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The Development of Hybrid Cooling Photovoltaic Panel by using Active and Passive Cooling System

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ABSTRACT

Photovoltaic (PV) panel are crucial in the conversion of solar irradiance into electrical energy. However, the efficiency of PV panel is indirectly influenced by the surface temperature of the panels. According to typical PV module standards, the effect of panel temperature on efficiency is -0.47 %/°C, which indicates that a rise of 1°C reduces the PV panel's efficiency by 0.47 %. The efficiency of the PV panel achieves its maximum value when the panel temperature reaches 25 ℃, which is the standard test condition (STC). Moreover, a high working temperature can also reduce the lifetime of the PV panel. Based on the limitations that have been highlighted above, this project aims to design and develop a hybrid cooling PV panel by using active and passive cooling system with Arduino UNO R3. In this project, 100 W monocrystalline photovoltaic panel has been selected to analyze the result before and after installation of hybrid cooling system. Active cooling system is a water sprinkler system which is applied in front of the PV panel. Meanwhile, the passive cooling system is a combination of hydrogel beads and the heat-sink cooling system which will be installed behind the PV panel. In result, the average power output of PV panel without cooling was 30.59 W while the average power output of PV panel with hybrid cooling was 34.66 W. Moreover, the average power increased due to cooling was 13.31 %. In a nutshell, the proposed project has the ability to develop a hybrid cooling system to improve the performance and efficiency of the PV panel in order to increase the power output of the panel.

1. Introduction

Global energy consumption has recently been on the increase, with fossil fuels making up the majority of it. However, fossil fuel supplies are finite, and the greenhouse effect caused by their usage

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has become a constant source of environmental degradation and fine dust [1]. Therefore, new and renewable energy sources are being developed and researched to replace the consumption of fossil fuel [2]. Consequently, Malaysia aims to change power generation from fossil fuels to sustainable energy. According to the government, sustainable energy sources such as wind, geothermal, biomass, hydro, and solar energy are expected to account for 20 % of total output by 2025. Solar energy is the most widely used renewable energy source in the world [3]. Malaysia is in the tropical zone, with an average monthly sunlight length of 4 to 8 hours. So, solar energy has a very good potential in Malaysia. In addition, solar energy reduces human dependency on fossil fuel, hence lowering global warming [3].

Firstly, the problem that is encountered by PV panel is the performance or efficiency of the panel. The PV panel convert a limited wavelength of incoming irradiation into electrical energy with an electrical efficiency of 15 % – 20 %, while the remaining energy is wasted as thermal energy, causing the major problem of PV module heating, which increases the surface temperature and thus decreases the electrical efficiency [4]. According to typical PV module standards, PV panel's efficiency decreases about 0.47 % for 1 ℃ surface temperature increment because of the heat energy of sunlight. In short, the PV panel performance decreases by the appearance of heat form that injected temperature increment on the PV panel surface. Besides, another problem that faced by PV panel is the lifetime of the panel. In a long run of working time, the PV panel may face a further decrease in efficiency because of the increase in operating temperature of the panel that surpasses a particular threshold. Due to the high operating temperature, the life expectancy of PV panel might be shortened. Therefore, the appropriate approach and methodology with the cooling system is the correct way to get the greatest results, which leads to an improvement in cell longevity, efficiency and performance which decreases the possibility of panel destruction [5]. In closing, a cooling system is used to keep the PV panel's surface temperature from rising too high, which might cause the panel to destruction.

There are many environmental factors that affected the performance of the efficiency of PV panel. The factors that focused in this project were solar irradiance, dust and operating temperature of PV panel. Usha Mandadapu *et al.,* [6] conducted an experiment on the performance of the PV panel at different condition of solar irradiance. In this research, MATLAB was utilized to forecast the true behaviour of PV panel. By using simulation model of MATLAB, the open circuit voltage and short circuit current can be examined by varying the solar irradiance. A single diode model is being used to analyse the variations in the solar irradiance of the PV panel. Theoretically, the efficiency of a PV panel is influenced by the input variable solar irradiance. As a result, as the solar irradiance increases, the efficiency and maximum output power increases. This is because as the solar irradiance increases, the amount of the photons indenting in the PV panel increases. Then, it would produce more power and cause the efficiency of PV panel increase.

Julie C. Ogbulezie *et al.,* [7] performed an experiment to study the effect of the solar irradiance on the efficiency of polycrystalline PV panel. In order to achieve objective, a solar box and tungsten light bulbs were employed to create a situation in which the irradiance level could be regulated. The solar panel was positioned facing the source of light within the solar box. In order to simulate the sun, tungsten filament bulbs have been used as a heat and radiation source. To determine the solar power and the irradiance level of the PV module, a digital solar power meter have been used. In result, the output voltage of the PV is similarly larger under tungsten light than under sunlight, but the efficiency of the photovoltaic in sunlight significantly exceeds that produced under tungsten light.

Mardy Huot *et al.,* [8] had conducted an experiment to study the electrical performance or efficiency of different PV panels which are monocrystalline and polycrystalline. In short, the PV panels provide more electrical output power when the sun irradiation is higher. However, when the solar irradiance increases, the cell temperature or panel temperature also increase. The rise in panel temperature would result in a fall in the panel's overall voltage and impacting the system's performance.

