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Estimated leakage current based on the thermal image of the polymer insulator using the color detection method

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Abstract. This paper reports estimates of leakage currents based on thermal images (infrared) of polymer isolators using color detection methods. In this study, laboratory pollution performance tests using sodium chloride and kaolin were carried out in accordance with the IEC 60507 standard with AC high voltage at 18kV. The severity of pollution is controlled and indicated by ESDD values of heavy pollutants, conditions of relative humidity controlled at 70RH and temperature of 26°C. The color detection method is used to obtain the color percentage of thermal images. The ANFIS method predicts leakage currents from contaminated polymer insulators with input from the percentage of thermal image color. The results show that the leakage current can be estimated based on infrared image analysis with a color detection method, where each current leakage level correlates with red, yellow and blue.

1. Introduction

Polymer insulators [1-4] gain popularity for use in high voltage transmission systems. This may be due to the ability to work efficiently during high voltage stresses under different climatic conditions [5-9]. However, under certain circumstances, current leakage (LC) [10-15] and partial discharge (PD) [16-21] have survived on the surface of the insulator which ultimately causes damage to the insulator and shortens the power transmission line. [21] This phenomenon is usually found in the field even though the insulator is still in operational age [3].

Previous studies have shown that current leakage still occurs because contaminants are deposited on the surface of the insulator and behave conductively in certain situations. The higher the level of contamination, the more conductive the surface of the insulator and the higher the leakage current [2]. At low contamination levels, the leakage current is also very small and the power transmission operates normally. However, at higher leakage currents, the electricity transmission is still operating normally but is under severe threat due to the high level of surface temperature of the insulator which ultimately results in a power failure. Most of the highest contaminated insulators can be found in coastal industrial estates and cement [6, 22]. Contamination deposited with salt has been determined as the main cause of the conductive path on the surface of the outer insulator [4].

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Different methods have been used to study leakage currents and PD behavior from contaminated surfaces of insulators [6-15, 20]. However, studies of the correlation between leakage currents and thermal behavior of surface insulation are found to be rare in the literature [5]. So in this work, a method is used to determine the amount of leakage current of contaminated polymer insulators. The method is an analysis of images where images are taken using a thermal camera [22-24]. Using this method, the structure of thermal images is associated with a certain level of contamination. In current work, correlations on infrared (IR) images and leakage currents from related polymer insulators under certain contamination conditions are investigated.

2. Experimental

2.1. Test Objects

The 20 kV polymer isolator used in this work is illustrated in Figure 1. The isolator tested was hung vertically [3, 7, 11, 12, 14, 15, 18-20] facing the thermal camera in space $(1.2 \times 0.5 \times 0.7 \text{ [m}^3])$ as shown in Figure 2. The test voltage is 18 kVrms at a frequency of 50 Hz. Room humidity is at 70RH and temperature is 26°C. The test is carried out in accordance with the IEC 60507 clean fog test procedure. Before testing, the insulator surface was cleaned with isopropyl alcohol and rinsed with distilled water to remove dirt and grease [22]. Typical beach salt pollution is produced by creating a surface layer of contaminants from the insulator. Contaminants are formed from NaCl with 40 gr of kaolin mixed with 1 liter of water. The NaCl salt concentration gives a density of equivalent salt deposits (ESDD) in mg / cm2 with a heavily contaminated value [22]. Liquid potassium sulfate-producing containers are used to maintain relative humidity in the fog room. The fog producing container is connected by two tubes to the polymer isolator test container. Relative humidity and temperature in the test container are maintained using an Arduino microcontroller with a temperature sensor, humidity sensor, 2 sets of 12 Vdc fan for air circulation, a 12 Vdc motor for potassium sulfate stirrer and a heater.



Figure 1. The polymer insulator of 20 kV under level (a) clean and (b) contaminated

2.2. Measurement System

As shown in Figure 2 that the voltage regulator is connected to the input part of the High Voltage Transformer (HVT) which is used as a test voltage regulator applied to the isolator polimer. High Voltage Amplifier in the form of (HVT) is used as a high voltage generator which is used as a test voltage [21] with a ratio of 1: 2000 Volt (peak to peak). DPO 5104 Oscilloscope is used to display the input voltage via a voltage probe P6015A, leakage current through the insulator and record the PD activity of the PD detector. The high voltage of the transformer through 25M Ω series resistance enters the 4000 pF insulator and capacitor filling. If there is a PD on the isolator then the capacitor will remove the charge so that the PD detector will detect PD occurring and displayed in Oscilloscope DPO 5104. Voltage Probe with a ratio of 1: 1000 V is used as a working voltage/test detector applied during testing. Leakage current can be calculated based on a voltage read by an oscilloscope on a shunt (shunt resistor) resistor [5], [8], [22] 4k7 Ω which are in series with the insulator. The purpose of using a 4k7 Ω sampling resistor is so that the leakage current signal is detected properly [7] for a high voltage range of 10k to 24kV. Thermal cameras from Thermograph FLIR [22] A-600 series are used



to take thermal images and then stored and processed to predict leakage currents with ANFIS intelligent systems on the Laptop.

Figure 2. A schematic diagram of the experimental setup

3. Results and Discussion

With a heavily polluted insulator given an 18kV AC high voltage of about 1 hour (529 data files), it will produce thermal on the surface of the insulator against time in the test container at 70RH humidity and temperature of 26° C. Thermal colors on the surface of the insulator are grouped into 3 main colors: blue (303.40K $\leq x \leq$ 3040K), yellow (3040K $\leq x \leq$ 306.50K) and red (> 306.50K) as shown by zooming from the thermal photo in Figure 3a and percentage thermal colors such as Figure 3b and PD pattern and leakage current are shown as Figure 4.



