Leakage Current Waveforms of Outdoor Polymeric Insulators and Possibility of Application for Diagnostics of Insulator Conditions

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Abstract - This paper reports the investigation results on the leakage currents (LC) on polymeric outdoor insulators. The samples used were EPDM (ethylene prophylene diene monomer) insulators used at 20 kV distribution lines. AC voltage was applied and the LC waveforms were measured under various environmental conditions (humidity and pollution). Digital data of the LC was transferred from a digital storage oscilloscope to a computer for further analysis. The LC waveform parameters such as magnitude and harmonic content (as indicated by the total harmonic distortion (THD)) were analyzed. The experimental results showed that 3rd, 5th and 7th harmonics and higher odd harmonics were observed for symmetrical-distorted LC waveforms while for unsymmetrical-distorted LC waveforms, odd and even harmonics were observed. The LC analysis indicated that there are 5 stages of insulator conditions from normal condition up to flashover correlated with different kind of LC waveforms. The results also showed that in general the magnitude of LC was good enough to show the condition of the insulators. However, under discharge condition (for example as a result of dry band arching) the LC magnitude should be combined by the THD to show a better correlation with the insulator condition. The product between THD and LC magnitude may be used as a diagnostic parameter.

Keywords: Leakage current, Outdoor insulator, THD, Diagnosis

1. Introduction

Outdoor insulator is one of the important parts in a transmission as well as distribution system. The insulators should be able to isolate high voltage line from the ground and other lines. The failure of the insulators may cause the failure of the power system. During operation, electric, mechanical, thermal and chemical stresses applied to the outdoor insulators. The stresses may degrade and reduce the insulation function of the insulators. If the insulation strength of the insulator is not sufficient to withstand the electric stress, flash over may occur causing a failure of the line.

It is important to know the status of insulator, whether it is in good condition or bad condition. For maintenance purpose it is necessary to diagnose the insulation condition of the outdoor insulators. In order to be able to diagnose the condition of the insulators it is necessary to identify signals or measures to be used as indicators. During operation, leakage current (LC) usually flows on the insulator surface [1] and it is commonly used to indicate the condition of insulators[2]. Several methods may be applied to diagnose the insulator. They are including acoustic emission (AE) method [3], infra red for hot spot detection, Ultrasonic, Radio wave detection, LC magnitude [4] and waveforms [5] and harmonic content[5-7].

In general, a health outdoor insulator associates with a small magnitude of LC and low harmonic content. On the other hand, big magnitude of LC with high harmonic content usually flows on severe condition of outdoor insulators. This paper describes the application of the LC magnitude and harmonic content to diagnose outdoor insulator.

2. Experiment

Samples used in this experiment are EPDM insulators used for 20 kV distribution lines. The sample was put inside a chamber with size of 90 cm x 90 cm x 120 cm. The sample was subjected to various artificial-environmental conditions (i.e. pollution and humidity) to simulate various conditions levels of insulators. Artificial pollution was applied in accordance with IEC Standard No. 507 1991. Kaolin of 40 g was used in every 1 lt water. NaCl was added to the solution to get the desirable value of conductivity. 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 detail of experimental conditions investigated in this experiment are tabulated in table 1.

The leakage current flowed on the insulator surface was

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Table 1 Experimental conditions

Stage	Insulator and environmental Condition	Applied voltage (kV)
1	Clean insulator; RH : 85-95 %	12
2	Insulator polluted with kaolin-salt pollution at 3.6 mS/cm; RH: 85-95 %	12
3	Insulator polluted with kaolin-salt pollution at 4 mS/cm; clean fog	25
4	Insulator polluted with kaolin-salt pollution at 4 mS/cm; clean fog	30
5	Insulator polluted with kaolin-salt pollution at 4 mS/cm; clean fog	32

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. The measurement system is shown in Fig. 1.

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 by applying FFT (fast Fourier Transform).

The harmonic content of LC was analyzed using FFT (Fast Fourier Transform). The THD is defined as the total ratio of the harmonic components and the fundamental which can be expressed as:

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

Where I_1 = 1st harmonic (fundamental)
I_n = nth harmonic for n = 2,3,4,....

The LC magnitude and harmonic content which is indicated by the total harmonic content (THD) are used as key LC parameters for diagnosis.

3. Experimental Results

3.1 Leakage Current

Fig. 2 shows typical LC waveforms and harmonic contents on the samples under various conditions.

