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Contemplation of Pollution Severity Analysis Of Virgin And Thermal Aged Polymeric Insulators For High Voltage Applications

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ABSTRACT : *This paper deals with analysis of thermal aged polymeric insulators. The analysis is based on partial discharge technique which is an effective and most efficient method almost applied in all the High Voltage power transmission and distribution system. In this work, laboratory based tests are carried out under ac voltage, at different humidity and at different contamination levels using Sodium Chloride, on virgin polymeric insulator. The insulator was thermally aged in laboratory inside the heating chamber for sixty days. This treatment represented the conditions similar to as those in the field. The Partial discharge is acquired through a PD monitoring system which is able to collect the PD waveforms along with patterns. Time domain and frequency domain characteristics of PD pulses are studied to imply the comparative assessment between the virgin and thermal aged polymeric insulator. From various results, we could infer that the performance of outdoor polymeric insulator deteriorates with thermal aging.*

I. INTRODUCTION

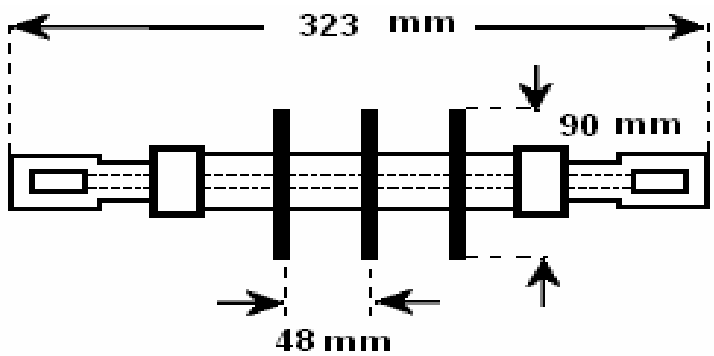
Porcelain and glass have traditionally been used as the oldest and most economic insulating materials and their advantages and drawbacks are well known. However, the polymeric insulators have replaced ceramic units due to wide range of reasons such as light weight, easy transportation and installation, high mechanical strength to weight ratio, combat to vandalism , aesthetic appearance i.e superior insulation performance [1,2]. During the last three decades the privilege to use the polymeric insulators has tremendously increased globally. When the polymeric insulators installed in tropic industrial or coastal areas, those are affected by severe weather conditions such as high temperature, large daily and seasonal variations and high humidity levels and UV radiations throughout the year. The salt and airborne particles are deposited on their surfaces and the pollution builds up gradually. Under dry conditions, these deposits do not decrease the surface insulation electric strength, where as in wet weather condition a conductive layer is formed which results in flow of leakage current. The density of leakage current is non-uniform over the surface of the insulator and when sufficient heat is developed leading to formation of dry bands. Redistribution of voltage causes along the insulator surface give rise to strong electric field intensity across the dry bands forms electric arcs known as partial discharge PD.

This dry band arc will cause erosion and chemical degradation of insulating material in polymeric insulators. When the surface resistance is low enough, these dry band arcs will grow along the insulator profile and may eventually cause insulator flash over. Preventive maintenance by insulator surface is one of the ways to reduce the flash over, but it is cumbersome and costly. Therefore, several studies have been performed to optimize the maintenance times. But it resorts to pollution charts which are widely used and are liable to abnormal seasonal and weather variations. The conventional Equivalent Salt Deposit Density (ESDD) method has been proposed, but it looks both time consuming and difficult to practice [3, 4]. In addition to contamination reducing the insulator performance, service experience of housing material which is subjected to aging can result further deterioration of the electrical performance. Determination of irreversible changes that will lead to loss of insulating properties i.e aging is a complicated process. It depends on the form of housing, design of insulator and environmental condition. Aging can lead to increased leakage current and flash over under wet and contaminated conditions. Gorur et al [5] proposed a methodology based on the surface resistance measurements to identify the surface degradation and concluded that surface resistance can be used as an indicator of aging of non ceramic insulator, but minimum value of surface resistance cannot be specified. Que et al [6] presented a methodology based on voltage – current phase angle measurements to understand surface degradation and aging of polymer. In general polymeric material offers good hydrophobicity for a long time. The long term maintenance of hydrophobicity is attributed due to its chemical stability and recovery phenomena resulting from diffusion of low molecular weight contents from bulk volume of the insulator to the surface of the material [7]. Hydrophobic polymers are characterized by high electrical surface resistance which however decreases due to water absorption during ageing and with increasing environmental temperature and contamination build up. There are numerous papers explain the change in the hydrobhobicity due to aging [,YY ,]. Kumagai et al [12],have shown that oxidation induces cross linking, branching , interchanging of silanol groups are the most dominant chemical reactions and the byproducts of oxidation restrict the diffusion of mobile low molecular weight chains, which decreases the recovery speed of hydrophobicity and accelerates ageing. There are several investigations explaining the mechanism of changes in hydrophobicity.