Figure 3. Testing of heavy pollutant isolators at 18kV test voltage, 70 RH humidity, and 26^oC temperature (a) Thermal Photo Zoom (b) Color Percentage



Figure 4. Heavy pollutant isolators (a) PD Pattern (b) leakage current

On thermal photos of the surface of the insulator, the red color will be wider along with the thermal increase.





3.1. Color detection method

By using the color detection method with the Matlab programming language, the thermal image isolator area of the thermal image zoom as shown in Figure 5a is 175,488 (384 x 457) pixels. The color detection process approaches red with the following equation: if (im (i, j, 1)> 100 && im (i, j, 2) <90 && im (i, j, 3) <90) (equation for detecting color in red range). Finally, the binary image is converted to a binary image negation as in Figure 6, resulting in a red area of 3,374 pixels. In the same way as Figure 6, the yellow area is gets 15,557 pixels and the color area of the insulator which covers an area of 74,519 pixels so that the percentage of thermal isolator color with the formula of the area of blue = the area of the insulator - (red area + yellow area).



Figure 6. Detect the red color of the Isolator thermal image

In the thermal percentage for the four thermal conditions of the surface of the insulator, if the greater the percentage of red then on the contrary, the smaller the percentage of blue as shown in Figure 7. Percentage of yellow remains, this means that PD activity is still large for 1 hour make the surface of the insulator hotter so that the leakage current becomes larger. The heat from the surface of the insulator will disappear and the dry band will be formed because the flow of leakage current makes water vapor evaporate from the surface of the insulator [19]. If the dry-band discharge is continuous, the surface becomes more porous which in itself reduces hydrophobicity and partial expansion of the discharge (PD) during some dry-bands that eventually produce flashover [28]. With contamination deposition on the surface of the insulator will have more influence on the flow of leakage current due to hydrophobic reduction [8].



Figure 7. Thermal percentage

3.2. Forecasts of leakage current with ANFIS

By using the fuzzy combined method with a neural network (ANFIS) in Matlab then it can be estimated leakage current of polymer insulator with ANFIS input data namely arusbocor.dat as shown in Table 1.

Table 1 Percentage of color data and output of insulator leakage current

Color detection method Processed Image (%)				Measured Leakage current
No.	Red	Yellow	Blue	(mA)
1	4	21	75	5
2	12	17	71	14
3	20	19	61	24
4	24	14	62	44

By using ANFIS toolbox from Matlab with percentage data of thermal color and leakage current of heavy insulated as in table 1. Table 1 is the result of experimental data analysis using heavy pollutant isolator with 18kV high voltage, 70RH humidity and 260C test container temperature for 1-hour, thermal color percentage using color detection method. In Figure 7, shows the results of testing the forecast program for leakage current with ANFIS with the percentage of thermal color that has been trained as shown in Figure 8a, which is tested as Figure 8b and the forecast of leakage current in the clean insulator as shown in Figure 8c. The results obtained are appropriate and examples of forecasting leakage currents in heavy polluted insulators with a percentage of red = 10, yellow = 20 and blue = 70 is 12.3895 mA.

>> fis=readfis('arusbocor18V70RH26C_anfis')

(a)

fis =

struct with fields:

```
name: 'arusbocor18V70RH26C_anfis'
type: 'sugeno'
andMethod: 'prod'
orMethod: 'probor'
defuzzMethod: 'wtaver'
impMethod: 'prod'
aggMethod: 'sum'
input: [1×3 struct]
output: [1×1 struct]
rule: [1×27 struct]
>> arusbocor18V70RH26C=evalfis([20 19 61],fis)
arusbocor18V70RH26C =
24.0000
```

```
>> fis=readfis('arusbocor18V70RH26C anfis')
(b)
             fis =
               struct with fields:
                          name: 'arusbocor18V70RH26C anfis'
                          type: 'sugeno'
                    andMethod: 'prod'
                     orMethod: 'probor'
                 defuzzMethod: 'wtaver'
                     impMethod: 'prod'
                     aggMethod: 'sum'
                         input: [1×3 struct]
                        output: [1×1 struct]
                          rule: [1×27 struct]
             >> arusbocor18V70RH26C=evalfis([10 20 70],fis)
             arusbocor18V70RH26C =
                12.3895
              >> fis=readfis('arusbocor18V70RH26C anfis')
 (c)
              fis =
                struct with fields:
                          name: 'arusbocor18V70RH26C anfis'
                          type: 'sugeno'
                     andMethod: 'prod'
                      orMethod: 'probor'
                  defuzzMethod: 'wtaver'
                     impMethod: 'prod'
                     aggMethod: 'sum'
                         input: [1×3 struct]
                        output: [1×1 struct]
                           rule: [1×27 struct]
              >> arusbocor18V70RH26C=evalfis([2 15 83],fis)
              arusbocor18V70RH26C =
                  1.2083
```

Figure 8. Evalfis instruction (a) leakage current is obtained according to training (b) tested in the form of leakage current forecast (c) forecast leakage current in the clean insulator.

4. Conclusion

The leakage current forecast based on the thermal image of polymer insulator using ANFIS method was successfully applied and the ANFIS method can speed up recognizing the value of leakage current with the acceptable accuracy.

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