Performance of Thermoplastic Elastomeric and Thermoset Insulators under Accelerated Acid Rain Multistress Conditions

Raji Sundararajan, Victor Godinez and Muhammad Amin

Abstract—Polymers are becoming the material of choice for high voltage outdoor insulators. However being mostly organic, they are susceptible to aging and degradation (weathering) due to environmental (and electrical) stresses. This necessitates the study of their long-term behavior. It is desirable to study the long-term performance of the insulators in the service environment under multistress conditions encountered by the insulators to better simulate the actual conditions. This paper presents the results of the studies of a novel, third generation, environmentally friendly thermoplastic elastomeric (TPE) insulators and conventional thermoset silicone rubber (SiR) insulators in Connecticut, USA and Taxila, Pakistan. 28 and 10kV insulators were used for this purpose. The aging phenomena were characterized by visual observations, hydrophobicity classification and using sophisticated materials analysis techniques, such as FTIR. The results indicated that the TPE insulators had discoloration and arcing after two thousand hours of aging while the silicone rubber insulators had no arcing.

Index Terms—multistress aging, acid rain, polymeric insulators

I. INTRODUCTION

Acid rain can deteriorate high voltage outdoor insulators and affect their performance in addition to their other surface degrading effects [1-4]. Polymeric insulators can especially be susceptible since they are mostly organic [5-6]. It is of practical interest to study the aging and degradation characteristics of commercially available polymeric insulators under acid rain + multistress conditions, simulating an actual service environment. Presented in this paper are the results of the studies on the effect of acid rain (pH 3.9) in the Connecticut area, USA [1] and at Taxila, Pakistan. Connecticut was chosen as failure of polymeric coating, Room Temperature Vulcanized (RTV) silicone rubber was observed within 6 years of in service performance in service under extra high voltage of 345kV [1, 7]. It is of practical interest to study the performance of High Temperature Vulcanized (HTV) silicone rubber (SiR) insulators in this environment at a lower voltage as distribution class insulators are more commonly used. Additionally, it was also intended to compare the performance of thermoset (SiR) and thermoplastic elastomeric (TPE) materials [8].

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II. BACKGROUND

Aging and degradation of polymers in normal and high voltage outdoor insulator applications is due essentially to the combined action of sunlight, especially low wavelength, high energy UV radiation [4, 5, 9]. Additionally, it has been observed that acid rain, containing NO₂ and SO₂ in trace quantities in air (acid rain) may also have a significant effect in shortening the useful life of certain polymers. Acid rain (with a pH < 5.6) refers to rain, fog and snow falling from atmosphere that is acidic. Sulfur dioxide (SO₂) and nitrogen oxides (NOₓ) are the primary causes of acid rain. The effects of acid rain have been observed around the world (Fig. 1) [10].

![Fig. 1: Examples of polluted cities around the World](image)

Acid rain can deteriorate high voltage outdoor insulator performance also [1-4, 8] in addition to their other environmental degrading effects. Reports of acid rain related aging and degradation RTV silicone rubber coatings showed that the material had depolymerized and became putty-like after 6 years of service in a 345kV switchyard located near Long Island Sound [1, 7]. It had lost its physical integrity. Aging by a combination of chemical, photochemical (weathering) and electrochemical mechanisms could be the reason is suspected.

It was proposed to study this weathering effect on the performance of 28kV distribution class polymeric insulators under accelerated multistress laboratory conditions [11]. Silicones being a thermoset polymeric material, it was also proposed to compare the performance of a 28kV two part thermoplastic elastomeric insulators with a silicone rubber insulator. Various stresses, such as UV radiation, heat (temperature), and acid rain, were used for aging.

The multistress chamber at ASU East [8] was used to study various environmental conditions and to perform the accelerated test in much less time than in reality. Three 28kV insulators, two TPE and one silicone rubber were used for this purpose and their arrangement is shown in Fig. 2. The aging was performed for 2304h. UVA radiation, temperature...
(40°C) and acid rain were the various stress applied. Voltage was on all the time in both cycles. The pH of the acid rain used was 3.9 [1] and the acid rain was prepared using NH₄Cl, NaCl, KCl, HNO₃, MgSO₄, and CaSO₄ [3]. Table I gives the insulator dimensions and Table II gives the acid rain preparation details.

In Pakistan, the acid rain + multistress effect was studied using 10kV silicone rubber insulators (Table III). The service environment chosen was Taxila, which is about 40km from Islamabad. The various stresses applied are shown in Table IV. This illustrates the weather cycle that was designed to simulate the environment [12] of the capital city Islamabad and surroundings using available data of meteorological department [12]. The applied stresses were set above normal environmental stresses to simulate accelerated conditions.

