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THERMAL IMAGE, PARTIAL DISCHARGE AND LEAKAGE CURRENT CORRELATION OF CERAMIC INSULATOR UNDER DIFFERENT CONTAMINATION LEVEL

Darwison[1,3], Syukri Arief[3], Hairul Abral[2], Ariadi Hazmi[1], M. H. Ahmad[4] and Aulia[1]
[1]Department of Electrical Engineering, Andalas University, Pauh, Padang, Indonesia
[2]Department of Mechanical Engineering, Andalas University, Pauh, Padang, Indonesia
[3]Department of Chemistry Engineering, Andalas University, Pauh, Padang, Indonesia
[4]Institute of High Voltage and High Current, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia
E-Mail: darwison@ft.unand.ac.id

ABSTRACT

This paper reports correlation on leakage current and thermograph infrared (IR) images of the ceramic outdoor insulator for the condition based monitoring purposes. In this work, laboratory pollution performance test using sodium chloride was performed according to the IEC 60507 standard with applied ac voltage from 12 kV to 18 kV. The severity level of pollution were controlled and represented by ESDD values of 0.00 to 0.25. Also, relative humidity conditions were controlled on the range between 60% to 100%. Statistical parameter of infrared images were evaluated to assess the severity level of contaminated ceramic insulator. The output IR images of the insulator were categorized as safe state, necessary maintenance and dangerous based on the level of contamination severity. The results showed that the severity of the pollution can be identified based on the analysis of infrared images, where each severity level of leakage current was correlated with a particular colour. Also, it was found that the phase difference between the leakage current to the reference voltage decreased along with the increase in the severity level of pollution.

Keywords: ceramic insulator, leakage current, partial discharge, infrared images, pollution.

1. INTRODUCTION

Ceramic insulator [1-4] is still gaining the popularity to be used in high voltage transmission system. This might be due to the ability to work efficiently during high voltage stress under different climatic condition [5-9]. However under certain condition, the leakage current (LC) [10-15] and partial discharge (PD) [16-21] have sustained on the surface of the insulator which eventually leading to the damage of the insulator and shortening the power transmission line [21]. This phenomenon is typical to be found in the field even though the insulator is still in its operational age [3].

The previous study suggested that the leakage current remained sustain due to the contaminant deposited on the surface of insulator and behave conductively under certain situation. The higher the contamination level the more conductive the insulator surface and the higher the leakage current [2]. In a low level of contamination, the leakage current is also very small and the power transmission operates normally. However, in a higher leakage current, the power transmission is still operating normally but under a severe threat due to the high temperature level of the insulator surface in which eventually results in the power failure. Mostly, the highest contaminated insulator can be found in the coastal and cement industries areas [6, 22]. The salt-deposited contamination has been determined as the major cause of the conductive path on the outdoor insulator surface [4].

Many methods have been used to study the leakage current and PD behaviours of the contaminated insulator surface [6-15, 20]. However, the studies on the correlation between leakage current and thermal behaviour of the insulator surface are found to be scarce in the literature [5]. Thus in this work, two methods were used to determine the contamination level of the insulator. The first method was the third harmonic analysis that can be used to calculate the noise ratio of the leakage current according to IEC 60507 [9]. The second method was the image analysis where the image is taken using a thermal camera [22]. By using these methods, the thermal structures of the image were associated with certain value of contamination level. In the current work, the correlation on infrared (IR) image and the related leakage current of ceramic insulator under different contamination condition was investigated.

2. MATERIAL AND METHODS

a) Insulator strength

Insulator surface resistance values depending on the pollutant material accumulated on the surface of the insulator as well as other factors such as the type of pollutants, climatic conditions, and the relative humidity. A solution such as water, fog and other compounds on the surface of the insulator can also reduce surface resistance of the insulator resulting in the increase in leakage current flowing on the surface of the insulation.

