Effect of cooling systems on photovoltaic efficiency

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Abstract

Solar power plant (SPP) is one of the alternative power generation systems with great potential to be developed in Indonesia because the climate is relatively constant throughout the year. The main component in the SPP is the photovoltaic (PV) system, which converts solar energy into electrical energy, directly. The ideal temperature of the PV module must be below 40 ℃ to maximize the power generated by photovoltaic, and to maintain this condition the cooling system should be installed in the PV system. In this research, the cooler effects on the electricity generated by the PV will have experimented. The type of PV module is monocrystalline silicon photovoltaic modules, with available in the 1000 Wp grid-connected PV system at the campus of Itenas Bandung. The PV module used 265 Wp (4 units) using 900 W of the inverter system. The results of these experiments get the difference in electricity generated by PV modules with a cooler (active cooling by spraying water) and PV modules without a cooler. Based on experiments on January 12, 2020, it was found that at 14:00, the PV modules' efficiency with and without cooler were 25.68% and 24.24%, respectively.

Keywords: solar power plant (SPP), monocrystalline, voltage, current, power output.

1. Introduction

Depletion of fossil energy today, bring humans to replace or look for another alternative energy, to meet their daily needs, especially electricity. The use of renewable energy is starting to be developed considering this situation. Renewable energy resources, such as sun, wind, water, geothermal, and biomass are essential. For Indonesia, the utilization of solar energy has the most potential due to the geographic location of Indonesia on the equator (Rusirawan, 2013). Solar energy can be converted directly into electricity by a photovoltaic (PV) system. Presently, research in the PV area is very important in the world, especially focus on how to increase the efficiencies as the progress of material technology.

In principle, the PV characteristic is affected by incoming radiation, ambient temperature, and cell temperature. The effect of cell temperature on the other parameters such as open-circuit voltage, maximum power, fill factor, and efficiency has been investigated previously by Sargunathan (2016). This research shows that all parameters will decrease with increasing temperature, and therefore is needed the cooling system.

In this research, investigated PV modules performance with and without cooling system have been performed, and the existing installation of the SPP at the campus Itenas is used as object research. The SPP system is a 100 Wp grid-connected system, with 4 pieces of PV modules @ 265 Wp.

2. Research Method

The electrical performance is primarily influenced by the type of PV used. A typical PV module converts 6-20% of the incident solar radiation into electricity, depending upon the type of solar cells and climatic conditions. The rest of the incident solar radiation is converted into heat, which significantly increases the temperature of the PV module and reduces the PV efficiency of the module. This heat can be extracted by flowing water or air beneath the PV module using a thermal collector, called photovoltaic thermal (PVT) collectors (Dubey, 2012).

This study modifies the PV system in Itenas, by dividing 4 PV modules into 2 (two) sections of PV systems, one system using a cooler and another without a cooler. For cooling systems using water spray, which is controlled automatically. The control system used an Arduino Uno Microcontroller, which is in the program to start the pump at a predetermined temperature. The data collection process is carried out starting at 6:00 a.m. to 6:00 p.m., with data collection intervals is once every/hour. The PV modules section as an experimental setup is shown in Fig. 1.

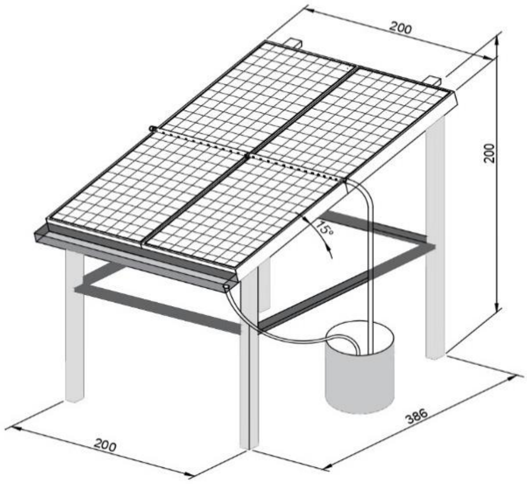


Fig. 1: Solar Power Plant Installation

2.1 Determine Operating Temperature

The cell temperature (T_c) operation can be evaluated using the following formula (Hadiwinoto, 2018):

$$\mathrm{Tc} = Ta + \frac{G\ measured}{G\ reference} + (\mathrm{NOCT} - \mathrm{Ta}) \tag{1}$$

where:

T_a (ambient temperature): obtained from several test results and averaged to get 32°C results.

