The results of the investigations have shown a clear influence of the silicone rubber insulators' profiles on their ageing performance in rain conditions.

1 INTRODUCTION

Silicone rubber has been widely used for outdoor high voltage insulators for the last 40 years. This type of insulators offer many advantages over ceramic (porcelain and glass) insulators, such as light-weight construction, ease of installation and maintenance, vandalism resistance, improved (thanks to hydrophobic materials) contamination performance and compact line design [1,2].

As a hydrophobic material silicon rubber is much less wettable than inorganic (ceramic) materials whereby it suppresses leakage currents and reduces the development of surface discharges.

But the hydrophobicity of outdoor polymeric insulators can be diminished by contamination buildup, corona and electrical discharge activity as well as weathering. Silicone rubber can recover the lost hydrophobicity if the surface is dry for more than ten hours. Silicon rubber is characterized by the stability and recoverability of its hydrophobicity by the transfer of low molecular silicone components (LMW) from the bulk of the material to its surface [3,4].

A deterioration (e.g. due to ageing) in the insulator's electrical performance may result in its electrical failure and so in increased probability of a flashover.

Rains constitute a major ageing stress for composite insulators. They can wash out low molecular weight components from the surface of silicone rubber, which may lead to loss of hydrophobicity by the insulator surface, an increase in leakage currents, the development of surface discharges and in consequence, the development of ageing processes and finally, a flashover.

The effect of rain on the clean or polluted surface of the insulator is reduced by its sheds. Thanks to the geometry (shape) of outdoor insulators and the properties of their surface they are more often partially than completely wet. The few investigations into the influence of the sheds' shape and the design parameters of composite insulators with silicone rubber housings have dealt only with the insulators' ageing performance for a clean or contaminated surface in clean or salty fog conditions [5-11]. Most of the researchers have concluded that shed design parameters have a significant influence on the insulator's contamination performance, erosion and tracking performance, maintenance of initial surface hydrophobicity, accumulation of pollution and the magnitude of leakage current. It is generally accepted that geometric design parameters are very important for the ageing processes of silicon rubber insulators. As S. Gubanski notes: *'geometric design is indeed of vital importance and much more attention should be paid to it when selecting insulator designs for various applications'* [12].

2 TESTED INSULATORS

This study was undertaken with the goal of investigating the early ageing processes of model composite insulators in a high-voltage artificial rain chamber. The same housing material – high-temperature vulcanised silicone rubber (HTV) – was used to manufacture the model insulators. The models have a very similar arcing distance gap in air l_a (275 - 300 mm) and leakage current distance l_c (645 - 665 mm), but they differ in their profile and shed parameters. Two groups of the insulators were tested: with conventional and unconventional profiles. The models with conventional profiles have the design features of commercially available composite insulators, i.e. a straight shed diameter (c) or an alternating shed diameter (a). The models' variable parameters are: number of sheds n, shed diameter d, shed spacing s and shed upper surface inclination angle α.

The main parameters of the insulators are shown in Table 1.

Tab. 1: Specifications of conventional model insulators

Model type	n	d	s	α	l_a	l_c
	-	mm	mm	deg.	mm	mm
4c10	4	135	50	10	280	655
4c30	4	130	50	30	275	650
6c10	6	105	30	10	290	645
6c30	6	105	30	30	290	660
5a10	3+2	130, 100	75 (35,40)	10	295	665
5a30	3+2	125, 95	75 (35,40)	30	300	650
5a130	3+2	135, 85	75 (25,50)	30	300	660

The unconventional model insulators have sheds with different diameters (150-85) and variable shed spacing (30-50 mm). Generally, their design may be described as an 'inverted Christmas tree' Fig. 1.

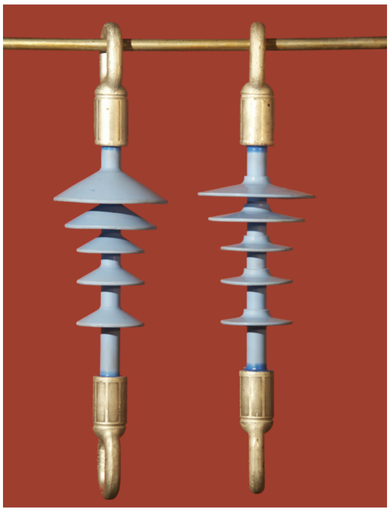

Fig. 1: 'Inverted Christmas tree' design of composite insulators: with shed inclination of 30° (left) and with shed inclination of 10° (right).

