Circuit: Jurnal Ilmiah Pendidikan Teknik Elektro
Volume 9 No. 1 September 2024 - February 2025
ISSN: 2549-3698; E-ISSN: 2549-3701
DOI: 10.22373/crc.v9i1.26963

Efficiency Analysis of PV with Composed Peltier as a Coolant

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Submission: 18-08-2023 Accepted: 02-01-2024 Published: 01-08-2024

Abstract

Solar energy provides a plentiful source of power, but the performance of photovoltaic (PV) panels is frequently reduced due to overheating issues. Power conversion performance may suffer as a result. This study uses a cooling device based on the Peltier effect to test PV efficiency. This study's methodology is a direct experiment that compares two PV operating conditions: one with Peltier cooling and the other without. The data collected include PV temperature, voltage (Vmp, VOC), current (Imp), and maximum power (Pmax). The monitoring system uses devices such as thermal imaging cameras and solar panel multimeters to obtain accurate measurement results related to PV performance. The results showed that the Peltier cooling system was able to significantly reduce the PV temperature in order for the PV's electrical power output to rise. PV with Peltier cooling outperformed PV without cooling in terms of power efficiency at lower temperatures. Because it provides a sustainable option for controlling PV temperature and can be widely used to increase solar panel energy efficiency, this technology has shown itself to be both environmentally friendly and energy efficient.

***Keywords**: Photovoltaic Efficiency, Peltier Module, Solar Energy*

Abstrak

Energi surya menawarkan solusi yang berlimpa, namun, efisiensi panel surya (PV) sering kali terhambat oleh panas berlebih. Hal ini dapat menurunkan kinerja konversi daya. Penelitian ini bertujuan untuk mengukur efisiensi PV dengan memanfaatkan sistem pendingin yang berbasis efek Peltier. Metode yang digunakan dalam penelitian ini adalah eksperimen langsung dengan membandingkan dua kondisi operasional PV, yakni dengan pendinginan Peltier dan tanpa pendinginan. Data yang dikumpulkan meliputi suhu PV, tegangan (Vmp, VOC), arus (Imp), dan daya maksimum (Pmax). Sistem pemantauan menggunakan perangkat seperti thermal imaging camera dan solar panel multimeter untuk memperoleh hasil pengukuran yang akurat terkait kinerja PV. Hasil penelitian menunjukkan bahwa sistem pendingin Peltier mampu menurunkan suhu PV secara signifikan, sehingga daya listrik yang dihasilkan oleh PV meningkat. Pada suhu yang lebih rendah, PV dengan pendinginan Peltier menunjukkan efisiensi daya yang lebih tinggi dibandingkan dengan PV tanpa pendingin. Teknologi ini terbukti ramah lingkungan dan hemat energi,karena menawarkan alternatif berkelanjutan dalam pengelolaan suhu PV dan dapat diaplikasikan secara luas untuk meningkatkan efisiensi energi pada panel surya.

Kata kunci: Efisiensi Fotovoltaik, Modul Peltier, Energi Surya

Introduction

Solar energy is getting more and more attention as energy demand increases, and awareness of the impact on the environment. This increase is in line with the increase in economic capability and human population. With the development of the region, the consumption of fossil fuels for vehicles and power generation is increasing. Operational reliability of the electricity system and user safety are important aspects that must be considered in the installation of electric power systems [1]. Therefore, one of the energy sources that has an advantage over fossil fuels is solar energy, and solar cells are used in the utilization process [2][3]. With its tropical climate and year-round sun exposure, Indonesia is one of the best places to utilize solar energy [4][5]. Solar Power Plant (SPP) is a renewable energy development that can be applied in Indonesia with an average solar radiation potential of 4.8 kWh/m2/day [5][6].