The aging was conducted for a period of 30days (720h) using a plastic chamber of 0.6x0.6x0.6m³ (Fig. 3). Two samples, each of rod, plate and full scale 10kV insulator were used. One sample of each type was energized and the other kept un-energized. UV radiation level at 4.16mW/cm² was applied using UV lamps fitted on three sides of the chamber. A spray gun was fitted on one side of the chamber to apply artificial acidic rain. The diameter of nozzle was 0.5mm and spraying pressure was 3.0kg/cm². The rate of rain was 0.5 liter/hour. The applied voltage was 10kV (line to ground). The arrangement of complete setup is shown in Fig. 3.

### III. RESULT & DISCUSSION

#### A. Connecticut acid rain aging

There was discoloration in both TPE and SiR insulators. The TPE material lost its hydrophobicity while SiR retained it. There was hardware corrosion in the TPE insulator 3 (Fig. 2). Figs. 4-6 show the various degradations observed in the insulators. Fig. 4 shows the various surface changes and Fig. 5 shows the Fourier Transform Infra-Red Spectroscopy (FTIR) spectrographs after 1152h aging. There was loss of hydrocarbons in both insulating materials indicating the deteriorating effect of acid rain + multistress on these materials. Fig. 6 shows the arcing in TPE 1 insulator. There was arcing also on TPE 3 insulator. The SiR insulator had no arcing.

#### B. Taxila acid rain aging

1) **Visual observations:** No cracking, chalking, erosion and discoloration were found after 5th and 10th days. On the 17th day, severe discoloration was found at the top shed of insulator as is shown in Fig. 7(a), (b) and (c). This discoloration was uniform on all the sheds, and there was no discoloration on the core. This might be due to the high...
conductivity and low pH value of the acid rain on the insulating material. The electrical stress would accelerate the aging/degradation. This may lead to increased tracking and consequently more leakage current \[13, 14\].

2) **Hydrophobicity**: The surface conditions per STRI hydrophobicity classifications \[15\] are given in Table V. Fig. 8 shows the nature of the surface after 24 days. CH\(_3\) methyl groups are responsible for hydrophobic behavior of silicone rubber material. When the number of such groups increases on the surface, it improves hydrophobicity characteristics and vice versa. Thus, with the variation in the surface nature, the hydrophobicity, and hence the leakage current and the FTIR spectra vary. Thus, the hydrophobicity of the sample can be related to the absorption value of CH\(_3\) at wave number 1258 cm\(^{-1}\). Table VI lists the percent decrease in absorption of C-H bond at wave number 1258 cm\(^{-1}\) for the energized insulator, illustrating the recovery behavior during aging.

3) **FTIR**: The absorptions at 2962 cm\(^{-1}\) refer to the C-H bond of methyl CH\(_3\), 1270 – 1255 cm\(^{-1}\) refer to the Si-CH\(_3\) bond and 1100-1000 cm\(^{-1}\) to the Si-O-Si main bond. The values of absorption at these wave numbers and the percent changes are shown in Table VI. The increase and decrease of absorption of the C-H bond of CH\(_3\) and Si-CH\(_3\) mean that the number of C-H bonds increased and decreased at the various stages and periods of aging.

4) **Leakage Current**: In this investigation, leakage current was also monitored regularly. Normally, the leakage current was of the order of 0.1 mA, but during rainfall increased leakage current activities were noticed and the magnitude of the leakage current was in the range of 1.85 - 2.7 mA. This could be due to the high conductivity of acidic rain. The magnitude of leakage current still remained within a few mA, illustrating that the integrity of the insulators are intact. This is also in line with the FTIR results and hydrophobicity performance observed in the present study. These findings correlate well with previous results \[13\].
Fig. 5 FTIR spectrographs illustrating the peak heights of various bonds of TPE and SiR after 1152h aging at Connecticut multistress conditions.

Fig. 6: TPE Insulator with arcing and SiR insulator (with no arcing) after 2304h aging.

(a) After 17 days   (b) after 24 days   (c) after 30 days

Fig. 7 Photographs illustrating the gradual discoloration and surface changes observed.

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<th>Hydrophobicity Classification of the 10kV Insulators</th>
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IV. CONCLUSIONS

- The 2304h acid rain + multistress aging study conducted at multistress conditions simulating Connecticut, USA indicated discoloration, loss of hydrophobicity and degradation of the surfaces (FTIR spectrographs) of the 28kV TPE insulators. There were arcing after 2000h and one of the TPE insulators (TPE 3) had severe hardware corrosion too. The 28kV silicone rubber insulators had discoloration, less loss of hydrophobicity and no arcing.

- The 720h acid rain + multistress aging study conducted at multistress conditions, simulating Taxila, Pakistan using 10kV silicone rubber thermoset insulators also showed similar findings as USA study; there was discoloration and erosion of the thermoset silicone rubber polymer. The hydrophobicity was HC 4. The leakage current levels were low, at 2.7mA.

- These insulator aging characteristics depicted a periodic nature i.e. a cycle of degradation and restoration of the surface. This indicates the dynamic nature of the aging kinetics.

- The major merit of these studies is that they investigate the whole insulator system for long term stress under multistress conditions that simulate the in service environment as closely as possible, not just the material, and thus, the results could be directly translated to the field conditions.

REFERENCES


