Jurnal Serambi Engineering JSE
Volume IX, No.2, April 2024 Hal 9015 - 9022
p-ISSN : 2528-3561
e-ISSN : 2541-1934

Effect of Heat Transfer on Solar Module Output Voltage

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Received: April 23, 2024 Approved: April 29, 2024

Abstract
Solar panels are an increasingly popular technology for generating electricity from sunlight. However, the performance of solar modules can be affected by various environmental factors, including heat transfer. High heat transfer can lead to an increase in the temperature of the solar panel and ultimately reduce the output voltage and energy conversion efficiency. Heat from the sun absorbed by the solar module can increase the temperature of the module and reduce the output voltage. Efforts must be made to reduce the temperature of the solar panel so that the performance of the solar panel remains optimal. This manuscript investigates the effect of heat transfer on the output voltage of solar modules. Various studies have been carried out to evaluate the effect of heat transfer on solar module performance, taking into account factors such as the thermal conductivity of the module material, cooling design and environmental conditions. The installation of a heat sink is one of the efforts made to cool the solar module. The heat sink can dissipate an average of 8710.16 joules/second, reducing the average temperature of the solar module by 37.57°C and increasing the average output voltage of the solar module to 19.4 volts. The results of this research show that the use of heatsink material is better for reducing the temperature of solar modules. The use of a heat sink with a large surface area further accelerates the heat transfer process in the solar module.
Keywords: *heat transfer, heatsink, output voltage, solar modules, temperature*

Abstrak
Modul surya merupakan teknologi yang semakin populer saat ini dalam menghasilkan energi listrik dari sinar matahari. Namun, kinerja modul surya dapat dipengaruhi oleh berbagai faktor lingkungan, termasuk perpindahan panas. Perpindahan panas yang tinggi dapat menyebabkan peningkatan suhu modul surya, dan akhirnya dapat mengurangi tegangan keluaran dan efisiensi konversi energi. Panas matahari yang diserap oleh modul surya dapat menaikkan suhu modul dan ikut menurunkan tegangan keluarannya. Perlu dilakukan suatu usaha untuk menurunkan suhu modul surya agar kinerja modul surya agar tetap optimal. Naskah ini melakukan penelitian terkait pengaruh perpindahan panas terhadap tegangan keluaran modul surya. Berbagai studi telah dilakukan untuk mengevaluasi dampak perpindahan panas terhadap kinerja modul surya, dengan mempertimbangkan faktor-faktor seperti konduktivitas termal material modul, desain pendinginan, dan kondisi lingkungan. Pemasangan heatsink merupakan salah satu usaha yang dilakukan untuk mendinginkan modul surya. Heatsink mampu melepaskan rerata panas sebesar 8710,16 Joule/s dan menurunkan rerata suhu modul surya sebesar 37,57°C serta menaikkan rerata tegangan keluaran modul surya menjadi 19,4 Volt. Hasil dari penelitian ini menunjukkan bahwa penggunaan material heatsink lebih baik untuk menurunkan suhu modul surya. Penggunaan heatsink dengan permukaan yang luas semakin mempercepat proses perpindahan panas pada modul surya.
Kata Kunci: *heatsink, modul surya, perpindahan panas, suhu, tegangan keluaran*

1. Introduction

A solar module is an electronic device that can convert sunlight into electrical energy [1]. In operation, the performance of solar modules is influenced by several factors, including environmental temperature and sunlight intensity, where the higher the intensity of sunlight, the greater the electrical energy produced by a solar module and vice versa [2]. Temperature has a different influence on the output parameters of a solar module such as current, voltage and power [3]. An increase in temperature can cause the voltage and power of the solar module to decrease according to the temperature coefficient of the solar module [4].

Efforts to reduce the temperature of the solar module so that it is at normal working temperature (25°C) can use several methods, including a water cooling system [5], and a combination of heatsinks and

Jurnal Serambi JSE Engineering Volume IX, No.2, April 2024 Hal 9015 - 9022 p-ISSN : 2528-3561 e-ISSN : 2541-1934

fans [6]. In a water cooling system, reducing the temperature of the solar module can actually increase the percentage of module power to an average of 3% when compared to without using this system [7][2]. The combination of heatsink and fan [8] to reduce the temperature of the module with this system can speed up the cooling process resulting in a decrease in module temperature of up to 28.20% with an increase in output reaching 1.64% when compared to conditions without using this system [9]. The methods mentioned above are considered incomplete because they do not take into account the heat transfer that occurs in the solar module, where this heat transfer element can be an indicator of whether the performance of the solar module is good or not.

