The Journal of CPRI,
Vol. 5, No. 1, March 2009 pp. 9–15

End-of-Life Evaluation of RTV Coated Porcelain and Glass Insulators Under Pollution Conditions

Shaik Abdul Saleem*, J Amarnath*, K A Aravind** and D Devendranath***

Ageing of Room Temperature Vulcanising (RTV) silicone rubber coated porcelain and glass disc insulators are reported under combined voltage stress and salt-fog conditions till the loss of hydrophobic properties of RTV coating in an ageing chamber. The electrical characteristics are obtained by online monitoring of leakage current and material characteristics are analysed by Energy Dispersive X-Ray (EDX) analysis. RTV coated glass insulators shattered into pieces after 2600 hours of ageing while RTV coated porcelain after ageing for 4600 hours lost its hydrophobic properties and started behaving like a normal un-coated porcelain disc insulator.

1.0 INTRODUCTION

Electric power is an important ingredient for the industrial and all round development of a country. With the ever increasing demand for electrical power, there has been a steady growth in high voltage transmission lines for the transfer of bulk power over long distances. To ensure continuous operation of the transmission system, it is not only very important to select appropriate insulation withstand levels for various power apparatuses, insulators, etc., but it is also necessary to consider the pollution withstand levels for external insulation. Problems arise when the insulators, which are polluted and exposed to fog and sunlight and rain under ambient conditions, flashover at the operating voltages. Attempts have been made and are being continued to ensure uninterrupted power supply at an optimum cost. There are a few anti-pollution measures like greasing, live-line washing, etc., to overcome the problem of pollution related outages. The former appears to be messy and the latter an expensive technique. In the late eighties, commercial grade Room Temperature Vulcanising (RTV) coating was applied on a large scale in U.S. utilities [1]. In all but a very few dirty environments, these coatings have lasted ten or more years without maintenance and where maintenance has been found to be necessary, water washing is performed by reducing the periodicity of the maintenance schedule. Thus the use of RTV coatings on the surface of insulators particularly under polluted conditions reduces the pollution triggered outages.

To reduce the flashover of porcelain insulators under polluted conditions, they are coated with Room Temperature Vulcanising (RTV) silicone rubber [2]. This coating is subjected to the ageing phenomena over a period of time. The degree of ageing of the RTV coated insulator depends upon the pollution level of the environment and voltage. The loss of hydrophobicity of a RTV coating occurs with time through natural washing and this process takes a very long time before the coating performance is affected. However, the RTV coatings lose their hydrophobicity very rapidly

*JNTU, Hyderabad, INDIA
**CPRI, Hyderabad, INDIA
***CPRI, Bengaluru, INDIA

in coastal areas where they are subjected to wetting frequently. Failure of glass insulators in coastal areas is attributed to the thermal runaway [3]. Long-term use of glass insulators in highly polluted areas is not recommended [4]. Performance of porcelain and glass insulators with RTV coating under polluted conditions is studied in the laboratory. The results of ageing tests conducted in an ageing chamber in terms of electrical and material properties are discussed in this paper.

2.0 EXPERIMENTAL TEST SET UP

2.1 Ageing test chamber [1]

The ageing test chamber has a base of 2.0 m x 2.0 m and a height of 2.5 m. This chamber is made of stainless steel to avoid corrosion due to the salt-fog. One pair of nozzles as per IEC 60507, 1991 in each corner facing diagonally is installed. The distance between the nozzles is same as in IEC. However, the distance between the nozzle columns, which are at opposite corners is 2 √ 2 m.

Saline water for salt-fog generation is pumped to the rooftop tank and the water flows to pollution nozzles through gravity. The water flow rate is controlled by a Rota-meter type flow meter. The required air pressure at the nozzle tip is obtained by a twin compressor system. The combination of compressed air and water flow at the pollution nozzle tip produces fog required for accelerated ageing. A suitable drain is provided at the floor of the chamber to let out the spent solution, which is collected in the chamber during testing. Provision is made with suitable hooks to suspend the test objects in the chamber. A 33 kV rated bushing is fixed in the steel wall of the chamber to energise the insulators.

