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Investigation of Ultra Violet Influence on the Surface of Silicone Rubber Insulator

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Abstract: Ultra Violet (UV) as an environmental aging factor is considered to have serious effects on polymers used in insulators especially on Silicone Rubber (SIR). This paper presents the experimental results on a 20 kV polymer insulator which subjected to accelerated aging cycle in the chamber containing nine UV (290 nm) lamps with intensity of 50 W/m2 for 5000 hours. Aging process has been performed in order to compare the effects of UV on surface characterization of the insulator with an unaged one of the same type**.** Both insulators were artificially contaminated according to IEC60507 standard and the leakage current (LC) has measured. Fast Fourier Transformer (FFT) method is used to analyze the LC waveforms. Results of the experimental studies showed that third and fifth harmonic components of LC are quite sensitive to the pollution and dry band arcing. Supporting the results from leakage currents analysis, thermogravimetric analysis (TGA) is applied to a sample from the surface of the insulators. Numbers showed a shift in the TGA figure of the aged sample and a clear difference in the temperature that degradation starts. In addition, Scanning Electron Microscope (SEM) results are presented and changes in the surface properties have been discussed through the aging cycle.

1 INTRODUCTION

Recent researches have clarified that UV radiation can deteriorate polymer insulators. Radiation sources are mainly sunshine, corona and dry band arcing. Also study showed that just about five person of total UV radiation (270-320 nm) of sunshine can reach the earth surface, it seems to be enough to affect the chemical and mechanical properties of polymer insulators and the effect would be intensified in case of a wet surface. Crazing, chalking, tracking and loosing hydrophobicity are mostly reported as the influence of UV radiation on polymer insulators [1-3].

In general, during aging test, two kinds of discharges are observed that can evaluate the insulation performance. One of them is corona partial discharge that occurs between water droplets. The other is dry band arc discharge that occurs between dry bands on the surface of the polymeric material that may cause tracking and erosion phenomena, its cumulative charge is much larger than that of a corona discharge [4, 5]. The herein-presented work has been performed to monitor accelerated UV-aging of a silicone rubber (SIR) insulator and how LC is alerted as the surface properties are changed. Studying LC is taken in to account for two main reasons. First, it provides information on the mount of contamination and the second, LC by itself can erode the surface [6, 7].

This report focuses on the relationship between the LC and the discharge phenomena on the polymer material under wet condition and degradation process due to UV radiation and changes in surface characteristics of the polymer.

2 EXPERIMENTAL

A new facility for UV accelerated aging has been built at University of Tehran. It is a chamber that contains nine UVC lamps with intensity of 50w/m2 and the samples were aged for 5000 hours.

2.1 High Voltage Test Setup

A setup consists of 100 kV, HV transformer that used for energizing the insulators to the required voltage stress and data acquisition system provided the LC related information, i.e. the time variation of LC such as maximum and average waveforms. Data acquisition consists of a digital oscilloscope to save data, back connected Zener diodes (15 V) for overvoltage protection and a shunt resistor for measuring LC.

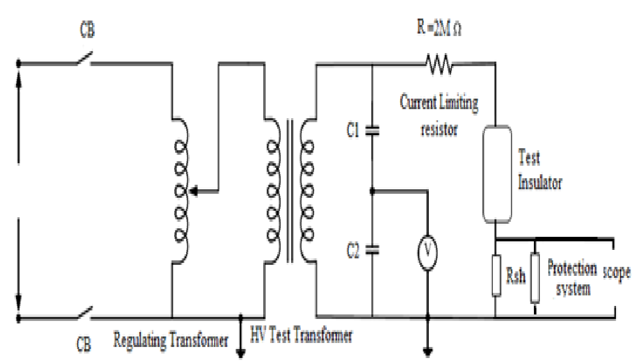

Figure 1: schematic of Experimental setup

Figure 2: Experimental setup

2.2 Insulator contamination

Here a method of application of artificial contamination on SIR which was reported to provide a uniform contamination layer is used [8]. According to this procedure Kaolin powder is deposited after spraying the surface with a fine mist of water droplets and allowing it to dry. The insulator is immersed in the slurry of contaminants and dried. Kaolin composition consists of 40 gr kaolin, 1000 gr tap water and 10 gr NH_4CL. When the Volume conductivity of tap water is higher than 0.05 S/m, the use of distillery water is recommended.