The aim of this research is to investigate heat transfer in solar modules and its correlation with the module's output voltage. Heat transfer in solar modules can affect the performance of the solar module itself, where the higher the heat transfer that occurs, the higher the performance of the solar module so that the electrical energy (voltage) produced by the solar module is greater [10][11]. The mode or method of heat transfer in this research can occur by convection [5].

$$ReL = \ (\rho x \cup \infty x L)/\mu \quad (1)$$

where: ReL = Reynold's number, ρ = Fluid density (kg/m3), U∞ = Fluid flow velocity (m/s), L = Length of convection layer (m), μ = Viscosity (Ns/m2).

2. Material and Methods

Geography of Aceh Besar

This research was conducted in Gampong Tanjong Deah, Aceh Besar which is located at the northwestern tip of Sumatra Island - Indonesia, located at 5.58 north latitude and 95.37 east longitude and located at an altitude of ± 8 meters above sea level. This district is close to the capital of Aceh Province, with a population of 1021 people [12].

This type of research is experimental testing, where the solar panel configuration is used to measure heat transfer directly under specified environmental conditions. Temperature measurements, air flow speed, and solar panel efficiency are some of the factors used to evaluate the effect of heat transfer [5]. **Figure 1** shows the flowchart of research stages.

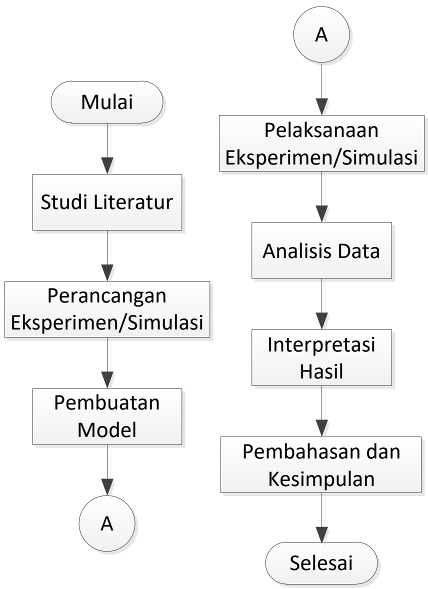

Fig. 1: Research Stages
Source: Processed

The sequence of research stages in **Figure 1** starts from a literature study which was carried out to gain a comprehensive understanding of the topic raised. This was done to study previous research relevant to heat transfer in solar modules, including theory, experiments and the latest findings. The experimental or simulation design stage is the application of literature studies used to design appropriate experiments or simulations. This includes selecting the parameters to be observed, such as solar panel temperature, ambient temperature, air flow velocity, and others. Model making is necessary if the research uses a numerical simulation approach or mathematical model, and the next step is to make the right configuration of the solar panels and the surrounding environment. This stage involves implementing experiments or simulations that have been designed. Furthermore, collecting accurate and relevant data is important to ensure reliable results. Data analysis is carried out after the data has been collected and analyzed thoroughly. This condition includes data processing, identifying patterns or trends, and drawing relevant conclusions. The final sequence is the interpretation of the results, which are the results of data analysis that must be interpreted in the context of the research questions [13]. This stage involves interpreting how heat transfer affects solar panel performance and the implications for future solar panel design and use.

Device Preparation

Preparing the necessary equipment is the first step carried out in this research. Several devices needed for this research are as mentioned below.

Solar Module

The solar modules used in this research are 2 Polycristalline 10 Wp Yunde brand products from China with specifications as shown in **Table 1**. Before being used for research, the solar module must be checked first to ensure it is functioning properly or not. The figure for the output voltage measured is 16.79 Volts with a module temperature of 48°C and an environmental temperature of 37°C.

Table 1. Specifications for 10 Wp polycrystalline type solar modules

Rated maksimum power	10 W
Voltage at Pmax (Vmp)	17,40 V
Current at Pmax (Imp)	0,58 A
Open - Circuit tegangan (Voc)	22,04 V
Short – Circuit (Isc)	0,63 A
Maximum sytem tegangan	700 vdc
Cell technology	Poly – si
Weight	1,2 kg
Dimension	350*235*18

Heatsink

The choice of heatsink was due to the nature of aluminum which easily or quickly releases heat, and the number of heatsinks required for this research only uses one piece. The dimensions of the solar module used to place the heatsink are: Length = 19.5 cm, Width = 9.5 cm, Fin length = 19.5 cm, Fin width = 2.5 cm, and Fin thickness and plate thickness = 0.2 cm.

Laser Thermometer

To measure the temperature, a BENETECH GM320 Non-Contact Laser brand laser thermometer is used with the aim of ensuring that there is no hand touch which can affect the measurement results later.

