Redesign of Optimum Photovoltaic Cooling System for Increasing the Performances Based on Active Cooling Method

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Abstract. In this research, the initial design of a solar PV cooling system based on TEC was built. This was a new design to improve the power output performance of the solar PV, i.e. the power and the efficiency of solar PV. The active cooling methods developed in this research were using 7 and 9 thermoelectric cooling (TEC) to maintain the surface temperature of solar PV. The TEC used in this research was the Peltier cell. The power output and efficiency of solar PV with and without a cooling system were observed and the result showed that by using 7 and 9 TEC, the surface temperature of solar PV decreased from 50.4°C without a cooling system into 47.6°C and 46.1°C. The power output of solar PV will increase by the decreasing of surface temperature. The solar PV power output was about 88.48 watts without a cooling system 91.99 watts, and 98.07 watts with 7 and 9 TEC. The efficiency of solar PV also increased from 13.83% to 16.69% and 19.51%.

Keywords: Cooling System, Redesign, Solar PV, TEC

1 Introduction

Indonesia has great potential for solar energy. This is because Indonesia's position is on the equator and as a tropical country which causes great potential in obtaining sunlight. With this potential, it can be maximally used the energy contained in the sun to be used as energy, especially as electrical energy (Tiyas & Widyartono, 2020). According to a news release from the Director General of EBTKE of the Ministry of Energy and Mineral Resources (2021), solar energy has a potential of 200,000 MW as a source of electricity, but it is now used for just about 150 MW or 0.08% of its potential. Solar cells, also known as solar photovoltaic panels, are electrical devices that use the photovoltaic effect, a physical and chemical phenomenon, to convert light energy directly into electricity. Solar cells are now widely used to generate ecologically friendly electrical energy. This is due to the limitless supply of solar energy. Photovoltaic cells (solar PV) require three essential conditions for operation: Light absorption, resulting in paired or precise electron holes; Separation of charge carriers with opposing kinds; and separate removal of the carriers to an external circuit (Bagher et al., 2015).

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To manage the surface temperature of the solar cell, many passive and active cooling technologies have been developed. A review of several cooling strategies for controlling the temperature of solar PV has explored experimentally and statistically the impact of the cell's operating temperature on the electrical and thermal performance of the PV systems. This study examines the benefits and drawbacks of ribbed wall heat sink cooling, array air duct cooling put beneath the PV panel, water spray cooling technology, and rear surface water cooling to determine their effectiveness in terms of PV panel performance. The results show that the water spray cooling method has a proper impact on PV panel performance (Zubeer et al., 2017). Some of them use water cooling to cool the surface of the solar cell (Dorobanțu et al., 2013). The solar cell's surface temperature is maintained below 40°C by spraying water over it. The results show that the solar cell's output power has increased by 30.19% (Laksana et al., 2022). In addition to using water, numerous passive cooling models based on phase change materials (PCMs) were developed to lower the temperature on solar cell surfaces. The combination of Al_2O_3/PCM and water showed higher solar cell power output than water cooling alone. This indicated that developing a hybrid cooling model is achievable and produces superior outcomes, however, the system components will be slightly more complex (Salem et al., 2019). Another research on the passive cooling method has been done by Rakino et al. (2019) and Wu & Xiong (2014), with results indicating that the passive cooling method was suited to control the surface temperature of solar PV.

In addition to passive cooling methods, active cooling methods were also developed to maintain the surface temperature of solar PV, such as the usage of Peltier cells. Thermoelectric cooling (TEC) has numerous advantages, including the absence of moving mechanical parts, compact size, and lightweight design, as well as the absence of the need for working fluids. Furthermore, TEC offers advantages in terms of operating methods, since it may be fuelled by a variety of direct current (DC) power sources, including photovoltaic (PV) cells, fuel cells, and automobile power sources (Zhao & Tan, 2014). Because of their tiny size, thermoelectric coolers are commonly used to cool electrical gadgets. The combination of Peltier and CWC (corona wind cooling) has been developed to optimize the heat exchange mechanism in LEDs, where the heat flux from LEDs typically increases as the increasing of time. The combination of these two active cooling systems can result in improved cooling and a higher coefficient of performance (Wang et al., 2021). Another research using Peltier cells was also done by (Rahim et al., 2016). The results show that the use of up to 5 TECs can reduce the surface temperature of solar panels and increase the output power of solar panels by up to 7.21%.