2.3 Characteristic of insulator

A 20 kV SiR insulator has been used for artificial ageing study. Table 1 shows the characteristics of tested insulator.

TABLE 1: CHARACTERISTICS OF INSULATOR UNDER TEST CONDITIONS

Voltage class	20 KV
Leakage distance	890 mm
Shed diameter	70 mm
height	280 mm
Mechanical tension Strength	70 kN

3 RESULT OF LEAKAGE CURRENT

Initially, clean SiR insulator was examined for rated voltages (20 kV) with applied voltage of 11.54 kV rms phase to ground. No visual discharges were observed under this test conditions. The LC on the clean surface contains the higher order harmonic components like 4th, 5th, and 7th. It should be also noted that in clean condition, the 5th harmonic component was always greater than the 3rd harmonic. When transmission lines passes near the coastal, desert and industrial areas, insulators are exposed to different types of contaminants such as NaCl, $CuSo_4$ coming from the different sources and deposited on the insulator surface. Salt contaminations play a key role in SIR insulator ageing [2].

Artificial ageing tests must simulate actual conditions as much as possible. The goal is to evaluate degree of ageing deterioration of a SiR insulator by means of measuring magnitude of LC flowing through insulator surface. However, that conductive current flowing on the contaminated wet surface of SiR insulator without any discharge would not deteriorate the surface so much compared with the case of corona discharge or dry band arc currents. The typical surface LC pattern has been recorded for the following three levels:

3.1 Conductive Current

For completely wet surfaces, which were obtained in the pollution tests, LC also appeared to be sinusoidal, but at higher level (Figure 3). The cases in which the hydrophobic properties were either partially lost or a weak dry band activity started, THD of LC could be high. Figure 4 shows the frequency spectrum of the LC during pollution surface condition. It is observed that the LC for polluted surfaces contains greater 3th harmonic components than other harmonic component. Figure 5 show that insulator which is subjected to UV has more LC due to loss of hydrophobicity compare to non-aged insulator. Figure 6 shows the frequency spectrum of the LC on the polluted surface which is exposed to UV radiation. Even higher 3rd harmonic content is observed for this case.

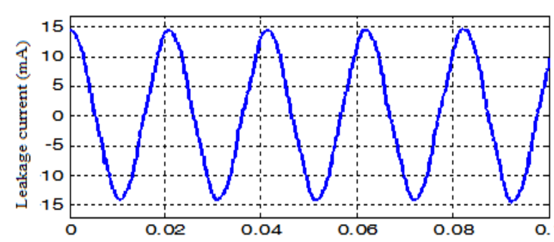

Figure 3: Leakage current of 20 kV polluted insulator

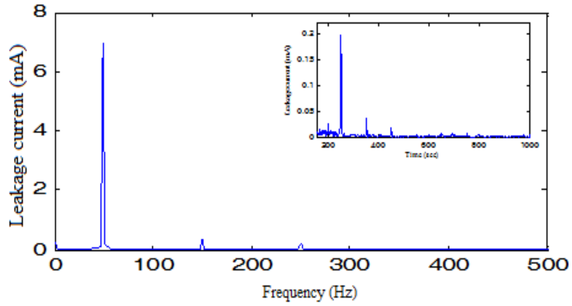

Figure 4: Frequency spectrum of Leakage current on 20 kV polluted insulator

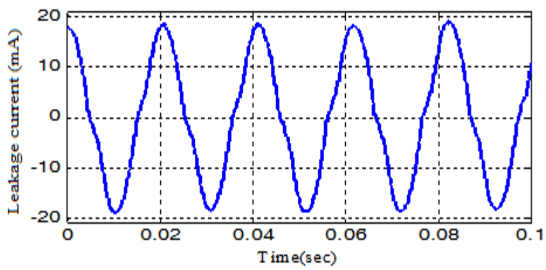

Figure 5: Leakage current of 20 kV polluted insulator Under UV

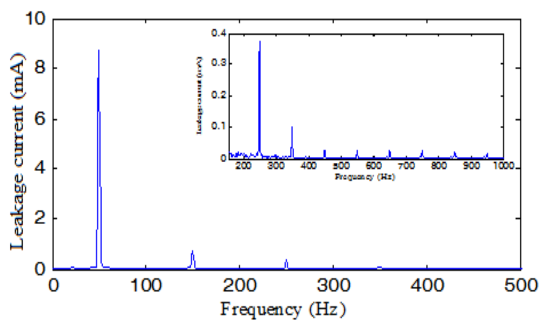

Figure 6: Frequency spectrum of Leakage current on 20 kV polluted insulator under UV