Naseer K. K *et al.,* [9] had focused the deposition of dust on the surface of PV panel. In fact, the dust particles on the surface of PV panel will diminish solar irradiation. Hence, it lowers PV solar system electrical performance. This research was to investigate and analyse the power efficiency of a PV system with and without an automatic-sprayer cleaning system. The automatic-sprayer cleaning system used can eliminates human work by washing the PV panel automatically that consumes less energy with a closed-cycle water. As a consequence, this cleaning system had improved performance ratio, efficiency, and average energy gain by 1.31 %, 4.34 %, and 7.69 % respectively. Therefore, cleaning the PV panel from accumulation of dust is required to increase the efficiency and performance of PV panel.

Zuyu Wu *et al.,* [10] developed a model of dust collection on PV panels to identify the impacts of changing wind directions and wind gusts on PV power generation. According to the results, the influence of dust on PV power efficiency increases the operating temperature panel's surface. PV panels are impacted by dust particles, which also raises their temperatures. It was discovered that the PV panel's output power had decreased from 46 % to 70 % due to dust collection and a change in the PV panel's surface temperature. As a consequence, it is possible to forecast the output power in a specific region.

The cooling system for photovoltaic panel is required to improve the electrical performance of the panel. Various methods which are related to the cooling system for photovoltaic panel have been proposed in previous study. Emy Zairah Ahmad *et al.,* [11] had conducted an experiment to investigate the electrical performance or efficiency of PV panel with passive cooling. The proposed passive cooling method was rectangular fins heat sink. The rectangular plate fins made of aluminium 6061 were connected to the back surface of the tedlar layer. In result, the developed cooling method reduces the PV panel’s temperature by 3.25 °C on mean. By adding the fin heat sink at the bottom of the PV module, the maximum electrical power production had improved by 14.2 %. In addition, the effect of cooling system on PV panel is more crucial at high solar irradiance than low solar irradiance.

K Rishi *et al.,* [12] had discussed about the different cooling methods used for PV panels and advises which sort of cooling should be selected based on the needs as well as an approach to separate the heat energy. The factors that affect PV panel’s efficiency are solar radiation and operating temperature of the PV panel. The cooling system is divided into active cooling and passive cooling. This research compared the active and passive cooling system in moving parts, efficiency, type of cooling, coolant, cost, and flow. It can be concluded that passive cooling applied natural ventilation while active cooling used forced ventilation. The efficiency of the PV panel with active cooling is higher than that of passive cooling. However, passive cooling has a lower cost and lesser maintenance. In addition, passive cooling is used where low amount of cooling is needed whereas active cooling is used where huge amount of cooling is needed.

Saber Abdo *et al.,* [13] had proposed the use of hydrogel beads with various bed layouts as a cooling attachment beneath a PV panel. Four distinct bed configurations were investigated, each with a different layer and fin arrangement. The best results were obtained using three rows of hydrogel beads with fins, with the panel temperature dropping by approximately 10 ℃ below the un-cooled panel at 1000 W/m^2 which represented a 14 % temperature drop compared to the panels' initial temperature. At irradiation intensity of 600 W/m^2 and 1000 W/m^2, temperature reductions of 9 ℃ and 9.6 ℃ were obtained correspondingly. In result, there was 7.2 % increase in electricity generation efficiency by using three rows of hydrogel beads with fins.

Rakino *et al.,* [14] had constructed a passive cooling system to increase the efficiency of PV panel. A passive cooling system had applied by using heat-sink or a bottle of water that absorbed by using cottons, another method was by keeping bottom part of solar panel in the water. A passive cooling system does not use electrical energy. So, it will increase the efficiency of the solar cell. The proposed solar panel passive cooling system in this project was to use both water and straight fins heat sink (SFHS) in the back side of solar panel. For water cooling, the water is stored in aluminum cuboids. Then, the aluminum cuboids were installed on the back of PV panel. At here, the conduction and convection of heat transfer had occurred to release the heat energy from PV panel to the surrounding. For straight fins heat sink, it was installed on the aluminum cuboids which was filled with water. As a result, the output power of the panel with the proposed cooling system achieved 47.71 % higher than the normal photovoltaic panel. The proposed cooling system had lowered the overall surface temperature by 12.66 %, 10.13 %, and 8.96 %, respectively compared to a basic PV panel, a PV panel with heat-sink, and a PV panel with water.

Olawole *et al.,* [15] had analyzed many strategies for controlling the deadly heat in electrical performance when a large amount of solar irradiation impacts the PV panel's surface. Appropriate active and passive cooling methods can be used to attain this goal. Air cooling, water cooling, phase change material, nano liquid, and refrigerant are the five cooling methods employed in this study. The cost-effectiveness of a cooling method is determined by the weather conditions and the intended use of the recovered heat energy. In result, the rapid rise in temperature of a PV panel, especially under strong solar radiation, can be mitigated using active and passive cooling technologies to prefer optimum power production and efficiency. Moreover, phase shift materials and refrigerant methods can boost PV panel efficiency above 45 %. Air cooling methods and nano liquid can increase the efficiency of PV panel by 14 %. For water cooling, it can increase 6 % to 14.2 % of efficiency of PV panel.

