Study on Leakage Current Characteristics of Epoxy Resin for Outdoor Insulators

SUWARNO and SIGIT K. ARDIANTO
School of Electrical Engineering and Informatics
Bandung Institute of Technology
Jl. Ganesha 10 Bandung 40132
INDONESIA

Abstract: - Polymeric insulating materials are now widely used in high voltage electrical apparatuses. Several of them are being used for outdoor insulators. For outdoor application, the insulation may severe a certain degree of pollution which may reduce their surface resistance and flash over voltages. Under these conditions 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. In this paper experimental results on the leakage current characteristics of epoxy resin insulation under various environmental conditions are reported. The samples used are blocks of epoxy resin with dimension of 250 x 50 x 20 mm^3. The samples were put in a test chamber with controlled humidity and pollution conditions. AC voltage with frequency of 50 Hz was applied. The LC waveforms up to flash over were measured. The magnitudes as well as harmonic content of the LC were analyzed. The correlation between LC waveforms and dry band arching phenomenon was elaborated. Visual observation of the arc on the sample surfaces was observed using a video camera. The hydrophobicity of the materials at different conditions was investigated by measuring the contact angle.

Key-Words: - epoxy resin, leakage current, harmonic, dry band, surface resistance

1 Introduction

In a power system, insulator plays an important role to 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 [1,2].

Recently, polymeric insulating materials are introduced to substitute conventionally used insulators like porcelains and glasses. There are several advantages of polymeric insulators compared to that porcelain or glasses such as lightweight, good water repellance and resistance to pollution.

Cycloalipathic epoxy resin is one of polymeric materials used for high voltage insulators. The characteristics of the epoxy resin such as leakage current, hydrophobicity and flash over voltage under various environmental conditions are important to be investigated. This paper reports the experimental results on the leakge current characteristics of epoxy resin for ourdoor insulator application.

2 Experiment

The samples used in this experimet were formed from diglycidil ether of bisphenol-A (DGEBA) and metaphenylene-diamine (MPDA) at 27^0 C and 1 atm in the form of blocks with dimension of 250 x 50 x 20 mm^3.

The samples were subjected to tests according to IEC 60-1 (1989) , IEC 507 (fog chamber test) and IEC 587 (inclined plane test) as shown in fig. 1.

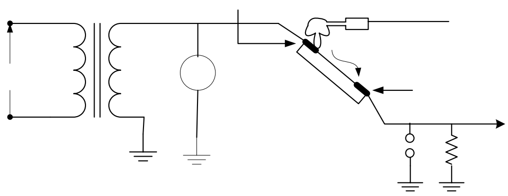


Fig. 1 Inclined plane test arrangement

Leakage Current measurement.

An AC high voltage of 50 Hz was applied to the insulators. The applied voltage was adjusted to get various conditions such as normal condition, small or high activity of dry band arcing. The leakage current flowed on the insulator surface was measured by measuring the voltage across a series resistance using a Digital Oscilloscope with digitizer of 8 bit, bandwidth of 100 MHz, and the maximum sampling rate of 1 GS/s. LC waveforms including low and high frequency components were obtained. 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).

Arc masurement

In order to observe the arc on the samples, an inclined plane method was used. The samples were put inclined in a chamber. The pollution and humidity were adjusted and the AC voltage was applied. Arcing took place on the sample surface was observed using a camera, and the corresponding leakage current was measured using LC measurement system as described before.

Surface ressitance measurement

In order to know the surface resistance of the samples, the resiatance was measured using mega ohm meter at operating voltage of 1000 V. The two end of the samples were coated with silver paint to form electrodes.

3 Experimental Results

Leakage Current Characteristics of Clean Sample

Fig. 2 shows typical dependences of leakage current on applied voltage under low, medium and high humidity.

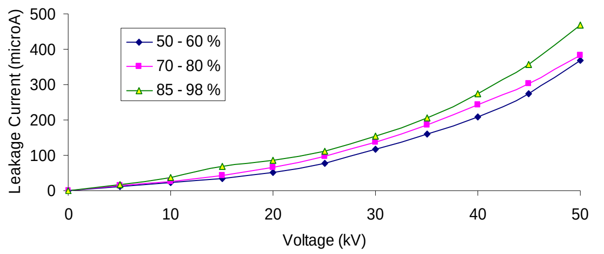


Fig. 2 Dependences of leakage current on applied voltage under low, medium and high humidity

From fig. 2 it can be seen that for clean samples the LC magnitude was slightly affected by the humidity.

