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A Leakage Current Forecast of the Polymeric Insulator Using ANFIS Method Based on LabView Pre-processed Thermal Image

Darwison Darwison[1, 2, *], Syukri Arief[2], Hairul Abral[3], Ariadi Hazmi[1], Novizon Novizon[1], Aulia Aulia[1], Eka Putra Waldi[1]

[1]Department of Electrical Engineering, Universitas Andalas, Padang, Indonesia
[2]Department of Chemistry, Universitas Andalas, Padang, Indonesia
[3]Department of Mechanical Engineering, Universitas Andalas, Padang, Indonesia

Email address:
ddarwison@gmail.com (D. Darwison)

[*]Corresponding author

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Abstract: This paper reports estimates of leaky currents based on Thermal (Infrared) images of polymer insulators using LabVIEW as preliminary data from the ANFIS method for the purpose of condition-based non-contact monitoring. In this study, images of very high contaminated polymer insulators were taken using the FLIR-A600 thermal camera series. The laboratory pollution performance test is carried out in accordance with the standards of IEC 60507 with an 18 kV AC voltage. The pollution severity is indicated because the ESDD value is very high contaminated and the relative humidity conditions are maintained at the range of 85% RH to 95% RH and temperature at 28°C. Humidity and temperature are maintained through a mist-producing container that is connected to a controlled polymer isolator test container using an Arduino microcontroller with temperature and humidity sensors. LabVIEW is used to calculate the percentage of RGB color from a thermal image related to a certain measured leakage current. This RGB data is training data for ANFIS to predict leaky currents. The results show that this method is able to predict current leakage without spending time to reach RMSE 0.00008. By adding a calculation to determine the condition of the insulator in the category of Safe, Maintenance or Hazard so that the Field Technician can decide whether the insulator must be replaced or not. With a non-contact method that only through thermal analysis of polymer insulators can accelerate the process of checking the condition of the insulator.

Keywords: Polymeric Insulator, Leakage Current, Partial Discharge, Infrared Images, Pollution

1. Introduction

One way to maintain the quality of electric power in the transmission of electrical energy is the need for good quality insulation. Failure or disruption of electricity transmission due to insulators often occurs even though the age of isolation is still within reasonable limits. One of the isolators that are widely used today are polymer insulators [1, 4, 5, 12-14, 20, 21]. Polymer insulators [1-4] gain popularity which mainly used in high voltage transmission systems. This may be due to the ability to work efficiently during high voltage stresses under different climatic conditions [5-8]. However, under certain circumstances, leakage current (LC) [9-12] and partial discharge (PD) [13-16, 22] have survived on the surface of the insulator which ultimately cause damage to the insulator and shorten the lifetime of the power transmission line. [16] This phenomenon is usually found in the field even though the insulator is still in operational age [3]. Phenomenon often found in the field and one of the causes of the initial failure of insulation is the greater the leakage current [4, 5, 7, 8, 11-14, 16-19, 20, 21]. Leaking currents that are getting bigger due to interference from climate and environmental factors causing a decrease in the quality of insulators in the isolation system.

Previous studies have shown that leakage current still occurs because contaminants are deposited on the surface of the insulator and behave conductively in certain situations. The higher the level of the 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 industrial areas [6, 17]. Contamination deposited with salt has been determined as the main cause of the conductive path on the surface of the outer insulator [4].

Different methods have been used to study leakage currents and PD behavior from contaminated surfaces of insulators [6-12, 15]. However, studies of the correlation between leakage currents and thermal behavior of surface insulation are found to be scarce in the literature [5]. Thus 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 [17, 18]. Using this method, the structures of thermal images are associated with a certain level of contamination. In current work, correlations between infrared (IR) images and leakage currents from related polymer insulators under certain contamination conditions are investigated.

From the background above, a Leakage Current Forecast of the Polymeric Insulator study was conducted using ANFIS Method Based on LabView Pre-processed Thermal Image. The LabView Pre-processed Thermal Image was used to obtain the color percentage of thermal images. Intelligent systems use a combination of Fuzzy Logic and Artificial Neural Networks that use the ANFIS toolbox (adaptive neurofuzzy inference system) from Matlab. Thermal images of thermal camera images are connected to laptops that have been installed by LabVIEW software. The ANFIS method predicts leakage currents from contaminated polymer insulators with input from the percentage of thermal image color. With the addition of the matlab program, the condition of the insulator can be grouped in the category of Safe, Maintenance or dangerous. Thus the field technician can make a decision that it is necessary or not to replace the insulator.