$G_{measured}$: obtained from several test results (averaged to get 574.7 W/m^2).

$G_{reference}$: obtained from the photovoltaic specification.

NOCT: obtained from the photovoltaic specifications (in this case is 45^{0}C)

Based on equation (1), it can be calculated the working temperature during operation, as:

$$\mathrm{Tc} = 32 + \frac{574.7}{1000} x(45 - 32) = 39^0\ \mathrm{C}$$

2.2 Programming Control System.

The input program uses the Arduino IDE software to enter commands automatically. The commands will be sent directly to Arduino UNO, to start the cooling system and these programs require 4 cell temperature data and 2 average temperatures. The details main program control system can be seen in Figs. 2, 3, and 4, and part of the controller is shown in Fig. 5.

Fig. 2: Programing (1)

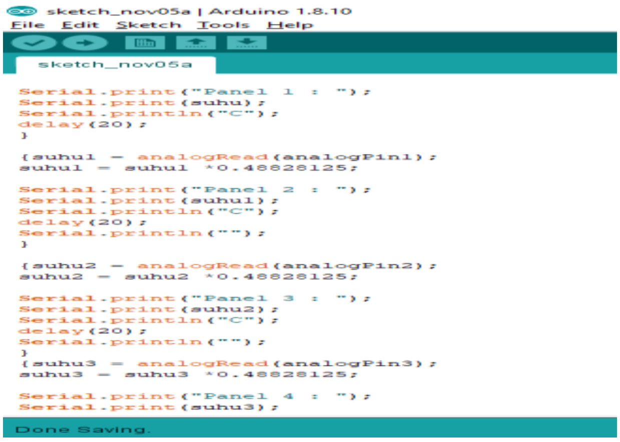
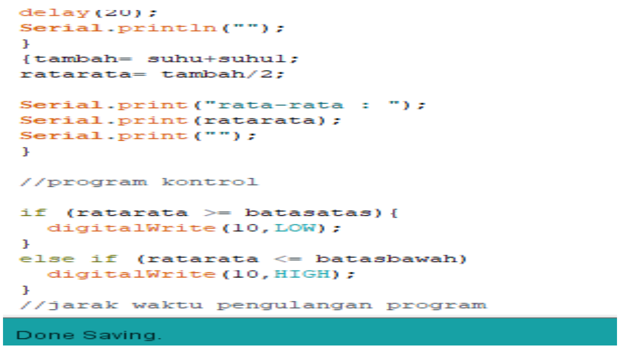


Fig. 3: Programing (2)



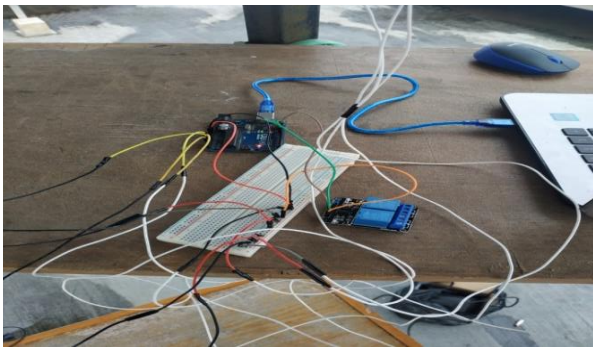


Fig. 4: Programing (3)

Fig. 5: Part of controller (3)

2.3 Parameters of Photovoltaic

Parameters on the I (current) – V (voltage) shows that the current and voltage are changeable depending on the amount of solar intensity. The I-V characteristics of PV solar cells with load conditions or different resistance can be seen in Fig. 6.

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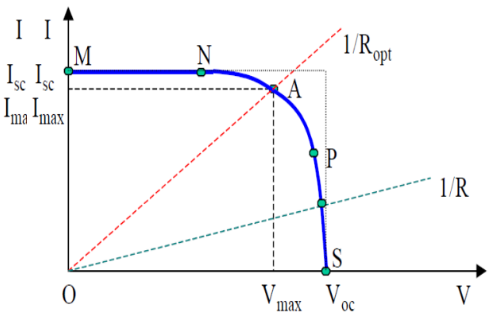


Fig. 6: Current characteristic curves and the voltage.