This research aims to design and develop a hybrid cooling system for the PV panel by using active and passive systems. The active system is a water sprinkler system with an automatic controller system. The Arduino UNO R3 is used to activate the DC water pump if the surface temperature of the PV panel exceeds 35 ℃. The passive system is a combination of aluminum cuboids filled with hydrogels and a heat sink. Moreover, a monitoring system was applied to monitor the current, voltage, power, and temperature of the PV panel through the Liquid Crystal Display (LCD).

2. Methodology

To complete this research, the main objective is to design and develop a hybrid cooling PV panel by using active and passive cooling for improving the output power of the PV panel. To achieve this main objective, there are few objectives need to achieve which are:

i. To analyze the thermal performance of passive cooling system for PV panel by using SolidWorks and ANSYS software.
ii. To design automatic controller system for active cooling system of PV panel by using Proteus software.
iii. To analyze the performance of the hybrid cooling PV panel by using active and passive cooling system.

Figure 1 presents the system block diagram of hybrid cooling system for PV panel. The system block diagram shows the architecture that illustrates the inputs, process, and outputs of this research. In this project, the input is the PV panel with LM 35 temperature sensors. A PV panel will convert solar irradiance into electrical energy. The electrical energy produced from the PV panel is used to activate the water sprinkler system for active cooling of PV panel. LM 35 temperature sensors and the passive cooling system were installed behind the PV panel. For passive cooling system, aluminum cuboids with hydrogels and heat sink were installed on the back side of PV panel. Next, the LM 35 temperature sensors will detect the surface temperature of the PV panel and send the data to Arduino UNO R3. In the processing stage, the electrical current from PV panel will flow to the solar charger controller and energized the battery. Then, the battery will act as a power supply to supply power to DC water pump and Arduino UNO R3. An Arduino UNO R3 controller will process the data from LM35 temperature sensor. In output stage, if the surface temperature of the PV panel exceeds than 35 ℃, then the DC water pump will switch ON and cool the PV panel. In addition, the measurement of the voltage and current for the power output of PV panel and the power output for activating the DC water pump is being determined by the current sensor and voltage sensor. The data of the current, voltage and surface temperature of the PV panel will be displayed on Liquid Crystal Display (LCD) which is connected to the Arduino controller.

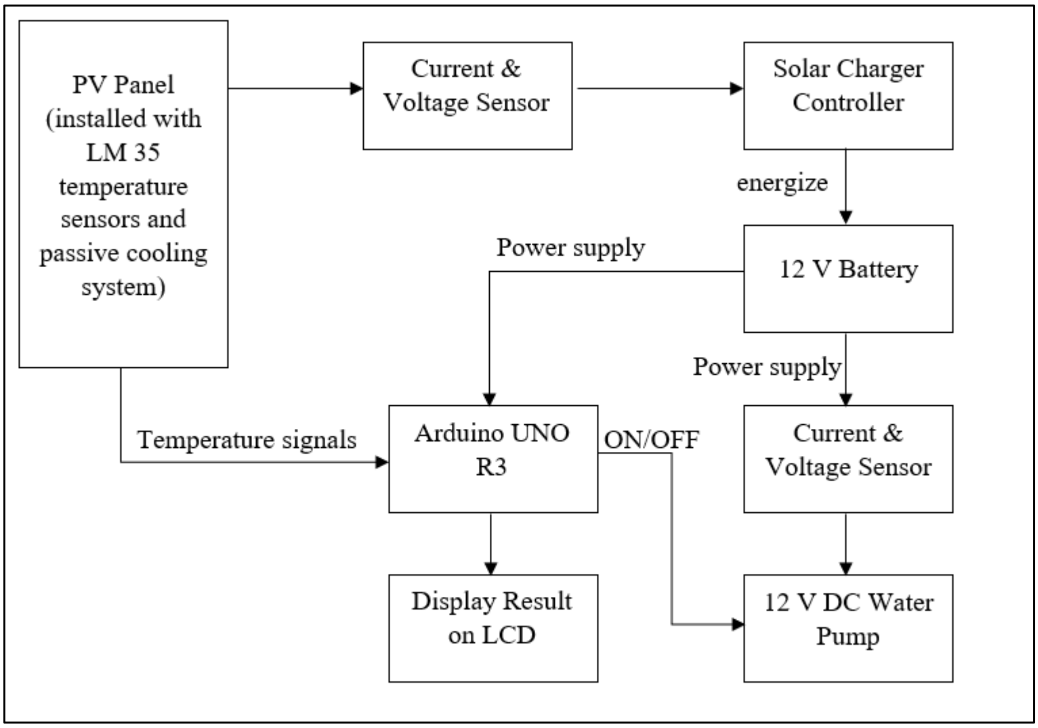

Fig. 1. Block diagram of hybrid cooling system for PV panel

2.1 Simulation in ANSYS Software

In this research, SolidWorks software was used to model the PV panel with and without cooling system. SolidWorks software is a computer-aided design (CAD) which is used to build three-dimensional (3-D) graphical representations of a PV panel. The selected PV panel is monocrystalline PV panel SNM-100P which is 120 cm in length, 54 cm in width and 3 cm in height. Table 1 shows the specification of selected PV panel. The maximum power of this PV panel is 100 W. Furthermore, ANSYS software was selected as the simulation tool in order to investigate the thermal behavior of the PV panel without and with cooling system. By using ANSYS software, it is possible to perform testing in a virtual environment before building prototypes. The CFX analysis system of ANSYS software was utilized to examine the effect of the solar irradiance and ambient temperature on the performance of the PV panel. By CFX analysis system, the thermal behavior and the operating temperature of the PV panel can be determined and observed [16].