2.2 Voltage source

The voltage source used is a 400 V/ 33 kV, 66 kVA, 50 Hz, single-phase transformer. In artificial pollution tests, the voltage source needs to have a short circuit current higher than in other types of insulator tests. Thus, the voltage source used for the pollution ageing test has a minimum short circuit current of 6.0 A all the time. The resistance/reactance (R/X) ratio is such that R/X ≥ 0.1. The Total Harmonic Distortion (THD) is less than 1%. In general, the test source conforms to the IEC 60507 (1991) specification. The ageing test chamber along with the transformer source is shown in Fig. 1.

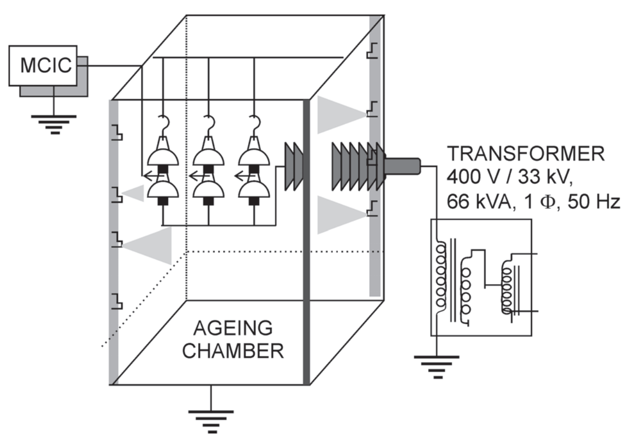

FIG. 1 AGEING TEST CHAMBER

2.3 Uniformity of fog in ageing chamber

Ensuring uniformity of the fog density in the test chamber is very difficult, whereas it is easy to measure the intensity of the salt-fog (amount of condensed water) and its distribution in the exposure zone. Standardising the salt-fog intensity in the exposure zone of the test objects is the best way to improve the repeatability and reproducibility of the salt-fog test [2]. IEC 68-2-11 [5] specifies jars for water collection during a specified time and is intended for calibration of the fog intensity. The jars are kept in the fog exposure zone at different places and the test specimens are kept at identified locations where fog collection is uniform.

3.0 EXPERIMENTAL TEST PROCEDURE

3.1 Test samples and test methodology

RTV coating is made up of Polydimethylsiloxane (PDMS) polymer with alumina tri-hydrate filler for increasing tracking and erosion resistance, a catalyst and a cross-linking agent. This coating is dissolved in naphtha solvent and is sprayed on to the insulator surface. The naphtha solvent evaporates from the surface and the moisture in the air triggers the vulcanisation, forming a solid rubber coating. One each of porcelain and glass disc insulators is coated with RTV coating. The disc insulators are of 165 mm height having a creepage distance of 330 ± 5 mm. The RTV coating thickness is 0.20 ± 0.01 mm on each disc insulator.

RTV coated porcelain and glass disc insulators and one porcelain disc insulator without coating are subjected to the accelerated ageing test in an ageing chamber under the combined stress of voltage and salt-fog. The porcelain disc insulator was used as a reference sample. The test voltage is 10 kV RMS, flow rate of salt-water is 250 ml ± 10 ml and salt-fog salinity equal to 0.15 kg/m^3. The test voltage applied is 40% more than the normal operating phase to ground voltage of an 11 kV system. Higher voltage is used to accelerate the ageing of the RTV coating in the test chamber. The parameters monitored are leakage current, cumulative charge, peak leakage, current pulses, etc., using PXI (Peripheral Component Interconnect Extensions for Instruments Specification) controller based data acquisition system explained in 3.2. Intermittently, RTV coating peeled off and it was subjected to EDX (Energy Dispersion X-ray) analysis. The photographs of RTV coated porcelain and glass insulators at the beginning of the test are shown in Figs. 2 and 3.

FIG. 2 RTV COATED PORCELAIN (CAP VIEW) DISC INSULATOR BEFORE AGEING TEST

FIG. 3 RTV COATED GLASS (PIN VIEW) DISC INSULATOR BEFORE AGEING TEST

3.2 Data acquisition system

The data acquisition system is designed to monitor leakage currents in a maximum of three insulators. An additional sinusoidal input voltage is used as a reference for analysing and classifying leakage currents occurring in each input channel during every half cycle of the reference channel. Peak leakage currents in each half cycle of reference sinusoidal input can be classified into a maximum of seven preset levels. Unlike a PC based MCIC (Multi-channel Current Integrator cum Peak Classifier) [6], the newly developed data acquisition system measures voltage on four channels using a PXI data acquisition card. Four isolation amplifiers are added into the PXI chassis before the input to the DAQ (Data Acquisition) card.