3.2 Dry band Arcing

In this case, we have investigated the relationship between the LC and the discharge phenomenon on the wet SiR surface. In general, two kinds of discharges are observed in this case. One of them is corona partial discharge that occurs between water droplets, in which Si-C bonding of SiR is broken down by photon energy because the photon energy due to the corona discharge is larger than the bonding energy of Si-C. Therefore, the corona discharge activity on the hydrophobic surface can be used to define the insulation surface condition. The second is dry band arc discharge that occurs between dry bands on the surface of the polymeric material. Thus, the dry band arc discharge and the corona discharge influence the wet insulator performance. The multi-frequency waveform, shown in Figure 7 occurred during and prior to the visible discharge and, therefore, the discharge currents can be considered as a spike appearing on the crest of a nonlinear LC waveform. Figure 8 shows the frequency spectrum of the LC for the wet polluted surface condition. It is observed that the LC for wet polluted surface contains the greater 3rd harmonic components than case A. Figure 9 shows that insulator which is subjected to UV has more LC due to loss of hydrophobicity compare to non-aged insulator. Figure 10 shows the frequency spectrum of the LC for polluted surface exposed to UV radiation.

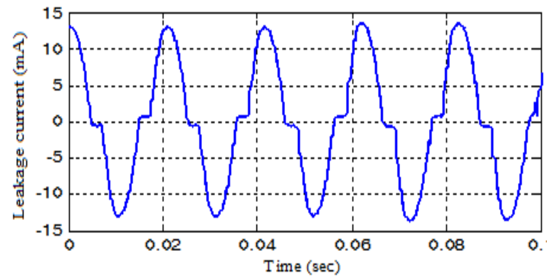

Figure 7: Leakage current of 20 kV polluted insulator contain dry band arcing

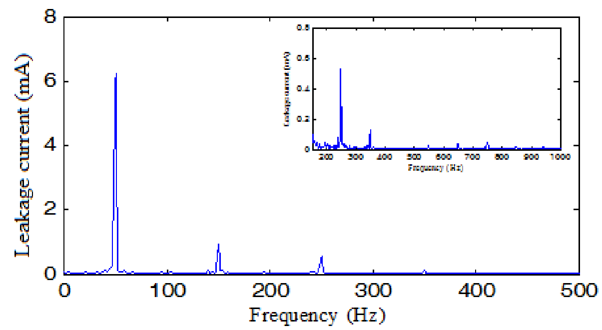

Figure 8: Frequency spectrum of Leakage current on 20 kV polluted insulator contain dry band arcing

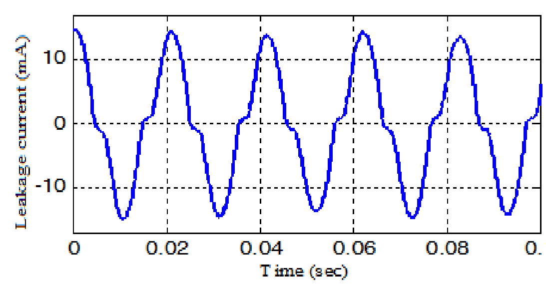

Figure 9: Leakage current of 20 kV polluted insulator under UV contain dry band arcing

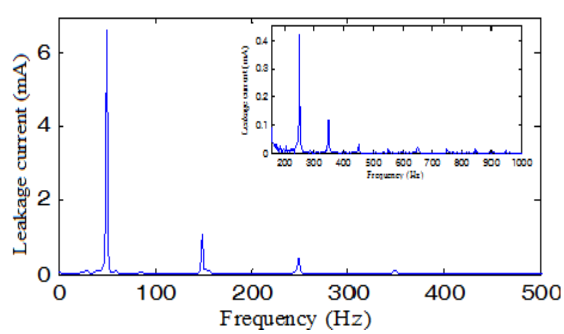

Figure 10: Frequency spectrum of Leakage current on 20 kV polluted insulator under UV contain dry band arcing

3.3 Fully formed arc with dry band arcing

Dry band discharges are observed during test which can evaluate the insulation performance, when discharge start, 3rd harmonic component increase obviously rather than foundation harmonic. Discharge activity, observed as spikes on the crest of the waveform due to formation of dry bands. The partial discharges will elongate along the surface and lead to fully arch. This condition is the previous stage of the insulator flashover. Figure (11-14) show these phenomena. It is observed that the 3rd harmonic components in unaged insulator have higher magnitude rather than aged insulator. Figure 13 shows that insulator which is subjected to UV has more LC due to loss of hydrophobicity comparing to the non-aged insulator. Figure 14 shows the frequency spectrum of the LC during polluted surface exposed to UV radiation which has higher 3rd harmonic content.

