Impact of Arid Desert's Simulated Environmental Conditions on High Voltage Polymeric Insulators

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Abstract — **Polymeric high voltage (HV) insulators are replacing ceramic insulator commonly used for HV outdoor networks. Their long term performance and reliability are major concerns to power utilities. To investigate their degradation under of thermo-electric stresses and ultraviolet (UV) radiations etc. due to arid desert's simulated environmental conditions, high voltage composite insulators were subjected under accelerated aging condition. This paper describes the experimental results of these tests under two different types of aging conditions. The results will help in assessing the performance and suitability of polymeric insulators for their applications in arid deserts environments.**

Index Terms — **high voltage, polymeric insulator, accelerated aging, UV radiations, Silicon Rubber (SiR), thermoplastic elastomer (TPE), flashover voltage.**

I. Introduction

The use of polymeric insulators for outdoor transmission lines has rapidly increased during the last two decades. Both service experience [1] and the laboratory tests demonstrated a better performance in contaminated conditions [2]-[3].

Porcelain and glass have traditionally been used as the oldest and most economic insulating materials and their advantages and drawbacks are well known. However, the polymeric insulators have replaced ceramic units due to several merits [1]-[3].

During the last three decades huge data is collected about the worldwide use and utility service experience of polymeric insulators by different manufacturers / research institutes such as CIGRE, EPRI, CRIEPI (Japan), etc.. A worldwide survey done in 2000 by CIGRE to investigate the global distribution of composite insulators at voltage levels above 100 kV indicated that GCC is one of the regions where composite insulators are gaining ground [4]-[5].

Polymeric materials are badly affected by environmental stresses like UV-radiations, heat, contaminations, moisture, etc. [2], [6]. The molecules in polymers are relatively dynamic in comparison to porcelain and glass and have much greater freedom for arrangement in the bulk or at the surface. The weather conditions in the Middle East including Saudi Arabia are significantly harsh and changing from the daytime to the night. The inland areas of Saudi Arabia are very hot, dry and dusty. The UV radiations that cause chemical changes on the composite insulators are extremely high in this region. The aim of this study is to determine the degree of degradation and decomposition of the SiR and TPE insulators due to thermo-electric stresses and UV-radiations.

This paper describes the experimental results of accelerated aging tests of the composite insulators under two different types of aging conditions based on the UV-A radiations level. The results will help in assessing the performance and suitability of polymeric insulators for their applications in those GCC countries whose environmental conditions are similar to central region of Saudi Arabia

II. Experimental Setup and Procedure

According to IEC std. 61109 [7] for the accelerated aging process of polymeric insulators, various stresses such as simulated solar radiation (1 mW/cm^2), dry heat (50°C), salt fog and artificial rain to be applied in a cyclic manner.

Unlike the coastal zones, the meteorology of the inland arid desert situated in the central region of Saudi Arabia are very hot, dusty and with long dry spells in summer months with no or very little precipitation. In winter months, there is sparse occasional rain or no rain at all for years. Keeping in view these environmental conditions of the central region of Saudi Arabia, the rain and salt fog / clean fog parameters are not taken into consideration while performing the accelerated aging. Furthermore, as shown in **Fig. 1**, the actual level of UV-A radiations and temperature variations in central region of Saudi Arabia is quite higher as compared to the values recommended in the IEC std. 61109 [7].

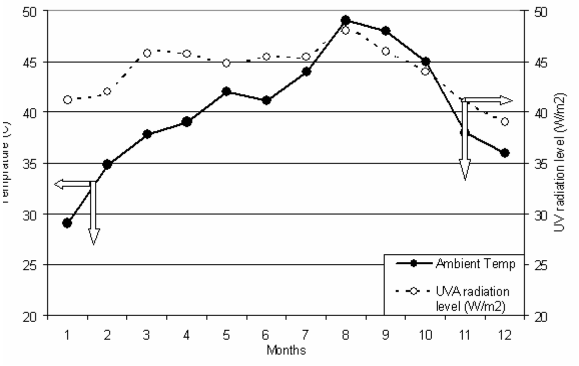


Fig. (1) Ave. monthly temperature (ambient) variation and actual UV-A radiation levels in Central region Saudi Arabia