Custom based software developed in Lab VIEW has two parts. The first part is called Field Monitor (FM), which runs on the PXI system. The FM software performs unattended operations for extended periods of time. FM software performs data acquisition, online analysis, local display in graphical and tabular format, stores data on the system hard disc and communicates with the second part of the data acquisition system which runs on a remote PC. The second part of the software is called the Remote Monitor (RM). This software developed in Lab VIEW runs on a remote PC with no data acquisition hardware. RM communicates with FM software over Local Area Network (LAN) to control and monitor data acquisition operations remotely. The overall system block diagram is shown in Fig. 4. The sampling rate of the data acquisition system is fixed at 4000 samples per second. The voltage appearing across the shunt resistors due to flow of leakage current is acquired by the FM software which divides it by the resistor value to get the leakage current.

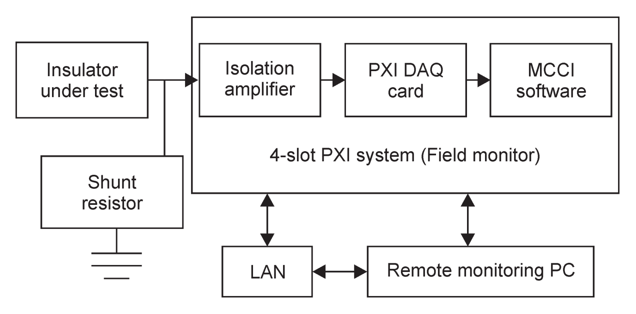

FIG. 4 BLOCK DIAGRAM OF DAS

The leakage current flowing in an insulator has resistive and capacitive components. The voltage applied across the insulator is constant throughout the test. The leakage current flowing over the insulator has two components. They are capacitive and resistive in nature. The resistive component is a function of the resistance of the coating of the insulator. Since the resistance of the coating degenerates with respect to time, the resistive component of current increases. However, the capacitive component is a function of insulator dimensions and the dielectric constant of the material of the insulator. Since the change in the dielectric constant of the material is negligible, the capacitive component of the leakage current is constant. To analyse pollution phenomena in an RTV coated insulator, we measure the resistive component of the leakage current.

The FM software analyses digitised data according to a specified algorithm, incorporated with a digital capacitive current compensation technique to nullify the capacitive component of the total leakage current on the RTV coated porcelain insulator. The software accepts user inputs like number of input channels, sampling rates, etc. and provides final outputs in graphical, tabular and spreadsheet file formats.

4.0 PRINCIPLE OF AGEING TEST

The basic principle of long-term salt-fog tests is the generation of continuous discharges by exposing the energised insulator to a salt-water spray [7]. The heat, UV-radiation and gases generated from the discharge activity influence the insulator performance in two ways. Firstly, the dielectric strength of the insulator can be reduced due to the salt severity and a subsequent reduction of the hydrophobicity. This can lead to a flashover without any visible surface damages. This test should be regarded as a flashover test. Secondly, different kinds of damages, such as tracking, erosion, cracks, etc., can be created during testing. In this case the test can be regarded as an ageing test.

5.0 RESULTS

The RTV coated glass insulator shattered at the end of 2600 hours of ageing. Shattering of the glass insulator under pollution is due to the electro-

FIG. 5 RTV COATED PORCELAIN DISC INSULATOR AT THE END OF 4600 HOURS OF AGEING TEST

FIG. 6 RTV COATED GLASS DISC INSULATOR (SHATTERED PIECES) AT THE END OF 2600 HOURS OF AGEING TEST

thermal runaway caused by the continuous discharges at the pin end of the insulator. The ageing test on the RTV coated porcelain disc insulator was continued up to 4600 hours. The porcelain disc insulator without coating was removed after 2600 hours of ageing. The photograph of the RTV coated porcelain insulator at the end of 4600 hours of ageing is shown in Fig. 5. The photograph of pieces of a shattered RTV coated glass insulator is shown in Fig. 6. It is seen that the RTV coating on the porcelain disc insulator is almost eroded due to continuous arcing.