At present, the common technique to detect the pollution severity is by means of analysis of leakage current. It indicates the surges occurring near the current peaks of dry band arcing phenomena [13]. For a given insulator, evolution of leakage waveform depends essentially on the changes occurring at the surface pollution layer and surface wetness of the insulator. Sarathi et al, [14] have proposed the multi resolution decomposition technique as an effective tool to understand time-frequency characteristics of leakage current signals and to identify the surface condition of the insulation. The dry band arcs are a precursor of flash over; hence the partial discharge detection will provide better mechanism to effectively assess the surface condition of the conductive pollution layer of the outdoor polymeric insulator [15]. Therefore the PD phenomena on thermal aged polymeric insulator shall be used to infer the performance under tropic polluted environmental conditions.There are several field investigations with the polymeric insulators provide useful and real time information about their performance but the information about their performance in the tropical environments rather limited**.** Hence, expectation of performance and life time of material in reference to laboratory test is considerably important, requiring the comparison of Virgin and thermal aged insulators. This comparative study implies the effects of conductive pollution on PD activity through experiments performed on virgin polymeric insulator and on thermal aged polymeric insulator at different pollution levels and at different relative humidity conditions. Typical PD waveforms along with PD patterns have been collected through an innovative PD detection system. The time domain and frequency domain characteristics of PD pulses observed on virgin and thermal aged polymeric insulators are compared.

II. EXPERIMENTAL SETUP:

Testing Objects: A 11KV Polymeric insulator with leakage distance 3mm and core diameter 70mm was used for aging experiments with contamination. Figure 1.1 shows the photograph and sketch of the polymeric Insulator in this study. To reproduce the Saline pollution typical of coastal areas, a contamination layer consisting of Nacl was sprayed over the surface of the polymeric insulator such that the salinity spread uniformly over the surface. To introduce the effect of thermal aging, the specimen was maintained at 150 degree centigrade inside the electric heater for the period of 1440hours. Four Ultrasonic Nebulizer were used to maintain the required relative humidity level inside the fog chamber. Relative humidity inside the fog chamber was measured using the wall- mount Hydrothermal instrument.



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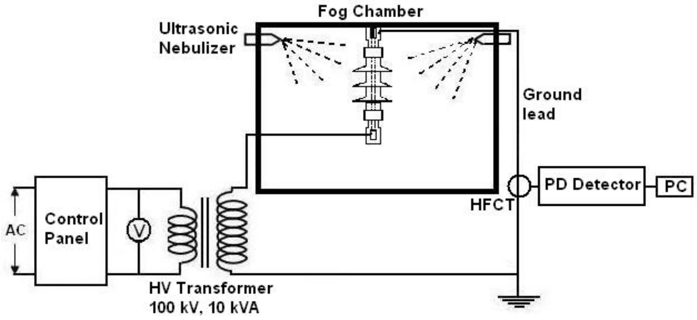


Figure 1.2 shows the circuit schematic of the experimental setup.

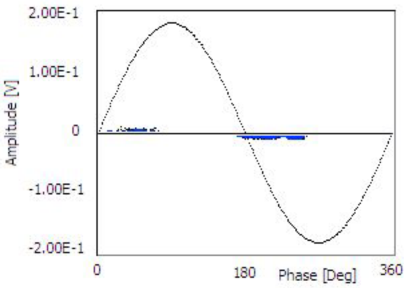
The test insulator was hung vertically inside the fog chamber. The test voltage was 11KV rms, 50Hz. Tests were conducted as per IEC 60507 clean fog test procedure. Before tests, the insulator was cleaned by wash with isopropyl alcohol and rinsing with distilled water, in order to remove any trace.

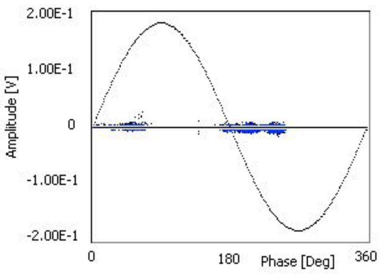
PD measuring system: Partial discharges were detected through a large bandwidth system able to sample complete PD wave forms at a sampling rate of 100 MS/s with an input sensitivity of <1mV. The characteristics of PD pulses were analyzed to find out whether some information about pollution severity could be provided by the PD waveform. No coupling capacitor was inserted in parallel to the insulator. PD pulses were picked up by the high frequency Transformer around the ground connection of the insulator.