If the high voltage AC [2, 6] was applied across the insulator, the surface current, I_P volume current , I_V and capacitive current, I_C would flow thru the insulator as shown in Figure-1. Capacitive currents occur because of the capacitance formed by the electrodes as insulators Figure-1(b). The leakage current, I_B flowing on the clean insulator surface will be capacitive, but if the surface of the insulator is contaminated, the resistive current will

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flow. The more contaminated insulator surface, the leakage current on the surface will be even greater.

From Figure-1(b), the flow volume can be ignored because the volume resistance is relatively large compared with the surface resistance so that the total leakage current becomes:

$$I_B = I_P + I_C \quad (1)$$

with phasor diagrams as depicted in Figure-2, the magnitude of leakage current, I_B is;

$$I_B = \sqrt{I_P^2 + I_C^2} \quad (2)$$

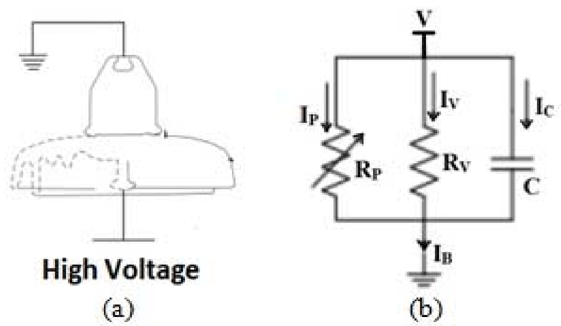


Figure-1. Leakage current on the insulator surface, (a) schematic diagram of the insulator, (b) equivalent circuit of the insulator.

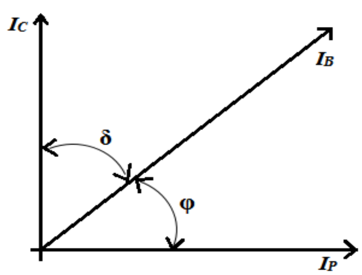


Figure-2. Phasor diagrams of the leakage currents.

b) Test objects

The 20 kV ceramic insulators used in this work are depicted in Figure-3. The tested insulator was suspended vertically [3, 7, 11, 12, 14, 15, 18-20] facing the thermal camera in the space (0.5x0.5x1.3 m^3) as shown in Figure-4. The test voltage is in the range of 12 to 18 kV rms at 50 Hz frequency. Room humidity is in the range of 60% to 100%. The tests were performed according to IEC 60507 test procedure of clean fog. Before the test, the insulator surface was cleaned with isopropyl alcohol and rinsed with distilled water to remove any traces of dirt and grease [22]. The typical salt pollution of coastal areas was produced by creating a layer of insulator surface contamination. Contaminants are formed of NaCl with 40 g of kaolin were mixed with 1 liter of water. The salt concentration of NaCl varied to provide equivalent salt deposit density (ESDD) in mg/cm2 with the different values of 0.06 (lightly polluted), 0.08 (moderately polluted), 0.12 (heavily polluted) and 0.25 (very highly polluted) [22]. Liquid potassium sulphate was used to constantly maintain the relative humidity level in a fog chamber. Relative humidity in the chamber was measured using fog humidity measuring instrument.

