IEEE Transactions on Power Delivery, Vol. 11, No. 2, April 1996

OUTDOOR LEAKAGE CURRENT MONITORING OF SILICONE COMPOSITE INSULATORS IN COASTAL SERVICE CONDITIONS

Antonios E. Vlastós, Fellow
Chalmers University of Technology
S-412 96 Gothenburg, Sweden

Tor Orbeck, Senior Member
Sediver Inc., York
South Carolina 29745, USA

Abstract - The behavior of the polymeric insulators under salt-storm conditions is crucial for their design. In this paper the leakage currents monitored on silicone composite insulators during two severe salt-storms on the Swedish West Coast are analyzed. The results show that reduction of the leakage distance on silicone rubber units causes considerable dry-band arc activity.

Keywords: Silicone insulators, coastal conditions, leakage currents.

1. INTRODUCTION

Service experience has shown that outdoor insulators exposed to pollution and moisture from rain, fog and condensation develop leakage currents. It was discovered early that ceramic insulators with a thin coating of silicone rubber performed very well in contaminated service. It was found that the advantage of the silicone surface is its ability to impart hydrophobic properties to a pollutant deposit on the insulator surface which suppress or limit leakage currents. The transfer of hydrophobic properties, the conditions leading to hydrophobicity loss and recovery mechanism have been the subject of many papers. A literature survey in this matter is given in [1].

The environmental and service conditions for an insulator vary considerably with location and time. Under severe conditions the leakage currents increase resulting in dry-band formation on the insulator surface followed by discharge and arcing that may cause degradation of the insulator surface properties and can increase the probability of flashover.

The degradation of wet surface insulation properties of inert, stable materials such as porcelain and glass can be explained by accumulation of contaminants on the glazing. However, the degradation on the surface properties of polymer insulators is a more complex combination of surface erosion and changes in the polymer surface chemistry caused by discharge effects and pollutants. The development of dry-band discharges and arcing is not only dependent on voltage stresses, insulator design and contamination conditions, but also very much dependent on a polymer's ability to suppress or limit dry-band currents.

To optimize insulator design and materials, it is necessary to study leakage current and dry-band current development on material samples and full size insulators. Such studies have been conducted in laboratories with tests simulating the specific contamination conditions experienced in service [2]. Existing methods for such accelerated aging tests of polymer insulators include long term exposure to discharges and arcing under wet conditions. The aging exposure cycle and the artificial surface discharge and arcing conditions have to be representative of the service conditions for the polymer insulators in a specific power system where the insulators are to be installed. It is therefore necessary to first conduct outdoor studies of leakage currents and dry-band discharge conditions, on full size insulators exposed to natural pollution, before the laboratory aging cycle is selected.

The Chalmers University of Technology in Sweden has established a test station in Anneberg on the Swedish West Coast to evaluate the performance of polymer insulators under coastal conditions. Results from such studies have been reported previously [3-5]. The present paper shows leakage current data on polymeric insulators with a silicone rubber housing. Porcelain and RTV silicone elastomer coated porcelain units are used as reference units. The test units are installed on a 220 kV system voltage test line (130 kV phase to ground) where a large number of units are evaluated. One of the silicone rubber composite units has been on line since 1987 and the leakage current data in this paper were recorded during two severe salt storms in 1993.

---

95 SM 394-7 PWRD A paper recommended and approved by the IEEE Transmission and Distribution Committee of the IEEE Power Engineering Society for presentation at the 1995 IEEE/PES Summer Meeting, July 23-27, 1995, Portland, OR. Manuscript submitted October 18, 1993; made available for printing June 5, 1995.

2. DATA ACQUISITION SYSTEM

The total capacity of the test line is twenty insulators on the AC side. All units are monitored by a digital data acquisition system. It is known that the leakage current below 1 mA does not produce significant arcing. Therefore, for pulse amplitudes up to 1 mA the leakage current data are registered once every 30 minutes. For current pulse amplitudes between 1 and 5 mA the data are registered once every 10 minutes and for pulse amplitudes higher than 5 mA the frequency of registration is one recording per minute. The system can during a salt-storm day register roughly half a million measurements. The data which are stored in the computer at Anneberg are transferred and stored in the main computer located at the Chalmers High Voltage laboratory.

Between the insulator and the tower an additional cap-pin glass insulator is added to allow the measurement of the leakage current. The current is conducted through a coaxial cable along the tower. In case of a flashover the discharge current passes through a lightning arrester flash counter which records the flashover.