To simulate the ambient conditions of arid desert, a wooden chamber of approximately 120cm (wide) × 120cm (high) × l80cm (long) dimensions was fabricated for the accelerated aging process for the Silicon Rubber (SiR) and Thermoplastic Elastomer (TPE) polymeric insulators. Up to 12 line post insulators or an equivalent number of suspension dead end insulators can be subjected to accelerated aging cycle in this chamber. A schematic diagram of the chamber with suspension insulators in place is shown in **Fig. (2).** For energizing the insulators to required voltage stress, a 0~100 kV, 5kVA, HV testing transformer is used.

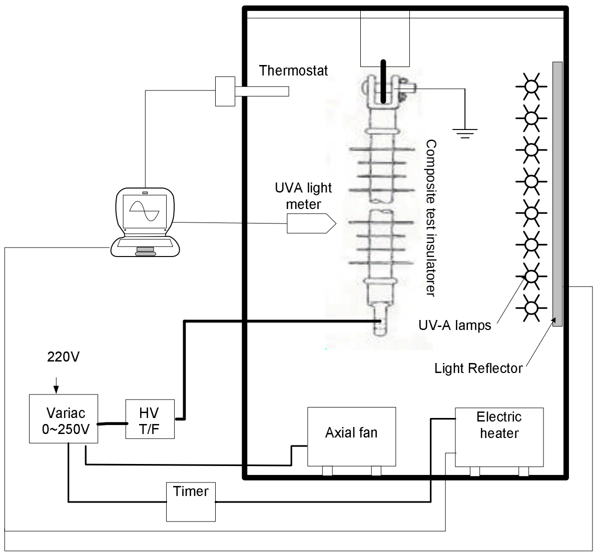


Fig. (2). Schematic diagram of accelerated aging cycle chamber.

Based on the above discussion, two different types of experimental conditions were created for the artificial accelerated aging of the composite insulators based on the IEC std. 61109 and modified aging cycle based on the actual temperature and UV-A radiations level. The level of the stresses applied is shown in **Table 1**.

Table (1): Applied stresses

No	Stress type	Exp-1	Exp-2
1	Voltage (p.u)	1	1
2	Temperature (°C)	60	60
3	UV- radiation (mW/cm^2)	1	4

As the temperature variations may cause some degree of mechanical stress, which are repeated several times in the course of a cycle. Each cycle lasts for 24 h and a programmed change takes place every 6 hours. During the time when heating is out of operation, the insulators return to room temperature. As per standard [7], the rise from ambient temperature to desired level should take less than 15 min. UVA-radiation around 1mw/cm² (in Exp-1) and 4mw/cm² (in Exp-2) were applied on the surface of insulators for a period of 6 hours. All stresses mentioned in Table (1) above are applied in cyclic manner to the samples for 1000 hours are shown below in **Table (2).**

Table (2): Accelerated aging cycle

Time (hours)	2~8 AM	8 AM ~ 2 PM	2~8 PM	8 PM ~ 2 AM
Voltage (1 p.u.)	ON	ON	ON	ON
Heating (58°C)	ON	OFF	ON	OFF
UV-A radiations	ON	OFF	ON	OFF

In order to simulate solar irradiations, UV lamps having the same law, end cutoff wavelength as sunlight were utilized. The UV-A spectrum (320nm ~ 400nm) produced by these lamps as compared with that of sunlight, is shown in **Fig. (3)** [8].