Table 1
Specification of selected PV panel (SNM-100P)

Specification	Value
Maximum output power, P_{max}	100 W
Maximum output voltage, V_{max}	18.5 V
Maximum output current, I_{max}	5.4 A
Open-circuit voltage, V_{oc}	22.2 V
Short-circuit voltage, I_{sc}	2.78
Temperature coefficients of P_{max} (%)	0.5 % / ℃
Temperature coefficients of V_{max} (%)	0.38 % / ℃
Temperature coefficients of I_{max} (%)	+ 0.1 % / ℃
Temperature coefficients of V_{oc} (%)	2.23 mV / ℃
Temperature coefficients of I_{sc} (%)	+ 0.05 % / ℃
Tolerance wattage	± 3 %
Number of cells	36 units

2.1.1 PV panel without cooling

The procedure to design the model of the PV panel without cooling system is explained in this section. First and foremost, SolidWorks software was used to model a PV panel. A PV panel consists of 6 different layers with different thickness and material properties. The layers are glass covering, Ethylene Vinyl Acetate (EVA) 1, PV cell, EVA 2, tedlar and aluminum frame [17]. According to the number, the first layer is the glass covering and the last layer is tedlar layer. These five layers were assembled together and were mounted on the sixth layer which is aluminum frame. Each layer of the PV panel was designed in SolidWorks according their thickness. After completing the assembly process in SolidWorks, the PV panel was imported into ANSYS software to run the CFX analysis system. After importing the PV panel into the ANSYS software, the thermal conductivity, specific heat capacity and density of each layer of the PV panel have to be defined in the Engineering Data Cell. Table 2 shows the material properties of each layer in a PV panel.

Table 2
The material properties of each layer of a PV panel [10]

No.	Layer	Thickness (cm)	Thermal conductivity (W/m°C)	Specific heat capacity (J/kg°C)	Density (kg/m3)
1	Glass covering	0.3	1.8	500	3000
2	Eva 1	0.05	0.35	2090	960
3	Pv cell	0.04	148	677	2330
4	Eva 2	0.05	0.35	2090	960
5	Tedlar	0.03	0.2	1250	1200
6	Aluminium frame	2	204	996	2707

After defining all the material properties of each layer of PV panel, the external geometry model CAD file was imported in an analysis system schematic. Each layer of the PV panel was named, and the properties of these layers were determined. After that, a meshing process was applied on the geometry model. A meshing process was used to split the geometry up into smaller elements [18]. After the meshing process had finished, the boundary condition of the PV panel was identified. The solar irradiance had applied on the surface of the glass covering. A natural convection had applied on the top and bottom surfaces of the PV panel which are the glass covering and tedlar. The ambient temperature was adjusted with a uniform temperature to the PV panel. Last but not least, the final step was using the CFX-Solver to import all initial weather and operating conditions. These initial weather and operating conditions were then used in the PV panel. All the data of the solar irradiance and ambient temperature had obtained by the Malaysian Meteorological Department that used in the simulation analysis.

2.1.2 PV panel with passive cooling

The procedure to design the model of the PV panel with passive cooling system is discussed in this section. First and foremost, SolidWorks software was used to draw the 3-D geometry model of the PV panel. For passive cooling system, the method that applied was aluminum cuboids with hydrogels and heat sink. The hydrogels were put into six units of rectangular aluminum containers. The internal dimensions of the rectangular aluminum containers are 54 cm × 2.5 cm × 1 cm (length (l) × Width (w) × Height (h)). After completing the assembly process in SolidWorks, then imported it into ANSYS software to run the CFX analysis system. Then, the next step was the CFX analysis system in the ANSYS software. The thermal conductivity, specific heat capacity and density of each layer of the PV panel had defined in the Engineering Data Cell as indicated in Table 1. After that, this geometry model was divided into smaller elements by automatic meshing process. Furthermore, the boundary condition of the PV panel had identified. The solar irradiance had applied on the surface of the glass covering. A natural convection had applied to the outer layer of the front and back surface of the PV panel. The ambient temperature was adjusted with a uniform temperature to the PV panel. For aluminum cuboids with hydrogels, the material properties of water had used because the hydrogels will absorb water and water will act as a cooling medium. For heat sink, the selected material was aluminum heat sink. So, the material properties of aluminum had considered into the PV panel. Table 3 shows the material properties of water and aluminum heat sink. Last but not least, the final step was using the CFX-Solver to import all initial weather and operating conditions. These initial weather and operating conditions were then used in the PV panel. All the data of the solar irradiance and ambient temperature had obtained by the Malaysian Meteorological Department that used in the simulation analysis.

