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Roles of Fog Conductivity and Humidity on Leakage Current of Ceramic Insulators

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Abstract: Since long time ago, ceramic insulators are widely being used in power systems. During operation, the insulators may severe a certain degree of pollution, which may reduce their performances such as surface resistance and flash over voltages. The pollution may arise in the form of fogs. A large Leakage Current (LC) may flow on the surface and degradation may take place. In long term the degradation may lead to the flash over of the insulators. This study reports the experimental results on the effects of humidity and fog conductivity on leakage current characteristics of ceramics. The samples used are blocks of ceramics with dimension of 250×50×20 mm^3. The samples were made from same materials for outdoor ceramic insulators. The samples were put in a test chamber with controlled humidity and artificial pollution conditions. AC voltage with frequency of 50 Hz was applied. The tests were conducted according to IEC 60-1 and IEC 507 (fog test). The magnitudes as well as harmonic content of the LC were analyzed. The experimental results indicated that under fog condition, LC magnitude increase with fog conductivity. At high fog conductivity the oscillation behaviour of LC magnitude dependence on applied voltage was observed due to the wetting effect of sample surface by the fog and drying effect caused by the higher LC. The THD of leakage current under salt fog increased with the applied voltage. LC amplitude increases with applied voltage and RH. LC waveforms distortion significantly decreased with the salt fog conductivity resulting in smaller THD. At given applied voltage the harmonic components decrease with the increase of fog conductivity.

Key words: Ceramic insulator, salt fog, humidity, leakage current, waveform, harmonics

INTRODUCTION

Consumption of electric energy steadily increased in the world. In order to deliver the huge amount of the electric energy efficiently, high voltage transmission systems are required. Insulators is one of the most important parts in modern electric power system. There are glass, ceramic and polymeric outdoor insulator widely used in an electric power system. They isolate among live parts and between live part and ground and as mechanical protector. The insulators are widely used at substations, transmission as well as distribution networks (Sharma, 2001). Among them ceramic insulators are the most intensively used worldwide since long time ago. This type of insulators show good mechanical and electrical properties and less expensive. During operation some pollution such as coastal pollution may attach to the ceramic insulators. The pollution may significantly reduce their properties such as reduction of the surface resistance particularly during high humidity climate. The reduction of surface resistance may enhance the leakage current to flow on the surface and bolster the aging of the insulator surface and promote flashover (Siderakis *et al*., 2004; Suda, 2005; El-Hag *et al*., 2003; Fujii *et al*., 2005). Investigation on the leakage current on the ceramic insulators under polluted condition and the role of humidity is important. The characteristics are useful for the diagnosis of the insulators (Kim *et al*., 2001; Suwarno, 2006a, b). This study reports the experimental results on the investigation on the effects of humidity and fog conductivity on leakage current characteristics of ceramic insulators.

MATERIALS AND METHODS

Experimental setup: Ceramic block samples with dimension of 250×50×20 mm^3 were used in the experiment. The picture of the sample is shown in Fig. 1.

The two ends of the sample were covered by silver paste to make good contact with the electrodes. The sample was put in a test chamber made from aluminium panel with dimension of 900×900×1200 mm^3. The front opening of the thest chamber was made from acrylic facilitate the observation of arcing on the sample surface.

The sample was subjected to salt fogs with various level of conductivity and humidity. AC high voltage of

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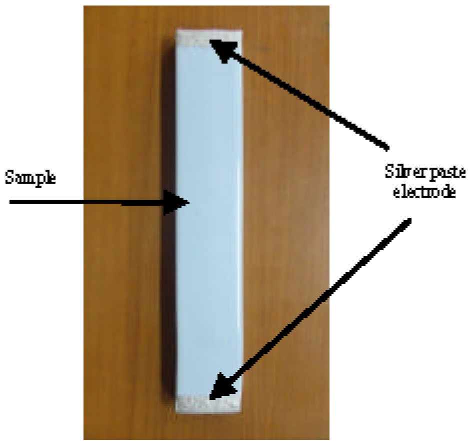

Fig. 1: Ceramic block sample

50 Hz was applied to the sample laid in the test chamber. The tests were conducted according to IEC Pub. 60-1 (1995) and IEC Pub. 507 (1991) (fog test). The leakage current flowed on the sample surface was measured by measuring the voltage across a resistance put in series with the sample using a Digital Oscilloscope TDS 220. The voltage waveforms recorded by oscilloscope reflected the LC waveforms. The oscilloscope has bandwidth of 100 MHz and the maximum sampling rate of 1 GS sec^{-1}. The digital data was transferred to a personal computer trough a GPIB for further analysis. Harmonic content of LC was analyzed using FFT (Fast Fourier Transform).