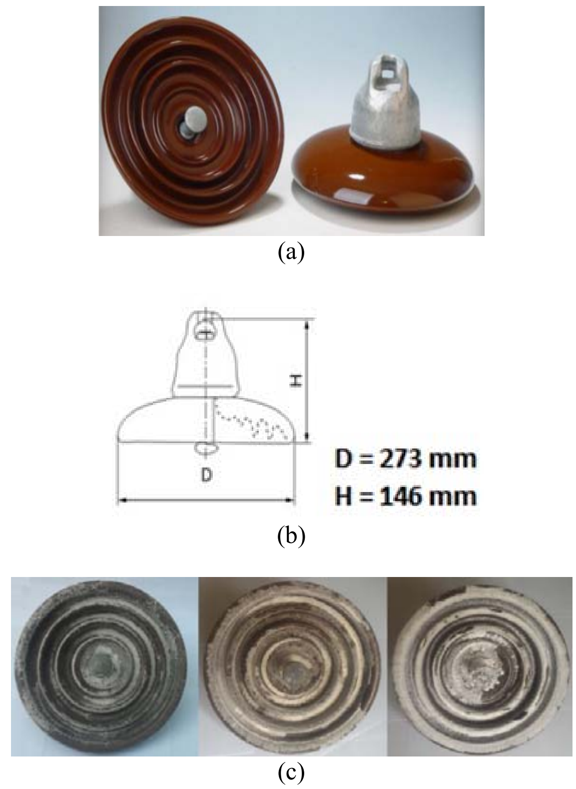


Figure-3. The 20 kV of ceramic insulators, (a) clean insulator, (b) insulator dimension, and (c) polluted insulators.

c) Measurement system

Figure-4 shows a schematic diagram of the experimental setup. The high voltage amplifier was used as a high voltage generator as well as the test voltage. The high voltage transformer (HVT) has a ratio 1: 2000. Voltage regulator was connected to the input of the HVT as a regulator of the test voltage. DPO 5104 oscilloscope was used to display the input voltage through a voltage probe P6015A, creeping leakage current ceramic insulators as well as recording the activity of PD which detected by PD detector (coupling capacitor and measuring impedance). The high voltage was subjected to the ceramic insulator and a 4000 pF capacitor charge for the case of measuring the PD events of the ceramic insulators, the capacitor will be throwing so PD detector will detect PD occurrences and shown on DPO 5104 oscilloscopes. Voltage Probe was used as a working voltage detection and test applied during experiment. With a ratio of 1: 1000V. The current probe P6021 was used as an insulator leakage current detection.