Arcing distance l_a and leakage current distance l_c of the insulators designated as 5u10 and 5u30 are identical: l_a = 295 mm and l_c = 655 mm.
The model insulators were manufactured in the Wroclaw Branch of the Institute of Electrotechnics which is the producer of composite insulators in Poland.

3 TESTS METHODS

The tests were carried out in a high-voltage rain chamber with a volume of 5 m^3 which was built in the High Voltage Laboratory of Wroclaw University of Technology. The chamber was equipped with a system of 6 water sprinkles and a water pump, controlled by a time programmer Fig. 2. The 24 hour testing cycle was as follows: 7 hours of voltage ageing (each hour comprising a 30 minute period of artificial rain and 30 minute period without rain) and 17 hours of resting.

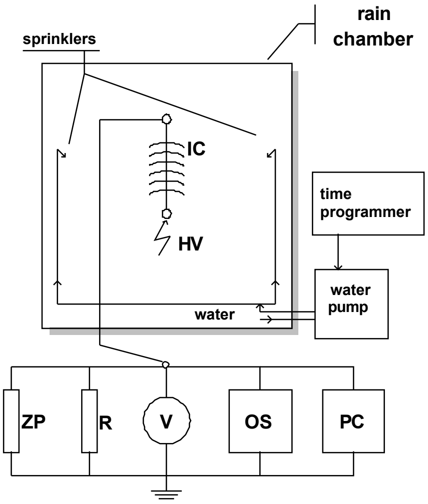

Fig. 2: Schematic of rain chamber system: IC – silicone rubber insulator, PC – personal computer, V – digital voltmeter, OS – digital scope, R – m easuring resistor, ZP – overvoltage protection.

The rain intensity was 0,1 l/min and conductivity was equal 200 μS/cm. During the ageing tests AC (50 Hz) voltage was kept at a level of 24 kV or 40 kV. Then the specific voltage gradient (calculated as the ratio of voltage to leakage path) was about 0.36 kV/cm or about 0.61 kV/cm. The leakage current values were automatically recorded every 5 sec by a PC coupled with a digital meter. The instantaneous traces of the current were registered by a digital scope. The changes in insulator surface hydrophobicity were evaluated by the STRI method.

4 TEST RESULTS

The currents measured in the first days of testing in the rain chamber were found to be practically identical for all the insulators. They had a capacitive character and at a voltage of 24 kV amounted to 0.1 mA. But in the next days of testing the influence of insulator shape became clearly visible. The tests showed that the insulators with small shed diameters, a small intershed spacing and a small shed inclination (insulators 6c10) are particularly susceptible to degradation of their properties under rain conditions. Water drops collecting on the sheds of such insulators are the cause of corona discharges [13] and lead to the formation of water channels, the collection of water on the sheds' edges, the bridging of intershed spaces by cascades of water drops falling down from time to time. Highly detrimental is the wetting of the sheds' undersides by water bouncing off the surface of the sheds situated below Fig. 3.
The above phenomena lead to an increase in the leakage current, the formation of highly nonuniform voltage distributions on the insulators and the appearance and development of surface discharges.

Fig. 3. Undersides of insulator 6c10 on sixth day of ageing in rain chamber.

Figure 4 shows an increase in leakage current already on the 7th day of ageing process of the insulator 6c10.

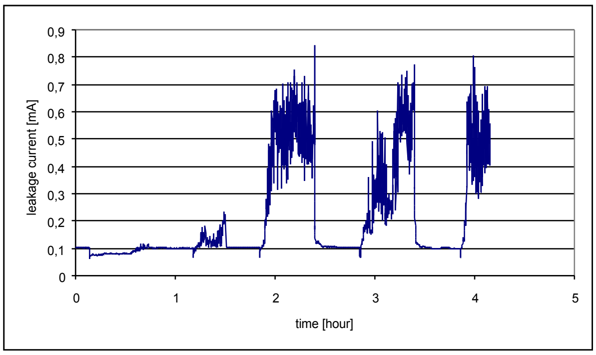

Fig. 4. Leakage current registered on 7th day of insulator 6c10 ageing in rain chamber. Test voltage 24 kV.

On that day surface discharges (still low-current) appeared on the trunk and on the sheds' undersides. They are visible as current pulses in the leakage current oscillograms Fig. 5.