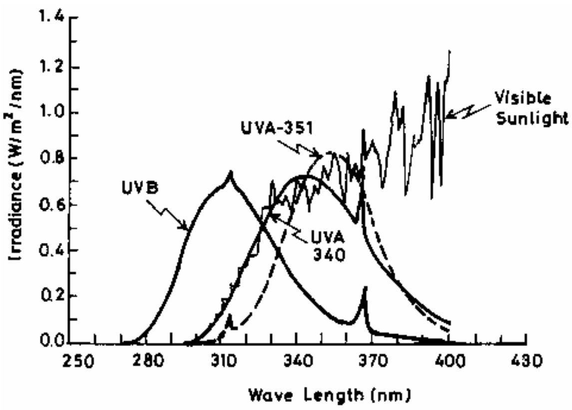


Fig. (3). Spectrum comparison of sunlight & UV radiations [8].

The UVA radiations in the chamber were measured with a precision UV-A sensor. The chamber shown in Fig. 2 is designed such that the tested insulator mounted can be adjusted for any desired level of the UVA radiation by adjusting the horizontal distance between the insulator and the UVA lamps.

(i) Details of Polymeric insulators Tested:

Three SiR and three TPE distribution / dead end type insulators of rating 28kVL-L, procured from GLP power, Canada were used for laboratory accelerated aging study. **Fig. (4)** illustrates the photographs of actual tested insulators.

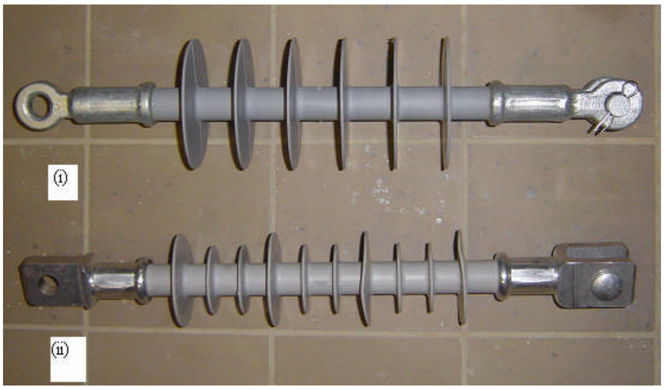


Fig. (4) Dead End / Suspension polymeric insulator (i) TPE & (ii) SiR.

The salient dimensions of both tested insulators are shown in **Table (3)** below:

Table (3): Tested insulators details

Specifications		Unit	SiR	TPE
Voltage class		kV	28	28
Section Length "L"		mm	433	438
Dry arcing Distance		mm	290	285
Leakage Distance		mm	590	675
Field strength		mm/kV	21.09	24.10
Power Frequency Flashover	Dry	kV	135	130
	Wet	kV	105	114
Impulse flashover		kV	225	211

(ii) Heating arrangement:

Since temperature effects the aging of polymeric materials and the aging rate is accelerated by some factor for each degree rise in temperature [6]. In central region, the maximum daytime temperature which remains almost stable around 1PM ~ 4PM varies during summer months in a range of 43 ~ 50°C with an average of 48°C, as shown in Fig. (1). The thermostat in the chamber is set at a temperature ~60°C. This temperature is selected such that the average ambient temperature is 48°C + around 12°C is temperature rise on the outdoor insulator surface with respect to ambient temperature measured in this laboratory [10].

A 2000W tubular heater is used to develop heat. A PC based ON-OFF control system is used to maintain a relatively stable temperature in the chamber. The heat generated by the heater is uniformly distributed by an axial blower installed inside the chamber.

III. Results and Discussions

After performing the modified accelerated aging tests of the SiR and TPE insulators as per Exp-1 and Exp-2 mentioned in section-II above, various electrical, SEM based optical and visual tests were performed and the results are summarized as follows:

3.1 Impulse Test

In order to investigate the effect of artificial aging, all the aged samples as well as one virgin insulator sample of both types (SiR and TPE) were subjected to impulse waveform. Impulse generator was adjusted to produce a standard wave of 1.2/50µs impulse with both positive and negative polarities.

