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Analysis of leakage current during water droplet discharge on silicone rubber adopting rc technique

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Corona activity can cause reduction in hydrophobicity of silicone rubber insulating material. Leakage current (LC) measured during water droplet discharge was analyzed through Recurrence Plot (RP) analysis. The RP obtained for the leakage current formed due to water droplet discharges under AC and DC voltages are different. Recurrent Quantification Analysis (RQA) is used to quantify the results of RP plots to classify the discharges formed under AC and DC voltages. Multi Resolution Signal Decomposition (MRSD) technique is adopted to understand the frequency contents present in the leakage current at different instants.

Keywords : *Corona, leakage current, recurrenceplot,recurrence quantification, Multiresolution signal decomposition.*

1.0 INTRODUCTION

In recent times, power transmission is being carried out at higher voltages because of itshigh transmission efficiency and high power transfer capability [1]. In recent times, polymeric insulators (especially the silicone rubber material) are used in transmission and distribution systems because of their reliability, better performance and hydrophobicity [2-3]. During rain and winter the condensation of a water droplet on the surface of insulating material is one of the common phenomena which can lead to corona inception and leakage current to flow through it, leading to flashover and complete outage of the power system [4].

To predict the level of damage due to electrical discharges on the surface of the insulating material, analysis of leakage Current (LC) in time and frequency domain is more popular. Li et al [5] used mean value, maximum value and standard deviation to analyse the properties of leakage current. Suda has analysed the leakage currents formed and classified the characteristics of discharges by using wavelet technique [6]. Pylarinos *et al* [7] compared classification performance of LC for temporal and frequency feature and concluded frequency components provide better feature. Sarathi *et al* [8] used MRSD technique to diagnose the characteristic variation in hydrophobicity variation in silicone rubber during tracking studies A.K. Chaou *et al* [9] stated that interpretation of LC temporal do not offer an overview about insulators performance and these features have to use as an input Artificial Neural network techniques for diagnosing the performance of insulators.

B.X. DU *et al* [10] used the recurrence plot analysis with the current measured during DC tracking and concluded that state of discharges. Subba Reddy *et al* [11] used the RC and RQA analysis for assessing the discharge characteristics during tracking test.

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In the present study,leakage current analysis was carried out by using wavelet technique and by use of recurrent plot studies, to understand characteristics of injected current formed due to water droplet sitting on the top of insulating material under AC and DCvoltages.

2.0 EXPERIMENTAL ARRANGEMENT

The typical experimental setup used for the study is shown in Figure 1. The high AC voltages were generated by a 100 kV, 5kVA discharge-free test transformer. DC voltage was obtained by use of voltage doubler circuit. The voltage was increased at a rate of 300 V/s up to the required test voltage. The applied AC voltage was measured using a capacitance divider and the DC voltage through resistance divider.

Experimental setup used for the present study is shown in Figure 2.The electrode gap consists of two angular stainless steel electrode tips cut at 45˚ (as per IEC 60112 [12]) placed on 6 mm thick flat silicone rubber material. The electrodes are separated by a gap distance of 10 mm. One electrode is connected to the high voltage source through a resistance of 10 MΩ and the other electrode connected through a resistance to ground to measure the amplitude and shape of injected current.

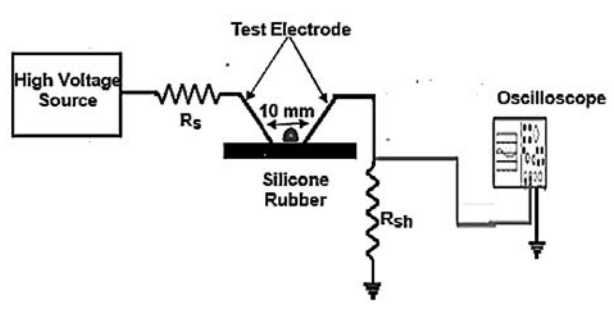


FIG 1. EXPERIMENTAL SET-UP

FIG. 2. TEST ELECTRODE ARRANGEMENT

3.0 INTRODUCTION TO WAVELETS AND MRSD

Wavelet is the flexible and versatile tool for the analysis of transients, non-stationary signals.The fundamental aspect of wavelets for analysis of tracking current was detailed by Sarathi et al [13]. Wavelet analysis involves the breaking up of a signal into shifted and scaled version of a single prototype function called mother wavelet [8].