Digital Luxmeter

To measure the intensity of sunlight, the HS1010 HS1010A LCD Digital Light Meter Illuminance 1-200000 LUX digital model is used and is equipped with various features including automatic measurement level selection, maximum and minimum reading holding function and automatic data recording [5].

Digital Multimeter

To measure electrical parameters such as current, voltage and resistance, a measuring instrument in the form of a Masda DT830B digital multimeter is used. Apart from measuring several electrical parameters, this measuring instrument can also test diodes and transistors [5].

Digital Thermometer

To carry out temperature testing in an open space, a digital infrared thermometer brand LUNA LIFE KF10 A was used. **Figure 2** shows the devices and measuring tools used in this research.

Fig. 2: Devices and Measuring Instruments Used

Research Equipment Installation

Before installing all the required devices, first determine the position of the solar module correctly so that the module does not experience shading so that it can get the maximum heat effect from the sun. The first step that needs to be done is to make a bracket for the solar module [14]. The brackets are made in such a way that the module can be placed correctly and the legs must be the same length so that there is no tilt in the position of the solar module.

The second step is installing a heat-absorbing device or component on one of the solar modules, and thermal paste is used to attach the component to the solar module [15]. Each component is attached to the bottom or back of the solar module. The third step is to ensure the condition of the existing measuring instruments whether they are still functioning properly or not by testing the measuring instruments one by one. After testing, the next step is ready for testing [16].

Fig. 3: Installation of solar modules on brackets and placement of heatsinks on solar modules

Temperature and Output Voltage (Voc) Measurement

After the above steps have been carried out, the next step is to measure the temperature and output voltage of the solar module. **Figure 4** shows the measurement process. Measurements and data collection were carried out from 08.00 to 16.00, with a measurement time span of every 30 minutes [17].

Fig. 4: Measurement of temperature, irradiation and output voltage

The data taken is in the form of temperature and voltage, where these two parameters are indicators of the performance of the material attached to the solar module, and the measurement results are shown in **Table 2**.

Table 2. Measurement results of environmental temperature, heatsink temperature, and output voltage (Voc)

Time (hour) WIB	Ambient temperature (˚C)	Temperature Heatsink (˚C)	Voc (Volt) Heatsink
08.00-08.30	28,8	32,7	21,4
08.30-09.00	29,7	33,4	23,3
09.00-09.30	28,4	33,7	20,8
09.30-10.00	31,8	32,9	22,9
10.00-10.30	31,5	32,5	17,3
10.30-11.00	32,4	34,3	20,1
11.00-11.30	30	35,7	20,8
11.30 -12.00	29,8	34,8	23,6
12.00 -12.30	31,7	35,9	19,3
12.30 -13.00	30,5	34,8	20,9
14.00 -14.30	30,4	34,3	21,2
14.30 -15.00	30,5	33,2	21,2
15.00 -15.30	30,5	32,9	19,8
15.30- 16.00	31,3	33,1	18,1

After data collection was carried out as shown in **Table 2**, data analysis was then carried out using the following equations for each data collection time.

Data Analysis

The data that has been obtained from direct observations and measurements is then analyzed on::

a. Free convection heat transfer rate on the heatsink
Analysis of this type of convection transfer rate requires several parameters that will be involved in this calculation, including the temperature of the surrounding air as the heatsink cooling fluid, the free convection coefficient, the Nusselt number, and the Rayleigh number [5], where:
- Heatsink dimensions
length: 19.5 cm, width: 9.5 cm, heatsink area: because the heatsink has 6 fins, the heatsink area must include the area of the base and fins, namely: heatsink base area = length x width = 19.5 x 9.5 = 185.25 cm2, Heatsink fin area = 6 (length x width) = 6(19.5 cm x 2.5 cm) = 292.5 cm2. Total heatsink area = heatsink base area + heatsink fin area = 185.25 cm2 + 292.5 cm2 = 477.75 cm2 heatsink circumference =2 (length + width) = 2 (19.5 + 9.5) = 58 cm.
- Air temperature and plate temperature (heatsink)
- $Ts_2 = 32{,}7 + 273 = 305{,}7^oK$ .... (2)
- $Ts_\infty = 28{,}8 + 273 = 301{,}8^{\circ} K$ .... (3)
- $\beta = \frac{2}{Ts_2 + T\infty} = 32x10^{-4}$ .... (4)
- $Ts_2 - T_\infty = 316{,}7^{\circ} - 309^{\circ} = 3{,}9^{\circ} K)$
- $L = \frac{luas}{keliling} - \frac{477{,}75}{58} = 8{,}2\ cm$