From the description above, it is interesting to develop a cooling system to maintain the surface temperature of solar PV at optimum conditions. Previous work has been done by designing a solar PV cooling system using 3 and 5 Peltier cells as surface temperature coolers. The result indicates an advantage in which the surface temperature of solar PV will maintain below 50°C (about 48.9°C with 3, and 47°C with 5 Peltier cells), and the power output of solar PV using 3 Peltier cells was increased by 5.15 % and using 5 Peltier cells the power will increase 9.65 % compared to the power output without the use of a cooling system. The efficiency of solar PV increased by about 0.17% (Wiryanta & Wibolo, n.d.). Based on these findings, this study produced an improved design for a solar PV cooling system. The redesign of the cooling system consist of increasing the number of Peltier cells to 7 and 9, as well as rearranging the combination or position of Peltier cells to optimize surface cooling coverage.

2 Methodology

In this research, firstly an improvement design from the previous work will be done. This redesign consists of the addition and arrangement of Peltier cells. The design of the cooling system is shown in Figure 1.

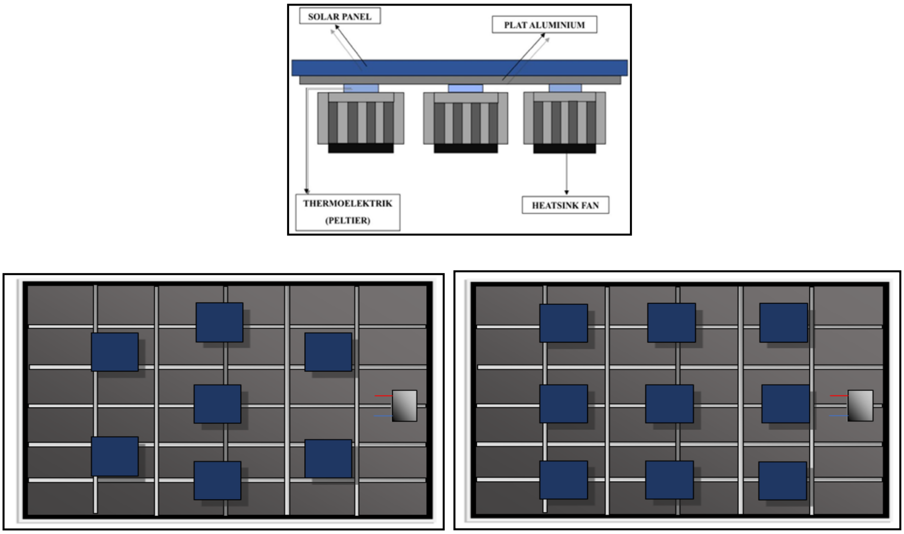

Figure 1. Schematic of Peltier cell design and arrangement

The cooling system is designed using seven (7) and nine (9) Peltier cells. The temperature of the solar PV surface was monitored with a K-type thermocouple. The voltage and current outputs of the solar PV were measured with a digital multimeter. An environment meter was used to monitor the intensity of light, solar radiation, and ambient temperature. The schematic of the system is shown in Figure 2 and the specification is shown in Table 1.

