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Fuzzy Logic-based Integrated Cooling System to Improve PV Efficiency

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Abstract— Photovoltaic (PV) temperature is an important parameter that can influence PV performance. The increase in PV temperature can cause a drop in PV output voltage, which indicates that the PV does not operate optimally. In this paper, a design of an integrated cooling system based on fuzzy logic to control the PV temperature is presented. This, in effect, will potentially ensure that the PV performance is at its maximum condition. In this work, the temperature of the PV is kept constant by attaching a cooling system that carries water inside it. The constant temperature of the cooling system is carried out through a radiator and thermoelectric with electronic control. The experiments are carried out using two 320-watt PV systems; one with the cooling mechanism and the latter without the cooling system as a control. Several important data such as temperature, voltage, current, and radiation measurement in each PV were collected for three days from 10:00 to 17:00 with an interval of 10 minutes for each measurement. The results of the integrated cooling system measurement showed an increase in PV power generation and efficiency of 1.32% compared to the control PV unit. From the results of the study, it can be concluded that the fuzzy logic-controlled cooling system contributed to the increase in PV performance.

Keywords: Integrated Cooling System, Fuzzy Logic, PV efficiency

1. Introduction

Implementation Implementation of renewable energy sources (RES) promotes decreasing carbon emissions, air pollution and preserving the supply of sustainable energy. Solar photovoltaics (PV) and Wind turbines (WT) are mostly used in recent years since their cost have gradually waned today, are ever-growing, and are environmentally friendly [1]. Based on the report of Renewable Energy Policy Network report (REN21), the capacity of global generation from WT and PV energy resources increased significantly from 2007 until 2020 almost 8-fold and 95-fold, respectively. Figure 1 shows the WT and PV installation in ten years from 2011, the PV technology exceeds the WT technology amount 17 GW [2]. The International Energy Agency (IEA) says that PV has a contribution of about 11% of the total RES over the world. This percentage means PV reduces the emission of CO2 by about 2,3 Gigatonnes every year [3].

Although PV has a large part in sustainable energy, it has an efficiency issue. Although in theory, the highest efficiency of PV can reach 29%, but in commercial products, the efficiency only reaches until 26% [4]. Various factors were influential to efficiencies like installation, construction, operation and maintenance, and environment. Environmental factors greatly affect the performance and efficiency of PV, such as radiation, amount of dust, dirt, wind, shadows, humidity, and temperature [5]. Sunlight is the source needed to generate electricity with a PV system. However, more sunlight means a higher temperature, and regardless of the requirement of the amount of

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sunlight, the temperature affects the PV panel efficiency [6]. The standard efficiency of the PV is tested in the standard temperature due 25ºC. When the PV temperature rise up above 25º C, the efficiency will go down [7]. It is known that a one-degree rise in temperature will decrease the 0,45% efficiency of PV [8]. This impact will make more efficiency drop since the temperature of PV increases to 80ºC especially in the summer [9]. To avoid overheating the PV panel, a cooling system is used, the passive or active cooling system [10]. The technique of passive cooling is the system without special power to operate like conductive, air passive and water passive cooling [11]. The active cooling system need a pump to spray the water or fan to blow the air.

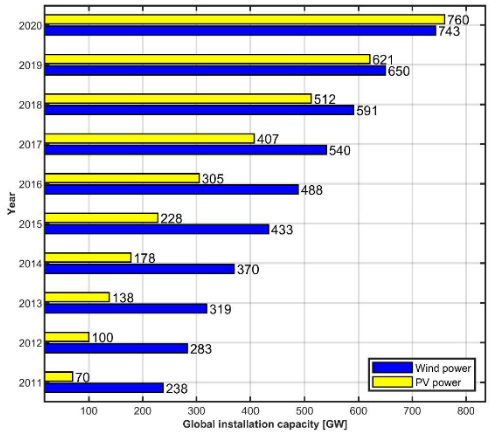


Figure 1. The Global Capacity of PV and Wind Installed Power Generation 2011-2020