Test Procedures:
Laboratory tests were carried out in the following test conditions.

[1] Virgin Silicone rubber insulator with clean dry and wet surface.
[2] Virgin insulator with different pollution levels, 10g/liter, 30g/liter and 100g/liter at a constant relative humidity
[3] Virgin insulator with constant pollution level at different relative humidity 60%, 80% and 100%.
[4] Procedures (ii) and (iii) repeated for thermal aged polymeric insulator.

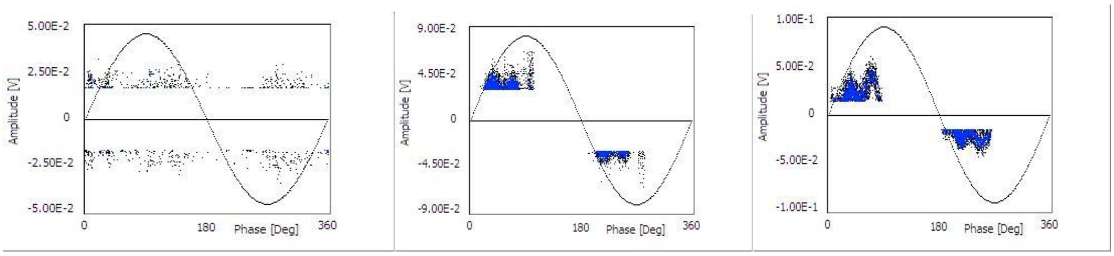
Test Results with clean surface: Initially Virgin silicone rubber insulator specimen was tested without applying and pollution with an applied voltage of 11KV rms with dry surface conditions at relative humidity level of 20-40%. Then the same Virgin insulator was tested inside the fog chamber without applying any pollution at relative humidity level of 100%. During both clean test, no significant discharge. Typical PD patterns obtained at the condition as shown in figure.





Virgin Specimen: Test with varying pollution level, constant relative humidity.

In this test, the occurrences of dry band arcing is observed by keeping the sample under different pollution level at a constant relative humidity. Initially the test specimen was kept inside the chamber at which the fog is maintained at 80% relative humidity. The contamination level is varied from 10gram per liter to 100gram per liter. Figures 4.a, 4.b and 4.c show the PD pattern.

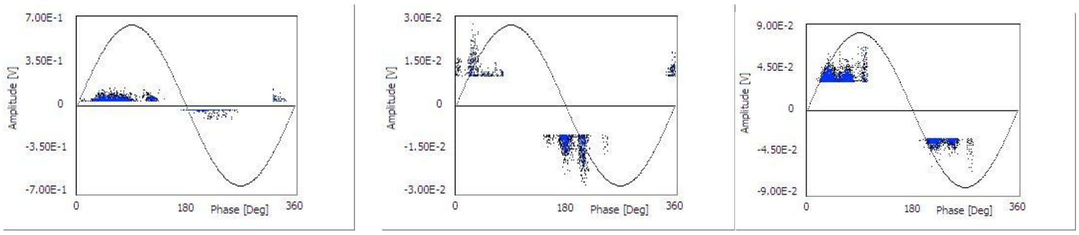


4.a) 10g/liter (80H) 4.b) 30g/liter (80) 4.c) 100g/liter (80H)

By comparing the above patterns it can be inferred that the magnitude of PD increases significantly with increasing contamination, when compared with dry clean surface. This is because of potential gradient along the surface of the conductor is high enough to form a conductive surface that establishes the arcing.

Virgin Specimen: Test with varying relative humidity, constant Pollution

Virgin polymeric insulator was treated by 30gram/liter Sodium chloride salinity and the fog inside the chamber was varied from 60% to 100%. The figures 5.a, 5.b and 5.c show the PD pattern at relative humidity.