Table 1. Specification of solar PV cooling system

No	Component	Specification
1	TEC Peltier	72 watt
2	Heatsink	10 cm × 10 cm
3	Fan DC	0.04 A
4	Thermocontroller w1209	10 A
5	Small Red and black cables	NYZ 2 × 23 Zigno
6	Red cables	300/400 V
7	Black cables	300/400 V
8	Watt Meter	100 A
9	MCB	DC 16 A

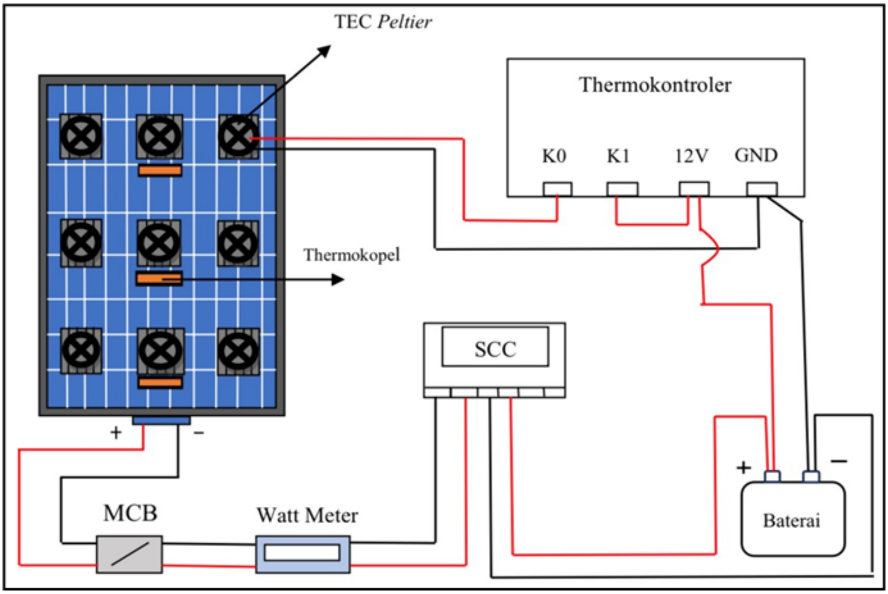

Figure 2. The schematic of the solar PV cooling system

3 Result and Discussion

3.1 Result

Solar PV without and with cooling systems were tested at the top of the clear area. The tests were conducted between 14.00 and 16.00 GMT+8. A digital multimeter was used to monitor the output current and voltage, a K-type thermocouple to measure the surface temperature, and an environment meter to measure the ambient conditions, such as ambient temperatures and light intensity. The results of the solar PV performances without a cooling system are shown in Table 2. The power input (Pin) of the solar panel can be calculated using the formula:

$$P_{in} = I_{rad} \times A \quad (1)$$

where:
P_{in} = Power input to solar PV (W)
I_{rad} = Light intensity (W/m^2)
A = solar PV cross-sectional area (m^2)

The power output (Pout) of the solar panel performance is calculated using the formula:

$$P_{out} = V_{pv} \times I_{pv} \quad (2)$$

where:
P_{out} = Power output (W)
V_{pv} = Output solar PV voltage (V)
I_{pv} = Output solar PV current (A)

The efficiency of solar panels is calculated using the formula:

$$\eta \, pv = \frac{P_{out}}{P_{in}} \times 100\% \quad (3)$$

Table 2. Solar PV performance without cooling system

Time	Output Solar PV		T Surface	Ambient		Power		Efficiency (η)
				Temperature	Light Intensity	Pin	Pout	
Minute	Volt	Ampere	Tpv °C	Ta °C	W/m²	W	W	%
5	12.33	9.71	45.5	30	647.81	642.36	119.72	18.63
10	12.41	7.31	46.8	30	560.91	556.19	90.71	16.31
15	11.12	7.91	49.3	30	616.22	611.04	87.95	14.39
20	11.62	6.37	50.5	31	695.21	689.37	74.01	10.73
25	12.15	5.89	48.2	29	600.42	595.37	71.56	12.01
30	13.12	6.32	48.2	30	553.11	548.46	82.91	15.11
35	12.13	7.54	49.5	31	861.14	853.90	91.46	10.71
40	11.43	7.39	48.7	29	687.32	681.54	84.46	12.39
45	12.23	7.72	48.9	29	379.22	376.03	94.41	25.10
50	11.12	8.03	51.3	31	742.61	736.37	89.29	12.12
55	11.13	8.38	51.6	31	876.95	869.58	93.26	10.72
60	11.85	9.05	53.5	31	932.23	924.39	107.24	11.60
65	11.02	7.47	52.9	31	608.31	603.21	82.31	13.64
70	11.94	8.04	54.7	31	861.12	853.88	95.99	11.24
75	11.53	6.59	54.1	31	529.32	524.87	75.98	14.47
80	11.52	8.69	53.2	30	655.71	650.20	100.11	15.39
85	11.31	7.61	53.1	30	600.43	595.38	86.06	14.40
90	11.33	7.51	51.3	30	600.43	595.38	85.08	14.29
95	11.78	7.53	50.3	30	624.11	618.86	88.70	14.33
100	11.32	7.53	49.3	30	726.82	720.71	85.24	11.82