Solar panels are one of the most commonly used to convert solar energy into electrical energy. Solar panels are used independently to generate energy from the sun in off-grid photovoltaic (PV) systems [7]. Due to the overheating of the temperature on the PV, it results in a decrease in the efficiency of the electric power produced [8][9]. PV efficiency is 6.1 - 6.7% when the temperature is between 46-49°C and if the temperature drops to 42°C the efficiency of PV will increase to 7-7.8% [10][11]. Therefore, temperature management in solar panels is a key factor in efforts to improve energy efficiency.

The Peltier effect is one of the cooling methods that have been proposed to address this problem [12]. The researchers conducted a study on low-concentration PV cooling using Peltier-based thermoelectric modules. The results show thermoelectric cooling improves temperature stability without the need for moving parts or coolant. This makes them effective and durable when used in extremely hot environments.

Research conducted by [13] produces cooling by using the Peltier effect. This happens by converting electrical energy into thermal energy. This then makes Peltier an environmentally friendly cooling solution, especially for reducing carbon emissions from older cooling systems dependent on fossil fuels. Despite the fact that TECs have a low coefficient of performance (COP) (around 0.5), research continues to improve efficiency through the manufacture of better thermoelectric materials and the design of the most efficient systems. In cooling applications, the integration of TECs and solar panels can improve sustainability and efficiency.

This research aims to improve PV efficiency by utilizing a Peltier effect-based cooling system. This is in line with the research [14] which shows the importance of renewable energy system optimization that also focuses on improving energy efficiency through innovative technologies. The Peltier effect can be used to lower the temperature of photovoltaic panels through thermoelectric technology. These thermoelectrics can convert electrical energy into temperature difference and produce cold and hot temperatures [15][16]. By using Peltier modules strategically positioned on the bottom surface of the PV, excessive heat is expected to be absorbed and transferred to the outside of the PV, ensuring the PV temperature remains stable and low [17].

Research and innovation in the use of these Peltier modules as coolers is expected to show great potential [18]. Thus, in order to optimally increase PV efficiency, the use of Peltier modules needs to be optimized to be able to maintain the panel temperature at an ideal level. If properly adjusted, Peltier cooling systems can also effectively improve PV performance without compromising the overall stability of the system.

Method

This study designed a Peltier-based cooling system integrated with PV panels. Then the system was tested to measure the performance of PV panels in two conditions, namely with Peltier and without Peltier. As in research [19] in the results of his research comparing two conditions. The data collected by this researcher includes panel temperature, voltage, and electric current generated in both conditions. The trial results were analyzed to evaluate the increase in PV panel efficiency based on the change in electrical output power when the panel temperature is lowered through the application of Peltier cooling.

a. System Block Diagram

The system block diagram illustrates the overall structure and workflow of the proposed design. It provides a clear visualization of the key components and how they interact within the system.

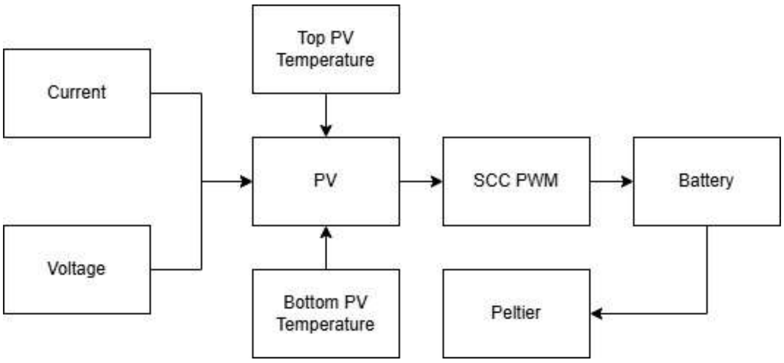


Figure 1. Block Diagram of PV System

Figure 1 is a depiction of the monitoring and control system for solar panels. This system is used to maintain its performance and efficiency. PV is the main component of this system, which is responsible for converting solar energy into electrical energy.

