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The Effects of Cells Temperature Increment and Variations of Irradiation for Monocrystalline Photovoltaic

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Abstract. Photovoltaic cell technology has been developed to meet the target of 17% Renewable Energy in 2025 accordance with Indonesia Government Regulation No. 5 2006. Photovoltaic cells are made of semiconductor materials, namely silicon or germanium (p-n junction). These cells need the light that comes from solar irradiation which brings energy photons to convert light energy into electrical energy. It is different from the solar heater that requires heat energy or thermal of sunlight that is normally used for drying or heating water. Photovoltaic cells require energy photons to perform the energy conversion process, the photon energy can be derived from sunlight. Energy photon is taken from the sun light along with the advent of heat due to black-body radiation, which can lead to temperature increments of photovoltaic cells. Increment of 1°C can decreased photovoltaic cell voltage of up to 2.3 mV per cell. In this research, it will be discussed the analysis of the effect of rising temperatures and variations of irradiation on the type monocrystalline photovoltaic. Those variations are analyzed, simulated and experiment by using a module of experiment. The test results show that increment temperature from 25° C to 80° C at cell of photovoltaic decrease the output voltage of the photovoltaic cell at 4.21 V, and it also affects the power output of the cell which decreases up to 0.7523 Watt. In addition, the bigger the value of irradiation received by cell at amount of 1000 W / m2, produce more output power cells at the same temperature.

1. Introduction

Photovoltaic cell technology has been developed to meet the target of 17% of Renewable Energy based on Indonesian Goverment Regulation No.5/2006[1]. Photovoltaic cells are made of semiconductor materials, namely silicon or germanium (p-n junction). These cells need the light that comes from solar irradiation which brings energy photons to convert light energy into electrical energy. It is different from the solar heater that requires heat energy or thermal of sunlight that is normally used for drying or heating water [2]. For every increment of 1 °C, it can cause the photovoltaic cell voltage of 2.3 mV down to every cell [3]. Sun, as a black object in which a process of fusion of hydrogen atoms into helium, produces heat energy [4]. When the heat continues, it would emit black body radiation spectrum peak heat to give a light color. The color of light depends on the wavelength to be shifted to accommodate the temperature of the object [5], so that the light can be ensured along with the heat. The heat causes the temperature rise of the cell. In addition, the heat makes the environmental hot conditions that raise the temperature of photovoltaic cell. The two-season region at equator brings benefits as well as disadvantages. The benefit is solar energy shines all year round, so it can get more energy. However, the value of the environmental temperature on average is higher than 4-season regions [6], and this condition can raise the temperature of photovoltaic cells.

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2. Method

2.1. Simulation

The first step in this simulation is to calculate the value of band gap (the gap between the conduction band and valence band) to the increment in temperature with the equation [7]:

$$E_g(T) = E_g(300K) + \frac{dE_g}{dT}(T - 300K)$$

E_g (300K) = band gap when the temperature of 300 K

T = temperature of photovoltaic cells (K).

After calculating the value of band gap, then the value of I_{sc}, I_o and V_{oc} from photovoltaic cell is calculated by creating MATLAB Simulink simulation [8] by applying the following equations:

$$Isc = \frac{G}{1000}[(Iscr + K_i(Tc - T_r)]$$

$$I_{or} = \frac{Iscr}{[\exp\left(\frac{qV_{ocr}}{nKTr}\right) - 1]}$$

$$Io = Ior\left[\frac{T_c}{Tr}\right]^3 \exp\left[\frac{qE_g}{nK}\left\{\frac{1}{T_r} - \frac{1}{T_c}\right\}\right]$$

K =Boltzman Constant
G =irradiation received by photovoltaic cells (W / m2)
Iscr =short circuit current T cell reference (A)
Ki =temperature coefficient (A / K)
n =factor ideal diode (between 1 and 2)
Tr =reference temperature, 298.15 (ºK)
Vocr =open circuit voltage when Tr (V)
Iscr =current Tr short circuit current (A)
Eg =bandgap (eV)
Ior =saturation current time Tr (A)

Table 1. Data result of simulation

T (°C)	Eg (Ev)	Voc (V)	Voc total (V)	Isc (A)	Io (A)	Pm
25	1.100426	0.6028	21.7008	0.59	3.89800E-11	10.07633
27	1.099966	0.599	21.564	0.591	5.28900E-11	10.02978
30	1.099276	0.5933	21.3588	0.5925	8.29300E-11	9.959555
35	1.098126	0.5838	21.0168	0.595	1.72100E-10	9.841432
40	1.096976	0.5743	20.6748	0.5975	3.48500E-10	9.721963
45	1.095826	0.5648	20.3328	0.6	6.90000E-10	9.601148
50	1.094653	0.5552	19.9872	0.6026	1.35400E-09	9.478854
55	1.093526	0.546	19.656	0.605	2.53600E-09	9.35891
60	1.092376	0.5366	19.3176	0.6075	4.71700E-09	9.235793
65	1.091226	0.5272	18.9792	0.61	8.60700E-09	9.111345
70	1.090076	0.5179	18.6444	0.6125	1.54200E-08	8.9873
75	1.088926	0.5085	18.306	0.615	2.71600E-08	8.860196

It is shown in Table 1 that when the temperatures increase then the value of band gap decreases. When the band gap decreases, it causes the distance between the valence band and the conduction become narrow, furthermore it causes the increment of value of the saturation current diode (Io) as a result of the number of electrons passing narrowed band gap [7]. There is also an increment in the thermal excitation effect on the intrinsic electron charge carriers (ni) [9] [10]. The increment in short circuit current (I_{sc}) is due to the rise of cells temperature (Tc) [8]. Due to the rise of diode saturation current (Io) and the increment in short circuit current (I_{sc}), a decrease in the voltage Voc occurs, because theere is inverse relationship between I_{sc} and Io versus Voc [11]. Voltage Voc decreases in maximum power from photovoltaic cells (Pm) because of the decrease of Voc is greater than the increment of I_{sc} and Io [12].

