COMPARATIVE PERFORMANCE OF SILICONE RUBBER AND PORCELAIN HOLLOW INSULATORS UNDER SPECIFIC ICE AND SALT FOG CONDITIONS OF ICELAND

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Abstract: A special test program has been created to simulate the specific environmental conditions of Iceland, i.e. salt fog during temperature at about 0^{o}C and combination of ice on the insulator surface with salt fog. This test program compares the performance of silicone rubber and porcelain hollow insulators. The test program included voltage tests, leakage current measurements and resistance measurements. The leakage current observed on the silicone rubber insulator stressed at 25 mm/kV was always lower than for the porcelain insulator with the same stress.

1. INTRODUCTION

The driving forces for expanded use of silicone rubber (SiR) apparatus insulators in Scandinavia are: better operation and personal security; marginal difference in price with porcelain alternative; positive known service experience; environmental-friendly designs [1]-[3]. The goal of the test program presented in this paper is to compare performance of SiR and porcelain apparatus insulators under specific environmental conditions of Iceland. The test program included salt fog during an ambient temperature of approximately 0 °C and combination of ice on the insulator surface with salt fog.

2. RESULTS AND DISCUSSION

Comparison of leakage currents between porcelain and SiR insulators is presented in Table 1 for standard salt fog test at low temperature.

Table 1: Maximum peak leakage current after 1 hour salt fog test performed at about 0^{o}C.

Test object	Maximum peak leakage current, mA		
	At 10 kg/m^3	At 20 kg/m^3	At 30 kg/m^3
Porcelain, 25 mm/kV	48	94	199
Porcelain, 31 mm/kV	16	20	18
Silicone rubber, 25 mm/kV	3	12	13

Example of leakage current measurements for all three insulators at the salinity 20 kg/m^3 is presented in Figure 1 below. The SiR insulator tested with/without ice accretion was always superior in leakage currents independently of the level of salinity.

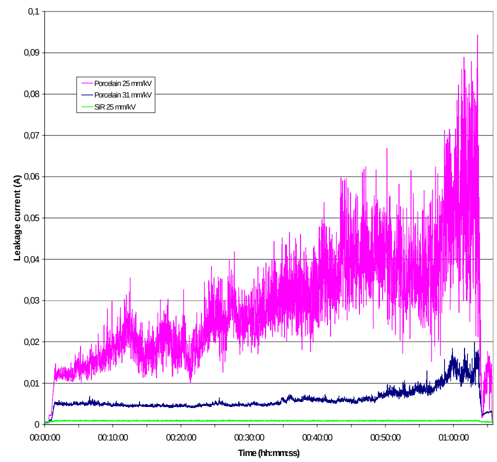

Figure 1: Details on leakage current measurements at 20 kg/m^3.

3. CONCLUSION

Specific environmental conditions of Iceland were simulated by application of salt fog of different salinities to the insulators with and without preliminary coverage of light level of ice. Comparative testing was performed on hollow porcelain insulators with two different specific creepage distances and one silicone rubber insulator with the specific creepage distance corresponding to the shortest porcelain insulator.

Because all insulators withstood the test at operating voltage, leakage current was used as criterion for comparison. The leakage current observed on the silicone rubber insulator stressed at 25 mm/kV was always lower than for the porcelain insulator with the same stress (for salt fog test with and without ice accretion).

4. REFERENCES

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[2] I. Gutman, J. Lundquist, T. Ohnstad, D. Hübinette: "Requirements on the Insulation for Different Applications of 400 kV Circuit Breakers in Pollution, Ice and Snow Environments", CIGRE Session 2006, A3-305

[3] I. Gutman, T. Ohnstad, L. Wallin, D. Windmar, U. Åkesson: "Field experience and test verification of HV composite apparatus insulators", CIGRE-2008, A3-302

Comparative Performance of Silicone Rubber and Porcelain Hollow Insulators under Specific Ice and Salt Fog Conditions of Iceland