2. Experimental

2.1. Test Objects

A 20 kV polymer insulator was used in this work as illustrated in Figure 1. The insulator tested was hung vertically [3, 7, 9-15] facing the thermal camera in a space (1.2 x 0.5 x 0.7 [m^3]) as shown in Figure 2. The test voltage was 18 kVrms at a frequency of 50 Hz. Room humidity was at the range of 85% RH to 95% RH and temperature was 28°C. The test was carried out in accordance to 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 [17]. Typical beach salt pollution was produced by creating a surface layer of contaminants on the insulator. Contaminants were formed from NaCl with 40 grams of kaolin mixed with 1 liter of water. The NaCl salt concentration gives a density of equivalent salt deposits (ESDD) in mg/cm^2 with a very high contaminated value [17]. Liquid potassium sulfate-producing containers were used to maintain relative humidity in the fog room. The fog producing container was connected by two tubes to the polymer insulator test container. Relative humidity and temperature in the test container were maintained using an Arduino microcontroller with a temperature sensor, humidity sensor, two sets of 12 V_{DC} fan for air circulation, a 12 V_{DC} motor for potassium sulfate stirrer and a heater.

(a)

(b)

Figure 1. *The 20 kV of polymer insulators (a) clean insulator and (b) polluted insulators.*

2.2. Measurement System

As shown in Figure 2 that the voltage regulator was connected to the input part of the High Voltage Transformer (HVT) which was used as a test voltage regulator applied to the polymer insulator. High Voltage Amplifier in the form of (HVT) was used as a high voltage generator which was used as a test voltage [16] with a ratio of 1: 2000 Volt (peak to peak). An oscilloscope (Tektronix, DPO 5104) was used to display the input voltage via a voltage probe (Tektronix, P6015A) as well as the leakage current through the insulator and also the PD activity was recorded by the PD detector. The high voltage of the transformer through 25MΩ series resistance enters the 4000 pF insulator and capacitor filling. If there was a PD on the insulator then the capacitor has removed the charge so that the PD detector would detect the PD occurrences and then the PD activity was displayed in the oscilloscope. Voltage probe with a ratio of 1: 1000 V was used as a working voltage/test detector applied during testing. Leakage current was calculated based on a voltage read by an oscilloscope on a 47 kΩ shunt resistor [5, 8, 17] which was in series with the insulator. The purpose of using a

47 kΩ sampling resistor was that the leakage current signal can be detected properly for a high voltage range of 10 kV to 24 kV [7]. Thermal camera from Thermograph FLIR A-600 series was used to capture thermal images and then stored and processed to predict leakage currents with ANFIS intelligent systems via laptop [17].

