ISBN 978-0-620-44584-9

Proceedings of the 16th International Symposium on High Voltage Engineering

SILICONE RUBBER INSULATORS WITH NOTCHED SURFACE

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Abstract: A modification of an insulator profile was proposed and the advantage of a new solution was shown. The pollution flashover voltage of an insulator with small notches is about 25% higher than the flashover voltage of a flat surface. The laboratory and field tests which show the effectiveness of surface modification made on silicone rubber were described. The possibility of further surface optimization was claimed.

1. INTRODUCTION

The first porcelain long rod insulators were designed and manufactured in Germany 70 years ago [1]. They displaced to a considerable extent the cap and pin insulators in Central Europe in 1950s and 1960s due to their advantages such as puncture proof solid core and smaller weight. Their construction has been gradually adopted to growing environmental contamination caused by industrial development. This problem has been solved by leakage distance elongation, increasing the number of sheds and their diameter. The classical insulator VKL75/14 with 14 sheds was replaced by insulators having the same height but equipped with a bigger number of sheds. The best example are the insulators VKLS 75/21 (which were also applied in Poland) and VKLN 75/27. Unfortunately, the excessive congestion of sheds aggravate the insulator performance under heavy pollution. The insulators with alternating sheds, introduced in 1970s, which can have a very long leakage distance became quickly a standard in heavy contaminated areas [1, 2].

The current application of silicone insulators started first in USA and Canada in 1980s and then expanded into the whole world. The construction of composite insulators is more complicated than the construction of porcelain long rod insulators. The glass fibre polymer core secures very high tension strength. The moulding technology enables manufacturing thinner silicone sheds than the technology applied in producing porcelain insulators (Figure 1). Therefore, at the same height, the leakage distance of composite insulators can be longer than that of porcelain insulators. This advantage, thinner shank diameter and hydrophobic properties of silicone rubber cause that the pollution flashover voltage of composite insulators can be about 50% higher than that of porcelain insulators [3].

The industrial dust emission has been decreasing in Western Europe for 40 years and in Central Europe for over 20 years [4]. In spite of that, the new silicone insulators which replace the old porcelain insulators have sometimes even longer leakage distance [5]. In this context, some questions arise: is such long leakage distance and such high pollution flashover voltage of composite insulators applied in Europe really necessary ? Should the profile of composite insulators be generally similar to that of porcelain long rods ? Is it possible to use better the material and technological properties of silicone rubber to decrease the insulator prices ? The author's investigations carried out at Cardiff University and at Glogow test station suggest the positive answer to all questions mentioned above.

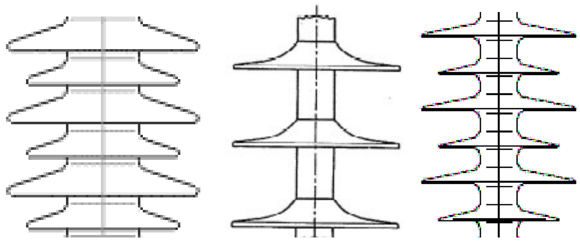

Figure 1: Profile of a porcelain insulator (a) and profiles of polymer insulators (b, c)

2. POSSIBILITY OF CHANGES IN THE PROFILE OF COMPOSITE INSULATORS

Recent studies have revealed that nearly the whole territory of Poland belongs to the pollution class light [4] where the recommended specific leakage distance of porcelain insulators is equal to 1,6 cm/kV (1,3 cm/kV) [6]. The opinion that the specific leakage distance of silicone insulators can be shorter for pollution class light seems to be justified [7]. The simplest design of silicone insulators meeting this suggestion is an insulator with a smaller number of standard sheds or an insulator with more sheds having a very small diameter. The second option is very interesting because the pollution flashover voltage is indirectly proportional to the equivalent diameter of an insulator [5]. Some investigations show that the smaller equivalent diameter of composite insulators increases the pollution flashover voltage by 20% (compared to porcelain insulators with a grater equivalent diameter) and the additional 30% increase is caused by the hydrophobic properties of silicone rubber [8].

The surface of the so far applied insulators is smooth (fig. 1). The smooth surface is better washed-off by rain precipitations. There are only a few insulator

ISBN 978-0-620-44584-9

projects with an uneven surface. Kurt Draeger from Rheinisch-Westfaelische Isolatoren-Werke in Siegburg patented an insulator with sharp edges (Figure 2a). Jerzy Ignacy Skowronski patented an insulator with stepped sheds in 1968 (Figure 2b) and Ron Thomas Waters with Manu Haddad patented an insulator with small hemispheres in 2003 (Figure 2c). Author proposed an insulator with small notches in 2005 (Figure 3). Small notches elongate considerably the leakage distance and do not increase the equivalent diameter of insulator.