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***Abstract*—Special test program was created and intended to simulate the specific environmental conditions of Iceland, i.e. salt fog during temperature at about zero degrees Celsius and combination of ice on the insulator surface with salt fog. This is to compare performance of silicone rubber and porcelain apparatus insulators. The results of the test program included voltage tests, leakage current measurements and resistance measurements. The leakage current observed on the silicone rubber insulator stressed at 25 mm/kV was always lower than for the porcelain insulator with the same stress.**

Apparatus insulator; porcelain; composite; ice test; salt fog test

I. Introduction

Silicone rubber *apparatus* insulators have a number of advantages in comparison with porcelain apparatus insulators, among them safe-explosion and better pollution performance in many different environments, including Scandinavian environment [1]-[3]. Scandinavian transmission system operators Svenska Kraftnät (Sweden) and Statnett (Norway) have recently taken a decision of new policy for using composite apparatus insulators in their network. Svenska Kraftnät has decided to use circuit breakers, surge arresters, bushings and instrument transformers only with silicone rubber housings. The driving forces were: better operation and personal security; marginal difference in price with porcelain alternative; positive known service experience; environmental-friendly designs. Statnett has decided to use all surge arresters and instrument transformers only with silicone rubber housings and is considering use of circuit breakers with silicone rubber insulators. These company decisions were taken after comprehensive investigation of composite and porcelain apparatus insulators of transmission voltage class [3].

Landsnet (Iceland) is also looking for the advantages of using silicone rubber apparatus insulators. A special test program was thus created by Landsnet intended to simulate the specific environmental conditions of Iceland, i.e. salt fog during an ambient temperature of approximately 0°C and combination of ice on the insulator surface with salt fog. The goal of the test program presented in this paper is to compare performance of silicone rubber and porcelain *apparatus* insulators.

II. Test Program

A. Test objects

Apparatus insulators were simulated by three types of hollow breaking chamber insulators:

- Porcelain insulator with specific creepage distance 25 mm/kV; Porcelain insulator with specific creepage distance 31 mm/kV
- Silicone rubber insulator with specific creepage distance 25 mm/kV

Test set-up is presented in Figure 1.

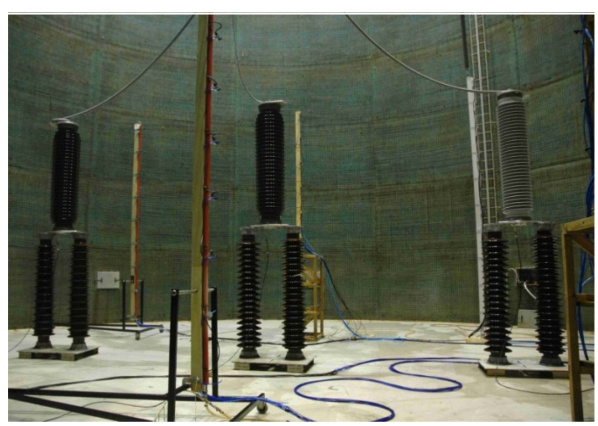

Figure 1. Three parallel insulators in the test set-up for salt fog test.

To avoid moisture condensation and risk for flashover inside the insulators the ends were sealed with covers and the insulators were pressurized with Nitrogen to 0,15 MPa. The insulators were cleaned and mounted on support insulators of 2 m height, to elevate and insulate them from the ground surface to enable leakage current measurements, as shown in Figure 1.

B. General test program

Environmental conditions in Iceland are characterized by conductive salt fog originating from the sea and coming inland during temperatures around 0°C. This means that in some cases insulators may be already covered by thin ice. Thus two types of tests were decided to simulate these conditions:

- Test A: Salt fog test at low temperature. Salt fog according to IEC 60507 with salinities 10; 20 and 30 kg/m^3 performed in the temperature range 0^{o}C÷+2^{o}C.
- Test B: Salt fog test at low temperature of ice-accreted insulator. Ice accretion at the temperature below -6^{o}C (thickness 3 mm at the standard rotating rod) followed by salt fog according to IEC 60507 with salinities 10; 20 and 30 kg/m^3 performed in the temperature range 0^{o}C÷+2^{o}C.

All three insulators were tested in parallel. Leakage currents during the test were measured at a phase-to-ground voltage of 141 kV (representing 245 kV system voltage). The test circuit is shown in Figure 2.