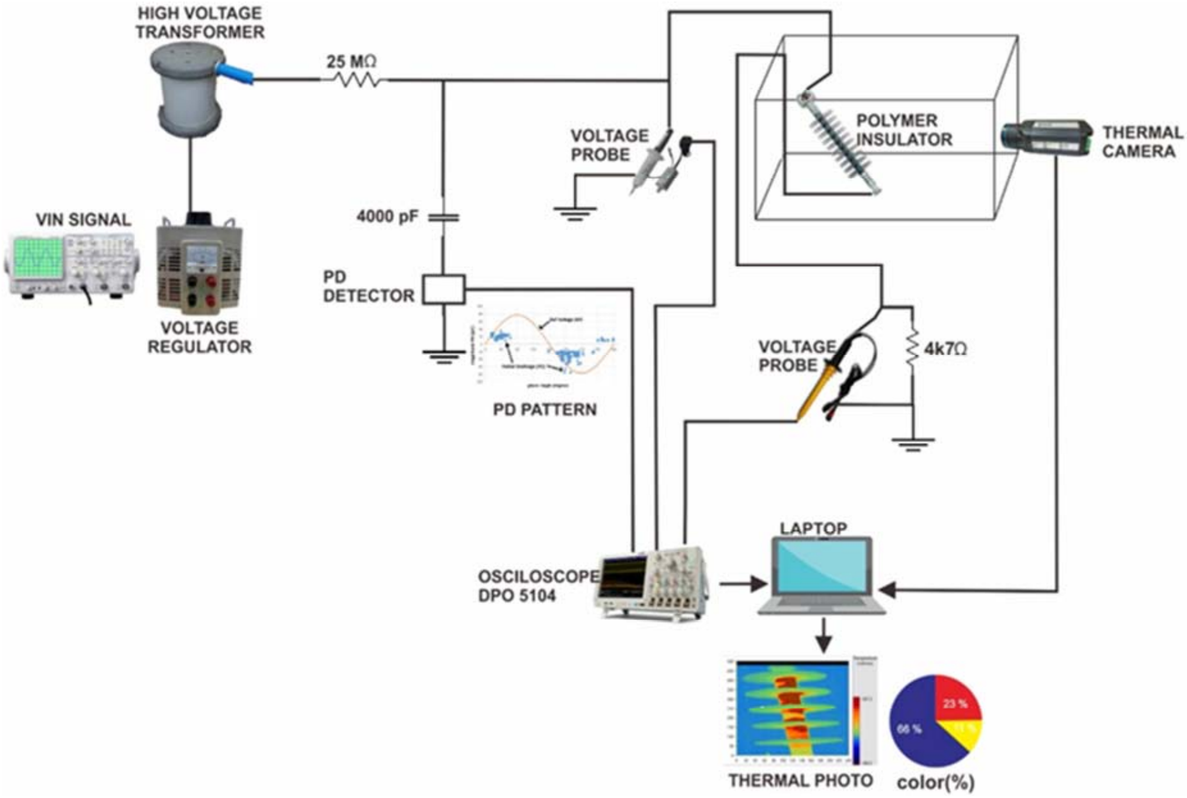


Figure 2. *A schematic diagram of the experimental setup.*

3. Results and Discussion

Figure 3 shows the thermal output of an infrared camera with a voltage of 18kV applied to a polymeric insulator. The thermal graph increased from 318°K to 339.9°K as shown in Figure 4. The color of the thermal photo is red, yellow and blue where the color will be changed based on the benchmark for the appearance of red.

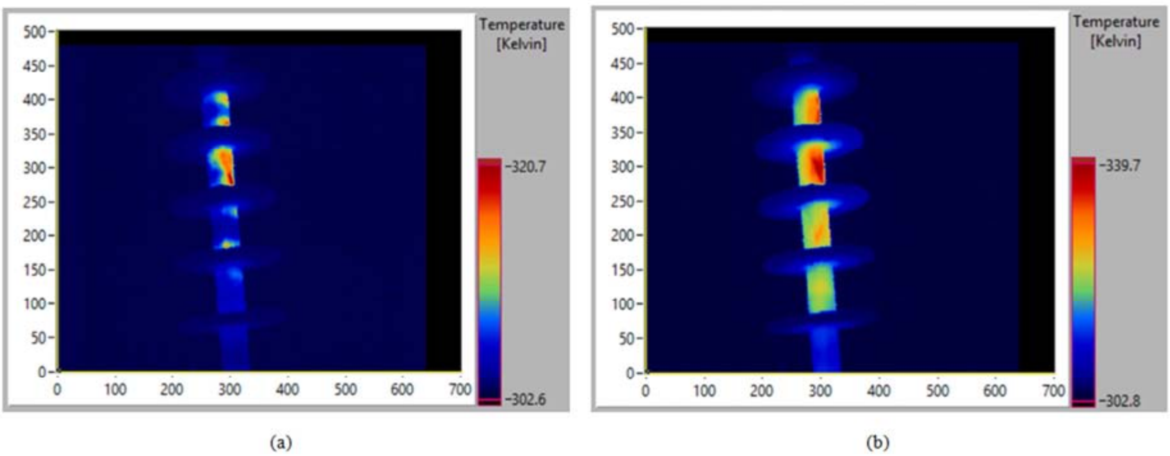


Figure 3. *Very high contaminated polymeric insulator (a) thermal 320.7°K (b) thermal 339.7°K.*