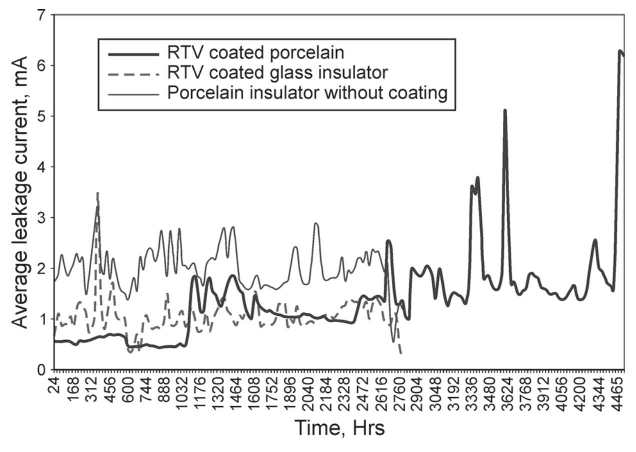

FIG. 7 VARIATION OF DAILY AVERAGE LEAKAGE CURRENT WITH TIME

5.1 Daily average leakage current

It is called daily average leakage current because the mean value of average leakage currents is obtained for every 24 hours from the existing database and plotted as multiples of 24 hours. It is shown in Fig. 7. The leakage currents are determined by the ability of the RTV material to prevent the formation of a continuous water film on the surface of the coated insulator with all other factors such as magnitude of the voltage stress and the conductivity of the contaminant being constant. At the beginning of the test, the average leakage current is less for the RTV coated porcelain insulator as compared to the average leakage current in the RTV coated glass and the porcelain insulator without coating. At the end of 1000 hours of ageing, the average leakage currents for RTV coated glass and porcelain insulators were almost same. The porcelain disc insulator was removed after the RTV coated glass insulator shattered at the end of 2600 hours of ageing. After 2760 hours of ageing, the average leakage current for the RTV coated porcelain insulator increased continuously to more than the leakage current in porcelain without coating at the end of 2600 hours. This indicates that the RTV coating started losing its hydrophobic properties. Also, at the end of testing, the RTV coating on the porcelain insulator was almost eroded from the surface of insulator. Hence the RTV coating on the porcelain insulator reaches its end as the current is more than the reference porcelain insulator sample.

5.2 Daily peak leakage current

The variation of peak leakage current with respect to time is shown in Fig. 8. This is called daily because the mean value of the peak leakage current for 24 hours is obtained from the existing database and the multiples of time are plotted on the X-axis. At the beginning of the test, the peak leakage current is 1.8 mA for the RTV coated porcelain insulator, 2.0 mA for the RTV coated glass insulator and 3.8 mA for the porcelain insulator without coating. The peak leakage current was less for RTV coated porcelain insulator compared to RTV coated glass insulator and more for porcelain insulator without coating up to 1030 hours. The peak leakage current for the RTV coated porcelain insulator remained practically constant up to 2470 hours and thereafter it continuously increased. The peak leakage current in case of the RTV glass insulator was practically constant throughout till it failed at 2600 hours.