MRSD performs two important functions .The first one is localisation property time to identify any characteristic change and second one is breaking signal in different frequency bands The standard deviation (STD) can be considered as a measure of the energy present in the signal with zero mean [14-15]. The schematic representation of MRSD implemented in present study is shown in Figure 3. Daub 4 wavelet is used as mother wavelet

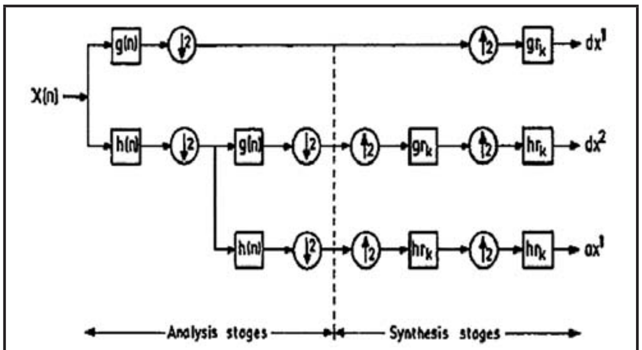


FIG. 3. SCHEMATIC REPRESENTATION OF IMPLEMENTATION OF MRSD.

TABLE 1

FREQUENCY BANDS CORRESPONDING TO MRSD ANALYSIS

Detailed component of DWT	Frequency Band (Hz)
D1	1250-2500
D2	625-1250
D3	312.5-625
D4	156.25-312.5
D5	78.125-156.25

4.0 RECURRENCE PLOT ANALYSIS

Recurrence plot is a visual tool to analyse the recurrence behaviour of the phase space trajectory of the dynamical systems. Maizel and Lenk [16] used the RP as a means of visualising the pattern in sequences of genetic nucleotides.

The following important parameters were studied to quantify the RP [9].

1. Recurrencerate (RR) is the percentage of recurrence points in an RP

$$RR(\varepsilon) = \frac{1}{N^2}\sum_{i,j=1}^{N} R_{i,j}(\varepsilon)$$

2. Determinism (DET) is the percentage of recurrence points which forms diagonal lines

$$DET = \frac{\sum_{l=l_{min}}^{N} lP(l)}{\sum_{l=1}^{N} lP(l)}$$

3. Average diagonal line length (L) is the average length of diagonal lines

$$L = \frac{\sum_{l=l_{min}}^{N} lP(l)}{\sum_{l=l_{min}}^{N} P(l)}$$

4. Longest Diagonal line L_{max} is the length of longest diagonal line

$L_{max} = \max\{l_i;\ i=1\ldots N_l\}$

5. Laminarity (LAM) the percentage of recurrence points which forms vertical lines

$$LAM = \frac{\sum_{v=v_{min}}^{N} vP(v)}{\sum_{l=1}^{N} vP(v)}$$

P (v) is the histogram of the length *v* of the vertical lines.

6 . Trapping Time (TT) is the average length of the vertical lines

$$TT = \frac{\sum_{v=v_{min}}^{N} vP(v)}{\sum_{v=v_{min}}^{N} P(v)}$$

7. Longest vertical line (V_{max})is the length of longest vertical line

$$V_{max} = \max\left(\{v_l\}_{l=1}^{N_v}\right)$$

8. Entropy (ENTR) is the Shannon entropy of the probability distribution of the diagonal line length *p (l)*

$$ENT = -\sum_{l=l_{min}}^{N} p(l)\ln p(l)$$

5.0 RESULTS AND DISCUSSIONS

5.1 Leakage current and Recurrence Plot Analysis

Figure 4 shows the typical (i) water droplet injected discharge current formed under AC and DC voltages and (ii) its corresponding RP. The RP obtained for the leakage current during water droplet initiated discharges are different under AC and DC voltages. It is observed that the magnitude of leakage current under negative DC voltage compared to positive DC and AC voltages.In RP, recurring white patches indicates intense arcing and high amplitude transients in the leakage current and dark patches shows less magnitude of discharges.