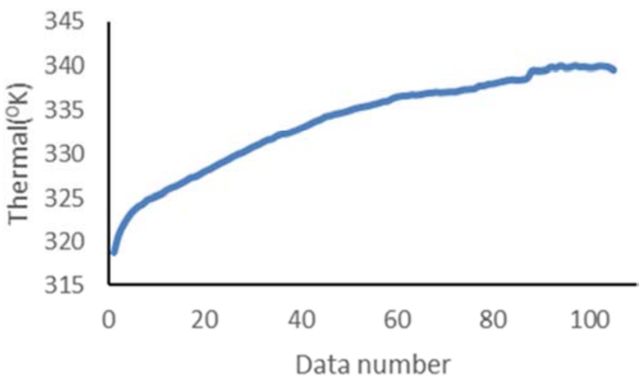
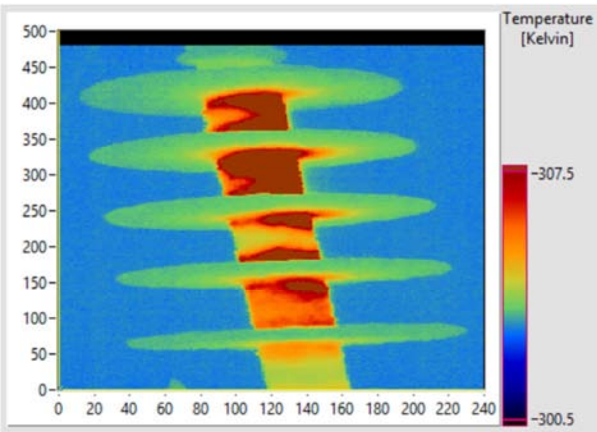
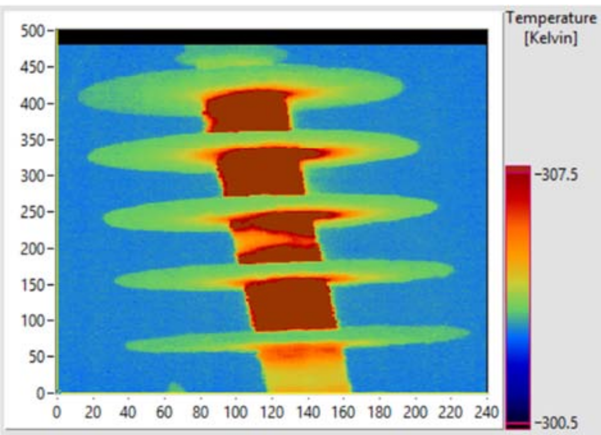


Figure 4. *Graph thermal insulator polymer.*

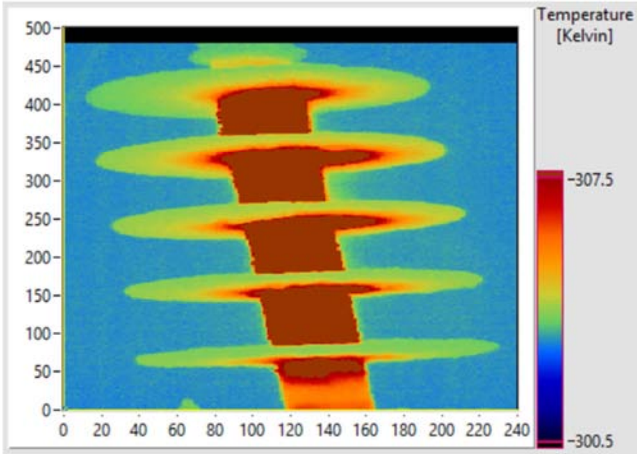
Figure 5 shows the thermal surface of the polymer insulator from an infrared camera for 5 different thermals. With standard red vision at 307.5°K and the color of polymer thermal insulator is divided into 3 colors namely blue (including greenish green) yellow and red (not including blue background).



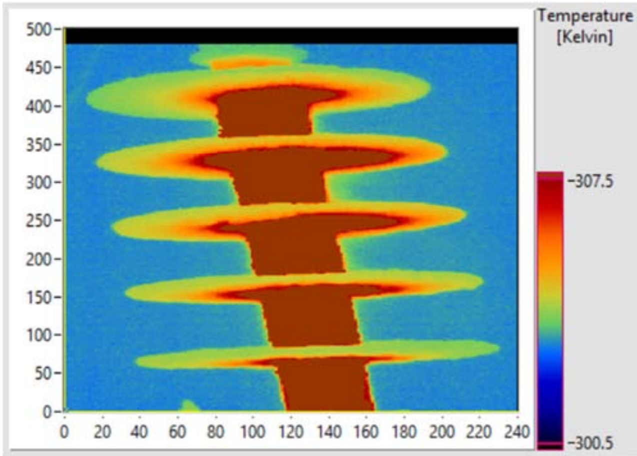
(a)