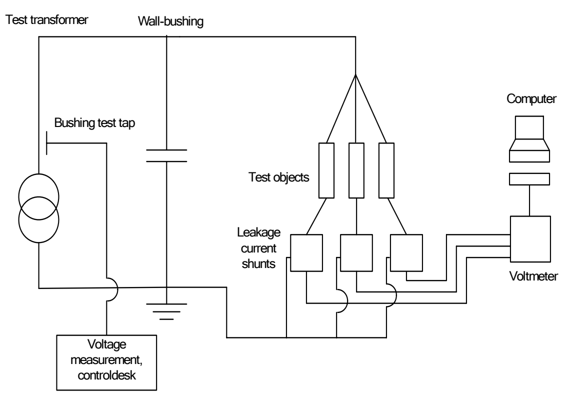

Figure 2. Test curcuit used for leakage current measurements.

For the salt fog tests six salt fog spraying ramps were used, two on each test object as specified in IEC 60507. The distance between the salt fog ramps and the test object was 3 m, according to IEC 60507.

III. RESULTS OF TEST A: SALT FOG TEST AT LOW TEMPERATURE

A. Test procedure

Testing was performed in STRI climate hall, 18 m in diameter and 23 m in height. The climate hall was cooled and in the beginning of the test the temperature was about +1^{o}C. The insulators were washed with tap water just before the salt fog spray was started. After about 10 minutes the resistance of all insulators was measured at 1 kV. The leakage current measurement was then started and the voltage was raised to 141 kV. The salt fog, voltage and leakage current measurements were maintained for one hour. Then the voltage was decreased and the resistance of all insulators was measured again at 1 kV.

B. Summary of test results

All insulators withstood 1-hour salt fog test at temperature close to 0°C without flashovers. Comparative leakage current measurements are summarized in Figure 3. and in TABLE I.

Comparative resistance measurements before/after the tests are summarized in TABLE II. The results of comparative porcelain/silicone rubber resistance measurements and leakage current measurements are well correlated with completely different hydrophobicity characteristics of tested insulators shown in Figure 4.

The leakage current observed on the silicone rubber insulator stressed at 25 mm/kV was always lower than for the porcelain insulators stressed at 25 and 31 mm/kV.
The resistance of the silicone rubber insulator at 25 mm/kV was also always much higher than for the porcelain insulators stressed at both 25 and 31 mm/kV.

TABLE I. MAXIMUM PEAK LEAKAGE CURRENT DURING 1-HOUR SALT FOG TEST

Test object	**Maximum peak leakage current, mA**		
	At 10 kg/m^3	***At 20 kg/m^3***	***At 30 kg/m^3***
Porcelain, 25 mm/kV	48	94	199
Porcelain, 31 mm/kV	16	20	18
Silicone rubber, 25 mm/kV	3	12	13

TABLE II. RESISTANCE OF COMPLETE INSULATOR BEFORE AND AFTER THE TEST

Test object	**Resistance of complete insulator, MΩ**			
	At 20 kg/m^3		***At 30 kg/m^3***	
	Before	***After***	***Before***	***After***
Porcelain, 25 mm/kV	10	7	11	1
Porcelain, 31 mm/kV	46	8	50	7
Silicone rubber, 25 mm/kV	>4000	3500	>4000	3000