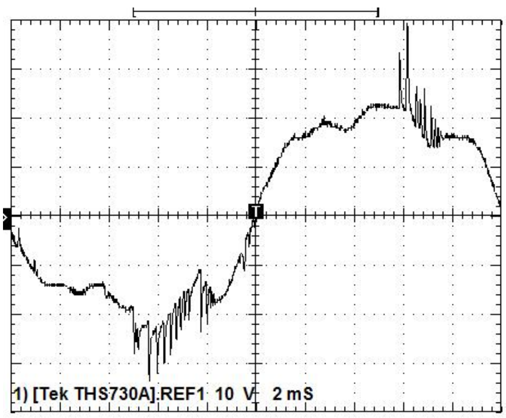

Fig. 5. Instantaneous traces of leakage current for insulator 6c10 on 7th day of ageing. Test voltage 24 kV.

The developing surface discharges are a serious hazard to composite insulators. They have a strong erosion effect on silicone rubber, which may cause damage to the insulator's housing. Discharge's tracks on the undersides of the sheds and deep erosion in the housing on the trunk of insulator 6c10 are visible in Fig. 6.

This insulator was damaged during ageing test in rain chamber. The aim of that test was to recognize events taking place on the insulator [14]. In the long-term test the following events were observed:

1. ignition of low current spark discharges,
2. intensification of discharges,
3. ignition of arc discharges.

Deep erosion of housing at the high voltage end fitting shown in Fig. 6 was caused by concentrated arc discharges.

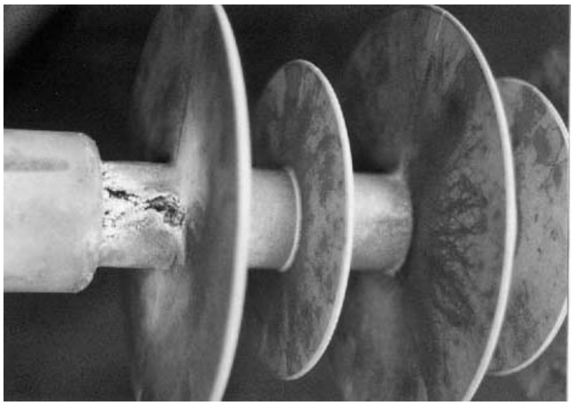

Fig. 6. Composite insulator after long duration ageing in rain chamber.

This means that the appearance of surface discharges can be the criterion for evaluating the resistance of composite insulators to ageing in a rain chamber. On the basis of the test results obtained for the insulator designs with a small shed inclination angle (10°) the insulators can be ordered according to their ageing resistance as follows: 5u10, 5a10, 4c10, 6c10. The best performance of the insulators in the shape of an inverted Christmas tree should be ascribed particularly to the absence of bridging of intershed spacings by falling down water drops. The shed inclination angle clearly affects the ageing resistance of insulators in rain conditions. Steeply inclined sheds effectively protect their undersides and a part of the trunk against rainwater. Moreover, water drops flow quite uniformly from steeply inclined sheds whereby intershed water bridges cannot form so easily. The effect of the steep inclination of sheds was particularly clear in the case of insulator 6c30. Figure 7 shows the leakage current of this insulator (6-shed insulator with a shed inclination angle of 30°), recorded on the 65th day of ageing in the rain chamber. The ageing test was conducted at a voltage of 40 kV. The maximum current spikes did not exceed 0.35 mA and no clear surface discharges were observed yet Fig. 7.

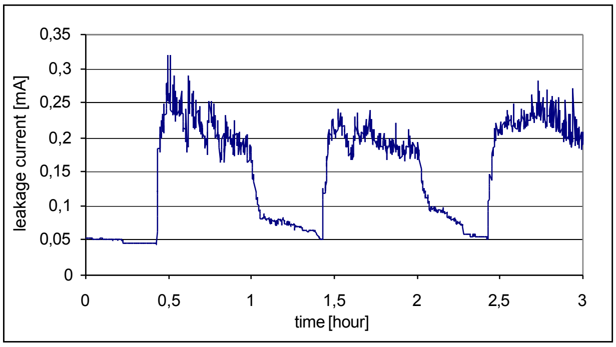

Fig. 7. Leakage current registered on 65th day of ageing insulator 6c30 in rain chamber. Test voltage 40 kV.