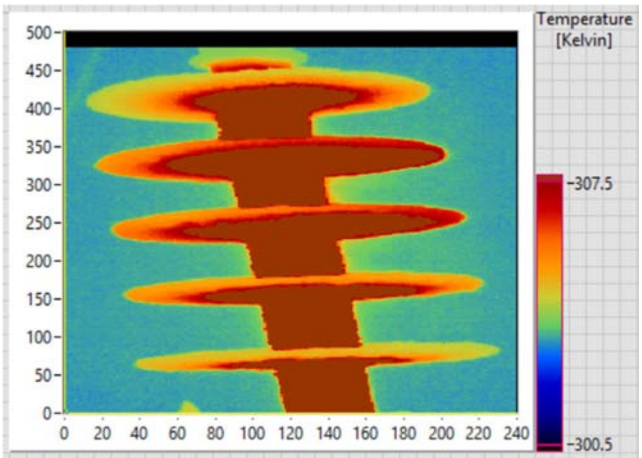
(b)



(c)



(d)



(e)

Figure 5. *Very high contaminated polymer insulators at surfaces Thermal (a). 320°K (b). 325°K (c). 330°K (d). 335°K (e). 340°K.*

The length and width of the reddish insulator surface of figure 5 based on LabView Pre-processed Thermal Image are like table 1.

Table 1. *Data on the length and width of the insulator surface are reddish.*

Thermal	**Size**		**Category**
	Long	**Wide**	
320°K	0.41	0.15	Secure, length ≤ 0.5
325°K	0.68	1	Danger, length > 0.67
330°K	0.78	1	Danger, length > 0.67
335°K	0.82	0.4	Danger, length > 0.67
340°K	0.95	0.58	Danger, length > 0.67

Based on table 1, it can be concluded that when thermal 320°K is included in the Safe category, while thermal 325°K, 330°K, 335°K and 340°K are categorized as Dangerous. When said isolator is categorized as dangerous because the leakage current is close to 50 mA or includes the Safe stage in the first 24 minutes of the experiment [19]. Guided by the classification of leaky currents [19], the experiments with insulating surfaces were very high polluted and 20 minutes of testing were carried out showing thermal increasing in the dangerous category so that flashover would occur after 28 minutes if the experiment continued. This is because when testing relative humidity (RH) can always wet the surface of the insulator with an 18kV test voltage. Therefore, contamination flashover must be prevented as soon as possible, in advance, during the Safe phase the test is not carried out any longer besides the sound due to the PD gets harder.

By using Labview, the percentage of color is proportional to the leakage current, the greater the leakage current, the larger the red area as seen in Figure 6.

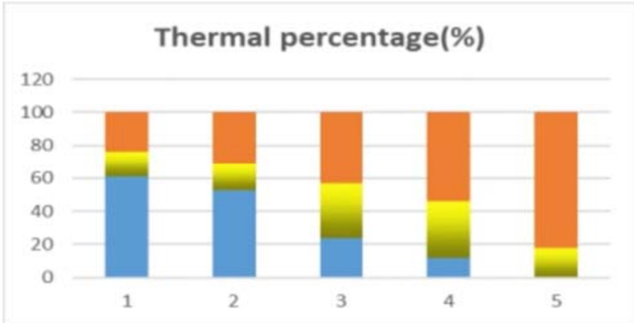
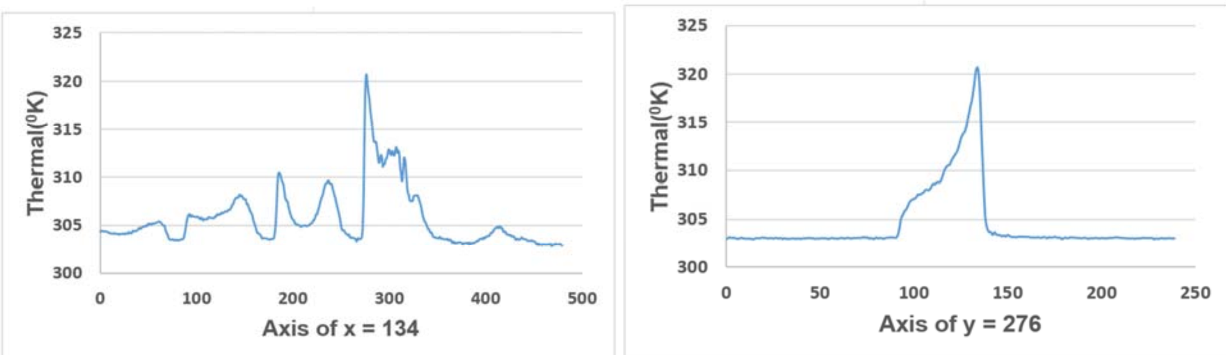
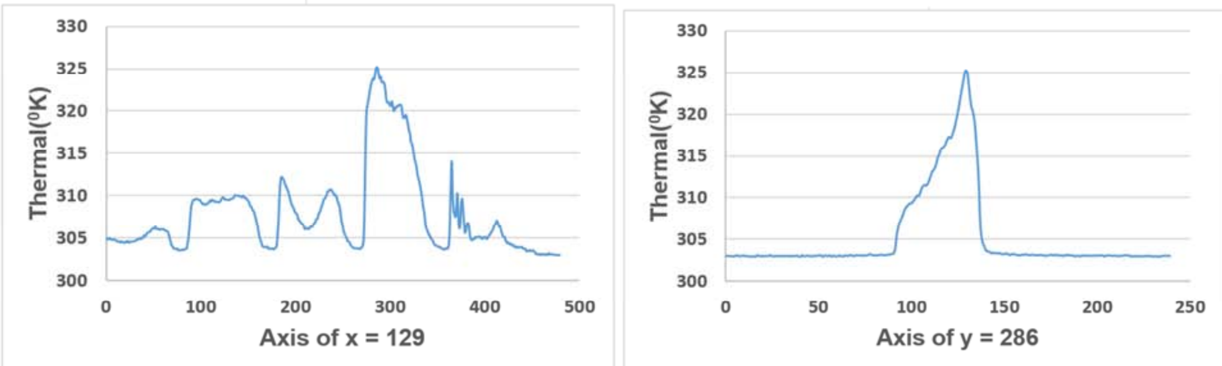