The results reported here were corrected to the standard atmospheric conditions as per IEC publication 60-1 [9]. **Fig. (5)** shows the comparisons of the breakdown voltages (kV_p)for all the artificially aged as well as new insulators for both materials (SiR and TPE) under both polarities**.**

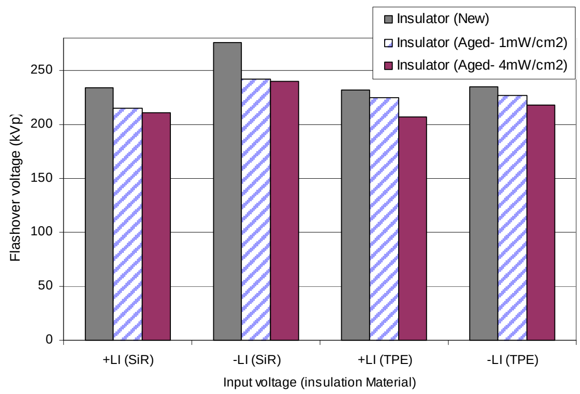


Fig. (5): Flashover voltages under lightning impulse

It is clear from Fig. (5) that TPE insulator comparatively better performs than SiR insulator as the effect of aging on TPE is slightly less as compared to SiR. For SiR insulator about 10% and 14% reduction has been observed under +LI and -LI respectively, whereas only about 7~11% reduction is observed in case of type TPE insulators.

3.2 Power-Frequency Test

Dry and wet power frequency tests were also performed using 200 kV power transformer. Artificial rain was adjusted as per IEC-383 [14] requirement for the resistivity and rain intensity (precipitation). The water resistivity was 105Ω-m and the intensity of rain fall was kept 1~1.5 mm/min., respectively. The flashover voltage values (kV_{rms}), after correction to standard conditions, are shown in **Fig. (6).**

Fig. (6) shows that around 13 % reduction in flashover voltages in case of SiR for dry and wet conditions, respectively, whereas, 4~5% reduction in flashover voltage was observed for the aged TPE insulators.

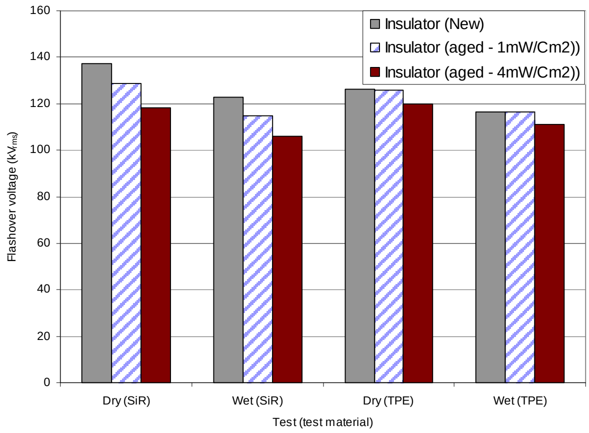


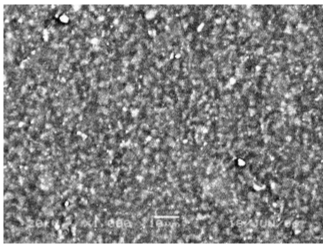
Fig. (6). Flashover voltage under 60-Hz AC voltage

All the results discussed above are summarized in **Table (4).**

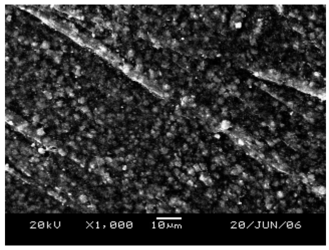
3.3 Scanning Electron Microscopy (SEM)

Small samples (5mm × 5mm) were sectioned from high voltage end of each insulator and their surface analysis was obtained using JEOL JSM-6360-A (Japan) SEM in high vacuum mode in order to avoid sample charging. Secondary Electron Imaging (SEI) was performed to study the surface morphology at an accelerating voltage of 20kV. SEM photographs were captured out for analyzing surface condition for both types of insulators at a magnification of 500, 1000, 2000 times.