The degree of distortion of the leakage current waveform from its sinusoidal form of the applied voltage is indicated by Total Harmonic Distortion (THD) which is defined as:

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1} \quad (1)$$

Where:

I_1 = Fundamental component of LC (1st harmonic)

I_n = The nth harmonic component of LC. High THD indicates a large LC distortion

RESULTS AND DISCUSSION

Effects of humidity and fog conductivity on LC magnitude and THD

Leakage current under salt fog of low RH: Figure 2 shows the dependence of LC magnitude on the applied voltage at various salt fog conductivity with low RH.

The Fig. 3 indicates that in general LC magnitude increase with fog conductivity. At fog conductivity of 0.6, 1.2 and 2.4 mS cm^{-1} the LC magnitude increases almost linearly with applied voltage. The approximate surface resistance is 26 MΩ for fog conductivity of 0.6 mS cm^{-1}, 20 MΩ for fog conductivity of 1.2 mS cm^{-1} and 18 MΩ for fog conductivity of 2.4 mS cm^{-1}. At fog conductivity of 3.6 mS cm^{-1} the LC magnitude is much higher than the rest of fog conductivity. The surface resistance drastically reduced to about 7 MΩ.

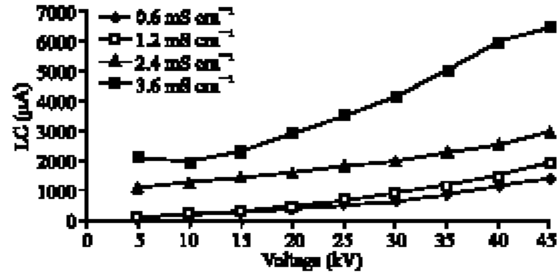

Fig. 2: Dependence of LC magnitude on applied voltage and fog conductivity at low RH

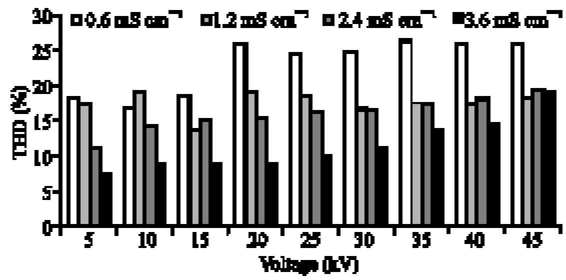

Fig. 3: Dependence of the THD of LC on applied voltage and fog conductivity at low RH

Figure 3 shows, the dependence of the THD of LC on applied voltage and fog conductivity at low RH. The figure clearly shows that THD significantly reduced with the increase of fog conductivity particularly at applied voltage of <30 kV. At higher applied voltage THD of LC waveforms tends to increase more rapidly for fog with higher conductivity. This is due to the appearance of intensive discharges, which strongly distorts the LC waveforms at high fog conductivity and increases their THD.

Leakage current under salt fog of high RH: Figure 4 shows, the dependences of LC magnitude on applied voltage for clean insulators under salt fog with conductivity of 0.6, 1.2, 2.4 and 3.6 mS cm^{-1} and at high relative humidity of 95%.

From the Fig. 4, it is seen that salt fog conductivity greatly affected the magnitude of the LC. Compared to the LC magnitude under clean fog, the LC magnitude under salt fog was much higher than those from clean fog. At fog conductivity of 0.6 mS cm^{-1}, the LC magnitude increased almost linearly with the applied voltage.