Figure 6. *Thermal percentage.*

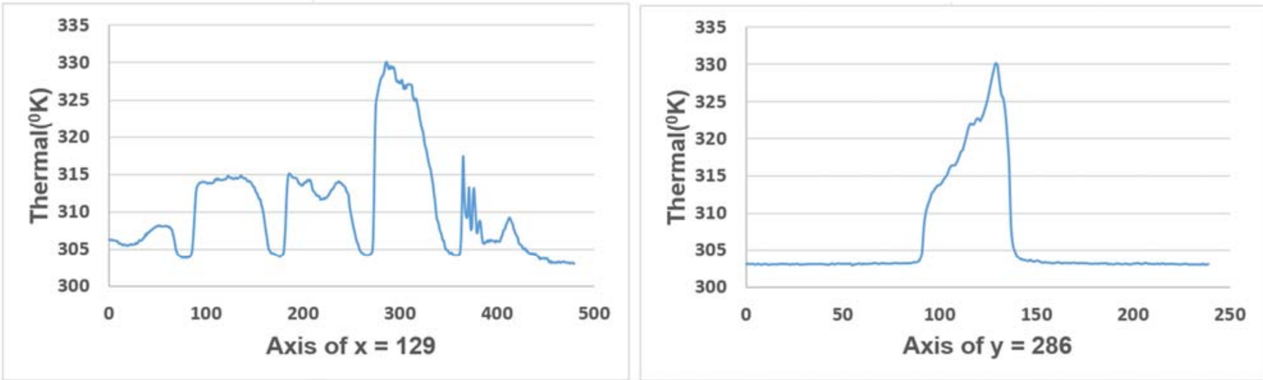
The maximum thermal when viewed from the x-axis and y-axis as Figure 7. With the increasing red area based on the x-axis and y-axis, it will make the leakage current of the insulator is greater. Based on the x-axis, the larger the thermal surface of the red insulator the greater the leakage current and finally can make a flashover.