The active cooling system is an effective technique to improve the PV efficiency beside it has the additional power to operate the system [12]. The intelligent based-control is the solution to optimize the active cooling system from technical and economic aspect [13]. In [14], the active cooling system can increase the PV efficiency around 12%-14% from 8%-9% whithout cooling system. The airflow used to cooling the 55 watt polycrystalline of PV from under side. By this cooling system, the PV temperature can keep constant at 38ºC with efficiency of electricity 12,5%. Without cooling system, the temperature was high until 68ºC and the efficiency go down until 8,6%. Comparison of PV cooling system between passive use heatsink and active by water cooler use dc motor to drive a pump in tropical area. Three polycrystalline PV modul 100 Wp was classified by normal, passive, and active cooling system. The output power each PV modul was test in the same time and condition. The result of the research declare the PV output power with active and passive cooling system are 8,64 Watt and 2,7 Watt more than the output power PV without cooling system. In the economic side, the passive has the advantages since no need power. But the automatic active cooling system becomes more effective because it will reduce the power consumptionn when cloudly or low irradiation in the morning or in the afternoon [15]. In [16] The pump was used to spray a thin film of water to front 1080 KW PV array continoustly. The increasing of PV efficiency was 17.8% for the active cooling system work along a day. The others research show that the affordability of active cooling system dan passive cooling system can reduce the temperature until 30ºC down and 20ºC recpectively. The other hand, an active cooling system can improve the efficiency up to 22% and the passive cooling system up to 15% [17].

Thermoelectric and water used in an active cooling system to improve the PV efficiency [18], [19]. The flow of water to cooling the PV can set at two method due to by open loop control or close loop control. The water will accros to front PV continuously at the open loop control mode. In the close loop mode, the water flow depent on the temperature setting. The sensor send the information to the controller and then pump will turn on to forced the water when the PV temperature above the setting [20], [21], [22]. In the case thermoelectric as coolant the PV, the controller will control the voltage of thermoelectric to respon the change temperature become the energy to coolant [23], [24]. Many method used to control the system like the artificial intelligence (AI). These technique such as nueral network and fuzzy logic controller have been used to improve the efficiency and performance the renewable energy system [25], [26]. The PID and Fuzzy-PID techniques have applied to improve the energy efficiency of PV cooling system [27]. The PV efficiency was increasing significantly by using the neuro-fuzzy based MPPT hybrid cooling system . Based on the background, this research use combination of water and thermoelectric together in the PV cooling system. Design of an integrated cooling system based on fuzzy logic to control the PV temperature is presented. The active cooling system use water and thermoelectric as coolant material. The system will working in the close loop control by arduino mega 2560 with fuzzy logic as a controller to keep the temperature of PV to improve it power output and efficiency.

2. Method

The research has been done in three main steps (1) design of the hardware of the cooling system, (2) design the software of the cooling system, and (3) testing and collecting the data.

2.1 Design The Hardware Of Cooling System

The aim of this step is to define how does the system work and design all of the hardware used in the system. The proteus software, diptrace software and AutoCAD were used along to design the hardware. The proteus software help to draw and simulate the electronic circuit, and AutoCAD software help to draw the cooling system block diagram. Several electronic circuits are (1) a schematic diagram of the cooling system, (2) a schematic diagram of the voltage sensor, (3) a schematic diagram of the relay module, (4) a schematic diagram of LCD 16x2 and I2C, (5) schematic diagram of DS18B20 sensor, (6) schematic diagram of a motor driver module and thermoelectric cooler, (7) schematic diagram of DHT11 module, (8) schematic diagram of RTC and Micro SD. Diptrace software is used to design the layout of the PCB.