The leakage current measuring system is protected by a discharge tube; a combination of a resistor and an inductance in a box mounted on the tower pole and by the capacitance of the coaxial cable. The inductance and the cable capacitance act as a low-pass filter and reduce the transmitted signal frequency to about 40 kHz. At the other end of the coaxial cable a Zener diode is used to reduce eventual overvoltage surges.

The detectors are designed to measure the pulse peak value and consist of four parts: An emitter follower, a comparator, a logic control circuit and a sample and hold (S/H) circuit. The input voltage is compared with the voltage held at the S/H circuit. This means that the registered pulse amplitude corresponds to the highest value of the pulse peaks arriving to the detector during the sampling interval.

The output of the leakage current detectors, the voltmeter for the AC supply and of the meteorological instruments (wind velocity, wind direction, air pressure and rainfall) is scanned by a 100 channel input scanner controlled by a work station. The scanning frequency is about 30 Hz and all the channels are scanned in a time of about 10 seconds. The work station consists of a multitasking Unix system. The measuring program is written in Basic/Unix. The data registration rate is determined by the peak values of the leakage current pulses. The data are stored as voltages in a file which is changed every 24 hours. From Anneberg the stored data are transmitted to Chalmers by means of a telecommunication line once a day and they are stored on tapes and magnetic discs. The receiving system is also Unix-based and the data processing and graphical presentation of data are performed by two commercial data processing programs. The programs enable a complete documentation of data and their graphical presentation, and the statistical and mathematical processing of the data.

3. LEAKAGE CURRENT RESULTS

Table 1 shows the technical data of four different insulators included in this study energized with AC. Insulators 2 and 8 were installed in December 1987, 9 in January 1989 and 7 in April 1991. All insulators have corona rings.

A relative comparison of leakage current data for insulators made with different materials can be made for insulators with similar leakage distance. Table 1 shows that insulators 2, 8 and 9 are similar, but unit 7 has a much reduced leakage distance. However, since insulators 2 and 7 are made with the same High Temperature Vulcanized (HTV) Silicone Rubber, it is important to see if the higher stressed silicone insulator behaves different than the unit with a longer leakage distance. Insulator 9 has a 0.5 mm Room Temperature Vulcanizing (RTV) Silicone Rubber coating on the porcelain surface.

Figure 1 shows the typical dry-band behavior of the ceramic insulators during salt-storm conditions. The measured currents on the porcelain unit are related to the salt deposit at the time of the measurement and are not a result of long term accumulation of salt particles on the insulator. The weather conditions on the Swedish West Coast include frequent rain and insulator self-cleaning between salt-storms.

AC	2	7	8	9
Number of longrods	1	4	1	1
Total length (mm)	1398	1624	1360	1465
Distance between fittings (mm)	990	948	1152	1290
Arcing distance (mm)	1055	1136	1246	1341
Creepage distance (mm)	3590	2244	3910	3700
Total number of sheds (large/small)	15/14	24	24	18/17
Distance between sheds (mm)	35	45	46	30/39
Shed diameter (mm)	170/130	97	202	175/145
Core diameter (mm)	41	29	75	75

Table 1.The design data for the different insulators of this work. Insulator 2 and 7 are insulators made with the same HTV Silicone Rubber. Insulator 8 is a porcelain longrod insulator and insulator 9 is a porcelain longrod insulator with a RTV Silicone Rubber coating 0,5 mm thick.