Table 3
The material properties of water and aluminum heat sink [18]

No.	Layer	Thermal conductivity (W/m°C)	Specific heat capacity (J/kg°C)	Density (kg/m3)
1	Water	0.0598	4200	997
2	Aluminium heat sink	204	996	2707

2.2 Designing the Automatic Controller System Circuit

The automatic controller system in this project is used to control the operation of the active cooling system which is the water sprinkler system automatically. This automatic controller system is not applied to the passive cooling system because passive cooling does not require any electrical energy from PV panel. Figure 2 shows the flow chart of the operation of the automatic controller system. In this automatic controller system, there are two LM 35 temperature sensors (T_1 and T_2) attached at the backside of the PV panel. These sensors are used to detect the surface temperature of the PV panel. Then, an Arduino UNO R3 will acts as a controller or processor to switch ON and OFF the active cooling system according to the surface temperature of the PV panel. Moreover, a programming coding had been developed and imported to the Arduino UNO R3. In the programming coding, the setting temperature in this automatic controller system is 35 °C because it is the average daily temperature captured in Malaysia [4]. In addition, the signals from the LM 35 temperature sensors are analog signal. So, the analog signal is converted into digital signal through the analog-to-digital converter in the Arduino controller. After that, the Arduino controller will display the surface temperature (T_1 & T_2) of the PV panel through the Liquid Crystal Display (LCD).

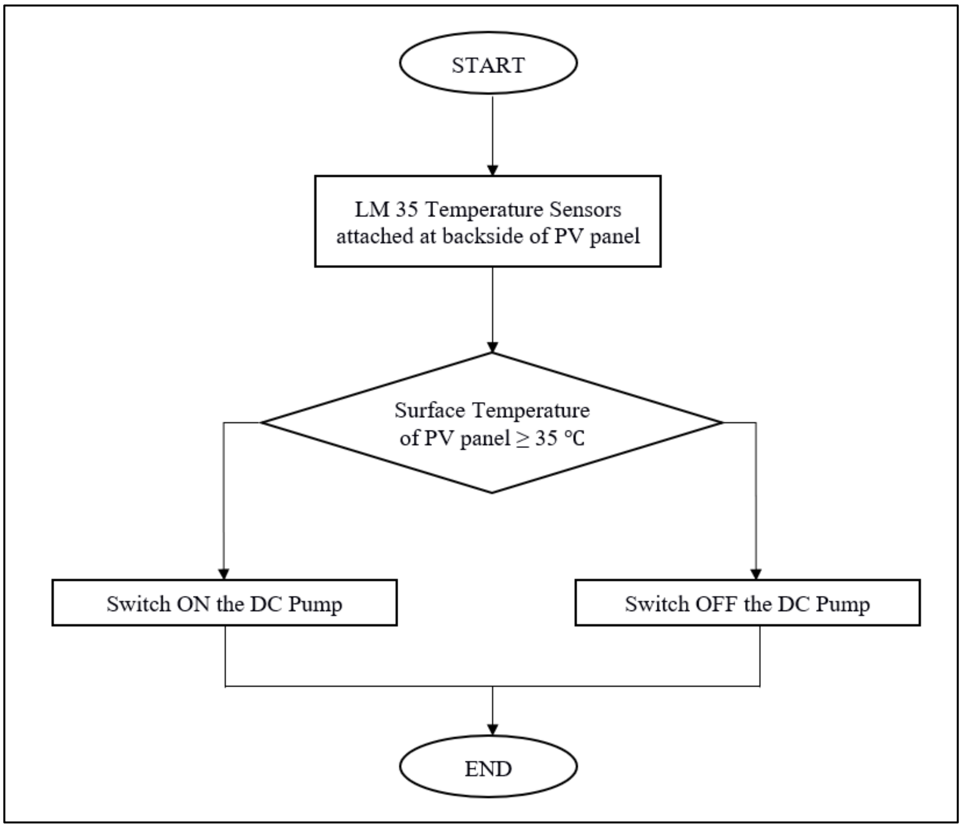

Fig. 2. Flow chart of automatic controller system operation

Figure 3 shows the circuit of active cooling system of a PV panel in Proteus software. For the automatic controller system, the components used are two LM 35 temperature sensors, Arduino UNO R3, LCD and DC motor. The DC motor will act as a DC water pump for active cooling system in Proteus software. The two LM 35 temperature sensors were connected to the A1 and A3 port of the Arduino controller to send the analogue signal to Arduino. Then, Arduino controller will convert it into digital signal. Furthermore, there is a DC motor connected into the port PD7 of Arduino controller. The PB0 to PB5 is used for the LCD to display the surface temperature of PV panel which are detected by the LM 35 temperature sensors. From Figure 3, The current sensor used in this project is ACS712 current sensor whereas the voltage sensor is a voltage sensor module 25 V. The ACS712 current sensor can sense between -30 A and 30 A whereas the voltage sensor module can sense the voltage value up to 25 V. A voltage sensor is consists of voltage divider circuit of two resistors which the resistances of resistors are 30 kΩ and 7.5 kΩ respectively. Since both sensors are analogue sensors, so the Arduino controller have to convert analogue signal to digital signal through analogue-digital signal converter. Then, the LCD will display the value of current and voltage from the PV panel and the DC water pump.