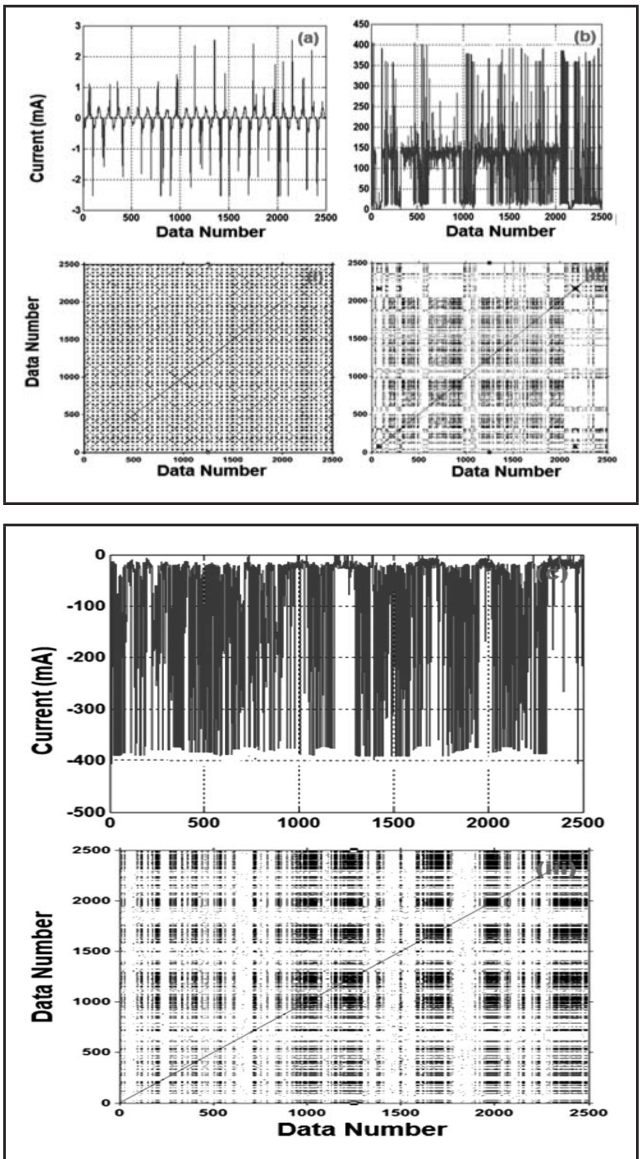


FIG. 4: LEAKAGE CURRENTS WAVESHAPES 4(A-C) UNDER AC, +DC AND –DC FIELDS AND THEIR CORRESPONDING RP 4(I-III)

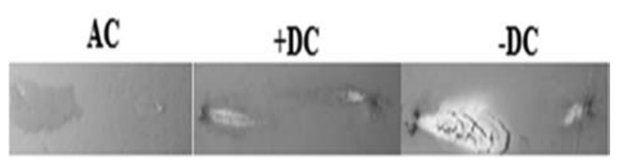
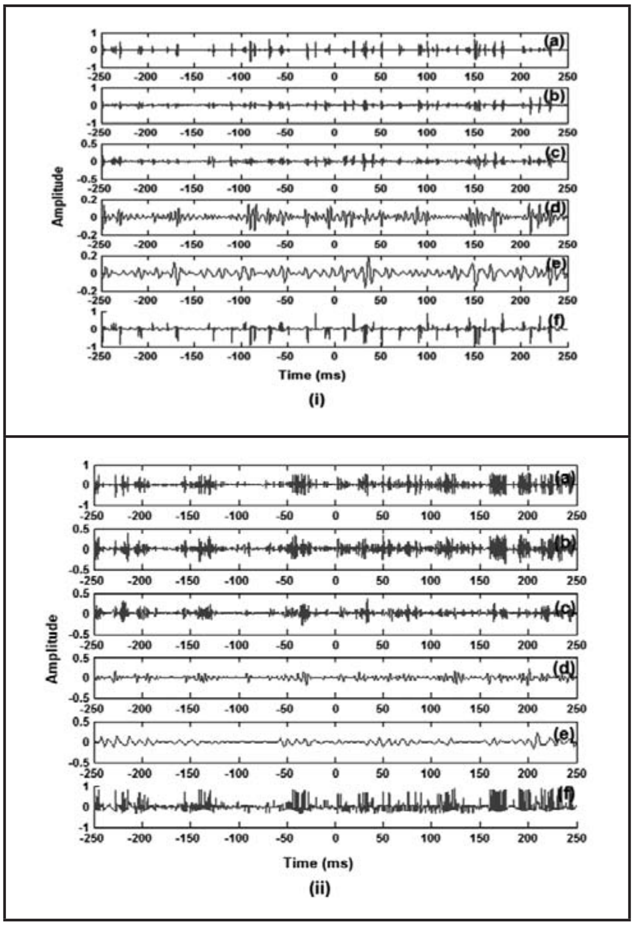