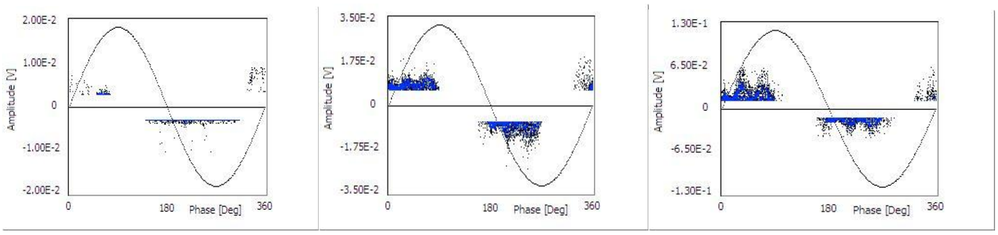


60H (30g/lit) 80H (30g/lit) 100H (30g/lit)

From the above PD patterns, it can be identified that, the magnitude of the PD increases with increasing relative humidity. This is mainly, because at high relative humidity, the collection of droplets along the surface of the polymeric insulator is more, causing high leakage current.

Thermal Aged: Test with varying pollution level, constant relative humidity.

The test specimen was kept at 150 degree centigrade for 60 days and the test procedure was repeated with constant relative humidity level of about 80% and the level of pollution salinity is varied viz 10g/lit,30g/lit and 100g/lit. Fig 6.a, 6.b, and 6.c show the typical PD patterns at various pollution levels.

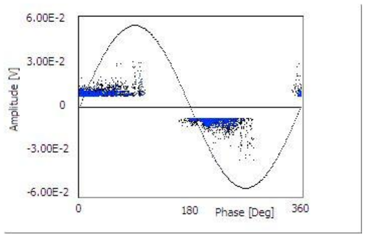


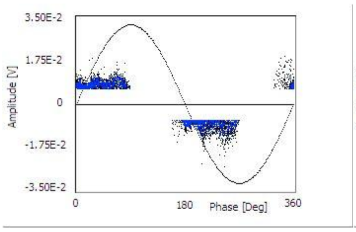
6.a) 10gram /liter (80H) 6.b) 30gram /liter(80H) 6.c)100gram /liter 80H

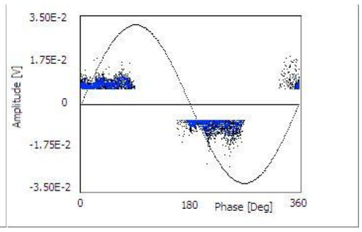
While comparing the patterns it can be inferred that the magnitude of PD increased and the density of pattern spread over the time scale. It indicates that the surface conductivity increases tends to formation of more leakage path and hence increase in more leakage current which is because of surface wetness [].

Thermal aged: Test with different humidity, constant pollution

In this test, the thermally treated specimen was spayed by Nacl pollution salinity of 30 gram per liter and the fog inside the chamber was varied from 60% to 100%. The typical PD pattern is as shown in the