The parameter to determine the value Outputs on solar cells include (refer to Fig. 6):

- Short circuit current or short circuit current (I_{sc}) is the current maximum output which is obtained from solar cells on condition there is no resistance (R), V = 0.
- Open circuit voltage or open-circuit voltage (V_{oc}) is output power and efficiency which can be achieved when no current.
- Maximum power (Pmax) is located at point A (V_{max}, I_{max}).
- Fill factor (FF) is a value that is close to a certain solar cell constant.

3. **Measurement**

The following data in Tables 1-2 were obtained from the experiment process on January 11-12, 2020.

Table 1: Test data for January 11th, 2020

Date : 11-Jan-20

NO	TIME	weather conditions	PARAMETER								
			G (Radiation)	Ta (Temperatur ambient)	T average 1-2	T average 3-4	Voc(Voltage 1-2)	Isc (Current 1-2)	Voc (Voltage 3-4)	Isc (Curent 3-4)	the Cooler
1	06.00	Cloudy	14,2	25,65	19,925	22,788	57	0,07	57,1	0,07	OFF
2	07.00	Cloudy	76,1	27,55	51,825	39,688	59,4	0,98	60,1	0,98	OFF
3	08.00	Cloudy	338	29,1	183,55	106,33	68	2,34	68,2	2,33	OFF
4	09.00	Cloudy	345,5	28,79	187,15	107,97	68,3	3,04	68,4	3,1	OFF
5	10.00	Bright	640	30,27	335,14	182,7	68,8	4,5	67,9	4,4	ON
6	11.00	Cloudy	465,2	29	247,1	138,05	70,1	3,91	68,1	3,93	ON
7	12.00	Bright	605	31,25	318,13	174,69	71,2	5,4	69,1	5,41	ON
8	13.00	Bright	679	32,71	355,86	194,28	70,1	4,7	66,7	4,7	ON
9	14.00	Cloudy	293,5	28,32	160,91	94,615	68,2	2,83	68,1	2,81	OFF
10	15.00	Cloudy	121	26,86	73,93	50,395	60	1,2	61,4	1,21	OFF
11	16.00	Cloudy	98,5	25,86	62,18	44,02	57	0,98	57,1	0,97	OFF
12	17.00	Cloudy	64	23,93	43,965	33,948	56,4	0,68	56,3	0,68	OFF
13	18.00	Rain									

Table 2: Test data for January 12, 2020

NO	Time	weather conditions	PARAMETER								
			G (Radiation)	Ta (Temperatur ambient)	T average 1-2	T average 3-4	Voc(Voltage 1-2)	Isc (Current 1-2)	Voc (Voltage 3-4)	Isc (Curent 3-4)	the Cooler
1	06.00	Bright	16	21,48	21,485	20,51	60,1	0,8	60,5	0,79	OFF
2	07.00	Bright	122,2	24,9	23,685	26,61	65,2	1,3	65,1	1,31	OFF
3	08.00	Bright	613,2	27,34	28,81	37,11	70	4,9	69,3	4,83	ON
4	09.00	Bright	656	27,83	36,665	42,26	71,9	5,2	70,9	5,4	ON
5	10.00	Bright	815	29,79	32,955	45,165	71,9	5,81	70,1	5,82	ON
6	11.00	Bright	1046	32,23	35,645	50,05	72,5	7,2	69,5	7,1	ON
7	12.00	Bright	933	30,76	36,905	45,155	72,9	8,5	69,9	8,7	ON
8	13.00	Bright	875	32,71	35,15	45,655	71,6	8,2	68,9	9,1	ON
9	14.00	Bright	617	31,11	36,61	42,6	71,8	8,1	69,5	7,9	ON
10	15.00	Bright	542	33,69	34,425	39,795	71,2	71,05	68,9	7,12	ON
11	16.00	Bright	153	31,25	33,935	30,51	71	4,87	68,5	4,73	OFF
12	17.00	Bright	64	28,81	27,74	26,235	69,6	2,73	68,9	2,53	OFF
13	18.00	Bright	8,1	27,34	25,62	24,18	66,9	0,57	66,9	0,55	OFF