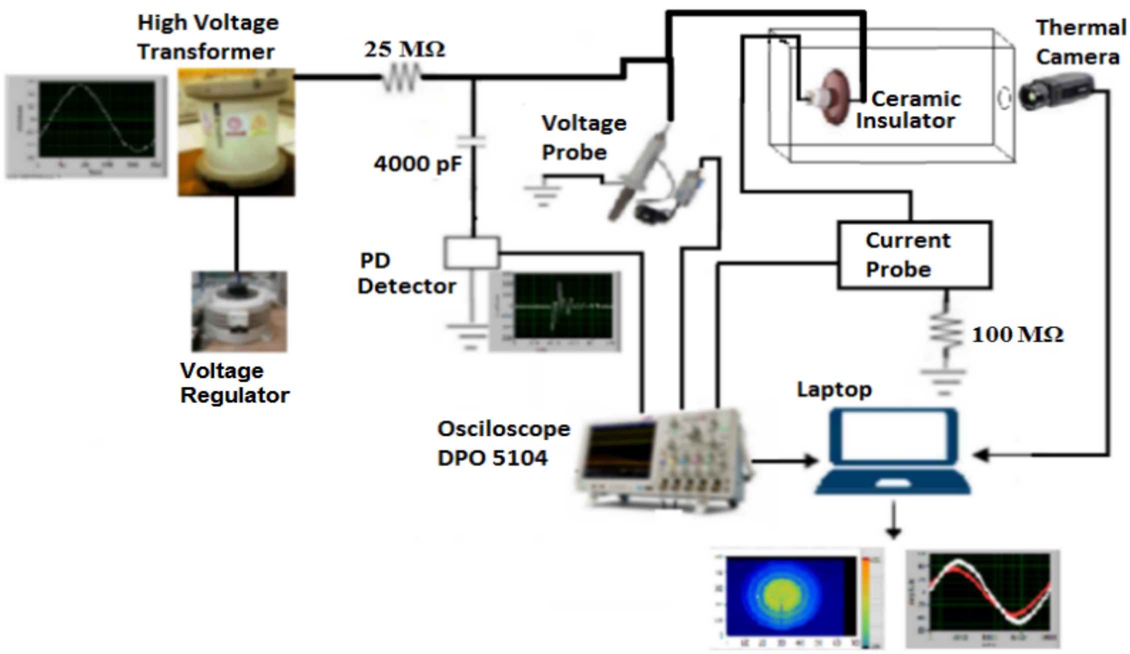


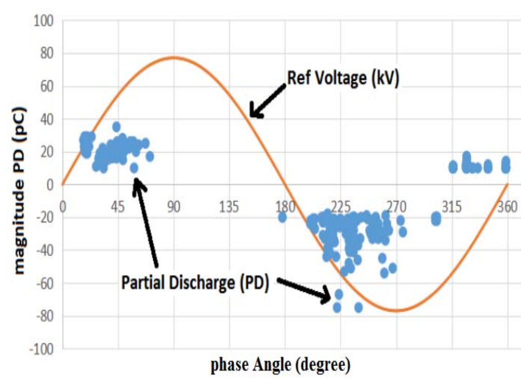
Figure-4. A schematic diagram of the experimental setup.

Thermal camera from FLIR thermograph A-600 series was used to capture the thermal images. The images were then stored and processed to measure the leakage current. As the par of measurement unit, laptop has been used to running the LabVIEW program for the recording data such as the test voltage, leakage current, PD, thermal images detected during the experiment.

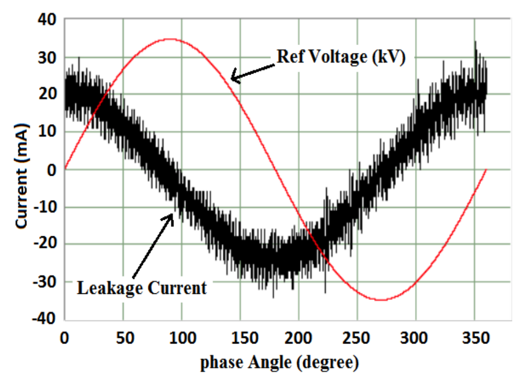
3. RESULTS

Figure-5 shows the PD pattern at different phases of the ceramic insulator that was moderately polluted, the reference voltage is 14 kV with 60% of humidity. Figure-5(a) is the chart patterns of the PD phase and Figure-5(b) is the graph of the phase difference between the reference voltage to the leakage current. It can be noted that the PD activity will increase when the humidity rises. Rising humidity will also result in the increase of leakage current [9, 12, 18-20]. Further result is the phase difference between the reference voltage to the leakage current will be smaller due to polluted insulator becomes more resistive.

Figure-6 shows the thermal images of the tested insulators under voltage of 16 kV, 0.12 (heavily polluted) ESDD pollutant levels (mg/cm2), 80% RH, and the temperature of 24 °C. The yellow color in the center of high voltage insulator as shown in Figure-6(a) indicates less activity of PD, whereas on Figure-6(b) shows lots of PD activity on the centre of the insulator which indicated by reddish colour of thermal image.



(a)



(b)

Figure-5. Polluted ceramic insulator at 14 kV and 60% RH (a) PD phase resolve (b) LC phase difference.

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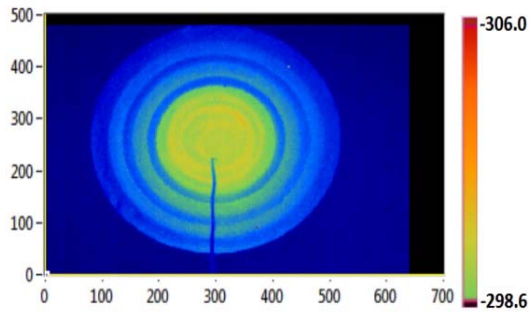
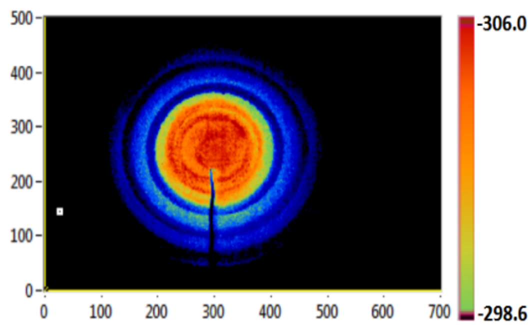


(a)



(b)

Figure-6. Thermal image of ceramic insulator under test, (a) low level of pollutan and, (b) highly polluted.