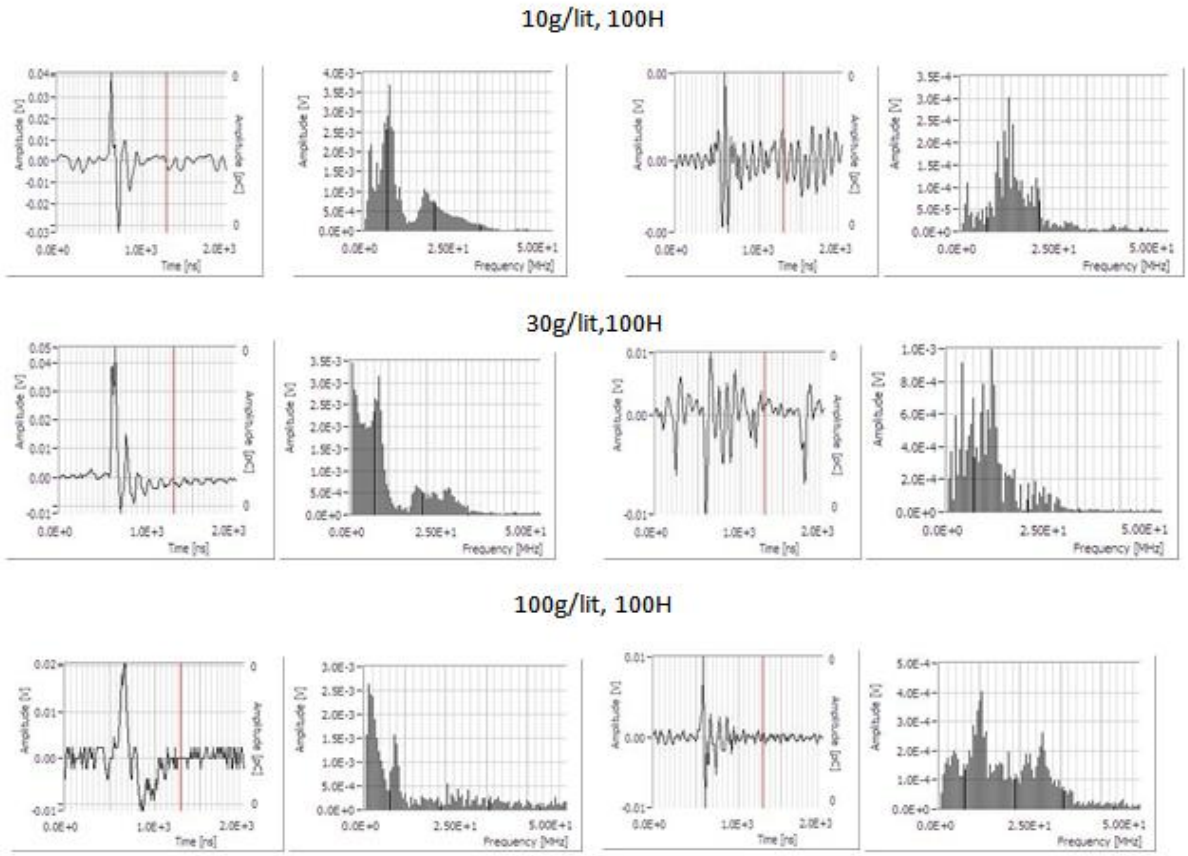


60H (30g/lit) 80H (30g/lit) 100H (30g/lit)

Sarathi et al arc burning is extinguished by the flow of contaminated bright spot occurring near the ground electrode causing high temperature rise leading to chemical change causing erosion and lose of hydrophobicity[]. Hence the specimen at virgin, the surface of the material is highly hydrophobic. After aging at 150°C for 60 days (Thermal aged) due to contaminations and high electric field of 11KV, the material slightly hydrophilic could cause slight increase in leakage current to flow. From the figures, it is observed that, as there is increase in relative humidity, there is significant increase the magnitude of PD amplitude level.

PD pulse and frequency spectrum:

Virgin Thermal Aged



Typical PD pulses and the frequency spectrum of virgin and thermal aged polymeric insulators are obtained at different surface pollution conditions are shown in the figures(?). From the pulses and spectrum, it is clear that multiple PD pulses of short duration existing in the thermal aged polymeric insulators. It is interesting to observe that PD pulses are almost series in nature at highly polluted surfaces. It is speculated that, when the polymeric insulators are erected at tropical regions of rapid temperature and seasonal variations due to heavy pollution,the rims os a dry band allowing a slight modification of electric field, a new PD can be triggered somewhere in neighboring dry band. Also when compared with virgin polymeric insulator, thermal aging spreads the frequency spectrum over a wide range and dominant frequency components are more.

From the above test results, the followings are observed

In virgin polymeric insulator

[1] PD pulses are characterized by a larger time length.
[2] Magnitude of PD pulses increases in both positive and negative cycles.
[3] Slight variations in magnitude of frequency components.
[4] At low pollution level, the dominant frequency components lying around 7.5MHz to 10.0MHz.
[5] As the pollution level increases, the frequency spectrum shifts slightly towards left of the spectrum and the dominant frequency components lies around 1-6MHz.

The thermal aging of polymeric insulator results in,

[1] Multiple PD pulses occur and are of short duration.
[2] PD pulses are having both positive and negative cycles.
[3] Significant increase in magnitude of frequency components of frequency spectrum.
[4] At low pollution level, the dominant frequency components exists around 12.5 MHz to 25MHz.
[5] As the pollution level increases, frequency spectrum spreads over wide range and significant frequency components lying around 1 MHz to 25MHz.

Statistical Analysis of PD Pattern : When polymeric insulator used as outdoor transmission tower insulators, the presence of significant noise and pulses emanating from various PD sources will make the diagnosis of pollution severity due to aging extremely difficult. Hence, an analysis of the stochastic features of PD pulse sequences with reference to both positive and negative polarity has been carried out. Cavallini et al proposed that the shape parameter and the mean phase angle of the Weibull function and some of the other parameters are used as a measure to estimate the amount of conductive pollution. Based on which Chandrasekar et al indicated that the shape parameter (β) of Weibull function takes a value smaller than 3 and mean phase angle value goes above 45 degrees for heavily polluted surface condition[x,y].