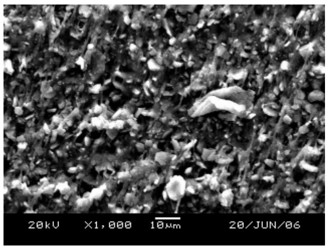
Fig. (7) shows SEM results of virgin and samples aged under UV radiation 1mW/cm^2 and 4mW/cm^2. The virgin samples have a smooth, more homogenous and less porous surface while for aged insulators the surface roughness and porosity has increased with very visible cracks aging as shown in Fig. (7). Moreover, it may be pointed out that surface roughness on SiR is more as compared to TPE when UV radiation intensity was 1mW/cm^2. However, with the increase in UV-intensity to 4mW/cm^2, very visible surface degradation such as cracking in both types of materials is observed, as shown in Fig. (7c & 7f). This surface roughness has resulted due to localized degradation in both tested materials.



(a) SiR (New) ×1000

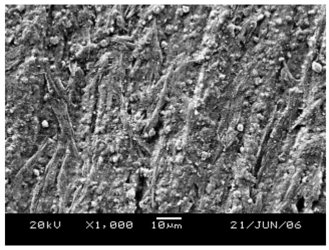


(d) TPE (New) ×1000



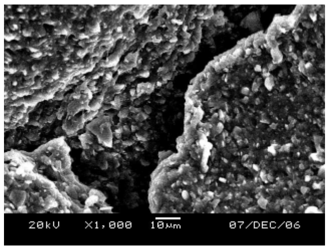
(b) SiR (Aged) ×1000

(UVA = 1mW/cm^2)



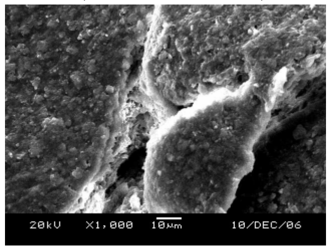
(e) TPE (Aged) ×1000

(UVA = 1mW/cm^2)



(c) SiR (Aged) ×1000

(UVA = 4mW/cm^2)



(f) TPE (Aged) ×1000

(UVA = 4mW/cm^2)

Fig. (7): SEM micrographs for virgin and the aged samples.

The above results indicate that UVA radiations and heat are important factors in the degradation of polymers. This results from the breakage of certain molecular bonds by the UV radiation on polymers as these are more susceptible to oxidation [11]-[13]. The surface roughness will be a source of dust and pollution accumulation and hence can cause decline in the dielectric performance of the composite insulator in the long term operation in actual power system.

Table (4): % V_{BD} reduction with respect to virgin insulators

Test type		% V_{BD} reduction w.r.t. New insulator			
		SiR		TPE	
		1 mW/cm²	*4 mW/cm²*	*1 mW/cm²*	*4 mW/cm²*
Lightning Impulse	*Positive*	9%	10%	4%	11%
	Negative	14%	14%	4%	7.5%
Power frequency AC	*Dry*	6.5%	13.8%	Negligible	4.7%
	Wet	7%	13%	Negligible	4.5%

IV. Conclusions

This study presents various results of the accelerated laboratory aged samples of the SiR and TPE composite insulators that were aged for 1000 hours as per modified IEC protocol [7]. It truly reflects the prevalent weather conditions related to arid desert conditions. The obtained electrical and optical results are compared with respect to new insulators and lead to following conclusions:

1. From the electrical tests results after the artificial accelerated aging, the dielectric response of TPE insulators under the tested thermo-electric cum UV-irradiations outperforms SiR insulators.
2. The SEM results indicates that surface roughness of the aged samples in case of SiR is more as compared to new insulator however, negligible surface roughness was observed in case of aged TPE insulator when exposed to UV radiation of 1mW/cm^2. Whereas, very visible surface degradation in both types of materials is observed, when exposed to UV-radiation of 4mW/cm^2.

V. Acknowledgements

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VI. References

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