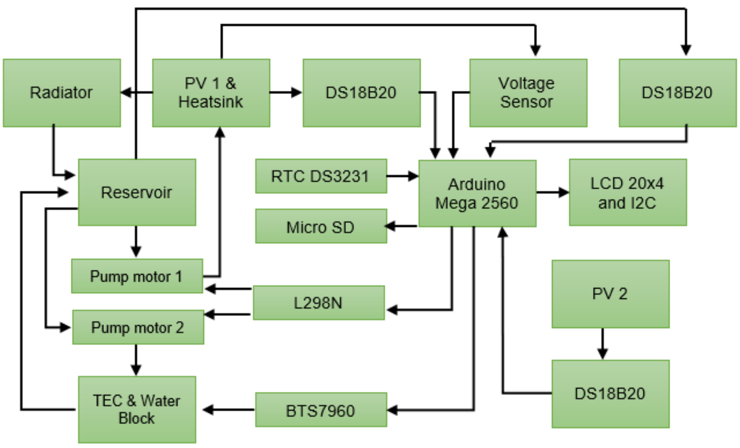


Figure 2. The Cooling System Block Diagram

Based on Figure 2, the Arduino mega 2560 control the speed of pump-motor 1, pump-motor 2, and thermoelectric. The speed of pump-motor and thermoelectric condition controlled by pulse width modulation (PWM) from Arduino Mega 2560. The Fuzzy Logic Controller use Mamdani method to control the system based on the temperature fluctuation on the PV. The triangle curve representatiton is used to show the input and output face. The triangle membership function can define by equation (1).

$$\mu[x]\begin{Bmatrix} 0; x \leq a \; atau \; x \geq c \\ \frac{(x-a)}{(b-a)}; a \leq x \leq b \\ \frac{(c-x)}{(c-b)}; b \leq x \leq c \end{Bmatrix} \quad (1)$$

The circulation of water in the cooling system will blowup the hot temperature at the heatsink. The hot of the water blowup to the air by the radiator and the water will be cooled by the thermoelectric cooler. The circulation of the water on the cooling system is as shown in Figure 3.

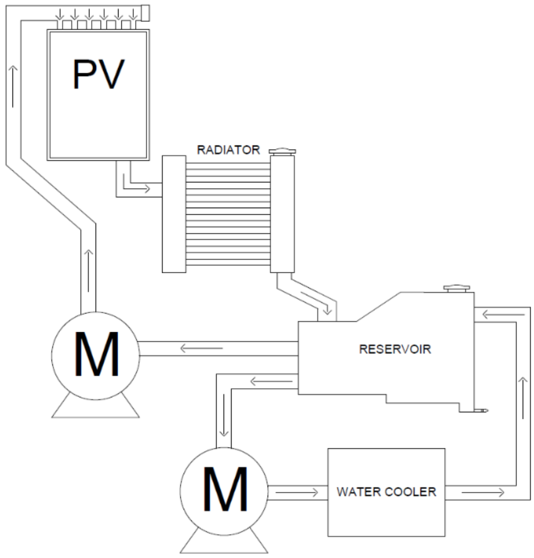


Figure 3. The Circulation Of Water In The Cooling System

2.2 Design of Cooling System Software

The objective of this step is to implementation of fuzzy logic to Arduino mega 2560. The IDE Arduino version 1.8.6 software is used to program the Arduino mega 2560 and Matlab software to simulate the fuzzy logic Mamdani method. Figure 4 shows the flowchart of the EFLL fuzzy logic in Arduino.