Result and Discussion on Virgin Polymeric Insulator:

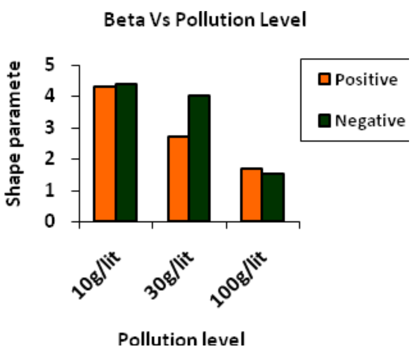


Fig a

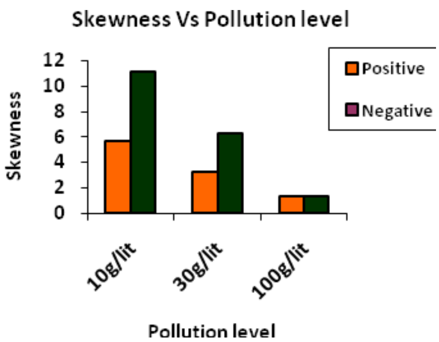
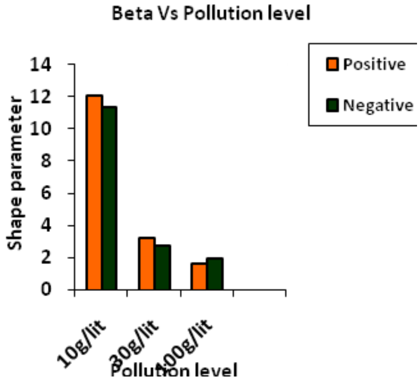


Fig b

Figure a reports the mean phase value of shape parameter with 95% confidence level at different pollution level. The relative humidity was maintained at 100% to have more probability of Partial Discharge. It is observed that, reduction in both positive and negative value of β is noticed, as the pollution level increases and its value is smaller than 3 for highly polluted surface. Also it is noticed that even though the value of β is less than 3, there is not sudden variation in it as the pollution level grows. Figure b shows the mean value of PD amplitude skewness together with 95% confidence intervals. It is noticed that, the value of skewness reduces but the actual rangeof variation is too low.

Result and Discussion on Thermal aged Polymeric Insulator:



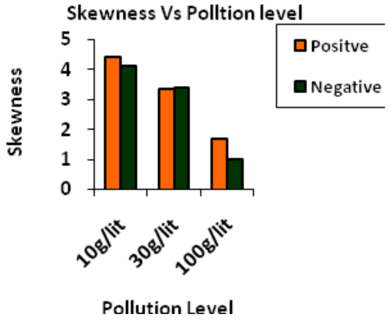


Fig a **Fig b**

Similar to Virgin polymeric insulator, figure a reports mean value of shape parameter together with 95% confidence interval after thermal aged for 60 days at 150°C at different surface pollution. In order to have more probability of partial discharge, the relative humidity of testing insulator is maintained at 100%. Similar ti virgin polymeric insulator , it is observed that, as the pollution level grows, there is considerable reduction in both positive and negative values of β. It is clear that, for heavily polluted surface the β value is smaller than 3. Figure b reports the mean value of PD amplitude skewness with 95% confidence intervals, at different pollution levels. From the figure it is observed that value of skewness considerably reduces. But the range of vcariation of skewness is too low. Hence it is very difficult to identify the surface pollution severity due to aging by skewness.Comparing the shape and the mean value of PD pattern amplitude of virgin and thermal aged polymeric insulator we could infer that, there is drastic change in the value of β in thermal aged polymeric insulator. And also both show less PD activity and good pollution performance even there is large seasonal variation. From the PD pulse and frequency spectrum, it is understood that there will be a slight variations in surface leakage current due to aging and slight degradation in hydrophobic surface. This degradation is temporary and not a permanent change. Therefore, the future work is being carried out by keeping the test specimen under highly concentrated UV radiations with very high temperature and measurements based on optically.

III. CONCLUSION:

Comparison of Virgin and thermal aged polymeric insulators based on monitoring of occurrences of PD pattern and PD pulses through the experimental set up have been presented in this paper. The tests are performed at different relative humidity and pollution levels as per IEC60507 test procedure. It is shown that variations in time and frequency domain characteristics of PD pulses are closely related to the surface condition of the polymeric insulator. These preliminary lab results on thermal aged polymeric insulator **shows** that, when these insulators are used in tropical regions, they are exposed to large thermal and ambient stresses variations for the entire life span will accelerate surface degradation.

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