Leakage Current Characteristics of Kaolin-salt polluted sample

Fig.3 shows typical leakage current magnitude of kaolin-salt polluted insulators as a function of applied voltage under RH of 50-60 %. The figure shows that the discrepancies of LC magnitudes of different pollution levels at low RH is larger at higher applied voltage. This indicates that the effect of kaolin-salt pollution becomes stronger at higher voltage.

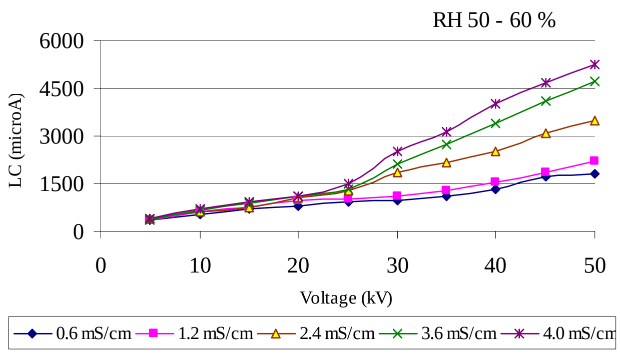


Fig. 3 Dependence of LC magnitude on applied voltage at low RH under various levels of kaolin-salt pollutions

Fig. 4 shows shows typical leakage current magnitude of kaolin-salt polluted insulators as a function of applied voltage under RH of 70-80 %. Difer from that of fig. 3, fig. 4 indicates that strong effect of kaolin-salt pollution on the LC magnitude at this level of RH is strong starting from a lower applied voltage. Under high humidity, the water molecules were absorbed by pollutant leading to the increase of surface conductivity and LC magnitude[3,4].

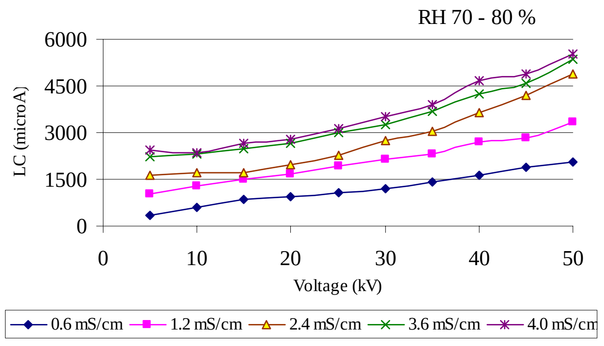
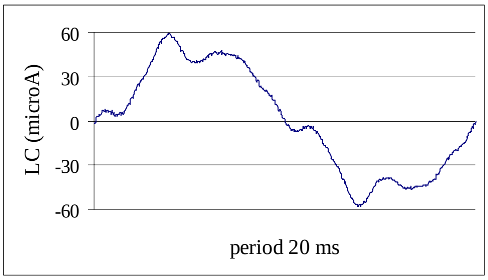
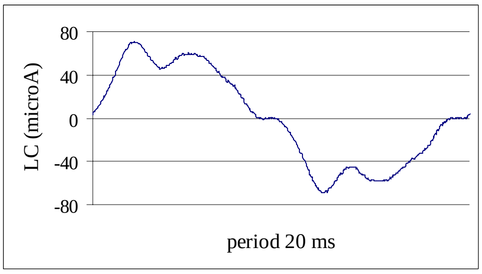


Fig. 4 Dependence of LC magnitude on applied voltage at medium RH under various levels of kaolin-salt pollutions.

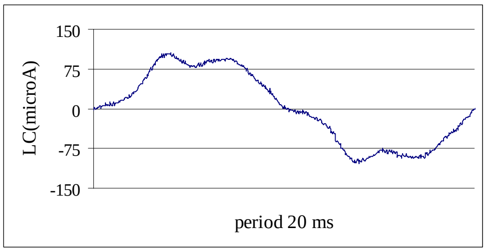
Leakage current waveforms



(a)



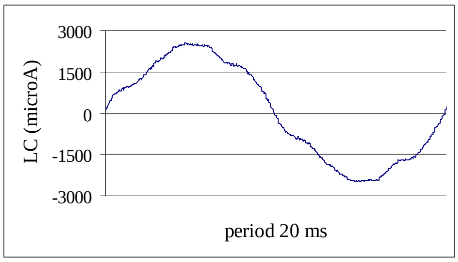
(b)