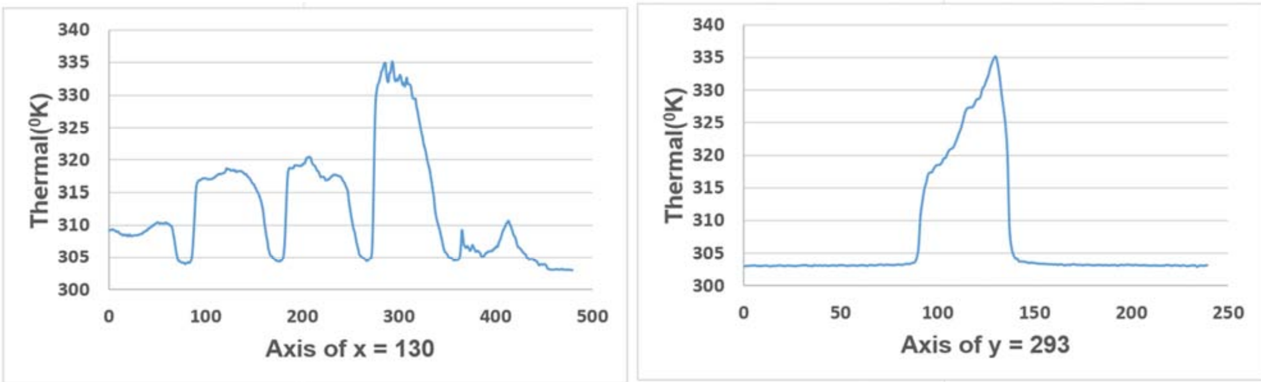
(a)



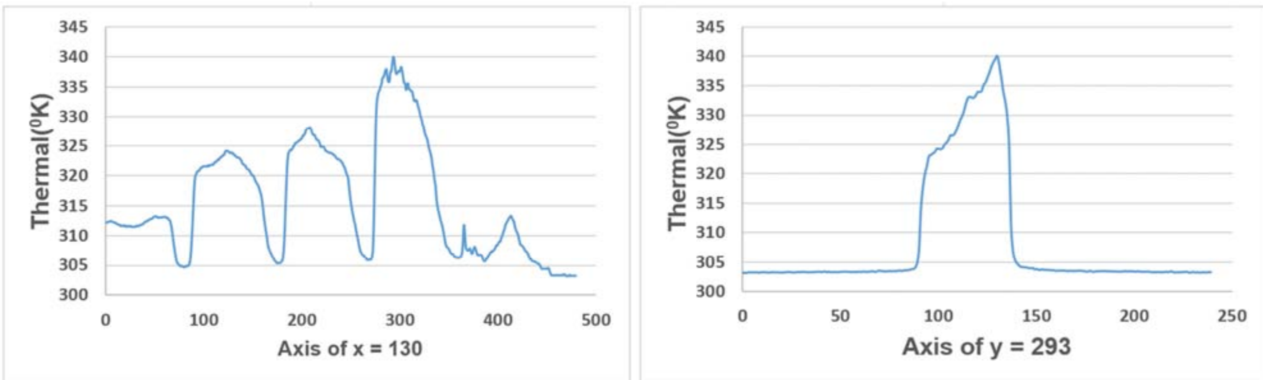
(b)



(c)



(d)



(e)

Figure 7. *Graph of Thermal surfaces at (a) 320°K (b) 325°K (c) 330°K (d) 335°K (e) 340°K.*

By using a fuzzy combined method with neural network (ANFIS) in Matlab, it can be estimated that the leakage of polymer isolator current with ANFIS input data is currentbocor.dat as shown in Table 2. This current of dcor.dat is ANFIS input data from previous studies on polluted polymer insulators very high.

Table 2. *Percentage of color data and output of insulator leakage current.*

No.	LabView Processed Image (%)			Measured Leakage current (mA)
	Red	Yellow	Blue	
1	6	12	82	4.2
2	23	11	66	14
3	30	15	55	24
4	39	12	49	47

With ANFIS neural structure as shown in Figure 8 with a number of rule fuzzy = 27 and hidden layer 27 neurons, the training can be done that results in very small errors (RMSE = 0.00008) as seen in Figure 9.