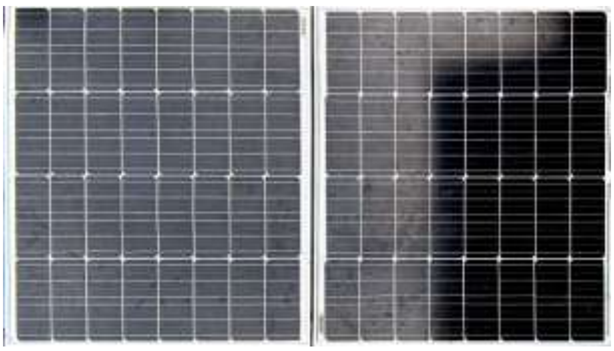


Figure 2. Photovoltaic Monocrystalline

In figure 2 are the monocrystalline PVs with a capacity of 100 Wp each used in this study. The choice of monocrystalline type is based on its higher energy conversion efficiency compared to polycrystalline PV. To maximize efficiency, the current and voltage generated by the solar panels are monitored continuously. As these changes can show an increase or decrease if there is any change in the system performance.

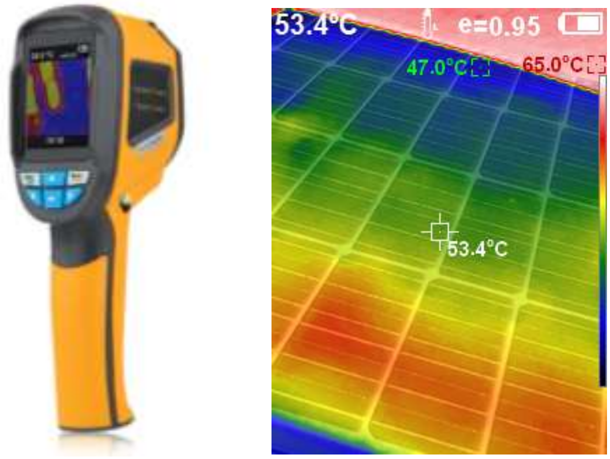
Figure 3. Solar Panel Multimeter

Monitoring is done using a solar panel multimeter. The tool in figure 2 serves to monitor the voltage (Vmp, VOC), current (Imp), and maximum power (Pmax) generated by the PV panel in real-time. The Vmp (Voltage at Maximum Power) and Imp (Current at Maximum Power) symbols serve to determine the maximum output released by the PV during operational conditions. While VOC (Voltage Open Circuit) is to determine the maximum voltage reached when there is no current. Then Pmax can show the highest power output produced by PV in watts. Pmax can actually be directly known from the reading of Vmp and Imp with the power formula as follows:

$$Pmax = Vmp \times Imp \quad \text{...} \quad (1)$$

Figure 4. Peltier SP1848 27145 SA

The Peltier in figure 3 generally functions to convert heat energy directly into electrical energy based on the Seebeck effect [20]. The Peltier measures 40mm x 40mm x 3,4mm and consists of 2 sides, namely the hot side and the cold side. In the research [17] The peltier effectively cools the PV and results in a high system efficiency of 9.1% on the PV. The installation of Peltier modules under the solar panel helps lower the temperature with the aim of stabilizing the photovoltaic operational temperature and increasing efficiency. A device that monitors temperature changes is required in order to compare the temperatures of PV with and without a peltier. However, the use of tools such as thermoguns tends to be less accurate and cannot provide real visual images.



(a) (b)
Figure 5. (a) Thermal Imaging Camera, (b) Visual Color Temperature

Therefore, a thermal imaging camera is needed to measure the temperature at the top and bottom of the PV. This is to ensure that there is a temperature balance and reduce the negative impact of high temperatures on energy conversion [21]. It provides a visual representation in the form of a color distribution that represents temperature.

Figure 6. SCC PWM

A PWM (Pulse Width Modulation) type Solar Charge Controller (SCC) with a maximum current of 20A is required to regulate the flow of electricity from the solar panel to the battery. The PWM SCC ensures safe and efficient charging [22].