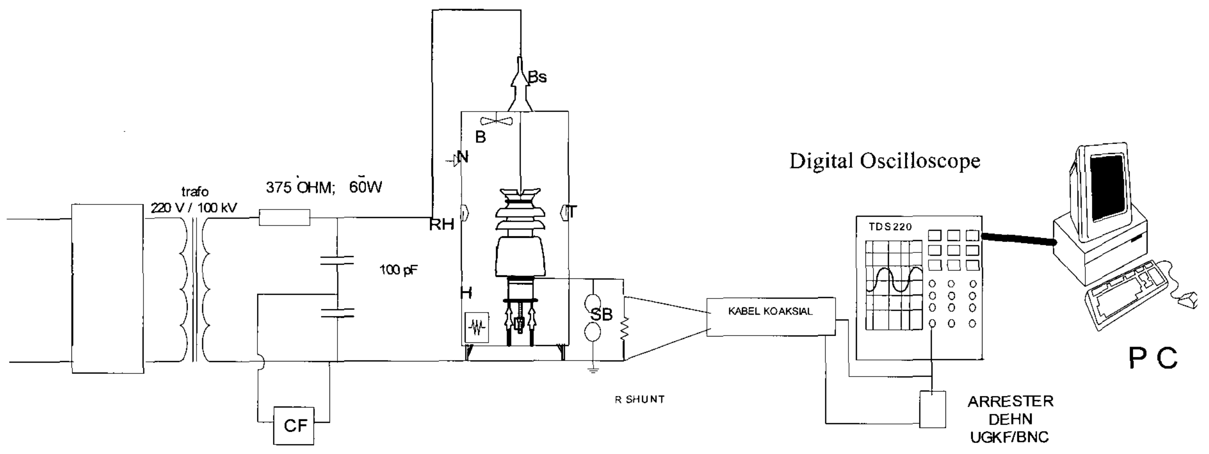
Fig. 2 shows that LC magnitude as well as THD may vary depend on the insulator condition. Under normal condition (a) the LC waveform was slightly distorted from sinusoidal wave. The LC magnitude and THD were low.

Under high pollution at humidity of 85-95 % and 12 kV applied voltage (b), no arc was observed. The LC magnitude was high but THD was low.

Fig 2 (c) is LC for kaolin-salt polluted insulator at 4 mS/cm under clean – fog and was energized at 25 kV. The LC fundamental was about 270 A and THD was around 14 %. The waveform is symmetrical both positive and negative half cycles and contain only odd harmonic components (3rd, 5th and 7th). These results indicated that small arc occurred. It was in good agreement with recently reported that 3rd and 5th strongly correlated with dry band arcing activity[7]

Fig. 2 (d) is typical LC waveform and harmonic content for insulator at same condition as (c) but under applied voltage of 32 kV. The typical fundamental value of the LC was around 250 A and contains large harmonics with THD of about 105 %. This LC correlates with higher activity of dry band arcing. The LC waveform is symmetrical between positive and negative half cycles. As shown in the figure only odd harmonic components are contained in the LC.

Fig. 2 (e) is LC for insulator at same condition as (d) but under applied voltage of 32.5 kV. The activity of arc increased drastically at negative half cycles. The typical value of fundamental component was about 440 A and THD was 220 %. The waveform is extremely unsymmetrical



CF : high voltmeter B : blower RH : hygrometer SB : spark gap
N : nozzle T : thermometer H : heater CX : coaxial cable