FIG. 5: SURFACE DAMAGE UNDER AC AND DC FIELD.

Figure 5 shows typical photograph of eroded surface due to water droplet. It is observed that amount of damage is high under negative DC voltage compared with positive and negative DC voltages. Also it is observed that the discharges are highly random under AC voltages than the DC voltages and hence the corresponding RP plot is almost uniform. On the other hand, under DC voltages, it is observed that discharges are continuous and it is reflected clearly in RP plots as this thick white patches. Also number of white patches is highest under negative DC polarity indicating severity of negative polarity.

5.2 Std_mra and Recurrence Quantification Analysis

FFT analysis can provide the frequency content in the signal measured but the instance of occurrence of the discharge can easily be recognised by the use of wavelets.It is observed that adding five level of decomposition, the error in the measurement is minimum. This characteristic is the same under AC/DC voltages.



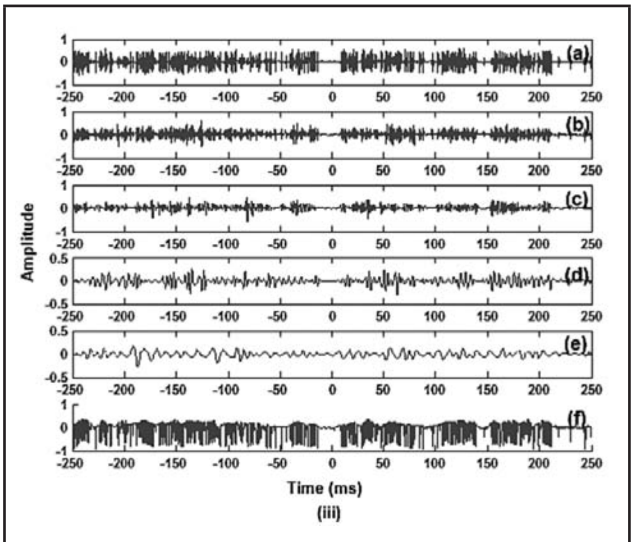


FIG 6. MRSD FOR (I-III) AC, +DC AND DC FIELDS AND THEIR CORRESPONDING (A-E) FIVE LEVELS DETAILED COEFFICIENTS (F) RECONSTRUCTED SIGNAL.

Figure 6 shows five level decomposition of the leakage currents under AC and DC voltages. Figure 7 shows STD_MRA plot for the leakage current obtained during arcing under AC and DC fields. It is observed that high frequency content is high in leakage current measured under negative DC voltage as compared with the positive DC and AC voltage. Also it is observed that for AC fields the value of standard deviation is least and for negative DC field it is highest for all levels of decomposition.