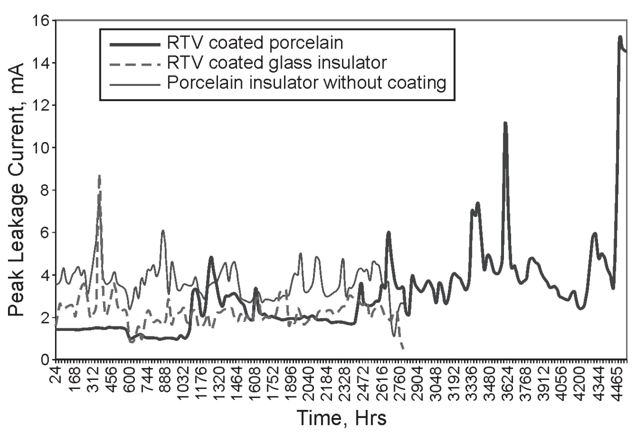

FIG. 8 VARIATION OF DAILY PEAK LEAKAGE CURRENT WITH TIME

5.3 Cumulative charge or cumulative integral of leakage current

The variation of cumulative charge, for RTV coated glass, RTV coated porcelain and the porcelain insulator without coating, which is the integral of the leakage current, is shown in Fig. 9. It is proportional to the energy dissipated by dry band arcing and is dependent on the magnitude of electric stress. It can be observed that the cumulative charge for the RTV coated porcelain insulator was 1632 C and for the RTV coated glass insulator and porcelain insulator without coating, it was 2030 C and 4150 C respectively, at the end of 2600 hours. At the end of 4600 hours of ageing, RTV coated porcelain has accumulated a total charge of 5450 C.

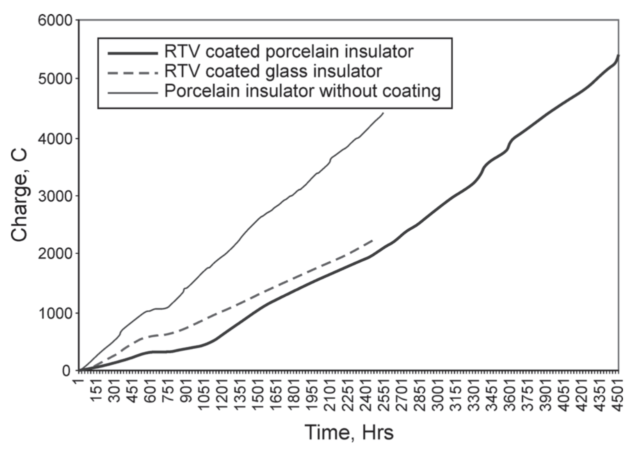

FIG. 9 VARIATION OF CUMULATIVE CHARGE WITH TIME

5.4 Cumulative integral of current squared (Coulomb-Amperes)

The variation of the cumulative integral of current squared with respect to time is shown in Fig. 10. They are in general similar to those for charge, except that the differences are accentuated because of the behaviour of weighted averages of higher current amplitudes when squared.

It is seen that the RTV coated porcelain, RTV coated glass and the porcelain without coating samples acquired 4.1, 9.7 and 16.1 Coulomb-Amps respectively at the end of an ageing test of 2600 hours. There appears a sharp rise of i^2t from 4.1 to 19.5 C-A, for the RTV coated porcelain sample because, there is a similar rise in the average leakage current and is hence reflected in this graph.

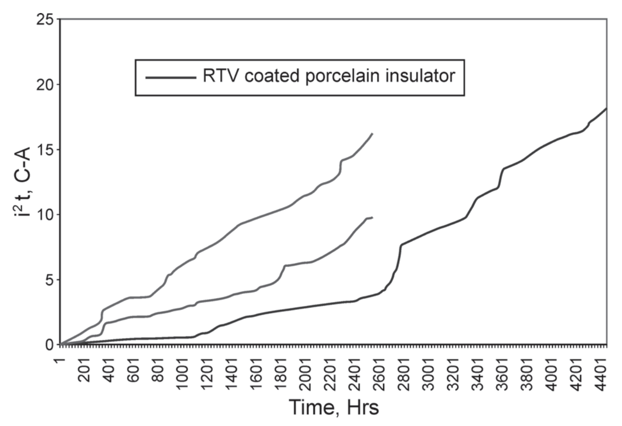

FIG. 10 VARIATION OF i^2t WITH TIME

6.0 ENERGY DISPERSIVE X-RAY (EDX) ANALYSIS

Energy dispersive X-ray analysis [8] is used to determine the various components of surface composition of RTV coating polymer material. The values are obtained in terms of percentages of various elements of the coating composition. This analysis can help in understanding the physical processes involved in the failure of RTV coating. RTV coating material cut from virgin samples and aged samples were subjected to EDX analysis. This technique is used to demonstrate the depletion of low molecular weight polymers on the surface of the aged material. The samples were the virgin and the aged samples at different times.