Figure 7. Battery 12V 50AH

Figure 7 serves to store the electrical energy generated by the PV. The battery allows the use of electricity generated by the PV panel when there is no sunlight. The system is expected to optimize photovoltaic performance, minimize energy loss, and ensure the battery stores energy appropriately to support sustainable use.

b. Flowchart

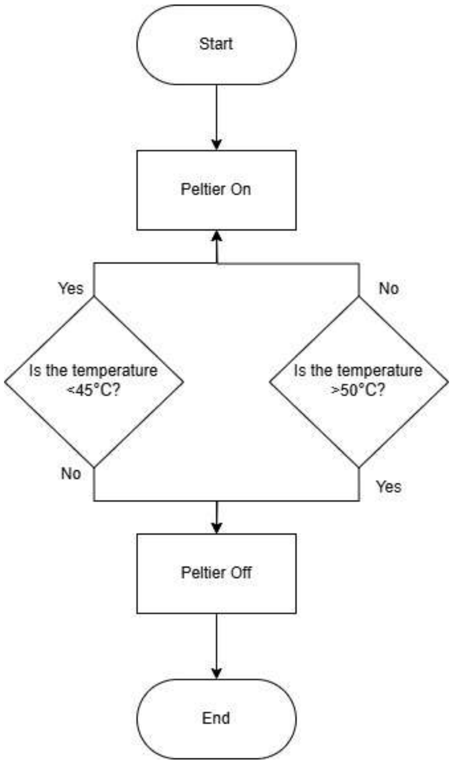


Figure 8. System Flowchart

The process in figure 8 starts from turning on the Peltier module to lower the PV temperature. The system will check the temperature condition with two different limits. When the temperature is less than 45°C, the peltier will turn off. When the temperature is more than 50°C, the peltier will turn on.

c. Hardware Wiring

The hardware wiring section presents the physical connections between the electronic components used in the system. It ensures proper communication and functionality by showing how each device is interconnected.

Figure 9. Hardware Circuit Wiring with Peltier

Figure 9 shows the PV system circuit with an additional Peltier module as a cooling system. Energy from the PV is regulated by SCC PWM to charge the battery. Furthermore, the voltage from the battery is forwarded to a step-down that has been set to 6 volts to power the Peltier module to regulate the PV temperature.

Figure 10. Hardware Circuit Wiring Without Peltier

Then figure 10 shows the circuit configuration of the PV system without the peltier module. The energy from the PV is passed directly to the SCC PWM and charges the battery without any additional cooling system. Below is the pin addresses connected to the above circuit according to the components:

Table. 1 Connection Circuit of Solar Panel and Peltier System

No.	Component	Component Pin Address	Connection Address
1	PV 1 and 2	Positive (+) Negative (-)	SCC PWM (+) SCC PWM (-)
2	SCC PWM	Positive PV (+) Negative PV (-) Battery positive (+) Battery negative (-) Positive load (+) Negative load (-)	Positive PV (+) Negative PV (-) Battery positive (+) Battery negative (-) Step down input (+) Step down input (-)
3	12 V 50 AH battery	Positive (+) Negative (-)	SCC PWM (Battery +) SCC PWM (Battery -)
4	Step down 300 W 20 A	Input (+) Input (-) Output (+) Output (-)	SCC PWM (Load +) SCC PWM (Load -) Peltier series (+) Peltier series (-)
5	Peltier 1	Positive (+) Negative (-)	Step down output (+) Positive Peltier 2 (+)
6	Peltier 2	Positive (+) Negative (-)	Negative Peltier 1 (-) Positive Peltier 3 (+)
7	Peltier 3	Positive (+) Negative (-)	Negative Peltier 2 (-) Step down output (-)

Results and Discussion

This section presents the outcomes of the experiments conducted and provides an in-depth analysis of the findings. It interprets the data in relation to the research objectives, highlighting key insights and their implications