Fig. 1 Leakage current measurement system

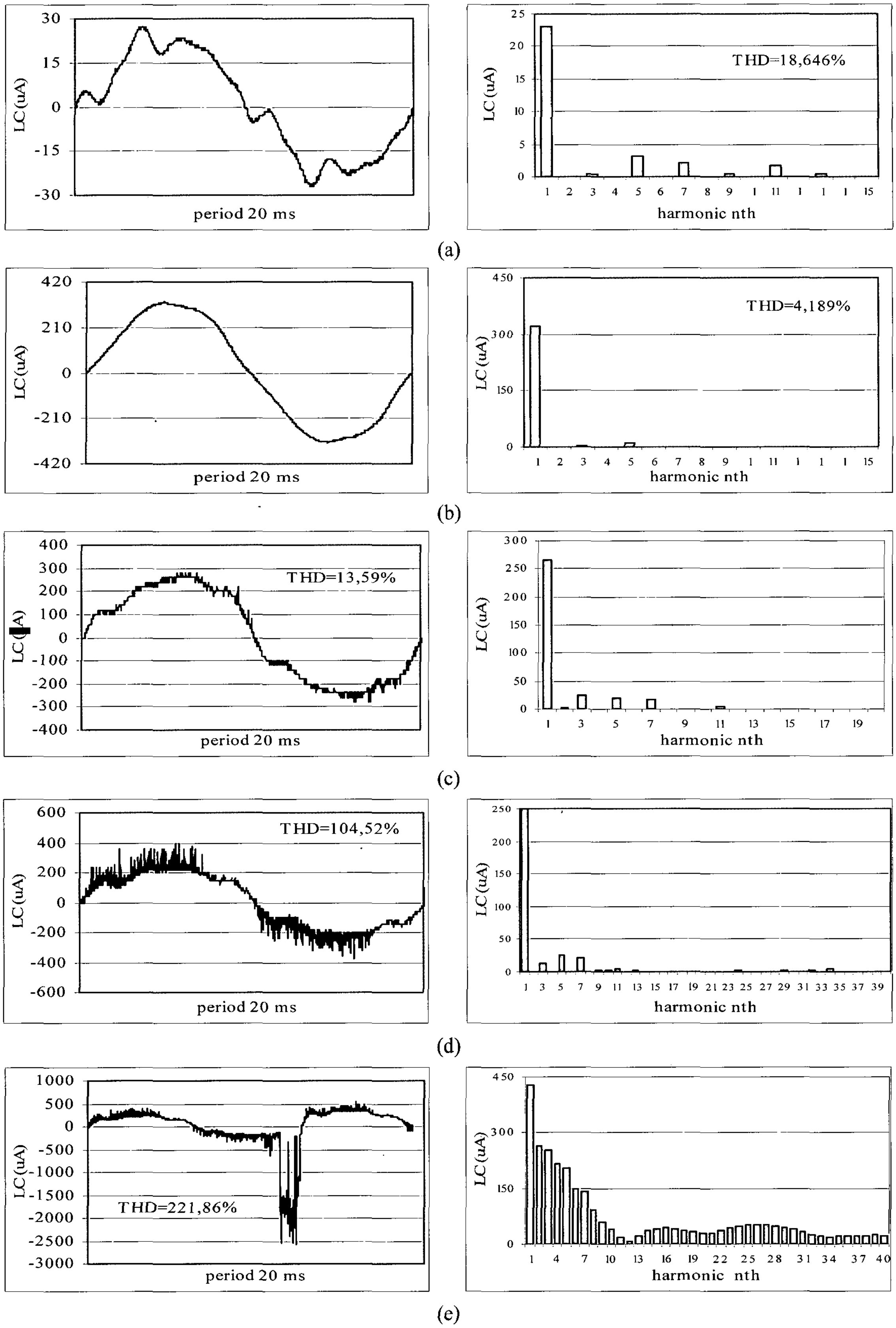


Fig. 2 Typical LC waveforms and their harmonc contents (a) Clean, RH 85-95 %, 12 kV (b) 3.6 mS/cm, RH 85-95 %, 12 kV (c) Kaolin-salt polluted at 4 mS/cm, clean fog 25 kV(d) Kaolin-salt polluted at 4 mS/cm, clean fog 30 kV (e) Kaolin-salt polluted at 4 mS/cm, clean fog 32 kV

Table 2 The characteristics of the leakage current at different stages and the insulator conditions

Stage	LC Magnitude	Waveform	Harmonic component	THD	Insulator Condition
1	Low	Almost sinusoidal	Odd - small	Low	Normal
2	High	sinusoidal	Odd- very small	Low	-High surface conductance -High Electric field -Heating
3	High	Symmetrical-distorted	Odd - medium	Medium	-High surface conductance - Heating -High Electric field -Small arc
4	High Symmetrical	Symmetrical - distorted	Odd - high	High	-High surface conductance -High Electric field -Heating -High arc
5	High Unsymmetrical	Unsymmetrical-highly distorted	Odd and even. Very high	High	-High surface conductance -High Electric field -Heating -Very high arc and precursor to flash over

resulting in large odd and even harmonic components. The 5 stages of insulator conditions may be used to characterize insulator surface prior to flash over.

Suda reported several stages of LC on a string of suspension insulators before the insulator flash over[8]. Three stages of LC and crossing analysis of the LC envelope of polluted insulators were reported by Amarh[9]. The characteristics of the leakage current at different stages and the insulator conditions are summarized in table 2.

The general explanation of the stages are as follows:

Stage 1: normal condition, very small distorted-sinusoidal LC. No discharge was observed. The distortion of the LC was due to the voltage source.

Stage 2: high LC magnitude due to decrease of surface resistance because of conductive pollution and high humidity. No discharge was observed. The LC waveform was almost sinusoidal with low harmonic content.

Stage 3: high LC magnitude due to high surface resistance because of conductive pollution and high humidity. Weak discharge was observed. Light distortion of LC waveform was observed at both positive and negative polarities. The LC waveform was symmetrical in both polarities and odd harmonic components were observed. The distortion caused a medium harmonic content due to initiation of dry band discharge activity on the insulator surface.