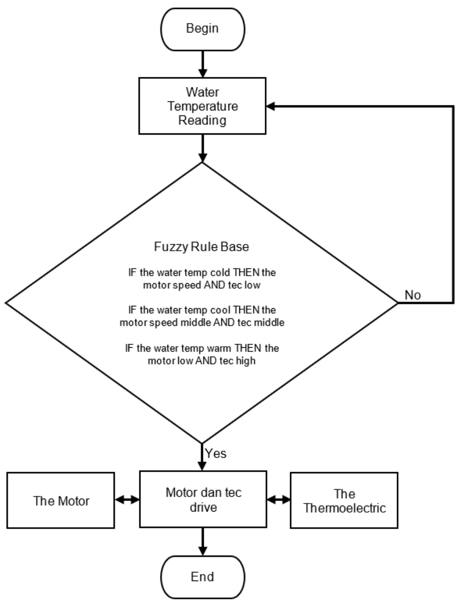
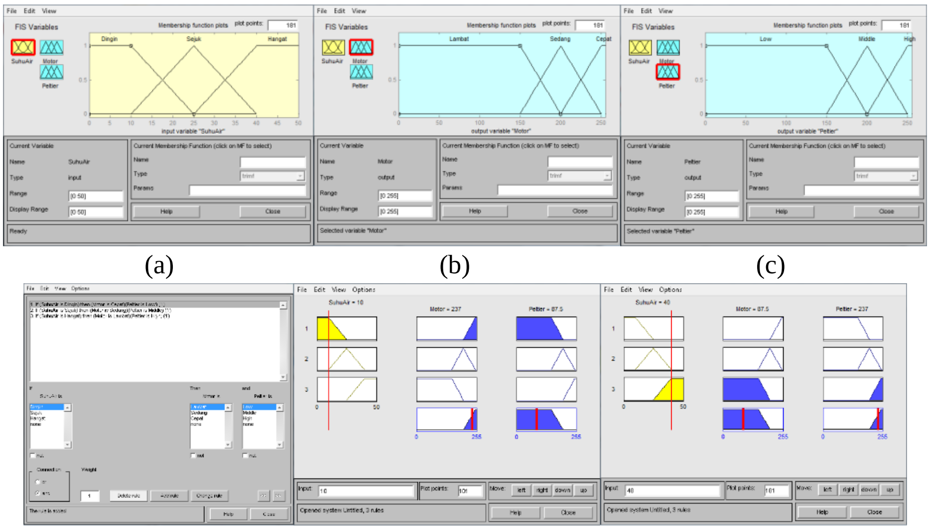


Figure 4. The flowchart of EFLL Fuzzy Logic in Arduino

Based on Figure 4, the water temperature is fuzzy logic input, and the motor and thermoelectric as the output of fuzzy logic. The rule base fuzzy in this research are (1) rule 1; If water temperature is cool Then motor fast and Tec low, (2) rule 2; If water temperature is fresh Then motor middle and Tec middle, (3) rule 3; If water temperature is hot Then motor low and Tec high.



(a) (b) (c)

(d) (e) (f)

Figure 5. (a) The Input Set and Fuzzy Member, (b) The Motor Output Set and Fuzzy Member, (c) The TEC Output Set and Fuzzy Member, (d) Fuzzy Rule Base, (e), (f) Fuzzy Rule View

2.3 Testing And Collecting The Data

The experiment was done at Latitude -6.35°S, Longitude 109. 69°, Altitude 65 m , Tilt angle 7°, and Azimuth 20°. There are two PV panels monocrystalline that are used, with output power 320 Wp and Vmp 37,28 Volt. Testing and collecting were done over three days over seven hours from 10.00 until 17.00 in real-time with an interval of ten minutes per data. The data consist of solar irradiation, pv temperature, water temperature, motor pwm, TEC pwm, PV Voltage, PV Current, PV Power, and PV Efficiency. The solar irradiation was measured by a solar power meter (SPM) in W/m^2. The PV temperature and water temperature are collected from the digital temperature sensor DS18B20 in °C. The PV Voltage and PV current are collected from the voltage sensor. PV Power and Pv efficiency are calculated by the formula (2) and (3).

$$P = V \times I \qquad (2)$$

$$\eta = \left(\frac{V\,max x I max}{G x Ac} x(100\%)\right) \qquad (3)$$

3. Result and Discussion

3.1 Solar Irradiation Measurement

Figure 6 shows a graph of sunlight intensity during data collection. On the first day, it is known that the average solar radiation intensity is 693.3w/m2 and has the highest solar radiation intensity of 1039w/m2 occurring at 12:10, and has the lowest solar radiation intensity of 172.4w/m2 occurring at 17:00 . From these results it can be said, where hot weather conditions occur four times, cloudy weather conditions occur twice, whereas sunny weather conditions dominate on day 1, as well as conditions where the sun's position is always moving and the sun's conditions are sometimes covered with clouds. can affect the intensity of solar radiation that leads directly to the solar panel. On the second day, it is known that the average solar radiation intensity is 687.9w/m2 and has the highest solar radiation intensity of 995.4w/m2 occurring at 11:20 a.m., and has the lowest solar radiation intensity of 57.4w/m2 occurring at 17:00: 00. From these results it can be said, where the hot weather conditions did not exist because at that time the weather was slightly cloudy and sunny, cloudy weather conditions occurred four times, whereas for sunny weather conditions it did not dominate on day 2 because sunny weather could change at any time being slightly overcast, as well as the position of the sun which is always moving and the condition of the sun which is sometimes covered with clouds can affect the intensity of the sun's radiation which leads directly to the solar panels. On the third day, it is known that the average solar radiation intensity is 625w/m2 and has the highest solar radiation intensity of 1118w/m2 occurring at 11:10, and has the lowest solar radiation intensity of 50.7w/m2 occurring at 17:00. From these results it can be said, where hot weather conditions occur six times, cloudy weather conditions occur five times, whereas sunny weather conditions dominate on day 3, as well as conditions where the sun's position is always moving and the sun's conditions are sometimes covered with clouds. can affect the intensity of solar radiation that leads directly to the solar panel.