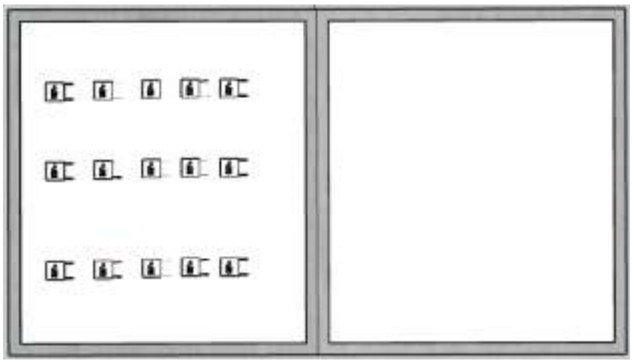


Figure 10. PV Bottom Design with Peltier and without Peltier

This device is a PV cooling system with 15 Peltier located under the PV to cool it. As in figure 10, the Peltier will be in series 3 to divide the voltage and 5 parallel. Data collection was carried out from 11:00 to 14:00. The first treatment of PV with Peltier, and the second treatment of PV without Peltier. Then the data results are obtained as follows:

Table 2. PV Measurement Data with Peltier

Time	Temp. PV		Temp. Peltier	Vmp	Imp	VOC	Pmax
	Up	Down					
11:00	48,7	53,0	48,4	14,90	4,06	20,03	60,49
11:10	45,6	45,5	41,6	16,04	4,06	19,92	65,12
11:20	46,1	49,2	44,0	16,26	2,58	20,36	41,95
11:30	50,1	51,0	48,4	16,85	4,06	20,47	68,41
11:40	53,5	52,9	48,0	16,19	4,75	20,21	76,90
11:50	51,3	52,9	49,4	16,52	4,20	20,29	69,38
12:00	52,0	51,8	47,6	16,12	4,60	20,14	74,15
12:10	50,4	51,3	48,2	16,12	4,20	20,21	67,70
12:20	50,1	50,5	47,5	16,04	4,45	20,29	71,38
12:30	48,0	51,7	48,3	15,71	4,45	20,18	69,91
12:40	50,8	49,0	46,4	15,12	3,73	20,25	56,40
12:50	49,5	49,7	47,8	15,97	3,81	20,25	60,85
13:00	50,4	49,9	47,7	17,20	2,04	20,14	35,09
13:10	51,2	50,8	49,5	17,41	2,74	20,14	47,70
13:20	46,7	48,9	46,3	15,53	3,73	20,14	57,93
13:30	46,6	47,5	43,5	16,63	3,09	20,18	51,39
13:40	40,9	44,3	41,9	12,76	2,30	14,09	29,35
13:50	37,3	39,4	39,7	12,13	2,74	20,02	33,24
14:00	33,9	41,5	40,7	12,65	1,48	13,83	18,72
Average Pmax							55,58

The data from table 2 is the measurement of PV with Peltier. The data is measured every 10 minutes starting from 11:00 to 14:00. An overall average Pmax of 55,58 Watts was obtained with the Peltier temperature maintained at 40,7°C to 49,5°C. The top temperature of the PV reaches 33,9°C to 53,5°C. While the bottom temperature of the PV reaches 39,4°C to 53°C.