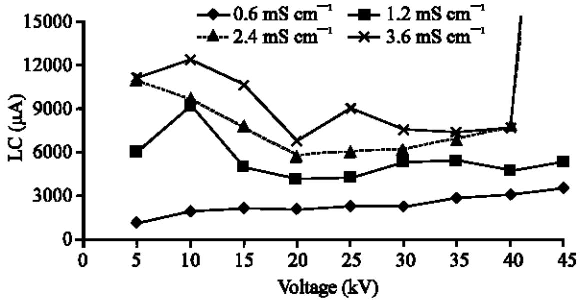

Fig. 4: Dependency of LC magnitude on applied voltage and fog conductivity

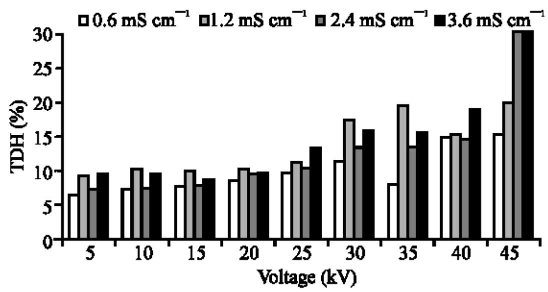

Fig. 5: THD as function of applied voltage and conductivity

However, at fog conductivities of 1.2, 2.4 and 3.6 mS cm^{-1} the oscillation behaviour of LC magnitude dependence on applied voltage was observed. This phenomenon was due to the wetting effect of sample surface by the fog and drying effect caused by the higher LC flew on the surface of sample in fog with high conductivity.

Flash over of the samples were observed at fog conductivities of 2.4 and 3.6 mS cm^{-1}. The flashovers were observed at applied voltage of about 40 kV. At this applied voltage no flashover was observed under clean fog experiment.

Figure 5 shows, the Total Harmonic Distortion (THD) as function of applied voltage at different fog conductivity. The Fig. 5 indicates that in general the THD of leakage current under salt fog increased with the applied voltage. This means that the increase rate of harmonic components of the leakage current were larger than those of fundamental components.

Effects of humidity and fog conductivity on LC waveforms: Figure 6 shows typical LC waveforms of clean sample under salt fog of 1.2 mS cm^{-1} at various humidity. The Fig. 6a-c contain harmonics that distort the waveforms. The similar results were reported by Suda (2005) The Fig. 6 clearly indicates that LC amplitude increases with applied voltage and RH. At low RH positive discharges started to grow at applied voltage of about 20 kV. The positive discharges became large at higher applied voltages. The appearance of positive discharges can be explain in term of the initial electrons, which initiated the discharge process. At low RH the initial electrons were ejected from the fog side. At medium RH the positive discharges started to appear at applied voltage of about 25 kV. At high RH larger distortion of LC waveforms were observed at negative half cycles. This means that the discharges were initiated from sample side. The discharges contribute to the harmonic especially the 3rd component. The amplitude of the LC increases with the applied voltage. However, the THD reduces with the increase of RH since the increase of harmonic components are smaller than fundamental as shown in Fig. 7.

Figure 8 shows, the typical LC waveforms under salt fog with conductivity of 0.6, 1.2 and 3.6 mS cm^{-1}, respectively. It is clearly seen that the LC amplitude increased significantly from 800 μA at conductivity of 0.6 mS cm^{-1} to 1100 μA at conductivity of 1.2 mA and >5000 μA at conductivity of 3.6 mS cm^{-1}. This was caused by the increase of sample surface conductivity due to salt fog conductivity.

The Fig. 8 also indicates that the waveforms distortion significantly decreased with the salt fog conductivity resulting in smaller THD. The THD reduced from 24.3% at 0.6 mS cm^{-1} to 18.3% at 1.2 mS cm^{-1} and further reduced to 9.9% at salt fog conductivity of 3.6 mS cm^{-1}.

Figure 8a and b show that there are distortion of LC waveforms at positive half cycle. The electric discharges ceased under salt fog conductivity of 3.6 mS cm^{-1} as showed at Fig. 8c. This is due to the increase of surface conductivity and reduction of electric field which is necessary to produce initial electron for initiating the electric discharges on the insulator surface.

Figure 9 shows, the dependence of harmonic components of LC on salt fog conductivity and applied voltage. In general, at applied voltage in the range of 15-25 kV the harmonic components increase with applied voltage at all fog conductivity. At given applied voltage the harmonic components decrease with the increase of fog conductivity.

The fundamental component increases significantly. At applied voltage of 15 kV, the fundamental increases from 375 μA at fog conductivity of 0.6 mS cm^{-1} to 450 μA at fog conductivity of 2.4 mS cm^{-1} and to 3200 μA at fog conductivity of 3.6 mS cm^{-1}. At applied voltage of 25 kV, the fundamental component increases from 700 μA under 0.6 mS cm^{-1} to 900 μA under 1.2 mS cm^{-1} and to 4900 mA under fog conductivity of 3.6 mS cm^{-1}.