The color variation of the insulator has physical correlation with number of PD activity. Also, Figure-6 shows two IR images obtained from the measurements with temperature indicator ranging from 298.60K (25.6°C) to 306.00K (33°C). This study has corroborated the works in reference [22] in which insulator temperature data obtained from the first step in the insulator segmentation of the background of the IR image and recorded the coordinates of the insulator region. Also, the second step was to read the temperature data corresponding to the recorded coordinates. Figure-6(b) shows the percentage of the color associated with the PD activity, and the temperatures of the surface of the insulator were shown in Figure-7.

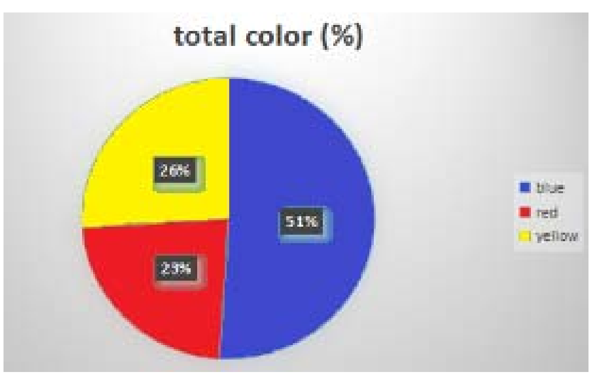
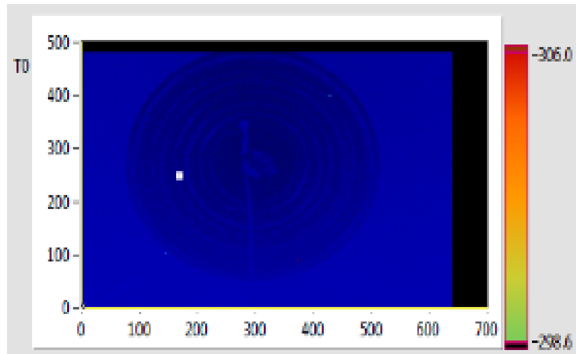
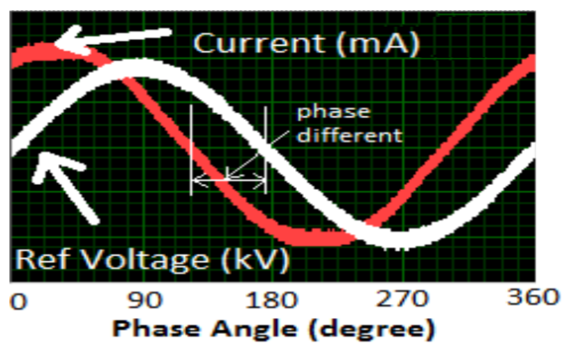


Figure-7. Colour percentage of thermal image of ceramic insulator.

In the same test, the color correlation of thermal images of the leakage current can be seen in Figure-8. When the ceramic insulator in a clean state and then tested with a voltage of 14 kV, the resulting thermal image was dark-bluish color and the phase difference between the leakage current and reference voltage are very large. Thermal image of dark-blue color indicates that the leakage current is highly capacitive.



(a)



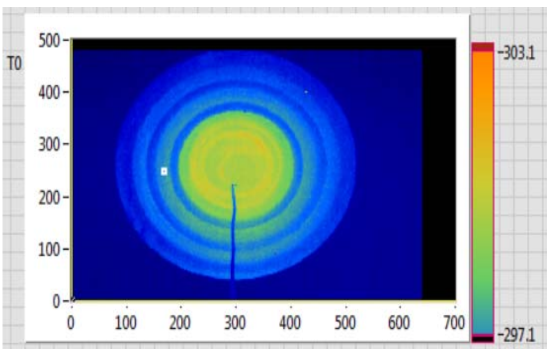
(b)

Figure-8. The ceramic insulator in clean condition rated voltage 14 kV, (a) thermal image and, (b) phase different.