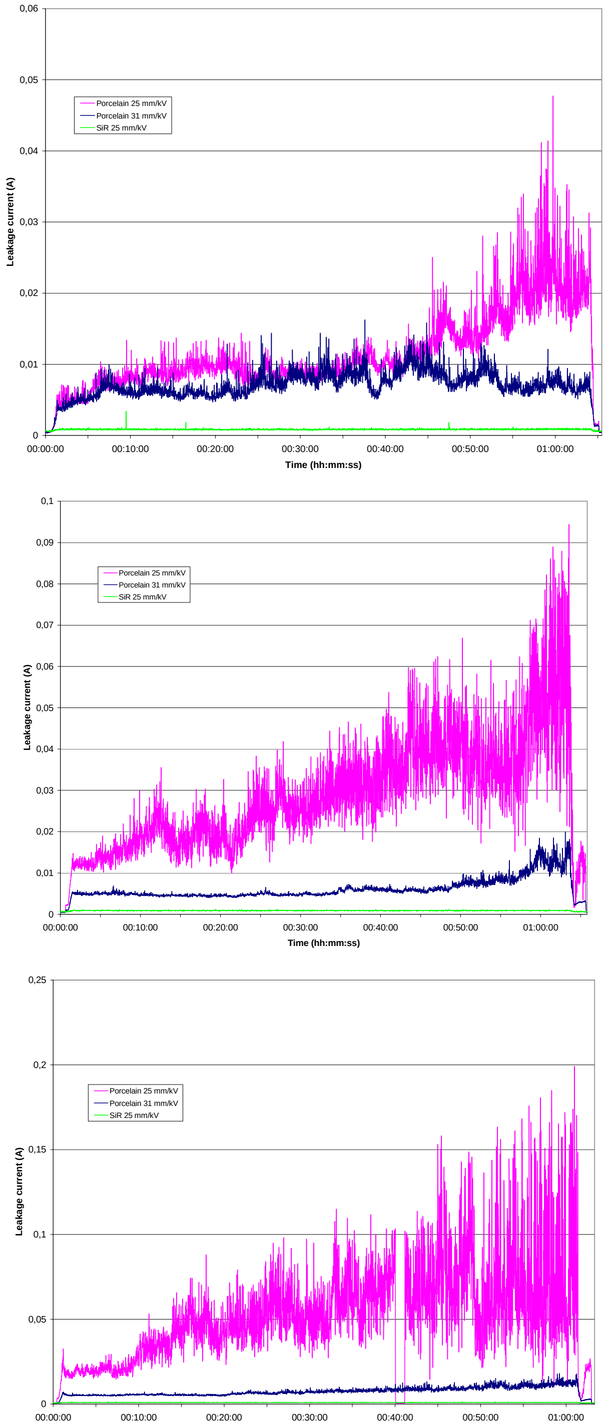

Figure 3. Details on leakage current measurements: from top to bottom tests at 10-20-30 kg/m^3 respectively. Note short interruption in measurements for the porcelain insulator 25 mm/kV at 30kg/m^3.

Figure 4. Hydrophobicity evaluation of the insulators after the three salt fog tests (10-20-30 kg/m^3) at low temperature: silicone rubber insulator at the top; porcelain insulator at the bottom.

IV. Results of Test B: Salt Fog Test at Low Temperature of Ice-Accreted Insulator

A. Test procedure

Testing was performed in STRI climate hall, 18 m in diameter and 23 m in height. For the ice accretion phase the start temperature in the test hall was about –6^{o}C.

A standard rotating cylinder (rod) according to [4] was put in the test hall to measure the thickness of the ice. Tap water with conductivity about 230 μS/cm was cooled to about +4^{o}C. The tap water was sprayed onto the insulators using the ice accretion ramps, see Figure 5. After 22-24 minutes of spraying the thickness of the ice on the standard rotating cylinder was 3 mm and the spraying was stopped, see view of the insulators in Figure 6. Actually, ice accretion was different on the silicone rubber and porcelain insulator, even not clearly seen in Figure 6. In case of porcelain insulators much more ice was accreted on the top of the sheds towards the trunk of the insulator then forming icicles from the edge of the sheds. In case of silicone rubber insulator most of the ice formed icicles from the edge of the sheds. This observation was valid for all three tests.

After ice accretion was finished, ice accretion ramps were taken out and salt fog ramps were put in. During the time for the change of the ramps, about 2-3 hours, the test hall was warmed up to the target temperature 0^{o}C; this temperature was then kept steady during the salt fog test.

Leakage current measurements were started and the voltage was raised to 141 kV. The salt fog, voltage and leakage current measurements were maintained for one hour. Then the voltage was decreased and the resistance was measured at 1 kV.