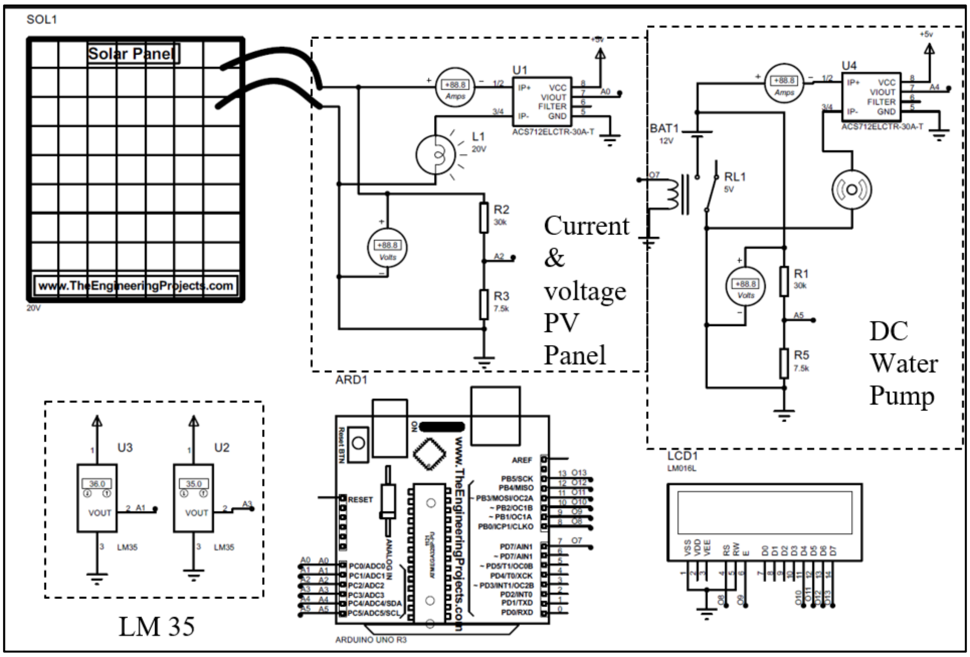

Fig. 3. Circuit design of active cooling system of PV panel in Proteus software

After getting the values of voltage and current generated from PV panel and from active cooling system, the power output generated from PV panel and power used by active cooling can be determined by Eq. (1), [19]. The reason that needs to calculate the values of power is to find out the net power output of the PV panel with hybrid cooling system. This is because the net power output of PV panel with hybrid cooling system can be compared to the power output of PV panel without the hybrid cooling system.

$$P = VI \tag{1}$$

P represents the power which is in watt (W), V is representing the voltage which is in volt (V), and I is representing the current in ampere (A). After calculating all the values of power, the next step is to analyse the performance of the hybrid cooling PV panel by using active and passive cooling system. Eq. (2), [20] below calculate the average increase in power of the PV panel due to hybrid cooling system.

$$P_{avg(increase)} = \frac{P_{avg(cooling)} - P_{avg(without\ cooling)} - P_{avg(used)}}{P_{avg(without\ cooling)}} \tag{2}$$

$P_{avg(increase)}$ is representing the average power increase of PV panel due to hybrid cooling. $P_{avg(cooling)}$ is representing the average power generated from the PV panel with hybrid cooling, $P_{avg(without\ cooling)}$ is representing the average power generated from the PV panel without cooling system and $P_{avg(used)}$ is representing the average power used by the active cooling system of the PV panel with hybrid cooling.

2.3 Passive Cooling Setup

The passive cooling system that proposed by this research is the combination of aluminum cuboid filled with hydrogels and heat sink. Aluminum cuboid and heat sink were attached to the backside of

PV panel to achieve a natural cooling which does not require electrical energy from PV panel and battery. Figure 4 shows the aluminum cuboids filled with hydrogels and heat sinks had attached on the backside of PV panel.

Fig. 4. Design of passive cooling system in hardware

2.4 Active Cooling Setup

The active cooling system that proposed in this research is the water-cooling system. In an active cooling system, there are two main parts which are water pump system and monitoring system. Figure 5 shows the active cooling system of PV panel. First, the PV panel will recharge the battery through the solar charge controller. Then, the battery will act as a power supply to DC water pump and Arduino controller. This is because the PV panel is unable to supply power to Arduino controller and DC water pump directly. For water pump system, the Arduino controller will control a relay to switch ON or OFF the DC water pump according to the condition of the surface temperature of PV panel. For monitoring system, there are voltage sensors and current sensors to measure the voltage and current generated from the PV panel and voltage and current used by the active cooling system. Next, the values of voltage and current will be displayed on LCD. In addition, there are two wattmeters to ensure the sensors take the value accurately.