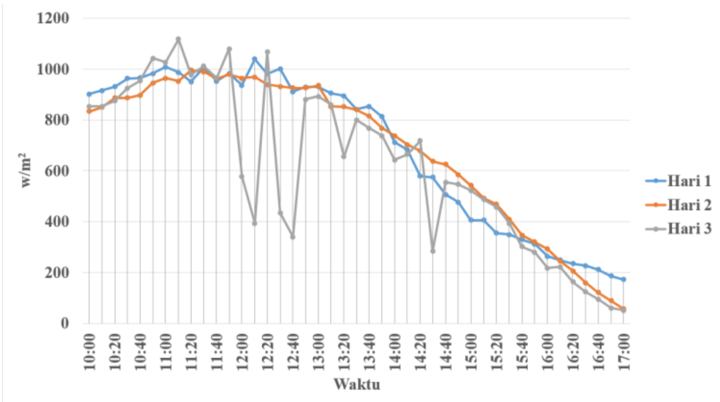
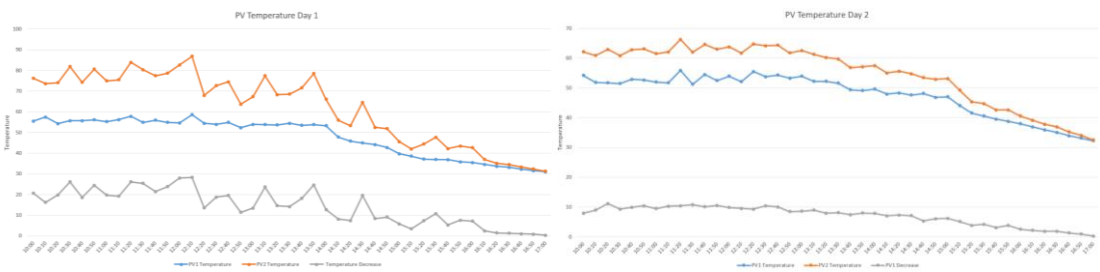


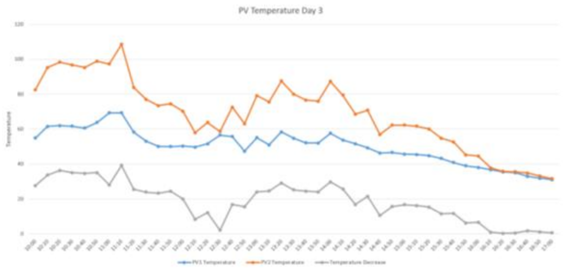
Figure 6. Solar Irradiation

3.2 PV Temperature Measurement

The objective of PV temperature measurement is to see how far the cooling sistem can reduce the temperature of PV a long it operation. This solar panel temperature measurement aims to determine the difference in the temperature of solar panels that use a cooling system and those that do not use a cooling system, where PV1 uses a cooling system and PV2 does not use a cooling system, the results of solar panel temperature measurements are carried out using a digital temperature sensor, namely DS18B20 with OC units. The results of solar panel temperature measurements for 3 days are shown in Figure 7.