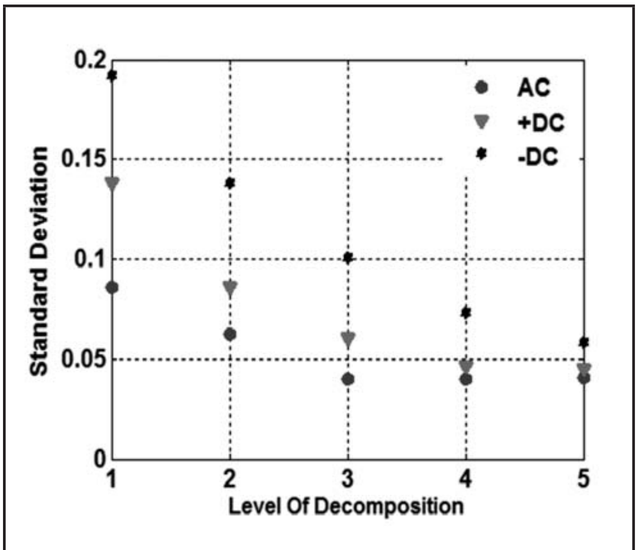


FIG. 7. STD_MRA CURVE UNDER AC AND DC FIELDS

Further for the quantification of results of RP Plot RQA analysis was carried out. Figure 8 shows the variation in the six RQA parameter for different level of decompositions of the leakage current. AK Chaou et al concluded that for better performance of the insulator higher values of all the RQA parameters is desirable [9] Similar results were obtained for water droplet initiated discharges.

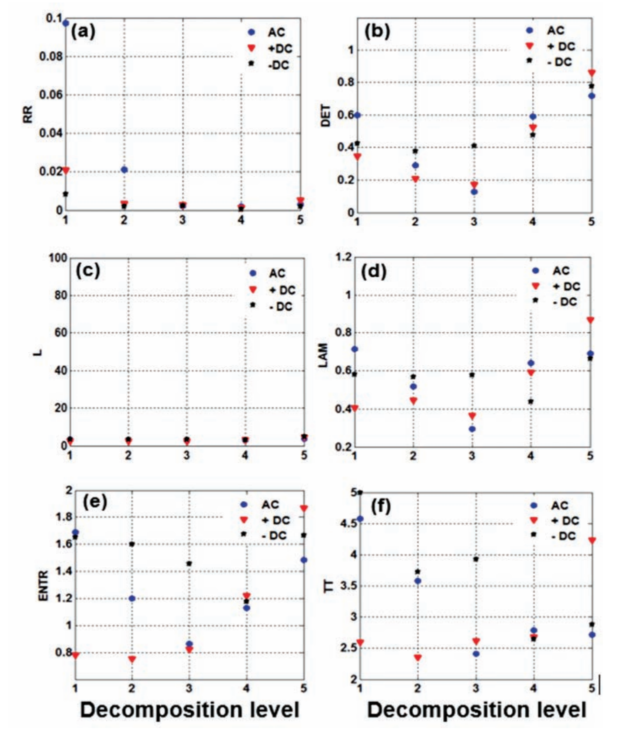


FIG. 8. RQA PARAMETER VARIATION (A) RECURRENCE RATE (RR) (B) DETERMINISM (DET) (C) DIAGONAL LENGTH (L) (D) LAMINARITY (LAM) I ENTROPY (ENTR) (F) TRANSITION TIME (TT).

As Gorur *et.al* [17] stated that surface discharge is high frequency phenomenon and on analysing the Figure 8 this phenomenon is clearly visible .It is observed that for the 1st and 5th level of decomposition the value of each parameter is higher than 2nd, 3rd and 4th level of decomposition. From this nature following conclusions with respect to each parameters are drawn for the 1st and 5th level of decomposition-

1. High RR and DET values indicate that high frequency components are recurring periodically.
2. High L and LAM values show that they are highly preedictable in nature
3. High ENTR and TT value shows their less exited state and stable nature.

6.0 CONCLUSIONS

Based on the above studies following conclusions are drawn-

Leakage current is an important performance parameter to evaluate the condition of insulating material prone to varying AC and DC fields.

Wavelet is a better tool than FFT to simultaneously monitor the time, magnitude and frequency content present in the leakage current.

RP provide a rapid overview over the insulator state and shift in LC dynamic during discharge process qualitatively. No pre-processing of data through artificial neural network is required for plotting recurrence plots. But RP plot does not quantify the results hence RQA analysis is used which quantifies the results making use of RQA parameters.

RP plots show that discharge characteristics under AC and DC fields are different and the damage caused to the insulating material is highest under negative DC fields.

STD_MRA analysis shows that high frequency components characterise the LC more than Low frequency components under arcing condition and the power content of LC is highest under negative DC field and least under AC field.

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