Table 3. Measurement Data of PV without Peltier

Time	**Temp. PV**		**Vmp**	**Imp**	**VOC**	**Pmax**
	Up	**Down**				
11:00	50,1	49,6	15,12	4,06	20,21	61,39
11:10	46,3	46,5	16,19	1,78	19,84	28,82
11:20	47,5	50,1	14,79	3,73	20,66	55,17
11:30	53,4	52,0	14,97	4,32	20,44	64,67
11:40	55,5	56,9	14,75	4,32	20,32	63,72
11:50	52,5	54,8	14,42	4,24	20,21	61,14
12:00	54,2	52,3	14,42	4,06	20,14	58,55
12:10	52,2	52,2	14,57	3,73	20,29	54,35
12:20	54,9	50,1	14,79	4,02	20,29	59,46
12:30	51,7	53,0	14,16	4,28	20,14	60,60
12:40	52,1	49,7	18,04	2,82	20,14	50,87
12:50	52,9	50,2	14,82	3,73	20,32	55,28
13:00	52,3	51,6	15,16	3,81	20,29	57,76
13:10	53,6	51,2	15,97	2,69	20,14	42,96
13:20	49,8	50,1	17,33	2,09	20,14	36,22
13:30	47,4	48,1	16,97	1,93	20,21	32,75
13:40	43,3	43,9	17,22	1,24	19,99	21,35
13:50	40,9	39,6	16,82	1,24	19,96	20,86
14:00	36,5	37,9	16,15	1,36	19,96	21,96
Average Pmax						47,78

The data from table 3 is the measurement of PV without Peltier. The data is measured every 10 minutes starting from 11:00 to 14:00. An overall average Pmax of 47,78 Watts was obtained. The top temperature of the PV reaches 43,3°C to 55,5°C. While the PV bottom temperature reaches 37,9°C to 56,9°C.

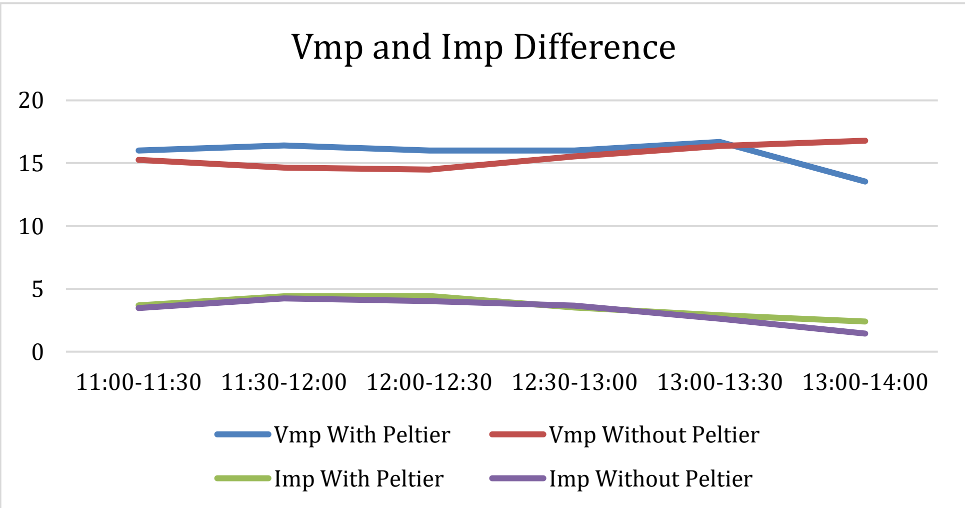


Figure 8. Vmp and Imp Difference of PV Using Peltier and Without Peltier

The graph in figure 8 is a comparison of Vmp and Imp with an averaged time distance of every 30 minutes which shows interesting characteristics between PV with Peltier and without Peltier. The Vmp values for both conditions are relatively stable and close to the range of 14-16 volts. PV without Peltier shows more stability and even tends to increase slightly at the end of the measurement. While PV with Peltier decreased after 13:30. The Imp value for both conditions shows an almost identical pattern with the highest value around 4 amperes at 11:00-13:00. Then the PV without Peltier experienced a significant decrease after 13:00 until it reached the lowest value of around 1-2 amperes at the end of the measurement.