(a) (b)



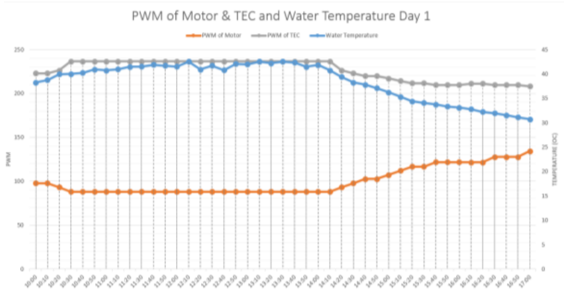
(c)

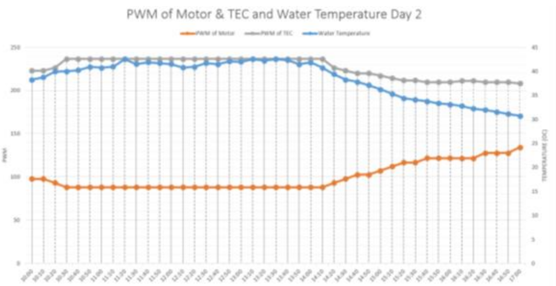
Figure 7. (a) PV Temperature Day 1, (b) PV Temperature Day 2, (c) PV Temperature Day 3

From the experiment, on Figure 7 (a) the highest different temperature between PV 1 and PV2 is 28,24ºC while the PV 2 and PV1 temperature is 86,87^{0}C and 58,63^{0}C with average 14,19 ºC along a day. On Figure 7 (b) the highest different temperature between PV 1 and PV2 is 11,19ºC while the PV 2 and PV1 temperature is 66,31^{0}C and 55,88^{0}C with average 7,08 ºC along a day. On Figure 7 (c) the highest different temperature between PV 1 and PV2 is 39,2ºC while the PV 2 and PV1 temperature is 108,5^{0}C and 69,3^{0}C with average 18,68 ºC along a day.

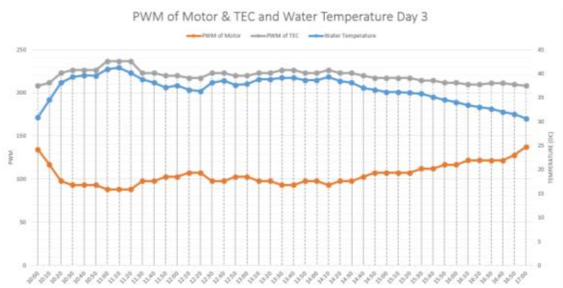
3.3 Water Temperature

Water temperature depend on the fluctuation of PV temperature. The measurement of water temperature as shown on Figure 8 (a), (b), and (c). Since the water circulation in the cooling system, the water temperature will give the effect to PWM of motor and PWM of TEC.





(a) (b)



(c)

Figure 8. (a) Water Temperature Day 1, (b) WaterTemperature Day 2, (c) PV Temperature Day 3

The highest and the lowest water temperature is 42,5ºC and 30,6ºC as show in Figure 8.(a), the highest and the lowest PWM of motor is 134,7 and 88,1, and also the highest and the lowest PWM of TEC is 236,53 and 208,15. From Figure 8.(b) the highest and the lowest water temperature is 42,5ºC and 30,6ºC, the highest and the lowest PWM of motor is 121,65 and 88,1, and also the highest and the lowest PWM of TEC is 236,53 and 209,49. From Figure 8.(c) the highest and the lowest water temperature is 41,2ºC and 30,6ºC, the highest and the lowest PWM of motor is 137,37 and 88,1, and also the highest and the lowest PWM of TEC is 236,53 and 208,15.

3.4 PV Voltage, Current, and Power

Measurements of voltage and current of solar panels are carried out directly using a multimeter. Meanwhile, solar panel power is calculated using the dc power equation, which is the product of voltage and current multiplication.