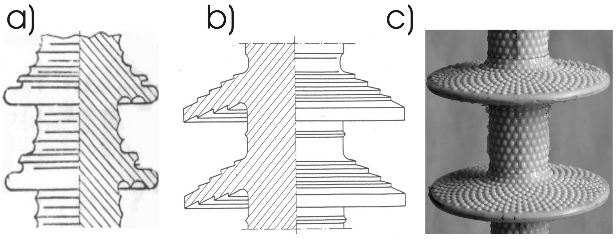

Figure 2: The insulator by K. Draeger (a) [9], the insulator by J.I. Skowronski (b) [10], the insulator by R.T. Waters and A. Haddad (c) [11]

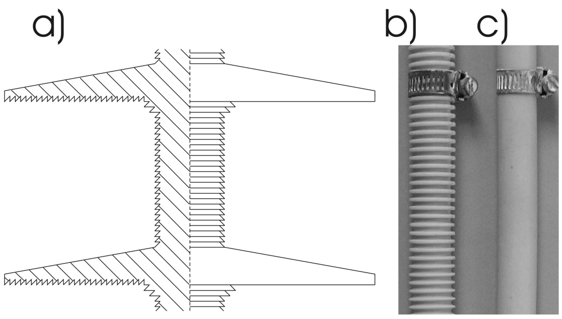

Figure 3: The insulator with small notches (a) [12], the cylindrical model of a notched insulator (b), the cylindrical model of an insulator with a smooth surface (c)

The sharp edges and sharp rims of steps are very difficult to manufacture from the glazed porcelain. Therefore the insulators with stepped sheds were not applied in spite of manufacturing and carrying out tests on 150 prototypes both in laboratory and in field conditions in 1970s. The technology used for manufacturing of polymer insulators enables to produce the objects with thin walls and sharp rims.

3. OBJECTS AND RESEARCH PROCEDURE

The cylindrical samples were moulded with the smooth or the notched surface using the RTV-2 HV 1540/10P silicone rubber from Dow Corning. The samples with smooth surface had the diameter of 1,6 cm, the diameters of notched samples were 1,8 cm and 1,5 cm. (Figure 3c). Both models of insulators had the electrode distance of 23 cm. However, the leakage distance of a notched sample was about 2,5 times longer than that of a smooth sample.

Tests in a fog chamber were carried out at Cardiff University. Four nozzles produced the fog from the tap water having the conductivity of 250 μS/cm. The intensity of wetting could be changed by changing of water pressure, the droplets dimension was influenced by the air pressure. The measuring set up was described in the paper [13]. The leakage current and voltage signals were acquired at a sample rate of 10000 sample per second, giving 200 samples for one cycle at 50 Hz. For each cycle of stored leakage current data, the following quantities characterising the leakage current were calculated within the developed LabView routine: r.m.s. and peak values of current, charge, power factor angle, average power, total harmonic distortion (THD) and accumulated energy [11]. The discharges were filmed by means of Olympus C-765 digital camera, the post processing picture analysis was performed with the Quick Move program.

The measurements of current and flashover voltage were carried out during various three trials:

a) Artificial rain with clean hydrophobic samples
To avoid the discharges on the back, a non-visible sample side, the nozzles from the left, foremost corner of the chamber were only used. The maximum wetting intensity was applied with the air pressure of 1,4 bars. The vertical component of water precipitation amounted 5,4 mm/h and the horizontal component amounted 3,6 mm/h. The insulators with hydrophobic surface were tested for 30 minutes. After the test, the samples were conditioned for 1 h in the temperature of 80°C to recover the surface hydrophobicity.

b) Artificial rain with clean hydrophilic samples
This procedure was similar to the test described above. However, the samples were not conditioned in higher temperature. After each test the insulators were washed in clean water and put again into the fog chamber for the next test. During the test, the silicone surface gradually lost the hydrophobicity, after a few trials the samples were totally hydrophilic.

c) Tests with hydrophilic pollution
The samples were contaminated by the mixture of water with 40 g/l kaolin, NaCl and with a surface wetting agent Triton X-100. The pollutant had the conductivity of 10,5 mS/cm. The wetting intensity was reduced to the level used in the test according to the clean fog method (air pressure 0,14 bar, water output 2,5 l/h or 200g/m^3·h, the vertical water precipitation of 0,08 mm/h). ESDD value on the smooth sample amounted 0,08 mg/cm^2 and on the notched sample – 0,14 mg/cm^2. The surface conductivity on insulators was measured at the voltage of 200 V.