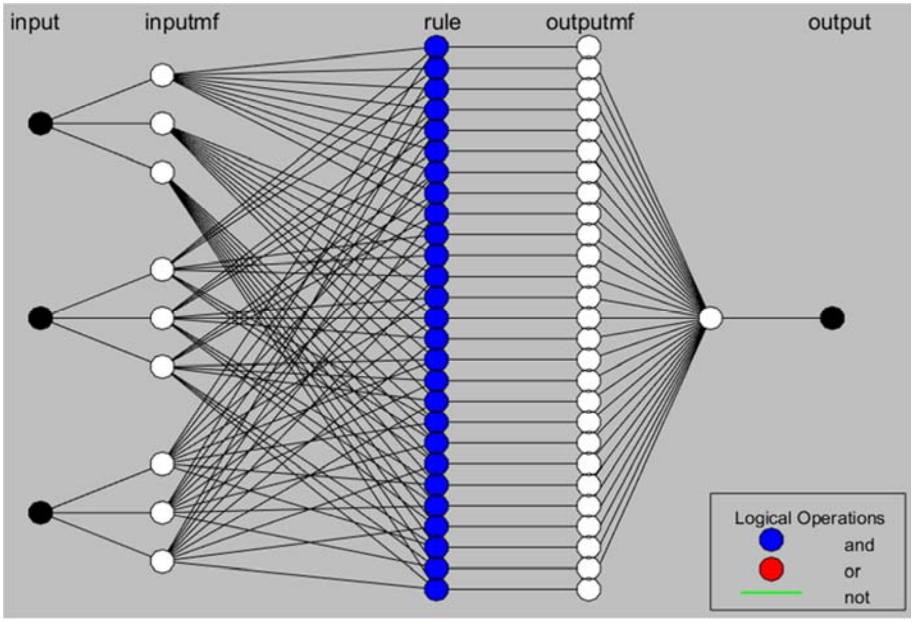


Figure 8. *Struktur neuron pada ANFIS.*

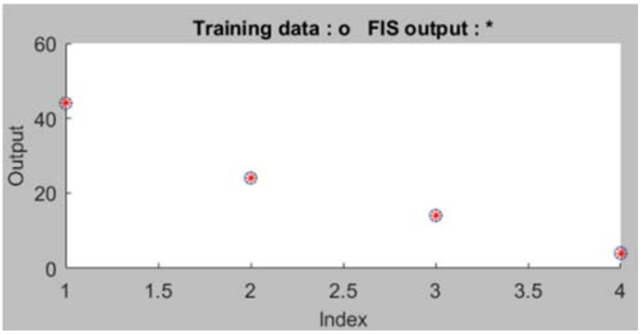


Figure 9. *ANFIS performance testing chart with initial training data.*

The surface viewer generated as Figure 10.

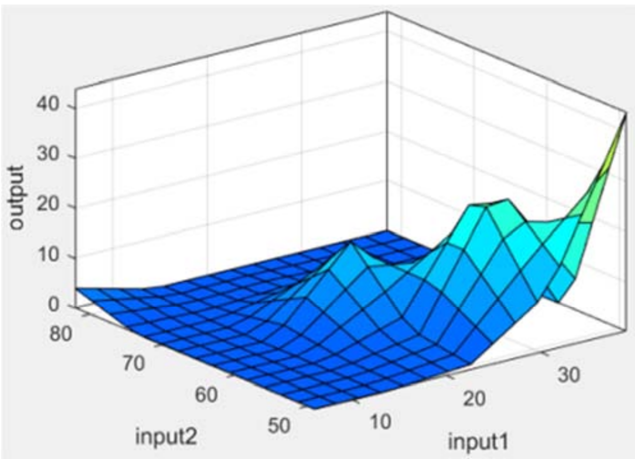


Figure 10. *Surface viewer arusbocor.*

Testing Sugeno fuzzy program that has been made using ANFIS is by typing fis = readfis ('curriculum') then MATLAB will load the created FIS. Furthermore, to test with thermal percentage input using *evalfis* instruction such as Figure 11.

```
>> fis=readfis('arusbocor3_anfis')

fis =

  struct with fields:

            name: 'arusbocor3_anfis'
            type: 'sugeno'
       andMethod: 'prod'
        orMethod: 'probor'
    defuzzMethod: 'wtaver'
       impMethod: 'prod'
       aggMethod: 'sum'
           input: [1×2 struct]
          output: [1×1 struct]
            rule: [1×9 struct]

>> arusbocor=evalfis([24 61],fis)

arusbocor =

   16.2233
```

Figure 11. *Evalfis instruction.*

4. Conclusion

Pre-processed using LabView for thermal images of very high pollutant polymer insulators that will accelerate the process of estimating leakage currents in a non-contact manner. Pre-processing produces a percentage of red, yellow and blue as input from the ANFIS method. Correspondingly, it is necessary to classify leaky currents to determine the classification of insulators in the Safe, Forecast or Danger stages. For classification of Safe stages (current leakage <50 mA) also need to classify the flow of leak isolators in the category of Safe, Maintenance or Danger. Safe stage classification with Maintenance and Danger categories is the time that technicians can use to prevent flahover from insulators. This time it can be used by technicians to clean insulators from pollutants. Forecasting leaky currents based on thermal insulators of polymer insulators using the ANFIS method was successfully applied and the ANFIS method can accelerate the process of introducing leakage current values with acceptable accuracy.

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