3.1 Data processing

Furthermore, the data will be processed to obtain all PV parameters such as maximum power (P). The maximum power can be obtained using the following equation:

$$Pmp = Vmp \times Imp$$
$$Pmp = 71{,}6\ V \times 1{,}12\ A$$
$$Pmp = 80{,}192\ Watt$$

On the other side, the maximum open-circuit power can be obtained using the following equation:

$$Poc = Voc \text{ x } Isc$$
$$Poc = 73{,}5 \text{ V x } 7{,}2 \text{ A}$$
$$Poc = 522 \text{ Watt}$$

The FF (fill factor) is approaching the constant value of a solar cell. The Fill Factor can be obtained using the following equation:

$$FF = \frac{\text{Vmp x Imp}}{V_{OC} \text{ x Isc}}$$

$$FF = \frac{80{,}192 \text{ Watt}}{522 \text{ Watt}} = 0{,}15$$

Finally, based on all parameters, the efficiency of PV can be obtained using the following equation:

$$\eta = \frac{Vmp \ x \ Imp}{FF \ x \ G \ x \ A}$$

$$\eta = \frac{71{,}6 \text{ V x } 1{,}12 \text{ A}}{0{,}15 \text{ x } 1046 \frac{\text{W}}{\text{m}^2} \ x \ 3{,}67 \ m^2} = 13{,}92 \ \%$$

4. Results

The Tables 3-4, and Figs. 7-8 shows the comparison of the PV efficiency with and without applying the cooler.

Table 3. The Comparison of the Efficiency

Time	G	With The Cooler							Without The Cooler						
		Vmp	Imp	Pmp	Voc	Isc	Poc	η (%)	Vmp	Imp	Pmp	Voc	Isc	Poc	η (%)
10.00	815	71,2	1,085	77,252	71,9	5,81	417,739	13,96629946	68,9	1,09	75,101	70,1	5,82	407,982	13,64009294
11.00	1046	71,6	1,12	80,192	72,5	7,2	522	13,59792853	67,4	1,13	76,162	68,5	7,1	486,35	12,66925774
12.00	933	70,6	1,09	76,954	72,9	8,5	619,65	18,0966733	68,2	1,1	75,02	69,9	8,7	608,13	17,76023551
13.00	875	70,8	1,089	77,1012	71,6	8,2	587,12	18,28322304	68,5	1,09	74,665	68,9	9,1	626,99	19,52479564
14.00	617	68,4	0,85	58,14	71,8	8,1	581,58	25,68373823	67,1	0,86	57,706	69,5	7,9	549,05	24,24714824
15.00	542	69,7	0,84	58,548	71,2	7,05	501,96	25,23502619	67,2	0,85	57,12	68,9	7,12	490,568	24,66231638