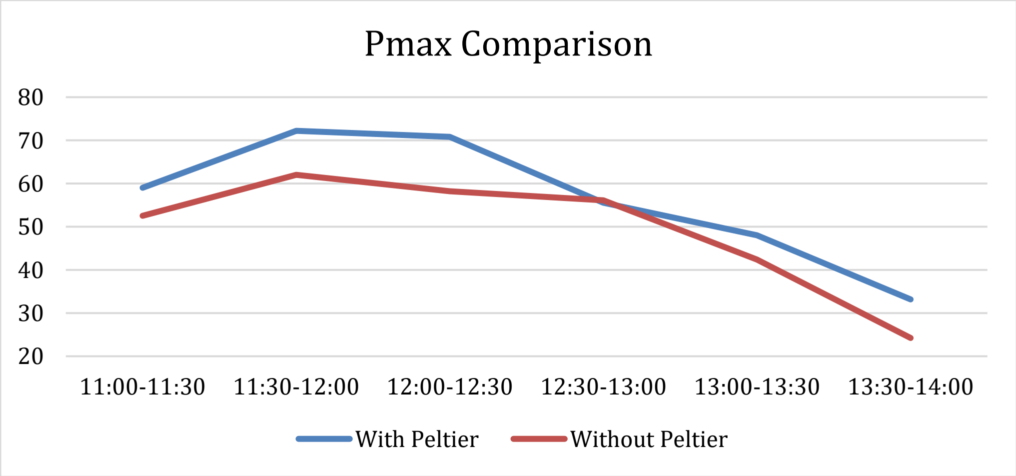


Figure 9. Comparison of PV Using Peltier and Without Peltier

Based on the figure 8 graph with a time interval of 30 minutes taken as an average, there is a clear difference between PV with Peltier and without Peltier. PV with Peltier shows superiority from 11:00 to 13:00, with peak Pmax reaching around 72 Watts at 11:30-12:00. While PV without a Peltier only peaks at around 61 Watts at the same time. Both conditions showed a similar decline after 13:00, but the PV with Peltier maintained a slightly higher Pmax value until the end of the measurement at 14:00.

To determine the efficiency of using a Peltier by not using a Peltier, it is necessary to calculate the power consumption of the Peltier module first as follows:

$$P_{Overall\ Peltier} = V_{Overall\ Peltier} \times I_{Overall\ Peltier} \qquad \ldots\ldots\ldots\ldots \qquad (2)$$

$$= 6\,V \times 0{,}48\,A$$

$$= 2{,}88\,Watts$$

After knowing the power consumption of the Peltier, the efficiency of the system with Peltier can be calculated using the equation:

$$\eta_{With\ Peltier} = \frac{P_{Output\ 1} - P_{Overall\ Peltier}}{P_{Input\ 1}} \times 100\% \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (3)$$

Based on the data obtained, the average Pmax of PV with Peltier is 55,58 Watts, and the input power of PV ($P_{Input\ 1}$) 100 Watts because the PV has a capacity of 100 Wp. So, the efficiency of the system with peltier is as follows:

$$\eta_{With\ Peltier} = \frac{55{,}58\,Watts - 2{,}88\,Watts}{100\,Watts} \times 100\% = 52{,}7\%$$

While the efficiency of the system without Peltier is calculated using the average Pmax ($P_{Output\ 2}$) of PV without peltier is 47,78 Watts.

$$\eta_{Without\ Peltier} = \frac{P_{Output\ 2}}{P_{Input\ 2}} \times 100\% \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (4)$$

So,

$$\eta_{Without\ Peltier} = \frac{47{,}78\ Watts}{100\ Watts} \times 100\% = 47{,}78\%$$

This comparison shows that the use of Peltier modules increases the efficiency of the system by:

$$\Delta\eta = \eta_{With\ Peltier} - \eta_{Without\ Peltier} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (5)$$

$$= 52{,}7\% - 47{,}78\%$$

$$= 4{,}92\%$$

Conclusion

The results show that the use of a Peltier-based cooling system is effective in reducing the temperature of photovoltaic (PV) panels and is able to significantly increase the power generated. In the analysis conducted, the efficiency of the system with Peltier was recorded at 52,7%, while the efficiency without Peltier only reached 47,7%. The 4,92% increase in efficiency shows that this cooling technology not only contributes to temperature reduction, but also plays an important role in improving the overall performance of the PV panels.

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