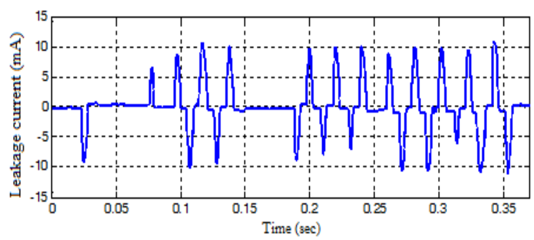

Figure 11: Leakage current of 20 kV polluted insulator contain fully formed arc with dry band arcing

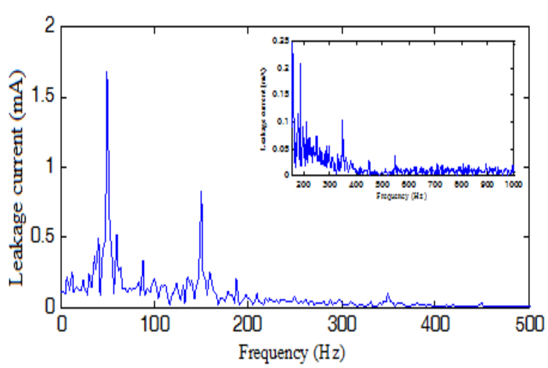

Figure 12: Frequency spectrum of Leakage current on 20 kV polluted insulator contain fully formed arcs with dry band arcing

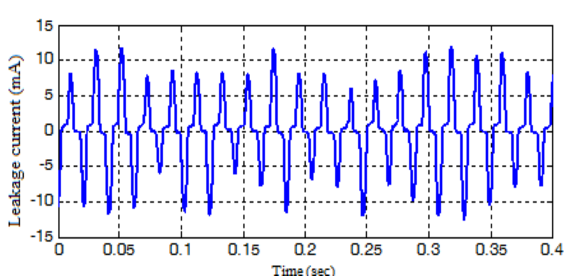

Figure 13: Frequency spectrum of Leakage current on 20 kV polluted insulator under UV contain fully formed arcs with dry band arcing

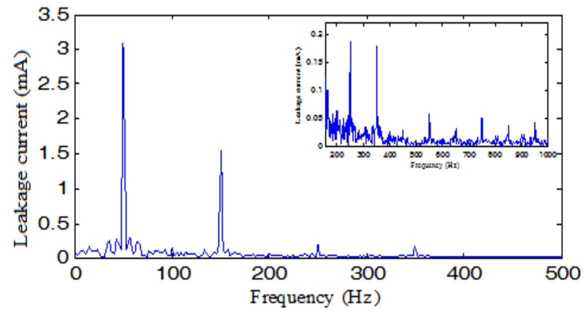

Figure 14: Frequency spectrum of Leakage current on 20 kV polluted insulator under UV contain fully formed arcs with dry band arcing

4 TGA AND SEM ANALYSIS

Thermo gravimetric analysis (TGA) is a thermal analysis technique used to determine changes in weight of a sample in relation to changes in temperature. Figure 15 shows TGA of HTV-SiR which evaluate the thermal stability of SIR before and after exposure UV. The measurement was carried out from 25 to 600^{0}C in a nitrogen atmosphere. It can be seen that for the unaged SIR, the first onset temperature in 195^0 C with a weight loss of 12%, while the second onset temperature is 310^0 C with weight loss of 41%. After 65 days of exposure, the first onset temperature in 195^0 C with a weight loss of 12%, while the second onset temperature is 308^0 C with weight loss of 33%.

From the above results it can be suggested that change of weight loss in aged SIR is higher than unaged SIR. In addition, the first derivation of TGA curves was used to see precisely at what temperature decomposition began for both aged and unaged SIR, Figure 16.The first peak, Which is not very strong, was noticed for both the aged and unaged silicone rubber around 195^{0}C. The second peak, which appears around 310^0 C and is caused by the liberation of the side chain (CH3) from the silicone backbone (Si-O-Si). Fig. (16) Shows a significant difference in terms of the steepness that corresponds to the rate of weight loss.