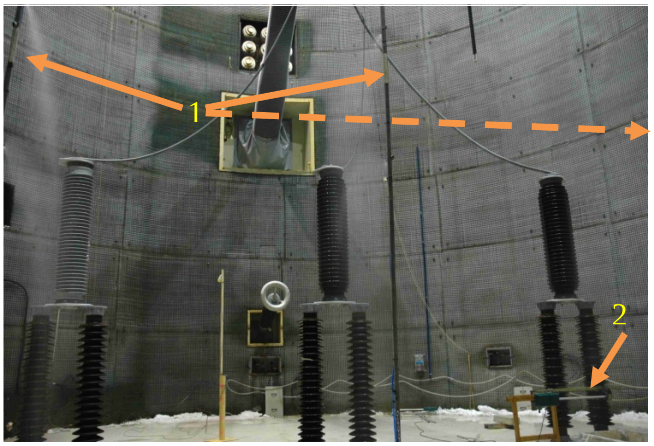

Figure 5. Test set-up for salt fog during ice accretion. The ice accretion ramps are standing 3 m from the test objects. One ramp at each test object, see arrows numbered by “1”. The right ramp is outside the picture. The standard rotating cylinder (rod) is located in front of the right test object, marked by arrow 2.

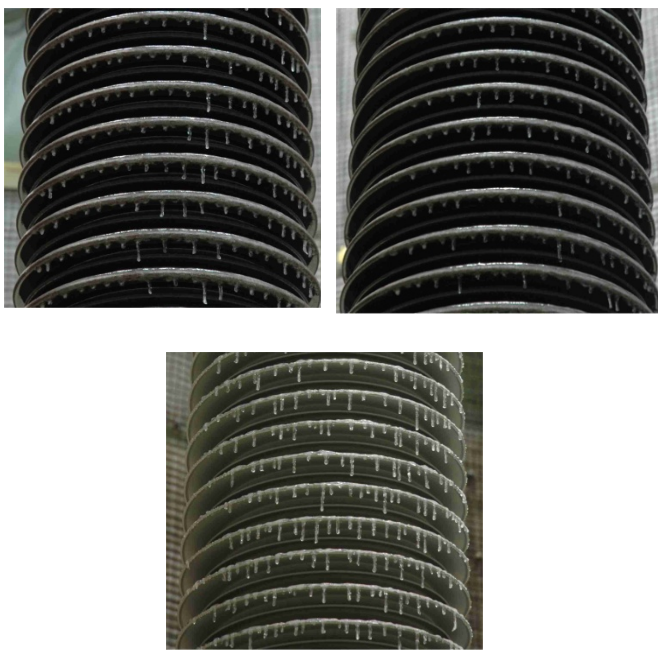

Figure 6. Close-up of the insulators with ice before the test with salinity 30 kg/m^3. Porcelain insulators are shown at the top and silicone rubber insulators is shown at the bottom.

B. *Summary of test results*

All insulators preliminary accreted by ice withstood 1-hour salt fog test at temperature close to zero degrees Celsius without flashovers. Comparative leakage current measurements are summarized in Figure 7. and TABLE III. Comparative resistance measurements after the tests are summarized in TABLE IV.