One longer insulator with a notched surface, with the electrode distance of 105 cm and the diameters equal to the diameters of small samples has been exposed to natural conditions at the Glogow test station under the voltage of 75 kV since 2005.

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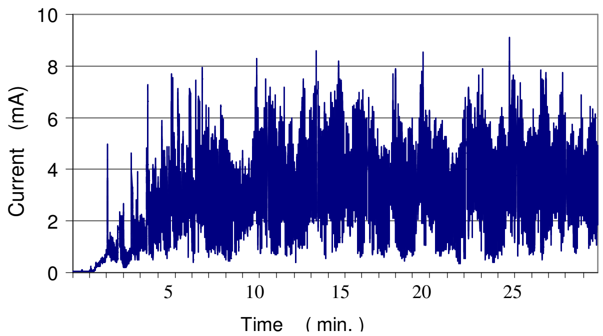
4. TEST RESULTS

The flashover voltage of notched samples was about 25% higher than the flashover voltage of samples with smooth surface (tab. 1). The notched surface allows also to improve the pollution performance of insulators.

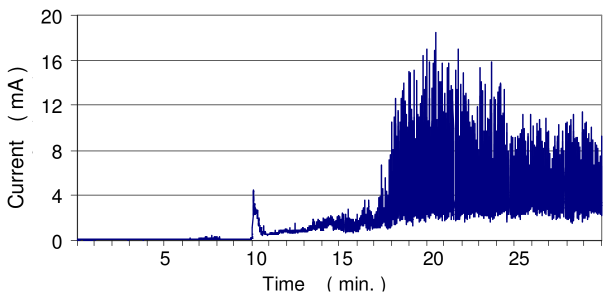
Table 1: 50% flashover voltage of cylindrical samples.

Test method	Cylinder with the smooth surface	Cylinders with the notched surface
Artificial rain, hydrophobic clean surface	42 kV	54 kV
Artificial rain, hydrophilic clean surface	42 kV	54 kV
Clean fog, hydrophilic pollution layer	31 kV	39 kV

The data from the tab.1 show that the flashover voltage of hydrophobic samples is the same as the flashover voltage of hydrophilic samples. The observation of insulators after or during the tests revealed that the surface relatively quickly loses its hydrophobic properties due to intensive discharges. Although the observation of wetting angle of droplets on the notched samples is difficult, the same process also occurs on this surface. However, the leakage current records show that the smooth surface becomes hydrophilic 2 minutes after beginning of the test and the smooth surface after 10 minutes (Figure 4). As a result, the energy recorded on the notched sample is smaller than that on the smooth sample (Figure 5).



a) sample with smooth surface



b) sample with notched surface

Figure 4: Leakage current on initially hydrophobic samples under artificial rain and the voltage of 35 kV.

The flashovers of smooth samples occurred usually a few minutes after the beginning of the rain, whereas on the notched samples the time to flashover was longer than 10 minutes. The water amount on the notched surface gradually increased with time of wetting. The water conductivity also increased as a result of self-contamination generated by surface discharges [14]. Fifteen minutes after beginning of the test, the conductivity increased from 250 µS/cm of tap water to the value of 600 µS/cm. This effect was not observed on the smooth samples because on this surface the droplets ran down. In spite of water accumulation and conductivity increase, the flashover voltage of notched samples was higher than that of smooth samples.

The water amount of 0,8 g was found on polluted smooth sample after 30 minutes of wetting in the fog. On the notched sample 8,3 g was measured after 100 minutes of wetting. The above values were measured during wetting of samples without the voltage stress. During the voltage tests, the water amount is smaller due to drying caused by the leakage current and discharges. It is possible to improve the shape of notches to decrease the water accumulation and further increase of the flashover voltage of notched samples.

After three years of test at Glogow station no flashover and no erosion changes were observed on 105 cm long model with the notched surface.

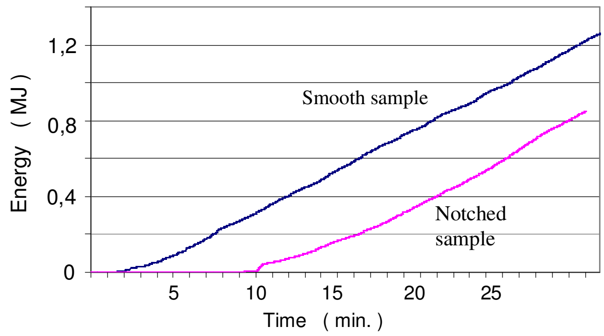


Figure 1: Leakage current on initially hydrophobic samples under artificial rain and the voltage of 35 kV.