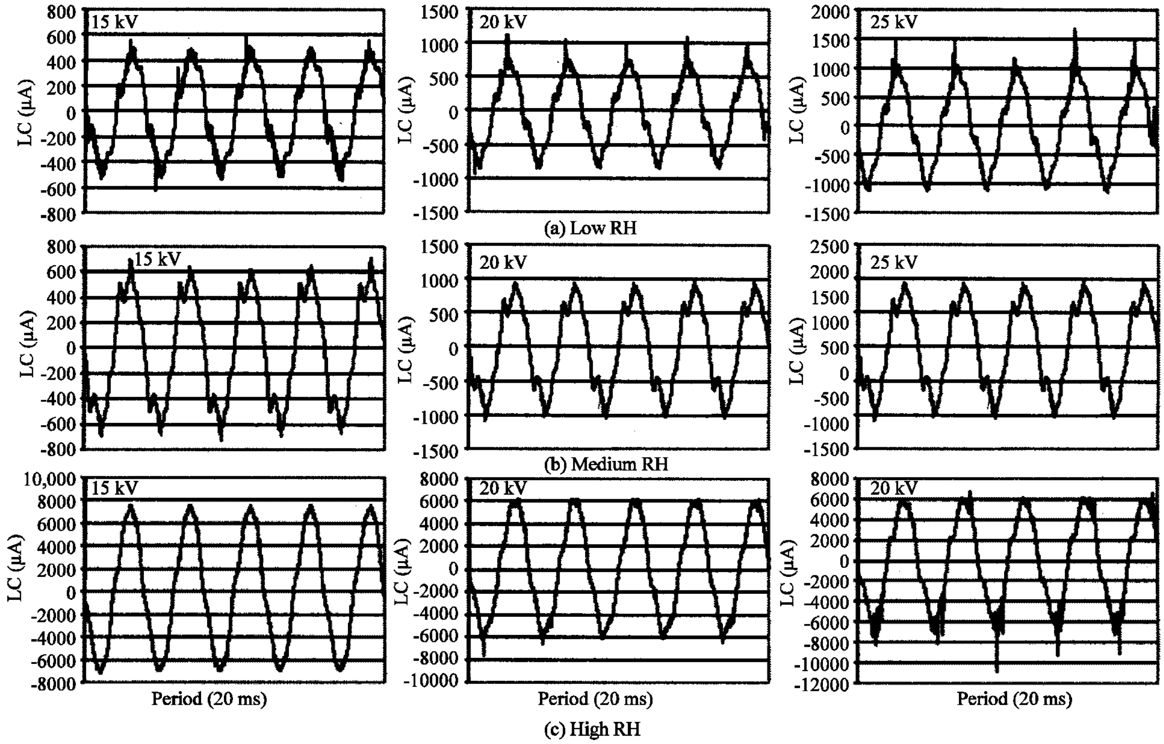

Fig. 6: LC waveforms of lean sample under salt fog of 1.2 mS cm^{-1} at various humidity at applied voltage of 15, 20 and 25 kV