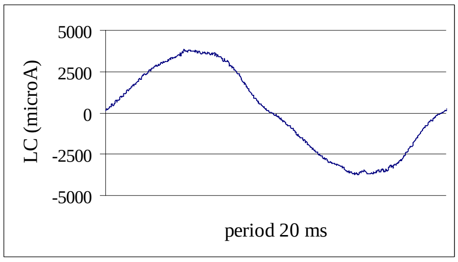
(c)

Fig. 5 Typical leakage current waveforms for clean insulators under 15 kV applied voltage at low RH (a), medium RH (b) and high RH (c)

Fig. 5 shows the typical LC waveforms and harmonic components for clean samples at 15 kV under low (a) medium (b) and high humidity. It is seen that increasing the humidity, slightly increased the LC magnitude from less that 60 mA at low humidity to slightly higher than 70 mA at medium RH and to larger than 100 mA at high RH. However, increasing the humidity, slightly reduced the THD of the LC waveform from 19.6 % at low RH to 18.2 % at medium RH and to 17.5 % at high RH.



(a)



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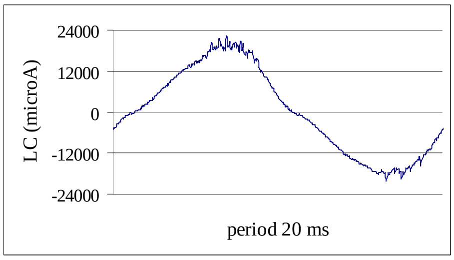
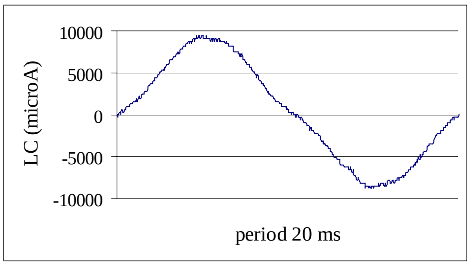


(c)

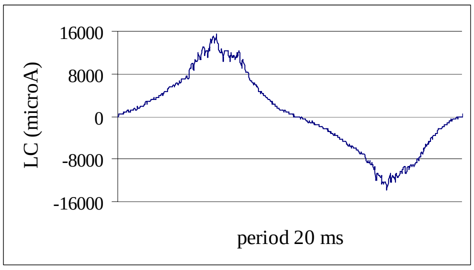
Fig. 6 Typical leakage current waveforms for kaolin-salt polluted insulators at 3.6 mS/cm under 15 kV applied voltage at low RH (a), medium RH (b) and high RH (c)

Figure 6 shows typical LC waveforms of kaolin-salt polluted insulators at 3.6 mS/cm at 15 kV applied voltage. From the figure it is seen that for kaolin-salt polluted insulators, a larger LC magnitude was observed at higher RH. Increasing RH also increased the THD of the LC waveforms. The increase of THD at high RH was observed due to the appearance of spark on the surface of the samples. Harmonic components especially 3rd and 5th were observed with a significant magnitude.

Leakage Current Waveforms



(a)



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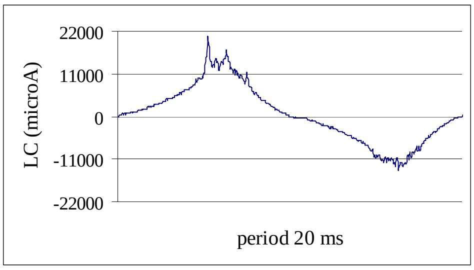
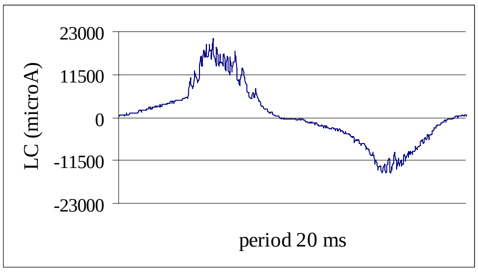


(c)



(d)

Fig. 7. LC waveforms of highly polluted insulator at 3.6 mS/cm under RH of 90 % at applied voltage of (a) 15 kV (b) 20 kV (c) 25 kV and (d) 30 kV