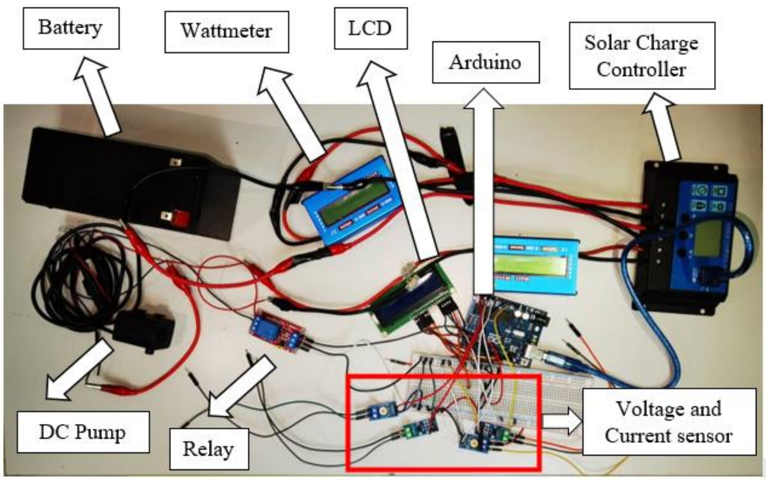

Fig. 5. Active cooling system

2.5 Hybrid Cooling Setup

This is the setup of hybrid cooling PV panel by using active and passive cooling system. Figure 6 shows the hybrid cooling PV panel. There are two PV panels on the rack. One is PV panel with hybrid cooling system, and another is PV panel without cooling system. The experiment was conducted on the rooftop of Uniciti Alam, UniMAP. After setup of the active cooling system and passive cooling system of the PV panel, the values of temperature, voltage, current and solar irradiance had been taken every hour from 9.00 a.m. to 5.00 p.m.

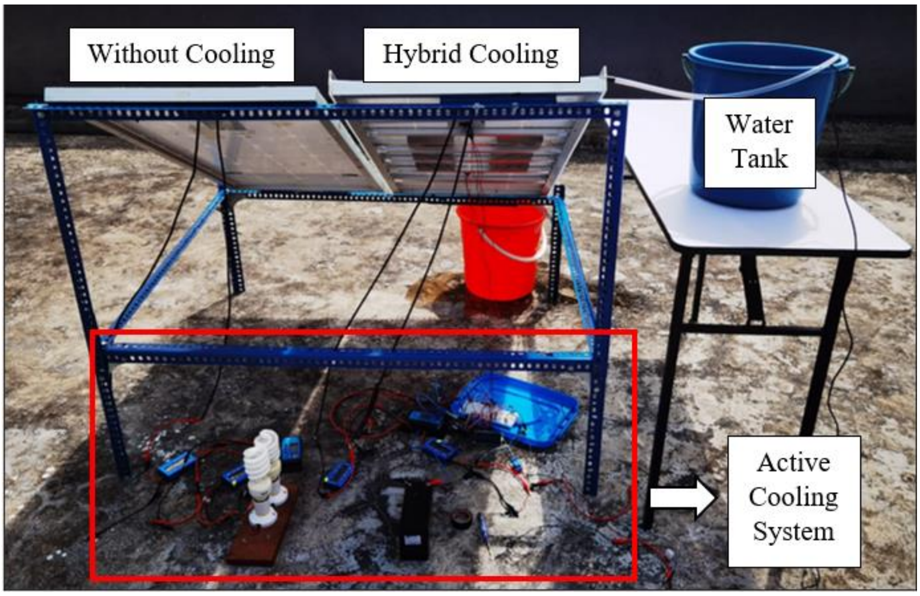

Fig. 6. Hybrid cooling system

3. Results and Discussion

Firstly, the simulation result of the PV panel with and without passive cooling system which analysed by the ANSYS software will be discussed and explained in this chapter. Furthermore, the experimental result of PV panel with and without cooling system will be presented and discussed in this chapter. Moreover, experimental result of PV panel with and without cooling system will be compared by investigate the temperature, solar irradiance, and power. Lastly, the average power increased due to cooling was determined and discussed.

3.1 Simulation Results of PV Panel with and without Passive Cooling System

Figure 7 presents a thermal image of a PV panel without cooling system that generated by using ANSYS software. The red colour of the PV panel indicates the thermal flow of the PV panel. In result, the maximum operating temperature of PV panel without cooling system is 38.2 ℃ while the minimum operating temperature is 29.6 ℃.The standard test condition for a PV panel is 25 ℃. Since each rise of temperature in ℃ will decrease 0.5 % of efficiency of PV panel, so cooling system is necessary for a PV panel. The passive cooling system that proposed in this research is the combination of aluminium cuboids with hydrogels and heat sink. Both of them were installed at the back side of the PV panel. Figure 8 shows the thermal image of a PV panel with passive cooling system. The red colour of the PV panel indicates the thermal flow of the PV panel. In result, the maximum operating temperature of the PV panel is 36.5 °C. The minimum operating temperature of the PV panel with passive cooling system is 27.6 °C.