Because this heatsink is installed horizontally, the heat transfer rate ($Q_{convection}$) that occurs in the heatsink can be approximated by the heat transfer rate equation on a flat plate as follows:

$$R_{aL} = \frac{g\beta(T_{s2} - T_\infty)L^3}{\alpha v} \quad \text{........ (5)}$$

$$R_{aL} = \frac{10\ x\ 32\ x\ 10^{-4}x3{,}9x(8{,}2)^3}{22{,}5\ x\ 10^6x15{,}89x10^6} \quad \text{........ (6)}$$

$$R_{aL} = \frac{80740{,}35x10^{-4}}{357{,}53\ x10^{12}}$$

$$= 1924{,}61x10^{-16}$$

$$N_{ul} = 0{,}54\ R_{al}^{1/4}$$

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Volume IX, No.2, April 2024 Hal 9015 - 9022
p-ISSN : 2528-3561
e-ISSN : 2541-1934

$$= 0{,}54\ x\ (1924{,}61\ x\ 10^{-16})^{1/4}$$
$$= 5{,}67\ x\ 10^{-4}$$
$$h_L = \frac{k}{L} N_{ul}$$
$$= \frac{26{,}3x10^3 x5{,}67\ x10^{-4}}{3{,}2}$$
$$= 46{,}6\ x10^{-1}$$
$$Q_{convection} = h_L x A x (T_{s2} - T_\infty) = 46{,}6x10^{-1} x477{,}75\ x\ 3{,}9 = 86826{,}28x10^{-1} = 8682{,}63\ Joule/s$$

To calculate heat release in other time ranges, it can be calculated in the same way [9].

3. Results And Discussion

From the results of data analysis, the comparison of each parameter can be seen in graphical form so that you can get an idea of the extent of the influence of heat transfer on the output voltage of the solar module. The observation time was taken from 08.00 – 12.30, this was done because the intensity of sunlight was at its highest point at that time.

Table 3. Heat transfer rate (Qconvection) for each type of cooling material against the output voltage (Voc)

Time (hour)	Irradiation (watt m^2)	Ambient temperature ($T\infty$)	*Heatsink* (Ts_2)		
			Temperature	heat rate ($Q_{konveksi}$)	Voc
08.00-08.30	136,41	28,8	32,7	8682,63	21,4
08.30-09.00	395,66	29,7	33,4	8692,7	23,3
09.00-09.30	249,51	28,4	33,7	8695,03	20,8
09.30-10.00	458,53	31,8	32,9	8574,51	22,9
10.00- 10.30	402,11	31,5	32,5	8566,83	17,3
10.30- 11.00	412,71	32,4	34,3	8732,44	20,1
11.00- 11.30	393,42	30	35,7	8812,23	20,8
11.30 - 12.00	384,73	29,8	34,8	8754,71	23,6
12.00 - 12.30	492,17	31,7	35,9	8838,45	19,3
12.30 - 13.00	457,41	30,5	34,8	8752,07	20,9
14.00 - 14.30	447,14	30,4	34,3	8873,19	21,2
14.30 - 15.00	452,67	30,5	33,2	8675,27	21,2
15.00 - 15.30	461,36	30,5	32,9	8689,35	19,8
15.30- 16.00	347,47	31,3	33,1	8673,95	18,1

The rate of convection value relative to the output value is clearly visible at each measurement time. Where at the beginning of the measurement at 08.00 - 08.30 with irradiation of 136.41 at an environmental temperature of 28.8, and the module temperature had reached 31.3. The resulting voltage is 17.6 Volts, while in the solar module that uses a heatsink, the heat transfer rate occurs at 8682.63 with an output voltage of 21.4. Here you can see the correlation between the convection rate ($Q_{convection}$) value and the output voltage. However, when the convection value continues to increase, on the contrary, the voltage value will continue to decrease until it reaches a value of 19.8 Volts at 15.00-15.30 pm.

4. Conclusion

To maintain the output voltage at the maximum position of the solar module, it is necessary to add various kinds of heat absorbing and releasing materials. The addition of a heatsink to reduce the temperature of the solar module turns out to be more effective than without the use of a heat absorber. It is recommended to continue this research by comparing several other types of heat absorbing materials besides heatsink materials.

5. Acknowledgment

Authors thank our colleagues from Universitas Teuku Umar, Sekolah Tinggi Teknik Iskandar Thani (STTIT) and Akademi Komunitas Negeri (AKN) Aceh Barat who provided insight and expertise that greatly assisted the research, although they may not agree with all of the interpretations/conclusions of this paper.

6. Abbreviations

Voc	open circuit voltage
%	Percentage
°C	degrees Celsius
Vmp	voltage at maximum point
Isc	short circuit current

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