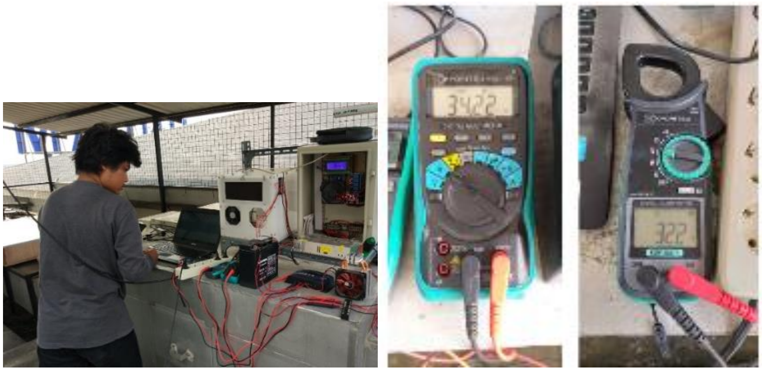
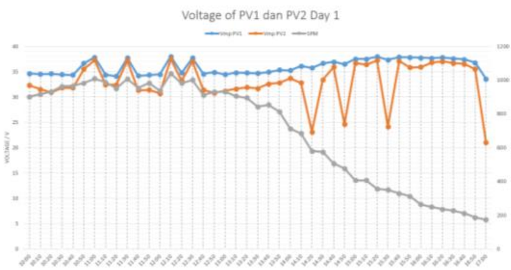
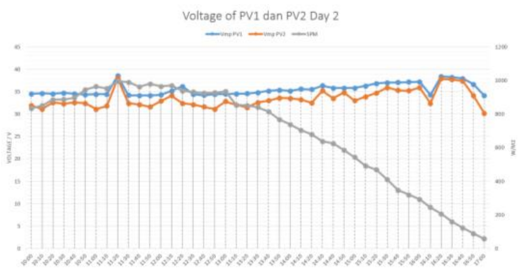


Figure 9. Voltage Measurement of Solar Panels 1 and Solar Panels 2

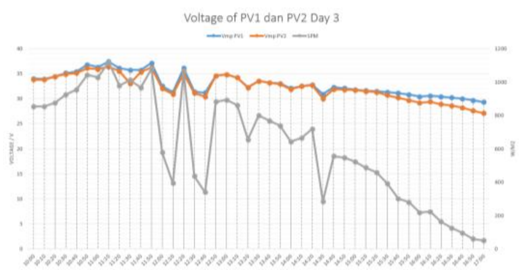
PV1 power on day 1 has an average of 309.3 watts and has a highest power of 326.8 watts occurring at 12:10 and has the lowest power of 288.5 watts occurring at 17:00, while PV2 power has an average of 283.6 watts and has the highest power of 322.5 watts occurred at 12:10 and has the lowest power of 180.6 watts occurred at 17:00. PV1 power on day 2 has an average of 305.1 watts and has a highest power of 331.6 watts occurring at 11:20 and has the lowest power of 293.2 watts occurring at 17:00, while PV2 power has an average of 287.1 watts and has the highest power of 326.8 watts occurred at 11:20 and has the lowest power of 259.7 watts occurred at 17:00. PV1 power on day 3 has an average of 283.4 watts and has a highest power of 321.6 watts occurring at 11:10 and has the lowest power of 251.9 watts occurring at 17:00, while PV2 power has an average of 278 watts and having the highest power of 313 watts occurred at 11:10 and having the lowest power of 233 watts occurred at 17:00. The graph of the difference in the power of solar panel 1 and the power of solar panels for 3 days is as shown in Figure 10. From Figure 10 it is found that there is a power difference of 16.3 Watt between solar panel 1 and solar panel 2.



(a)



(b)