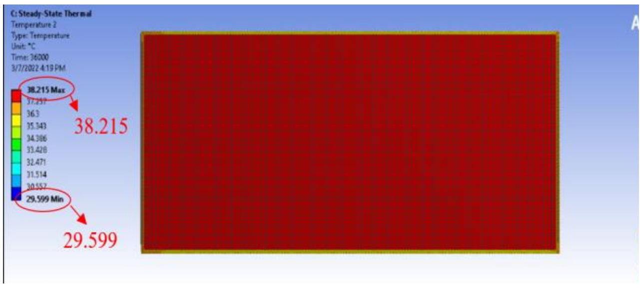

Fig. 7. Thermal image of PV panel without cooling system

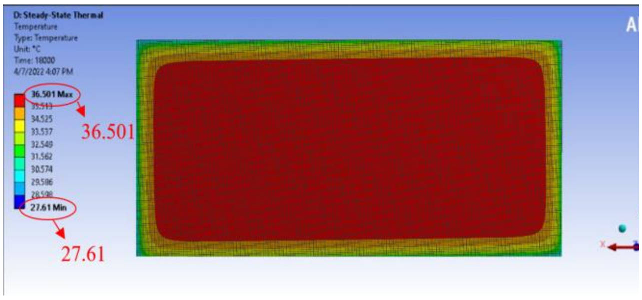

Fig. 8. Thermal image of PV panel with passive cooling system

Table 4 shows the simulation result of PV panel without and with passive cooling system. In result, the maximum operating temperature of the PV panel is 36.501 °C which is decreased 1.714 °C compared to PV panel without cooling system. The minimum operating temperature of the PV panel with passive cooling system is 27.610 °C which is decreased 1.989 °C compared to PV panel without cooling system. A PV panel with passive cooling system is successfully decreases the operating temperature of a PV panel. However, there is only a slight decrease of the operating temperature of PV panel with passive cooling system. This is because a passive cooling system is a natural cooling and does not require electricity. Therefore, PV panel with passive cooling system takes longer time to dissipate the heat of PV panel to the surrounding. The benefits of installing a passive cooling system are low cost, low maintenance and easy to install. Moreover, higher operating temperature of PV panel will cause lower electrical performance of PV panel. The power output as well as the voltage and current output from the PV panel will decrease due to high operating temperature.

Table 4
The simulation result of PV panel without and with passive cooling system

PV panel	Minimum temperature (°C)	Maximum temperature (°C)
Without cooling	29.599	38.215
With passive cooling	27.610	36.501

3.2 Experimental Results of PV Panel with and without Hybrid Cooling System

In this research, the electrical performance of PV panel with and without hybrid cooling was the most essential part. Active cooling system will need electricity to operate while passive cooling system did not require electricity. Therefore, the net power output had to be calculated for PV panel with hybrid cooling system. After that, the result of net power output of PV panel with hybrid cooling and the result of power output of PV panel without hybrid cooling were compared.

3.3 Summary of Experimental Results of PV Panel with and without Hybrid Cooling System

Table 5 shows the power output performance of PV panel with and without hybrid cooling. The average power output was calculated by finding the mean of all the power output of PV panel with and without cooling system. In result of day 1, the average power output of PV panel without cooling was 31.90 W while the average power output of PV panel with hybrid cooling was 34.48 W. Therefore, the average power increased due to cooling was 8.09 % which can be determined by using Eq. (2). For day 2, the average power output of PV panel without cooling was 31.09 W while the average power output of PV panel with hybrid cooling was 35.50 W. Therefore, the average power increased due to cooling was 14.19 %. For day 3, the average power output of PV panel without cooling was 28.78 W while the average power output of PV panel with hybrid cooling was 34.00 W. Therefore, the average power increased due to cooling was 18.14 %. In overall, the average power increased due to cooling in these three days were 13.47 %. Although the percentage of increase was low, but hybrid cooling PV panel had successfully increased the electrical performance of PV panel.

Table 5
The power output performance of PV panel with and without hybrid cooling

Day	PV panel	Experimental result of average power (W)	Average power increased due to cooling (%)
1	Without cooling	31.90	8.09
	Hybrid cooling	34.48	
2	Without cooling	31.09	14.19
	Hybrid cooling	35.50	
3	Without cooling	28.78	18.14
	Hybrid cooling	34.00	
Average	Without cooling	30.59	13.31
	Hybrid cooling	34.66	

4. Conclusions

This research aims to design and develop a hybrid cooling system for the PV panel by using active and passive systems. The active system is a water sprinkler system with an automatic controller system. The Arduino UNO R3 is used to activate the DC water pump if the surface temperature of the PV panel is exceeding 35 ℃. Moreover, there are temperature sensors, voltage sensor and current sensor to measure the values. Furthermore, the values taken had displayed on the Liquid Crystal Display (LCD). This is a monitoring system which is used to monitor the current, voltage, power and temperature of photovoltaic panel. The passive system is a combination of aluminium cuboids filled with hydrogels and a heat sink. The aluminium cuboids filled with hydrogels and heat sink had installed on the back of photovoltaic panel. It had achieved a natural cooling to remove excess heat of the panel to surrounding. In simulation result, the maximum operating temperature of the PV panel is 36.5 ℃ which was decreased 1.7 ℃ while the minimum operating temperature of the PV panel with passive cooling system was 27.6 ℃ which was decreased 2.0 ℃ compared to PV panel without cooling system. The thermal performance of passive cooling system for PV panel had successfully analyzed by using SolidWorks and ANSYS software. In experimental result, the average power output of PV panel without cooling was 30.59 W while the average power output of PV panel with hybrid cooling was 34.66 W. Moreover, the average power increased due to cooling was 13.31 %. It can be concluded that the hybrid cooling system had successfully decreased the surface temperature of PV panel and slightly increased the electrically performance. By using hybrid cooling PV panel, the maintenance cost will be lower even the lifetime of PV panel will be lengthened. The proposed hybrid cooling system can be used on household, industry and for every PV panel. It will help to reduce the electricity cost and store electricity for emergency purposes. In future, investigation can be made on the phase-change material (PCM) with appropriate thermos-physical properties, long-term reliability, cost competitiveness to achieve cooling and improve the electrical performance of PV panel. Next, a solar tracker may also can installed on the PV panel to track the sun direction. Then, it will turn the PV panel to face the sunlight directly in order to increase the power generated from the PV panel. In addition, the water-cooling system can be replaced by air-cooling system to prevent the dusts and watermarks caused.

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