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Interpretation of surface degradation on polymeric insulators

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ABSTRACT

Silicone rubber based polymeric insulators are being used widely used as outdoor insulation for high voltage applications. However, their long-term service life performance is highly dependent on local environmental conditions that cause deterioration of material properties of the insulators. In the present work, tracking and erosion studies are conducted on silicone rubber samples using. Inclined Plane Tracking (IPT) and Erosion method based on IEC 60587. The contaminants used to simulate different environmental conditions are as per standard and in addition acidic rain composition is used. Leakage current flowing through samples was continuously monitored and recorded over the experimental duration. The consequence of leakage current variation is analyzed using. Recurrent Plot (RP) Analysis and this resulted in variation of quantitative parameters Recurrence Rate (RR), Determinism (DET), Entropy (ENT) and Length (L) these are used to interpret the tracking and erosion performance of silicone rubber samples. Further, physico-chemical analysis is conducted using Scanning Electron Microscopy (SEM), Energy Dispersive X-Ray (EDAX) and Fourier Transform Infra-Red (FTIR) spectroscopy to observe surface morphology and chemical changes happened in the samples. Thermo-Gravimetric Analysis (TGA) is performed to observe thermal stability and presence of Aluminum Tri-hydrate (ATH) fillers before and after experiments. The investigations show RP method as a potential tool for detection and diagnostic of polymeric insulators.

1. Introduction

Overhead power transmission lines are of key importance for transmitting the bulk electrical power. The power transmission from generating station to load end is carried out by overhead conductor (bare conductor or cables) and supported by electrical insulator. Conventionally, porcelain or glass insulators are used in overhead transmission lines, recently, polymeric insulators are employed in our country. These insulators provide advantageous properties over conventionally used glass or porcelain insulator [1,2]. One of the important properties is the hydrophobicity that provides the better pollution performance. Polymeric insulators consist of three main components which are silicone rubber as housing material, central core of Fiber Reinforced Plastic (FRP) and metal end fittings. The silicone rubber-based polymer material has main compound Polydimethylsiloxane (PDMS), Si-O-Si as main chain and two methyl group attached to Si as side chain. Further, the fillers are added to PDMS to enhance its material properties, Aluminum Trihydrate (ATH) is used as filler which is used as flame retardant and higher thermal stability.

Polymeric insulators are quite sensitive to the local environmental conditions such as moisture, fog, mist etc., and their performance highly depends on these factors. Further, despite being used in service life for a decade, long term performance data of these insulators is not available and proper estimation is still a challenge. However, the short-term pollution performance of these insulators is shown to be relatively better as compared to conventional insulators.

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To understand the loss of material properties with aging, evaluation of tracking and erosion resistance is one of the important parameters. Albright et al. [3] extensively worked on the evaluation of tracking and erosion of different insulating material with higher degree of reproducibility. Later, the service life condition was correlated to laboratory test with controlled parameter [4]. Several methods are proposed for tracking performance evaluation for different insulating materials, the Inclined Plane Test (IPT) method was standardized: IEC 60587 [5] and ASTM D2303 [6]. According to CIGRE working group D1.14 the tracking and erosion is one of the important parameters that must be evaluated based on the available standards. However, standard IPT method deals with AC voltages with specific flow rate of contaminant accordingly. For DC voltages many researchers [7–9] have contributed to evaluate material degradation and tracking and erosion resistance of polymeric material. It is reported that under positive DC application, least tracking resistance is observed followed by negative DC. The severity of material degradation depends on type of voltage and its polarity; however, the effects of environmental stresses also play a role [10]. The biological degradation alters the hydrophobic characteristic in polymeric insulators and results in material degradation [11,12]. But quantification of such degradation is still a challenge and it is important to detect, monitor the health of insulation system and the changes in insulation material that results in decrease in its service life. In the present investigation Recurrence Plot (RP) analysis is adopted for the investigations.

RP analysis is one of the methods that provide the dynamics of a highly random signal such as chaotic dynamics present in measured signals in physics [13], in eco system time-based time series and in financial time-based nonlinear data [14]. This approach is based on chaos theory and extensively used in medical signal processing to understand the physiological systems. RP analysis was proposed first by Maizel and Lenk [15] in 1981 as a tool to visualize patterns in specific sequences of genetic nucleotides. This tool provides very intuitive outcome showing visual changes in healthy and unhealthy persons such as heart disease, muscle fatigue, Electromyography (EMG), and several other medical signal processing [16–20]. One of the important applications is reported by Yang [21] who reported the ability to detect and prevent heart attack by studying the Vector cardiogram (VCG) signals using RP approach. Liu et al., used RP based approach and investigated the leakage current for hydrophobicity evaluation [22–24]. They reported that decrement in quantification parameter; recurrence rate and determinism reveal the decrement in hydrophobicity. Chaou et al. [25] utilized this RP based approach and proposed the method to detect the severity of contamination level on high voltage insulators. These behavioral changes in leakage current signal are analyzed as a detection technique using RP analysis. Reddy et al. [26] applied RP based methodology to analyze the surface erosion of silicone rubber insulator samples.

In the present work, effort is made to study the effect of degradation from the leakage current waveforms. The measured leakage current is analyzed based on recurrence plot (RP) analysis that provides the visual recurrence patterns to understand and interpret the behavioral changes in leakage current with the level of degradation.

The experimental setup is fabricated for the present work, the test specimen is prepared as per standards. Physicochemical analyses are conducted on the degraded samples. Scanning Electron Microscope (SEM) is used to observe the surface morphological changes, EDAX to find the elemental presence over the surface of test specimen, FTIR to examine the breakage and formation of various chemical bonds. Interestingly, the visual pattern provides the clear discrimination between fresh and degraded sample. Different quantitative analyzers such as Recurrence Rate (RR), Determinism (DET), Average length (L) and Entropy (ENT) are obtained from recurrence matrices showing interesting patterns. In the present work, the authors propose the RP method using experimental leakage current data from inclined plane method for detection and diagnosis of material degradation for polymeric insulating samples.

2. Experimental arrangement

The experimental arrangement is indigenously developed for the present studies.

2.1. Experimental set-up

The inclined plane tracking and erosion facility is fabricated as per IEC 60587 [7]. The block diagram of IPT setup for AC voltage application is shown in Fig. 1. The high voltage source is rated for 5 kV/1A, the applied AC voltage is 4.5 kV, a series resistance of 22

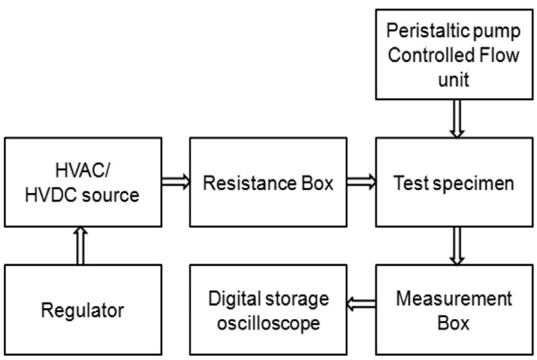

Fig. 1. Block diagram of experimental setup used for IPT studies.