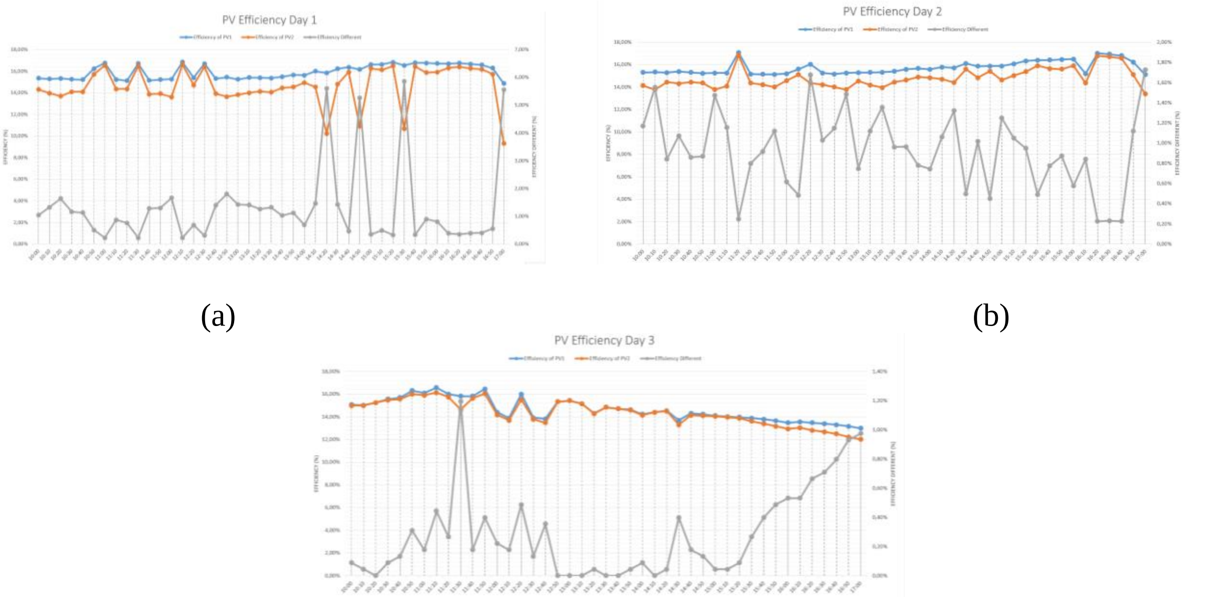
(c)

Figure 10. (a) PV Temperature Day 1, (b) PV Temperature Day 2, (c) PV Temperature Day 3

3.5 PV Efficiency

Calculation of the comparison of the overall difference between PV1 power efficiency and PV2 power efficiency is carried out to determine the effectiveness of the cooling system on PV1 power efficiency to improve the performance of solar panel power efficiency on the power efficiency produced by solar panels. Calculation of the difference between PV1's power efficiency and PV2's power efficiency by subtracting the average power efficiency produced by PV1 with the average power efficiency produced by PV2 and adding up the results of reducing PV1's power efficiency against PV2's power efficiency for 1 day, this is done for 3 days as in Figure 11 the difference between PV1 power efficiency and PV2 power efficiency based on average power efficiency.

On day 1, the average power efficiency produced by PV1 was 15.94% and the average power efficiency produced by PV2 was 14.62%, from the results of reducing the average power efficiency of PV1 to the average power efficiency of PV2, the difference in power efficiency was 1.32 %, so on day 1, PV1 using a cooling system experienced an increase in power efficiency of 1.32%. On day 2, the average power efficiency produced by PV1 was 15.73% and the average power efficiency produced by PV2 was 14.80%, from the results of reducing the average power efficiency of PV1 to the average power efficiency of PV2, the difference in power efficiency was 0.93 %, so on day 2, PV1 using a cooling system experienced an increase in power efficiency of 0.93%. On day 3, the average power efficiency produced by PV1 was 14.61% and the average power efficiency produced by PV2 was 14.33%, from the results of reducing the average power efficiency of PV1 to the average power efficiency of PV2, the difference in power efficiency was 0.28 %, so on day 3, PV1 using a cooling system experienced an increase in power efficiency of 0.28%.



(a) (b)

(c)

Figure 11. (a) PV Efficiency Day 1, (b) PV Efficiency Day 2, (c) PV Efficiency Day 3

4. Conclusion

The conclusion of the research results is that the power generated by PV1 using a cooling system is 309.3 watts, and the power generated by PV2 which does not use a cooling system is 283.6 watts, and has a power difference of 25.6 watts, meaning that solar panels using a cooling system experience an increase in power, with a panel area solar area of 1.94 m2. The power efficiency produced by PV1 using a cooling system is 15.94%, and the power efficiency produced by PV2 which is not using a cooling system is 14.62%, and has a difference in power efficiency of 1.32%, with a solar panel area of 1.94 m2. meaning that solar panels that use a cooling system experience an increase in power efficiency.

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