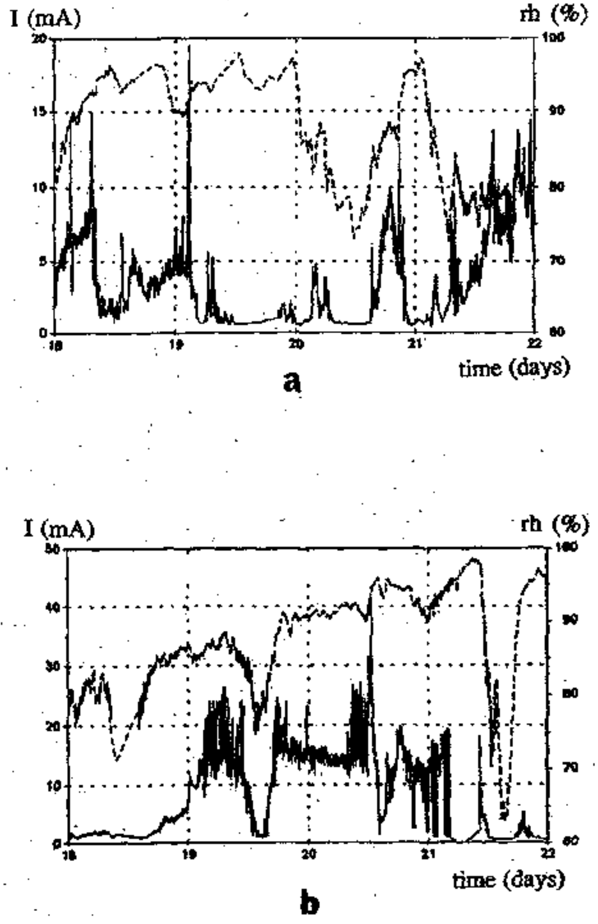

Fig 1. Leakage currents measured on the Porcelain unit 8 insulator during salt-storm conditions. Creepage distance 3910 mm (30 mm/kV). Upper trace: Relative humidity. Lower trace: Leakage current.

a. Period 19-22 January 1993 b. Period 19-22 March 1993

Figure 2 is showing very low currents on the silicone RTV coated unit which maintains high surface resistance during the two salt-storms. This observation is very important since in the artificial aging tests, the acceleration conditions reduce significantly the surface resistance of the silicone insulator. Such conditions seems not be representative for the performance of silicone insulators under actual service conditions.

Figure 3 is showing the leakage currents on the silicone composite insulator 2 made with HTV Silicone Rubber. The leakage distance for this unit is similar to the value for the porcelain insulator 8. The peak current values for this unit are very low, indicating continued high surface resistance for the silicone surface during salt-storm conditions.The records from 1987 until the end of 1994 show that the leakage current values for insulator 2 have remained low during all weather conditions.

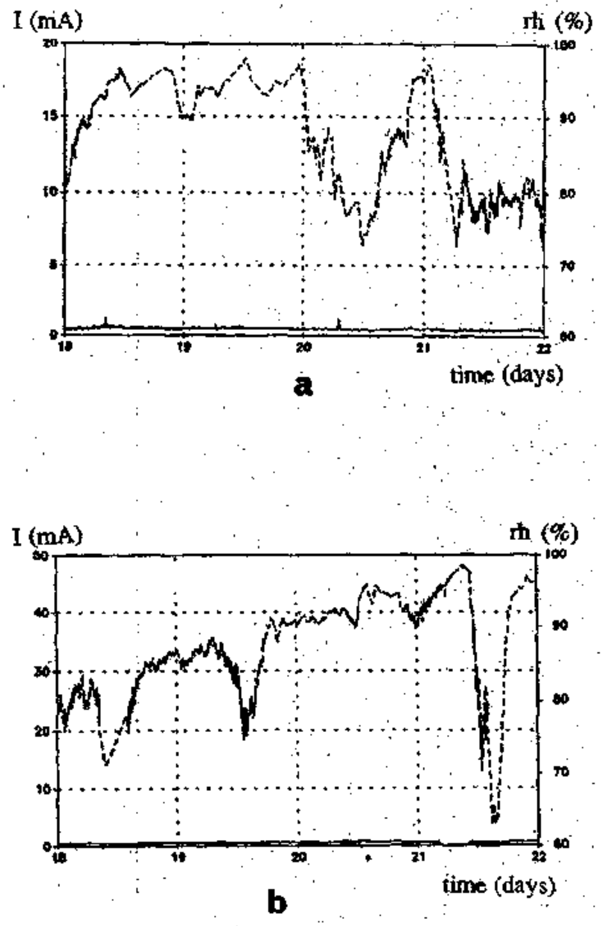

Fig 2. Leakage currents measured on the RTV Silicone Elastomer Coated Porcelain Insulator unit 9 during salt-storm conditions. Creepage distance 3700 mm (28.5 mm/kV). Upper trace: Relative humidity. Lower trace: Leakage current.

a. Period 19-22 January 1993 b. Period 19-22 March 1993

It is interesting to observe in Figure 4 that the insulator with the same silicone rubber, but with a very different design and higher stress shows reduced surface resistance and considerable dry-band activity.