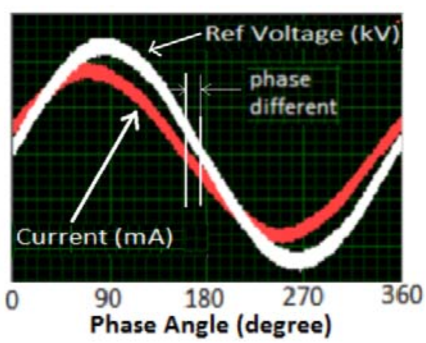
Figure-9 shows the ceramic insulator which was tested with the same method as the previous test, but with a higher level of pollutants, 0.08 ESDD (mg/cm^2). It was seen that the resulting thermal image was a blue-yellow and the phase difference was vanishingly small. The smaller phase difference was due to the more resistive leakage current flow on the surface of the ceramic insulator(see Figure-9). By applying higher level of voltage, 16 kV and pollutant, it is shown that the generated thermal image was also different with smaller phase different thereby indicating that resistive current became more dominant. (see Figure-10)

Based on the assumption, yellow thermal image in Figure-10(a) should be greater than or even become redder than the thermal image in Figure-9(a), but this did not happen. The greater the area of the yellow color of the image due to the corona 9(a) is happening at the bottom of the insulator. But by raising the voltage to 16 kV as can be seen in Figure-10(a), the insulator surface becomes dry faster and corona is significantly reduced, so that the yellow thermal image becomes smaller as the temperature insulator is affected by PD activity alone. Based on the obtained results, insulator conditions detected by the thermal image associated with leakage current were categorized into the following 3 categories groups;

i. Safe state :when less than half the radius of the insulator surface is red.
ii. Necessary maintenance: when the insulator surface has reddish colour with a radius ranging from 0.5 to 0.8.
iii. Dangerous: if the insulator surface is red with a radius exceeds 0.8. In the dangerous condition of the insulators, the flashover would most likely to occur because the top insulator has been highly contaminated.

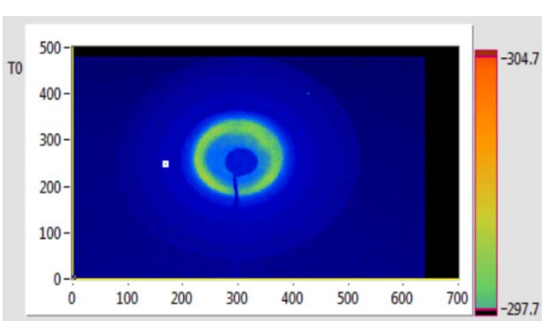


(a)

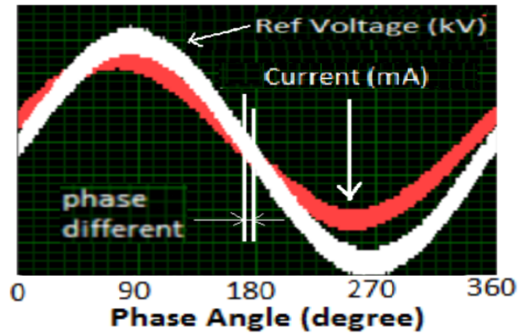


(b)

Figure-9. The ceramic insulator with the moderate pollutant was tested with 14 kV, (a) thermal image, (b) phase different.



(a)



(b)

Figure-10. The highly polluted ceramic insulator was tested with 16 kV, (a) thermal image, (b) phase different.

4. CONCLUSIONS

The result shows that it is feasible to accurately recognize insulator contamination grades using fused information from both IR images. The higher the pollution level and the greater the applied voltage, the more flushed thermal image. Increasing the insulator pollutants, the smaller the phase difference between the reference voltage and the leakage current.

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