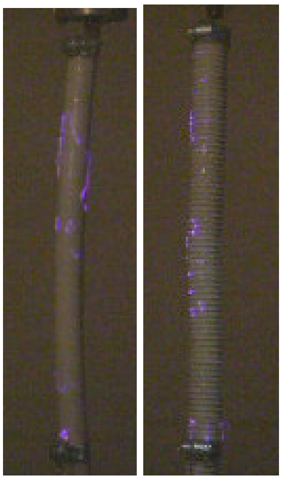
5. DISCUSSION

The efficiency of leakage distance of the notched sample is very low. Despite 2,5 longer leakage distance, the flashover voltage is only 25% higher than that of the smooth sample. The higher electrical strength results not only from the longer leakage distance. The partition of arc on many small partial discharges is a very important factor. Under the same condition, the arc on smooth sample can develop to longer length. Different discharges on the smooth and on the notched samples are shown in Figure 6. The total voltage of all short arcs is higher than the voltage of one arc with the length equal to the total length of short arcs. The cathode and anode spot voltage of arc burning on a polluted insulator with the current smaller than 1 A, amounts about 700 V [10]. The equation describing the pollution flashover voltage can be written as follows:

$$U_P = B \cdot X \cdot I^{-n} + I \cdot r(L - X) + m \cdot \Delta U \qquad (1)$$

Where: I – current,
L – leakage distance,
X - critical arc length,
m – number of serial arcs,
ΔU - cathode and anode spot voltage
B, n – constants of arc column

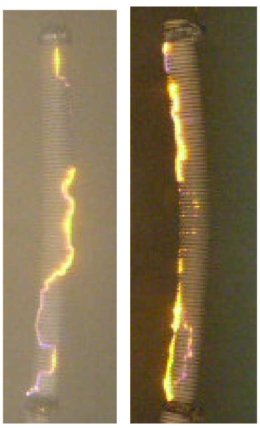
This formula is usually written without the last component but with the constant A in the place of B. Such a form is appropriate for a model of a polluted insulator with a single, longer arc.



a b

Figure 6: The discharges on the smooth sample (a) and on the notched sample (b) under the test voltage of 35 kV.

The analysis of film frames showed, that the critical arc length on the notched sample was longer than the 60% of electrode distance (fig. 7). Whereas the critical length of the arc on the smooth surface is equal to about 60% of electrode distance (Figure 8).



test 1 test 2

Figure 7: The polluted samples with notched surface. Very long discharges which did not lead to flashover

The model with the notched surface and with the electrode distance of 105 cm has been tested for 3 years at Glogow station under the voltage of 75 kV. The specific leakage distance (not taking into account the notched shape) is very low and amounts 0,8 cm/kV of phase to phase voltage. This value is twice lower than the shortest specific leakage distance recommended for porcelain insulators by IEC 60815 standard for a very light pollution class [6]. The model was moulded in a primitive form. Therefore, the notches profile of the model is not optimal. In spite of this fact, the field experiment shows the possibilities of silicone rubber material and the potential in shaping of an insulator profile for outdoor insulation used in light pollution class.

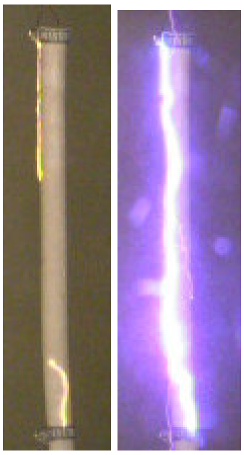


Figure 8: The polluted smooth sample. The discharge just before the flashover and the flashover.

6. CONCLUSION

The pollution flashover voltage of samples with the notched surface is about 25% higher than the pollution flashover voltage of smooth samples.

The small notches divide the discharges into many short arcs what increases the flashover voltage and limits the leakage current. The notched surface loses the hydropbobicity later than the smooth surface what should increase the resistance of the notched silicone surface against erosion under heavy pollution.

Three years of tests carried out on the notched insulator under natural conditions show that under light pollution the specific distance of silicone insulators with the notched surface can be considerably shorter than 1,3 cm/kV.

The improvement of the notches profile can further increase the pollution performance of silicone insulators.

7. ACKNOWLEDGMENTS

Author thanks Prof. R.T. Waters and Prof. A. Haddad for the possibility of carrying out the laboratory test at Cardiff University.

ISBN 978-0-620-44584-9

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