The typical elemental analysis of RTV coating for various ageing times is shown in Table 1. Each test sample, of scraped RTV coating, at four different locations is subjected to EDX analysis. The elemental analysis of aluminium and silicon were obtained by taking the mean of the locations for each sample and tabulated in Table 1. Generally, the ratio of Si/Al reduces with respect to ageing [8].

TABLE 1

RESULTS OF EDX ANALYSIS

Ageing time (Hours)	Surface composition of RTV coated porcelain (%)			Surface composition of RTV coated glass (%)		
	Si	Al	Si/Al	Si	Al	Si/Al
Virgin 0 hrs	28.35	20.34	1.39	28.35	20.34	1.39
1600	26.81	21.75	1.23	20.42	23.42	0.87
2600	25.92	25.33	1.02	2.89	<0.1	–
4600	23.58	23.50	1.00	–	–	–

From Table 1, it is observed that the ratio of Si/Al is decreased from 1.39 (virgin sample) to 1.00 at the end of an ageing period of 4600 hrs for an RTV coated porcelain sample compared to 0.87 at the end of 1600 hours of ageing for an RTV coated glass sample. There is a marginal decrease in the Si element on the surface of the RTV coated porcelain sample. However, the same Si element is very low i.e. 2.89% at the end of 2600 hours of ageing for the RTV coated glass sample, which eventually shattered into pieces. The RTV coating is made of Low Molecular Weight (LMW) polymer chains on both the RTV coated porcelain and glass insulator samples. However, due to ageing, the coated porcelain sample loses Si marginally but the loss in the coated glass sample is considerably higher. Thus, the RTV coated porcelain sample experiences a slow depletion of LMW polymer chains compared to the fast depletion of the LMWs for the RTV coated glass insulator.

7.0 CONCLUSIONS

At the end of the ageing test of 4600 hours, the RTV coated porcelain insulator loses its hydrophobic properties and starts behaving like a normal porcelain insulator without coating due to end-of-life of the RTV coating. The RTV glass insulator fails after 2600 hours of ageing indicating that the RTV coating on the glass insulator is inferior to RTV coating on the porcelain insulator in terms of performance under polluted conditions.

8.0 ACKNOWLEDGEMENTS

The authors thank the management of CPRI for carrying out the work and giving permission to publish the results. The authors also thank Mr A Ramulu for the services rendered to the project.

REFERENCES

[1] Devendranath D, Channakeshava and Rajkumar A D, "Leakage Current and Charge in RTV Coated Insulators Under Pollution Conditions", IEEE Trans DEI, 2002, Vol. 9, pp. 294-299.

[2] Gutman I, Hartings R and Riquel G, "IEC 5000 Hours Ageing Test: Critical Review and Further Test Development", Proceedings of the International Symposium on Electric Power Engineering, Sweden, Vol. High Voltage Technology, pp. 310-315, 1995.

[3] Carrano de Almeide L E and Hylten-Cavallius N, "A Model for Thermal Runaway of HVDC Line Insulators", CEPEL Report 2013/80.

[4] Grouch A G, Swift D A, Parraud R and De Decker D, "Ageing Mechanisms of AC Energised Insulators", 22-203, 26th August – 1st September 1990 CIGRE Session.

[5] "Basic Environmental Testing Procedures, Part 2, Tests Ka. Salt Mist", Publication IEC 68–2–11 (1981).

[6] Devendranath D, Girija G, Shivkumara Aradhya R S, Gunasekaran B and Bhaskaran A, "Development and Application of a Multi-channel Current Integrator-cum-peak Classifier for Online Monitoring of Leakage Current on RTV Coated Insulators", IEE Proc. GTD, Vol. 152, No. 2, pp. 247-252, March 2005.

[7] Gutman I, Hartings R, Matsuoka R and Kondo K, "Experience with IEC 1109, 1000h Salt-fog Test: Experience and Suggestions for Improvements", Nordic Insulation Symps., 1996, June 10-12, pp. 389-398.

[8] Gorur R S, Karady G G, Jagota A, Shah M and Yates A M, "Ageing in Silicone Rubber Used for Outdoor Insulation", IEEE Trans. PD, 1992, Vol. 7, pp. 525-538.

Readers are invited to offer their comments on the article. Please fill in the Reader's Forum.