Stage 4: the LC magnitude was high. A higher arc activity was observed. The high distortion of LC waveform was observed at both positive and negative polarities. The LC waveform was symmetrical in both polarities and odd harmonic components were observed at this stage. The distortion caused a high harmonic content due to high activity of the dry band arching.

Stage 5: The LC was high in magnitude and harmonic content. Intermittent and strong arcs were observed during this stage. The LC waveform was extremely unsymmetrical and odd as well as even harmonic components were observed. The distortion of the LC waveform caused very high harmonic content due to very high activity of the dry band arcing prior to the flash over of the insulator.

3.2 LC Magnitude and THD and Diagnosis

Arc current analysis is important since dry band arching may contain in the LC. It is reported that the appearance of arcing of 3rd harmonic is always insignificant until an arc present on the surface of insulator[10]

The fundamental wave of LC which greatly affects the magnitude of rms of LC correlates with the surface resistance of the insulator or electric field strength. Big LC corresponds with low surface resistance which indicates low quality of insulator or high electric strength. The high magnitude of LC in turn will heat the insulator surface and may promote the degradation of the insulator.

The experimental results indicated that the harmonic content in the LC waveforms strongly correlate with insulation condition. For insulator under normal condition usually the LC is small in magnitude and THD and the waveforms are symmetrical for both positive and negative half cycles. As the surface conductivity or electric field increases, the LC magnitude increases and THD is small.

Unsymmetrical waveforms of LC were observed for insulators under severe conditions (case 2 (d) and (e)). This condition usually corresponds to high LC magnitude and high THD. These indicated that LC magnitude and THD may represent the insulation condition of the insulators.

Therefore the harmonic distortion in LC waveform may be attributed to the presence of severe condition (i.e. arc) on the insulator and THD can be justified as a candidate for diagnosis of insulator conditions.

Fig. 3 shows the correlation between condition stage

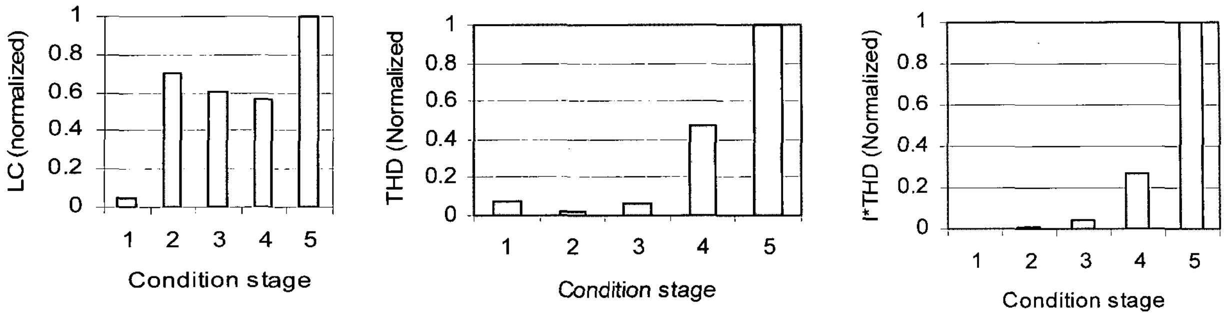


Fig. 3 Correlation between indicators and insulator condition stage: (a) the LC magnitude, (b) THD and (c) product between LC magnitude and THD

(from 1 to 5) and the values of indicators. Fig 3.a. is for LC magnitude. From this figure it is seen that LC magnitude is not adequate to be used as indicator of insulator condition. Fig. 3 (b) is the correlation between insulator condition stage and THD. This figure shows a better indication than that of LC magnitude. Fig. 3 (c) shows the correlation between insulator condition stage and product between LC magnitude and THD. This is the best indicator among others since this indicator is monotonically increased. Evaluation of the indicators using polynomial fitting of 3rd order indicated that the correlation factor (R) for the product of LC magnitude and THD was 0.9999 while for THD was 0.9970 and for LC magnitude was 0.8326. Therefore, cross product between LC magnitude and THD is considered to be better than LC magnitude or THD and is proposed as the candidate for insulator diagnosis.

4. Conclusion

We have investigated LC waveforms on the insulators under various conditions. The results showed that the LC waveforms strongly correlated with insulator conditions. There are 5 stage of LC waveforms correlate with insulator condition stages with different LC magnitude and THD. Further analysis indicated that the product of LC magnitude and THD is the best in indicating insulator conditions than that of LC magnitude and THD. Therefore, it is proposed as candidate for indicator to assess the condition of insulators.

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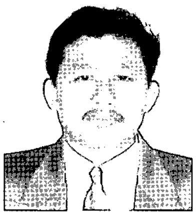

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