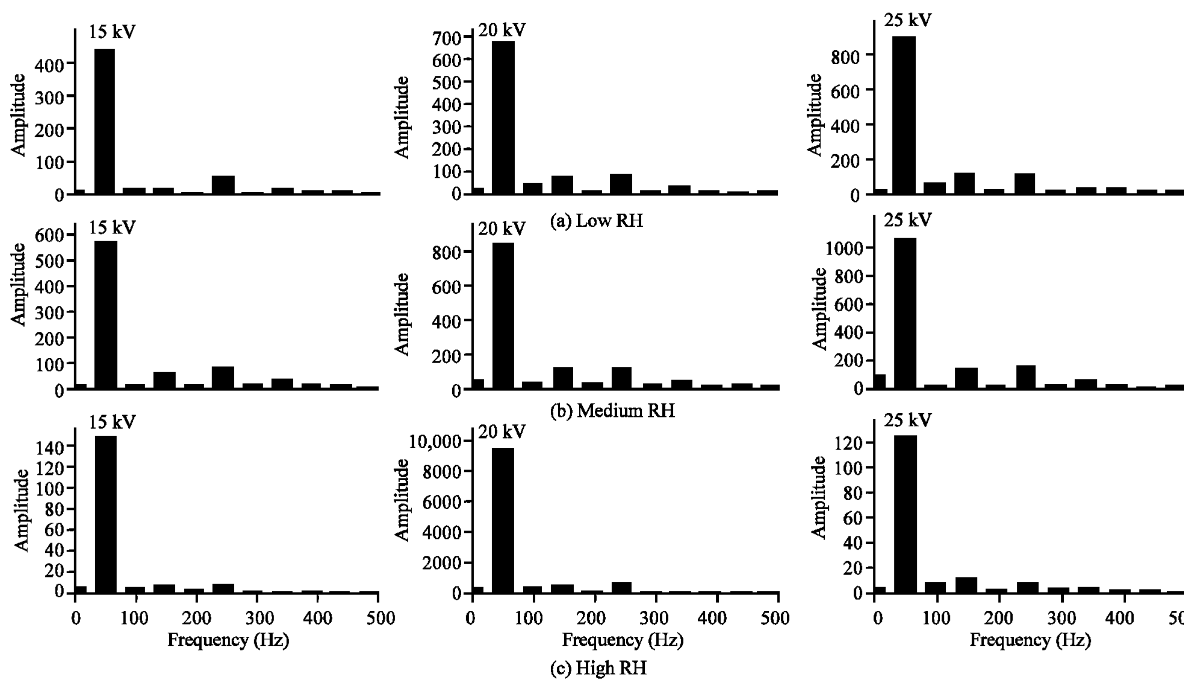

Fig. 7: Harmonic components of LC under fog of 1.2 mS cm^{-1} at low, medium and high RH at applied voltage of 15, 20 and 25 kV

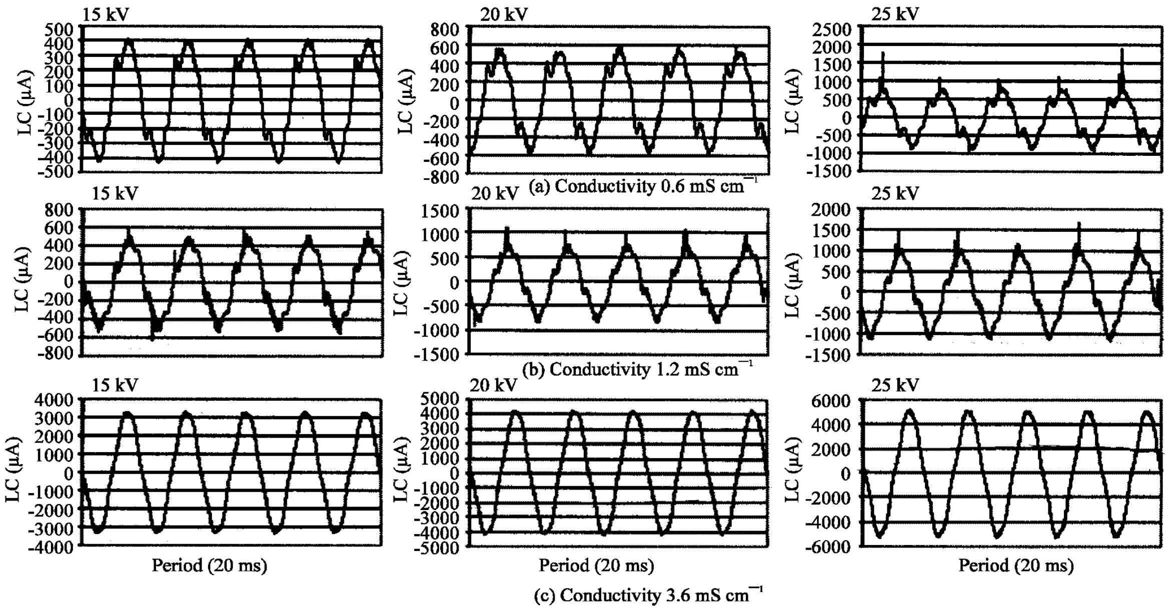

Fig. 8: LC waveforms under salt fog with various conductivity at low RH under fog with conductivity of 0.6, 1.2 and 2.4 mS cm^{-1} at applied voltage of 15, 20 and 25 kV