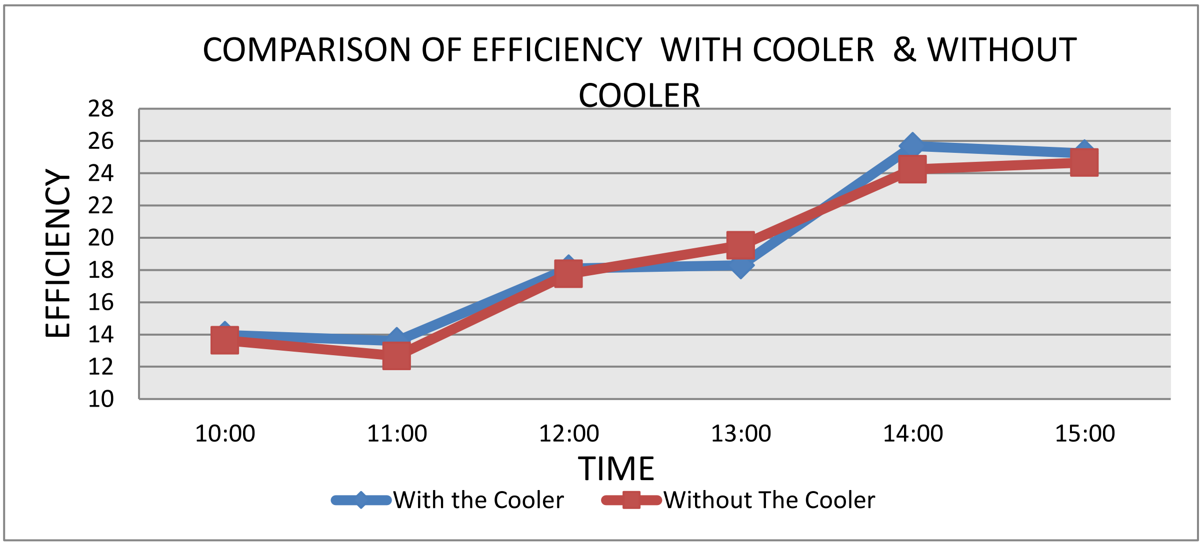
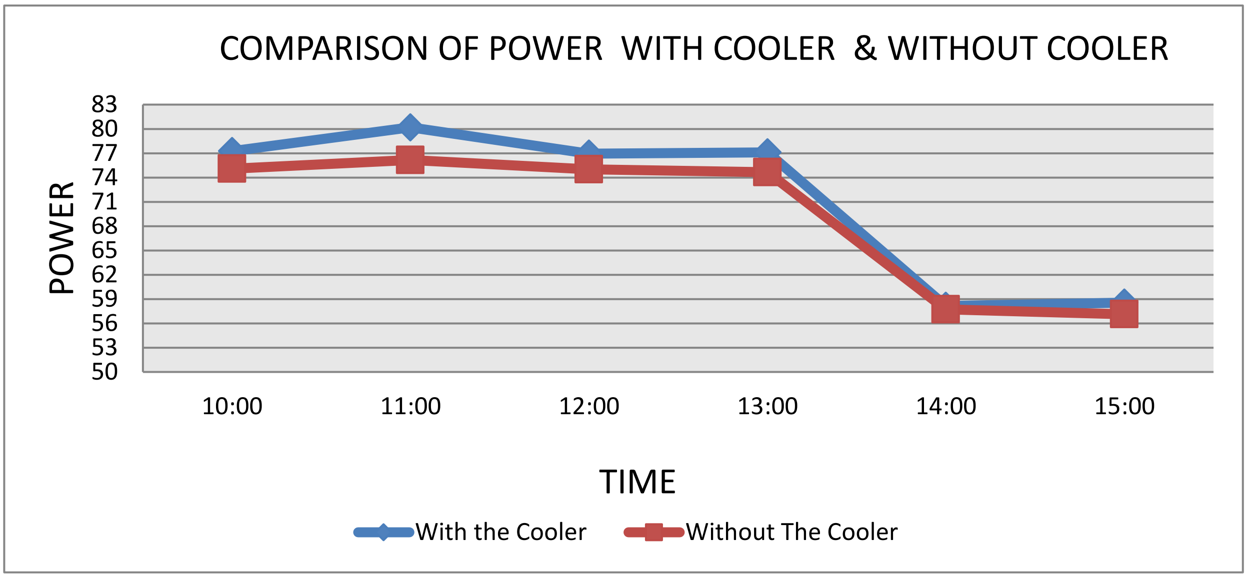


Fig. 7: Difference of efficiency characteristic between PV module with and without a cooler



Graph 2. The Comparison of efficiency

Fig. 8: Difference of power characteristic between PV module with and without a cooler

5. Conclusion

The temperature parameter can affect the PV module performance. In the high-temperature condition, the temperature of the PV module will increase and the performance of the PV module decreases. The comparison of power generated by the PV has evaluated on January 12, 2020. It is found that at 11:00 power generated by PV modules with and without cooler were 80.192 W and 76.12, respectively. There was a difference of about 4.072 W. At 14:00, there was a small difference in power generated by PV modules with and without cooler, due to the temperature differences of both PV modules were small (close to 6°C). Based on the evaluation, it is shown that in the high temperature, the voltage will decrease but the current generated by PV increased, although not significant. It is shown also that at 14:00, the PV modules' efficiency with and without cooler were 25.68% and 24.24%, respectively, and the difference was 1.44%.

6. Nomenclature

I	Current	A
G	Irradiation	W/m^2
P	Power	Watt
Tc	Cell temperature	^0C
V	Voltage	V
FF	Fill Factor	-
η	Efficiency	%

7. References

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