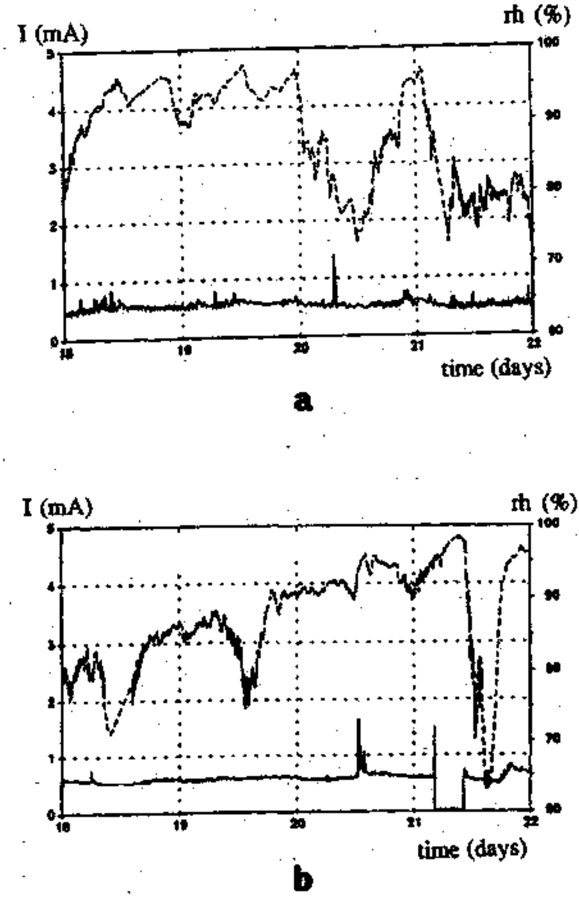

Fig 3. Leakage currents measured on the HTV Silicone Rubber Insulator unit 2 during salt-storm conditions. Creepage distance 3590 mm (27.5 mm /kV).Upper trace: Relative humidity. Lower trace: Leakage current.

a. Period 19-22 January 1993   b. Period 19-22 March 1993

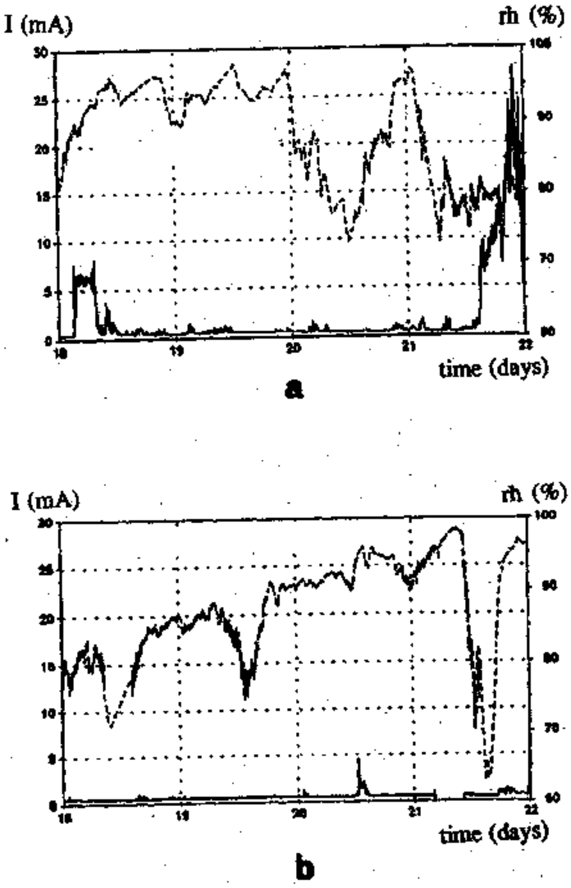

Fig 4. Leakage currents measured on the HTV Silicone Rubber Insulator unit 7 during salt-storm conditions. Creepage distance 2244 mm [37% shorter than insulator 2] (17.3 mm/kV). Upper trace: Relative humidity. Lower trace: Leakage current.

a. Period 19-22 January 1993   b. Period 19-22 March 1993

4. DISCUSSION OF RESULTS

In this study the HTV silicone rubber insulator 2 with 27.6 mm leakage path per kV showed continued high surface resistance with maximum current leakage current pulses not exceeding 2 mA.

On the other side, the other HTV unit with 17.3 mm leakage path per kV showed currents exceeding 25 mA which coincides with the maximum current pulses recorded on the porcelain insulator with 30 mm per kV leakage path.