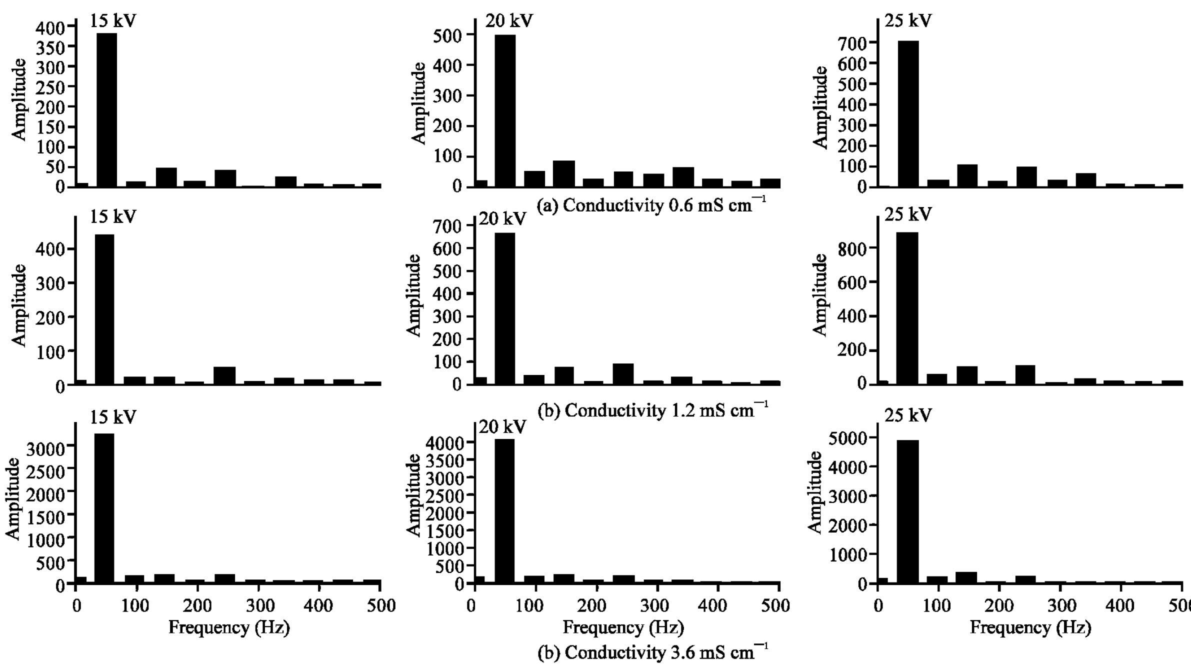

Fig. 9: Harmonic components of LC under fog of 1.2 mS cm^{-1} at low, medium and high RH at applied voltage of 15, 20 and 25 kV

Figure 9 shows that the dominant harmonic components are 3rd and 5th except fog fog conductivity of 0.6 mS cm^{-1}, the LC waveforms contain the 7th harmonic component with considerable large amplitude.

CONCLUSION

Leakage current and its waveform of ceramic insulator have been investigated under clean and salt fog conditions. The effects of humidity and fog conductivity on the LC magnitude and its waveform was elaborated. The experimental results indicated that under clean fog, LC magnitude almost linearly increased with applied voltage at low and medium RH. At high RH, LC magnitude drastically increased compared to those of low RH. At low RH the waveform distortion was observed at positive half cycles at applied voltage of higher than 20 kV. The LC waveform distortion drastically reduced at high RH and LC waveforms almost sinusoidal. The results also clearly indicated that at given applied voltage THD of LC decreased with RH.

At low RH the dominant harmonics number are 5th, 3rd and 7th with relatively large amplitude while at medium and high RH the dominant harmonic components of the LC waveforms are 5th and 3rd with smaller amplitude compared to it fundamentals resulting in smaller THD.

Under fog condition, LC magnitude increase with fog conductivity. Compared to the LC magnitude under clean fog, the LC magnitude under salt fog was much higher than those from clean fog. At fog conductivity of 0.6 mS cm^{-1}, the LC magnitude increased almost linearly with the applied voltage, while at high fog conductivity the oscillation behaviour of LC magnitude dependence on applied voltage was observed due to the wetting effect of sample surface by the fog and drying effect caused by the higher LC. The THD of leakage current under salt fog increased with the applied voltage.

LC amplitude increases with applied voltage and RH. At low RH positive discharges started to grow at applied voltage of about 20 kV. The appearance of positive discharges can be explain in term of the initial electrons, which initiated the discharge process. At medium RH the positive discharges started to appear at applied voltage of about 25 kV. At high RH larger distortion of LC waveforms were observed at negative half cycles. The discharges contribute to the harmonic especially the 3rd component. THD reduces with the increase of RH since the increase of harmonic components are smaller than fundamental.

LC waveforms distortion significantly decreased with the salt fog conductivity resulting in smaller THD. In general, at applied voltage in the range of 15-25 kV the harmonic components increase with applied voltage at all fog conductivity. At given applied voltage the harmonic components decrease with the increase of fog conductivity.

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