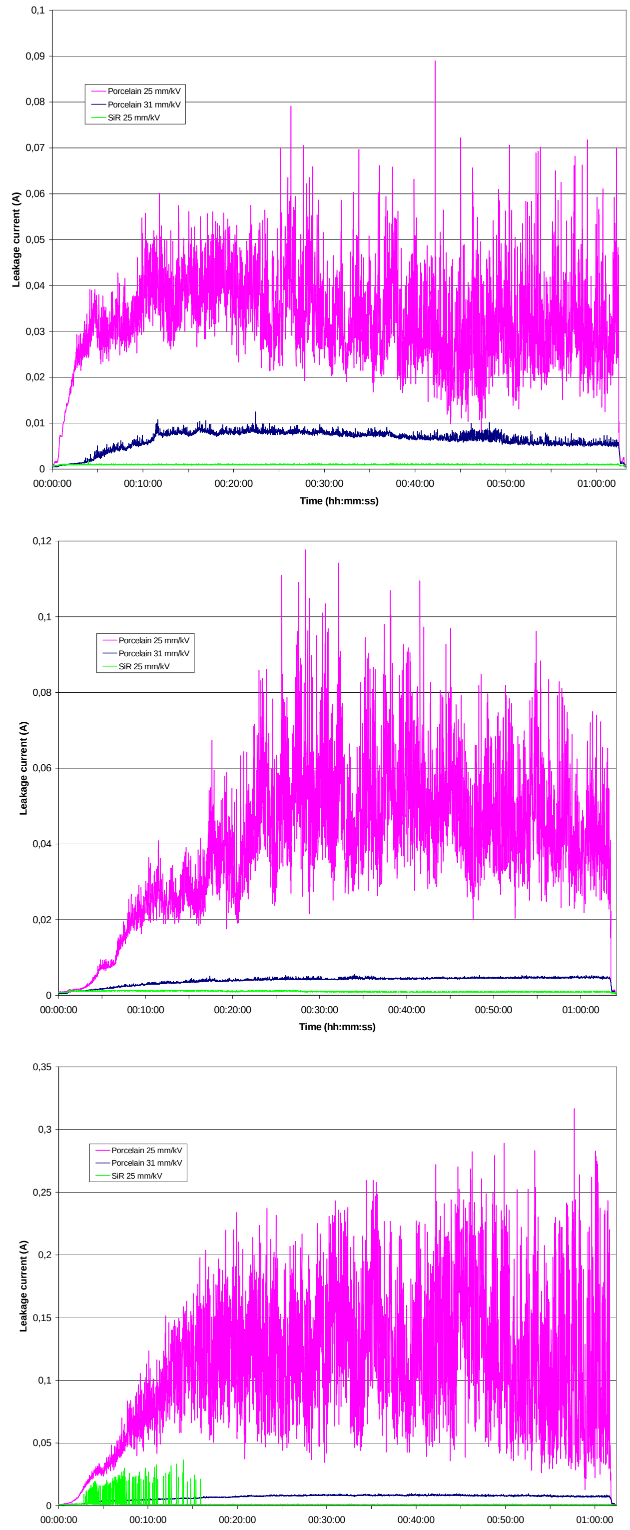

Figure 7. Details on leakage current measurements for the insulators preliminary accreted by ice: from top to bottom tests at 10-20-30 kg/m^3 respectively.

TABLE III. MAXIMUM PEAK LEAKAGE CURRENT DURING 1-HOUR SALT FOG TEST OF ICE-ACCRETED INSULATORS

Test object	**Maximum peak leakage current, mA**		
	At 10 kg/m³	***At 20 kg/m³***	***At 30 kg/m³***
Porcelain, 25 mm/kV	89	118	317
Porcelain, 31 mm/kV	12	5	10
Silicone rubber, 25 mm/kV	2	2	37

TABLE IV. RESISTANCE OF COMPLETE INSULATOR AFTER THE SALT FOG TEST OF ICE-ACCRETED INSULATORS

Test object	**Resistance of complete insulator after the test, MΩ**		
	At 10 kg/m³	***At 20 kg/m³***	***At 30 kg/m³***
Porcelain, 25 mm/kV	1	4	4
Porcelain, 31 mm/kV	7	6	7
Silicone rubber, 25 mm/kV	5	28	11

The leakage current observed on the silicone rubber insulator stressed at 25 mm/kV was always lower than for the porcelain insulators stressed at 25 mm/kV and approximately the same as the porcelain insulator stressed at 31 mm/kV. The deviation in peak current on the silicone rubber insulator at the salinity 30 kg/m^3 can be explained by the specific statistical interaction between accreted ice and salt water.

The resistance of the silicone rubber insulator and porcelain insulators was almost the same indicating that in this type of test the results are mostly governed by ice formation (in comparison to standard salt fog tests) .

V. SUMMARY

Specific environmental conditions of Iceland were simulated by application of salt fog of different salinities to the insulators with and without preliminary coverage of light level of ice. Comparative testing were made on hollow porcelain insulators with two different specific creepage distances and one silicone rubber insulator with the specific creepage distance corresponding to the shortest porcelain insulator.

Because all insulators withstood the test at operating voltage, leakage current was used as criterion for comparison. The leakage current observed on the silicone rubber insulator stressed at 25 mm/kV was always lower than for the porcelain insulator with the same stress (for salt fog test with and without ice accretion).

REFERENCES

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