The study shows that for the service conditions encountered on the Swedish West Coast, the HTV silicone insulator 2 maintained high resistance even under severe salt storm conditions. The unit did not develop continued dry-band activity and the surface of the unit and after 7 years of outdoor high voltage exposure, showed no degradation or erosion. The service conditions on the Swedish West Coast are the most severe in Sweden. An evaluation of the long term stability of the HTV silicone insulator of the design described in this paper predicts that the insulator for the service conditions encountered on the Swedish West Coast should not be exposed to extended dry-band currents and discharge at levels exceeding a few mA.

Since a general artificial aging test cannot be designed to cover all conditions of insulator service, each test procedure related to specific power systems must be based on outdoor data and lead to results which are in agreement with those obtained under realistic operation conditions.

5. ACKNOWLEDGEMENTS

The work was carried out mainly at the Anneberg field station of the Department of High Voltage Engineering, Chalmers University of Technology. The senior author wishes to express his appreciation to the Swedish National Board for Industrial and Technical Development, Vattenfall, Swedish National Grid, Swedish Power Association Development Foundation, ABB Corporate Research and ELSAM for their financial support of the project as a whole. We like to thank Mats Sjöberg and Torbjörn Sörqvist for their excellent work with the data acquisition system and the graphic presentation of the results and Maj-Britt Schönbeck for her assistance in typing the manuscript.

REFERENCES

[1] R.S. Gorur and T. Orbeck,"Surface Dielectric Behavior of Polymeric Insulation under HV Outdoor Conditions" IEEE Trans. Electrical Insulation, Vol. 26, pp 1064-1072, 1991

[2] H.M. Schneider, W.W. Guidi, J.T. Burnham, R.S. Gorur and J.F. Hall, "Accelerated Aging and Flashover Tests on 138 kV Nonceramic Line Post Insulators", IEEE Trans. Power Delivery, Vol. 6, No 1, pp 325-336, Jan 1993

[3] A.E. Vlastós and E. Sherif, "Experience from Insulators with RTV Silicone Rubber Sheds and Shed Coatings", IEEE Trans. Power Delivery, Vol 5, No 4, pp 2030-2038, Oct 1990.

[4] S.M. Gubanski and A.E. Vlastós, "Wettablidity of Naturally Aged Silicone Rubber and EPDM Composite Insulators", IEEE Trans. Power Delivery, Vol. 5, No 3, pp 1527-1535, July 1990

[5] A.E. Vlastós and E. Sherif, "Natural Aging of EPDM Composite Insulators", IEEE Tans. Power Delivery, Vol 5, no 1, pp 406-414, Jan 1990

Antonios Vlastós (Fellow IEEE), born in 1931 in Constantinople, is a graduate of the Universities of Istanbul (MSc in EE), Athens (MSc in ME and EE) and Uppsala (Fil lic 1964 and Fil dr 1967). He became an associate professor at Uppsala University in 1968 and at the Royal Institute of Technology, Stockholm, in 1977. He was, with permanent tenure, appointed as full professor in Experimental Power Engineering at the Technical University of Denmark, Copenhagen, in 1980, and as full professor in High Voltage Engineering at the Chalmers University of Technology, Gothenburg, in 1982. Since 1983 he is head of the High Voltage Engineering Department. His research work is mainly in the field of experimental power engineering and is related to power transformers (mineral oils), cables (polymers, XLPE), GIS (electronegative gases, SF_6), insulators (composite materials, EPDM and silicone rubber), and inorganic materials, (porcelain and glass), electrostatic precipitators (corona). His work includes fundamental research in long sparks, exploding wires, coronas and experimental techniques.

Tor Orbeck (Senior member IEEE)has more than 30 years of experience in Electrical/Electronic Insulation Engineering in Europe and in the USA. His work assignments have covered Dielectric Research, Insulation Development, Manufacturing of Insulation Systems and Materials, and Marketing of Insulating Materials. Tor Orbeck was born in Norway in 1932 and has received degrees in Electrical Engineering from Gothenburg Technical Institute of Sweden, in 1955 and Carnegie Institute of Technology in Pittsburgh, Pennsylvania, in 1962. He has been a Senior Member of the Institute of Electrical and Electronic Engineers, Inc. (IEEE) since 1975, and has a long record of service as Chairman of several committees and Officer in IEEE. He has served as President of the Dielectric and Electrical Insulation Society (DEIS) and is still actively participating in IEEE work. He was also active in standard activity in ASTM and IEC for many years and is presently involved in CIGRÉ.