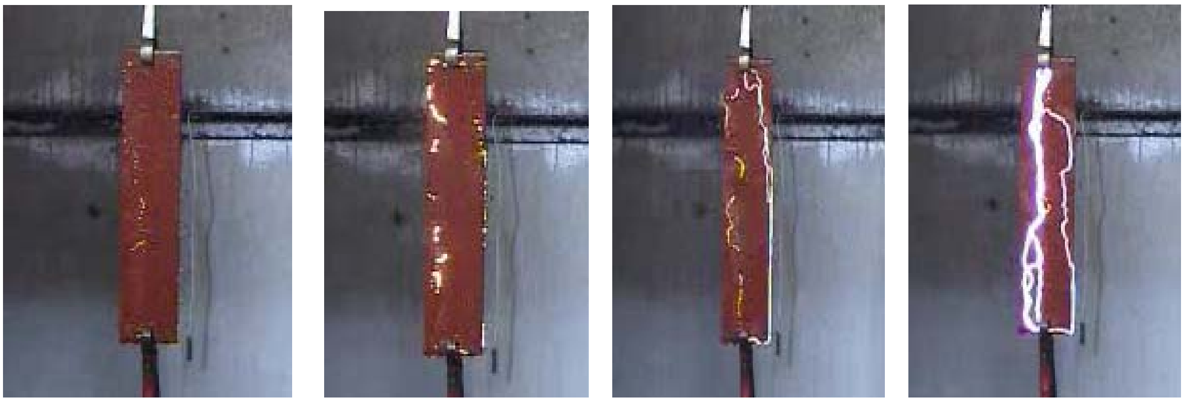
Figure 7 shows typical leakage current waveforms of epoxy resin samples with kaolin-salt pollution of 3.6 mS/cm at RH of 90 % under various applied voltages. At this condition the LC magnitude as well as harmonic content increased with the applied voltage. Strongly distorted LC waveforms were observed at high applied voltage when spark took place. Pre-flash over Lc waveforms may be useful for indicating the insulator conditions. Positive half cycle of the LC waveforms is more distorted than that of negative one. This indicated a higher activity of discharge in this half cycle. Similar phenomenon was reported for silicone rubber[5] and EPDM[6].

Figure 8 shows pothographs of samples with kaolin-salt pollution of 3.6 mS/cm at RH of 90 %. At 25 kV applied voltage dry band arching was observed and distorted LC waveform with peak magnitude of around 20 mA was recorded. Typical THD at this stage was 42 %. Increasing voltage to 28 kV made the arc more clearly observed. From harmonics analysis it was found that high 3rd and 5th harmonic components were observed. This in good agreement with reported by El Haq[7] At applied voltage of 31 kV, a fine arc bridged the electrodes. A LC waveform with magnitude about 35 mA and THD of 48 % was recorded with a higher degree of unbalance between positive and negative half cycles of the leakage current waveforms. Finally, a complete flash over on the sample was observed under applied voltage of 42 kV.

Surface Resistance

Surface resistance plays an important role in the leakage current magnitude as well as dry band arcing and flash over. The surface resistance greatly affected by the surface condition such as pollution level, the degradation and the environmental humidity. In order to know the change of surface resistance, a measurement was done under various relative humidity (RH) and pollution levels from 0.6 mS/cm to 4.0 mS/cm. The results are shown in table 1.

From table 1 it is seen that in general the surface resistance decreased with the increase of relative humidity and pollution levels. Under dry condition and 0.6 mS/cm the resistance was 63.61 MW but this resistance drop drastically to 2.47 MW under high humidity at pollution level of 4.0 mS/cm. These results indicated that pollution greatly affected the resistance at high himidity and therefore enhance the leakage curreny to flow on the surface of the insulator.



(a) **(b)** **(c)** **(d)**

Fig. 8 Dry band arcing and flash over at applied voltage of (a) 25 kV (b) 28 kV (c)31kV and (d) 42 kV

Table 1

Surface resistance of sample at different pollution and humidity

RH (%)	Surface Resistance (MΩ)				
	0.6 mS/cm	1.2 mS/cm	2.4 mS/cm	3.6 mS/cm	4.0 mS/cm
50-60	63,61	43,82	22,8	22,74	20,47
70-80	21,85	9,62	8,5	7,6	7,51
85-95	16,55	7,27	2,6	2,56	2,47

4 Conclusion

From these experimental results following conclusions can be drawn:

1. Clean epoxy resin insulator has contact angle of slightly less than 90^o and humidity only slightly affects the leakage current magnitude and harmonics.
2. Under pollution and high humidity the resistance of epoxy resin decreased significantly and greatly affects the leakage current magnitude and harmonics.
3. Pre-flash over of epoxy resin samples strongly correlated with the increase of leakage current magnitude and total harmonic content in the leakage current waveforms.
4. It is suggested that epoxy resin insulators may perform well at clean condition but the performance drop significantly under polluted condition.

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