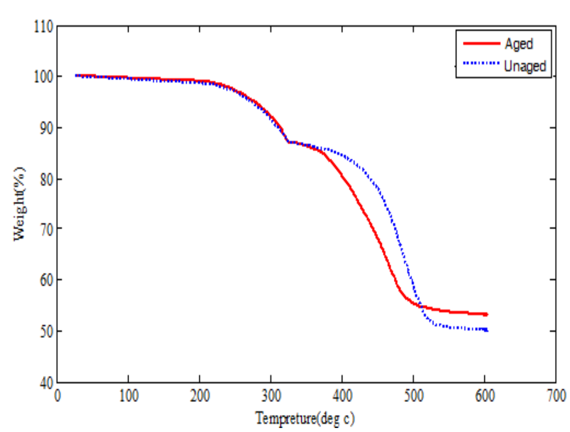

Figure 15:TGA analysis for aged and unaged polymer insulator

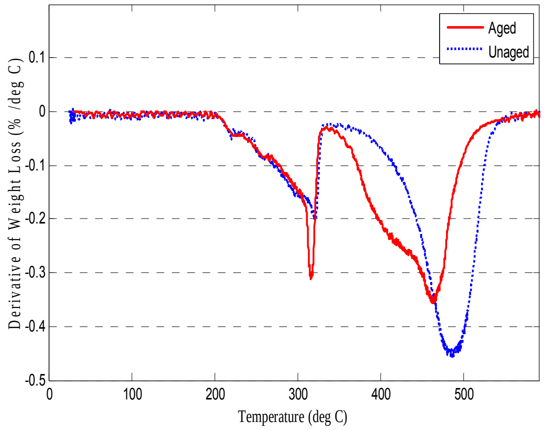

Figure 16:Derivative of Weight loss for aged and unaged polymer insulator

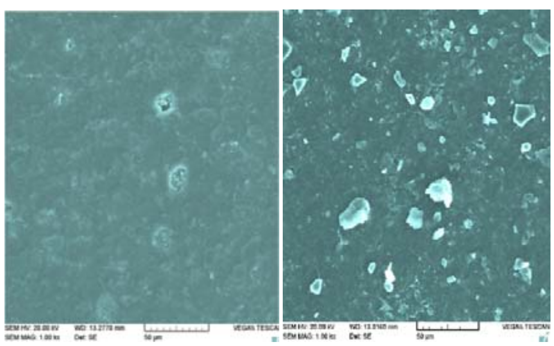

Figure 17: SEM analysis for aged and unaged SIR sample

Small samples (1 mm × 1 mm) were removed from the high voltage end of each insulator and their surface analysis was performed using Scanning Electron Microscope (SEM). The analyses were made in high vacuum mode in order to avoid sample charging. SEM photographs were captured for analyzing surface condition for SiR insulators at magnifications of 1000×. To compare the two surfaces (aged and new), the probing depth of the electron beam in materials was kept at 50µm. Fig. 17 shows SEM results of new and aged samples. The overall visual observation is that there is no major degradation, such as cracking, however, it can be seen that these micrographs have different microstructures. The unaged (new) samples have a smooth, more homogenous and less porous surface while the surface roughness and porosity increases with aging for aged SiR Insulators.

5 CONCLUSION

After an experimental test results on a 20KV SIR insulator, LC monitoring showed third harmonic components of leakage current waveform is closely related to the pollution on the insulator, and ultraviolet emissions locally destroy the hydrophobicity of the surface insulator. Under clean conditions, no flashover occurred during the rated voltage tests. Taking a look at TGA analysis results there is a shift in the figure for the aged sample and degradation starts in a lower temperature for the aged sample comparing to the unaged one. Also SEM analysis showed that the unaged sample has a smooth, more homogenous and less porous surface while the surface roughness and porosity increases with aging.

6 CONCLUSION

After an experimental test results on a 20KV SIR insulator, LC monitoring showed third harmonic components of leakage current waveform are closely related to the pollution on the insulator. Taking a look at TGA analysis results there is a shift in the figure for the aged sample and degradation starts in a lower temperature for the aged sample comparing to the unaged one. Also SEM analysis showed that the unaged sample has a smooth, more homogenous and less porous surface while the surface roughness and porosity increases with aging.

7 REFERENCES

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