Time	Output Solar PV		T Surface	Ambient		Power		Efficiency (η)
				Temperature	Light Intensity	Pin	Pout	
Minute	Volt	Ampere	Tpv °C	Ta °C	W/m²	W	W	%
105	11.19	6.97	51.4	30	639.92	634.54	77.99	12.29
110	12.40	6.67	49.2	30	592.55	587.57	82.70	14.07
115	12.23	7.39	50.2	30	703.12	697.21	90.38	12.96
120	11.95	7.19	49.8	30	663.65	658.07	85.92	13.05
Mean	11.75	7.53	50.47	30.79	664.94	659.35	88.48	13.83

3.2 Discussion

Based on the data and calculations acquired from the solar PV test results, the data is input into a graphical to analyze the performance of cooling systems that have been built with 7 TEC, and 9 TEC. The solar PV surface temperature is shown in Figure 3.

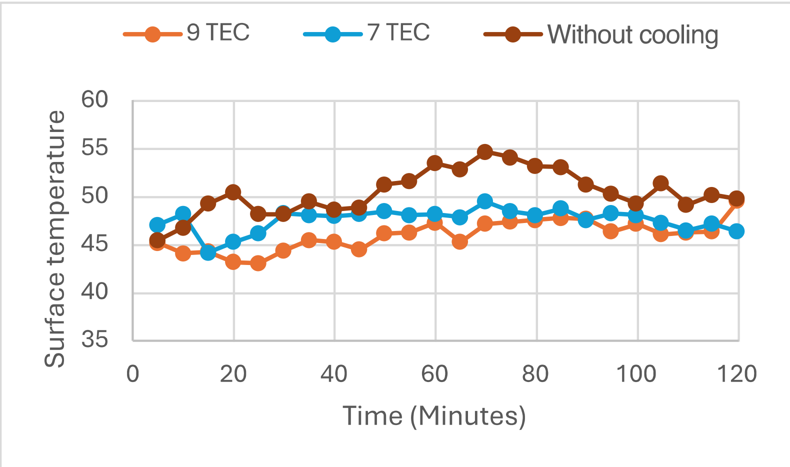

Figure 3. Surface temperature of solar PV

Figure 3 shows that the surface temperature generated by 9 TEC cooling reaches a minimum of 44.1 °C and an average of 46.1 °C. utilizing 7 TEC cooling results in the lowest temperature of 44.2 °C, with an average surface temperature of 47.6 °C higher than 9 TEC. Without TEC cooling, the lowest temperature is 45.7 °C, with an average of 50.47 °C greater than those utilizing 7 TEC and 9 TEC cooling systems. This is because using TEC allows for more even cooling. The power output and the efficiency of solar PV are shown in Figure 4 and Figure 5.