For comparison, in the case of insulator 6c10 with sheds inclined at an angle of 10° an increase in leakage current occurred and surface discharges appeared already on the 7th day of ageing under a voltage of 24 kV Figs 4 and 5.

5 CONCLUSION

The results of the investigations have shown a clear influence of the silicone rubber insulator's profiles on their ageing performance in rain conditions. It has been found that the insulators with densely spaced small-diameter sheds with a typically small inclination angle have a low ageing resistance.
The angle of shed inclination is a distinctive design parameter. The ageing performance of the insulators with the steep shed profile (shed angle 30°) is decidedly better than that of the insulators with the small shed inclination (shed angle 10°).
Interesting results – with regard to the optimisation of silicone composite insulator profiles – were obtained for the insulators with the 'inverted Christmas tree' shape.

6 ACKNOWLEDGMENT

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7 REFERENCES

[1] R. Hackam, "Outdoor HV Composite Polymeric Insulators", *IEEE Transactions on Dielectrics and Electrical Insulation*, vol.6, No. 5, 1999, pp. 557-585.
[2] CIGRE Working Group 22.03, "Worldwide Service Experience with HV Composite Insulators", Electra, August, 2000, No. 191, pp. 27-43.
[3] R. S. Gorur, "Hydrophobicity", *Insulator News and Market Report*, vol. 7, No. 4, July/August 1999, pp. 64-68.
[4] H. Hillborg, U. W. Gedde, "Hydrophobicity Changes in Silicone Rubbers", *IEEE Transactions on Dielectrics and Electrical Insulation*, vol.6, No. 5, 1999, pp. 703-717.
[5] S. M. de Oliveira, C. H. de Tourreil, "Aging of Distribution Composite Insulators under Environmental and Electrical Stresses", *IEEE Transactions on Power Delivery*, vol .5, pp. 1074-1077 Apr. 1990.
[6] R .S. Gorur, E. A. Cherney, R. Hackam, "Polymers Insulator Profiles Evaluated in a Fog Chamber", *IEEE Transactions on Power Delivery*, vol .5, No. 2, pp. 1078-1085, Apr. 1990.
[7] R. Matsuoka, S. Ito, K. Tanaka, K. Kondo, "Contamination Withstand Voltage Characteristics of Polymer Insulators" in *Proc.10th International Symp. on High Voltage Eng., Montreal ,Canada*, August 25-29, 1997, vol.3, pp. 81-84
[8] A. H. El-Hag, S. H. Jayaram, E. A. Cherney, "Influence of Shed Parameters on the Aging Performance of Silicone Rubber Insulators in Salt-fog", *IEEE Transactions on Dielectrics and Electrical Insulation*, vol.10, No. 4, pp. 655-664, Aug. 2003
[9] B. K. Gautam, M. Ito, B. Marungsri, R. Matsuoka, S. Ito, K. Arakawa, "Contamination Flashover Performance of Hydrophobic Polymer Insulators with Different Core Diameters", in *Proc. 2004 International Conf. on Solid Dielectrics, Toulouse, France,* July 5-9, 2004, pp. 355-358
[10] B. Marungsri, H. Shinokubo, R. Matsuoka, S. Kumagai, "Effect of Specimen Configuration on Deterioration of Silicone Rubber for Polymer Insulators in Salt Fog Ageing Test", *IEEE Transactions Dielectrics and Electrical Insulation*, vol. 13, No.1, pp. 129-138, Feb. 2006.
[11] F. Perrot, S. Clift, "The Effects of Profile Geometry on the Long-Term Performance of Outdoor Insulatrs", *in Proc. 10th Insucon International Conference, Birmingham 2006,* pp.246 - 251.
[12] S. Gubanski, "Geometric Design in Composite Insulator Performance", *Insulator News and Market Report*, vol. 12, No. 2, March-April 2004, pp. 14.
[13] A. J. Philips, D. Childs, H. M. Schneider, "Water Drop Corona Effects on Full Scale 500 kV Non-Ceramic Outdoor Insulators", *IEEE Transactions on Power Delivery*, vol .1999, pp. 258-265.
[14] W. Bretuj, J. Fleszynski, "Degradation Processes of Silicone Rubber Composite Insulators During Ageing Test in Rain Chamber" (in Polish), *Przeglad Elektrotechniczny*, Konferencje, No. 1, 2004, pp. 23-26.