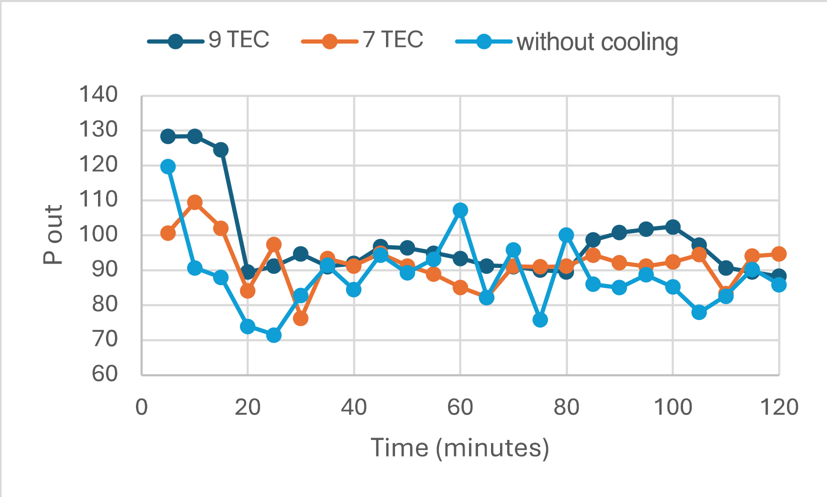

Figure 4. The power output of solar PV

From Figure 4, it can be seen the average output power using 7 TECs is 91.99 watts, and without TEC cooling is 88.48 watts. This is due to the increasing surface temperature of the solar panel, which averages 50.47 °C. Using 9 TECs resulted in a higher average output power of 98.07 Watts due to a more even cooling distribution. The surface temperature remained stable at 46.01 °C compared to without TEC cooling. However, using 7 TEC yielded a higher average.

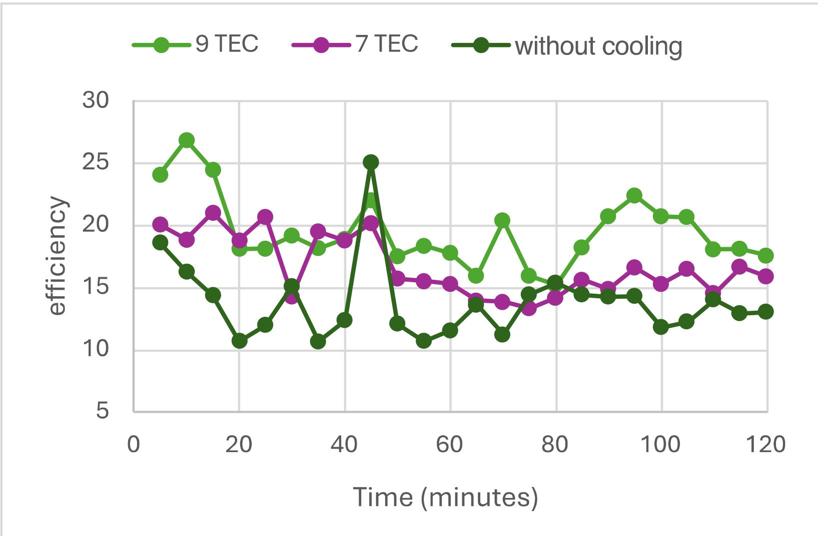

Figure 5. The efficiency of solar PV

From Figure 5, it can be shown that the average efficiency obtained in testing without TEC cooling is 13.83%, an increase in efficiency of 2.8%, testing with 7 TEC yields a result of 16.69%, and testing with 9 TEC yields the highest results, reaching an average efficiency of 19.51%. This is because the output power generated is extremely large. This is based on the notion that efficiency is calculated by dividing output power by input power.

4 Conclusion

Based on the above analysis of solar PV performance, it can be conclude that the redesign of Solar PV cooling system can work properly. The use of 7 and 9 TEC in solar PV can increase the performance of solar PV. The average surface temperature of solar PV increased about 5.6% using 7 TEC and 12.42% using 9 TEC compared to the surface temperature without cooling system. This was much higher compared to the previous work using 5 TEC (9.6%). The average power output of solar PV increases, with the addition of a cooling system into solar PV. The increasing about 3.9% using 7 TEC and about 10,83% using 9 TEC. Compared to the previous work, this was much higher. The efficiency of solar PV is similar also increasing by 2.8% using 7 TEC and increasing about 5.68% using 9 TEC compared to without a cooling system. This was much higher than the previous work i.e the increase of only 0.17%.

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