2.2 Hardware Design

In this study, the experiment module is used for data collection. This module consists of a single photovoltaic cell, and then a series of microcontroller and sensor LM 35 is used to measure temperature. Halogen lamps are used to simulate the sun, because the spectrum of halogen lamp is nearly equal [13] [14]. There are several equipments added such as a direct current cooling fan cooling, resistive load, AC regulator to regulate the level of irradiation of light irradiation, and DC regulator to power the cooling fan. Measurement tools such as multimeter and clamp meter, all equipment components are assembled into an aluminum box as a test site. Figures 1 reveals the flow chart of the simulation based on Matlab, while Figures -4 show the construction of the experiment module.

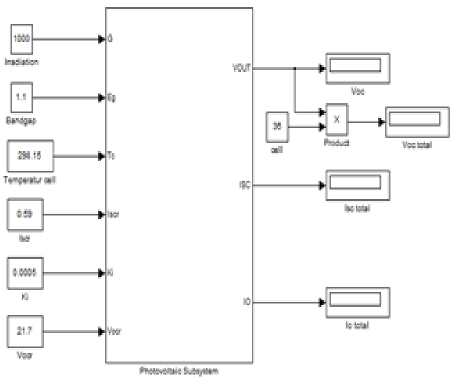

Figure 1. Matlab simulation of photovoltaic

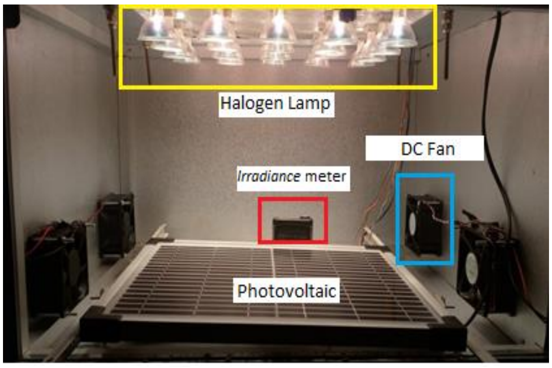

Figure 2. Inside the experiment module

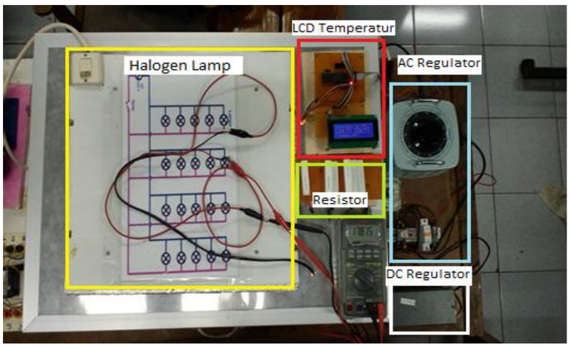

Figure 3. Experiment module from the above

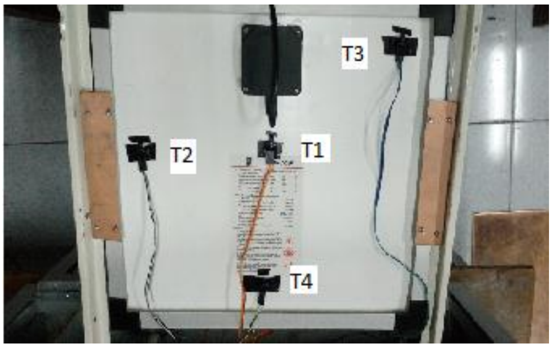

Figure 4. Temperature sensors based on IEC 60891:2009 [15]

With no load condition, the experiment is conducted to measured is the value of open circuit voltage (Voc). On loading condition, several parameters are measured such as short circuit current (Isc), voltage (V), current (A) and the photovoltaic cells temperature (°C). Multiplication of Voc and Isc are called maximum power (Pm). Maximum power is the highest power that can be issued photovoltaic cells. The results of measurement using a multimeter and clamp meter, with variations in the amount of irradiation are 1000 W / m2, 750 W / m2 and 500 W / m^2. Voltage and current data retrieval is done at a temperature value from 27 ºC to 80 ºC, with a difference of 3 or 5 ºC for each increment. Specifications photovoltaic cells are 10 Watt, Voc: 21.7 V, Isc: 0.59 A, Vmp: 18 V, Imp: 0.56 A, in standard test condition (STC) 1000 W / m2, and cell temperature is 25 ˚C. The tests are conducted at the Laboratory of Electrical Energy Conversion and Power Systems, Diponegoro University. In the first experiment, it is performed in a non- loaded condition with variation of irradiation and temperature.

3. Test Result and Analysis

3.1 Experiment non-loaded and short circuit

In the non-loaded conditions, the open circuit voltage (Voc) reaches a peak value at 21.16 V on irradiation 1000 W / m^2, then 20.81 V on irradiation of 750 W / m^2, and 20.08 V on irradiation of 500 W / m^2. At the highest temperature of 80 ºC voltage value drops, i.e. 16.95 V on irradiation 1000 W / m^2, then 16.51 V on irradiation of 750 W / m^2, and 15.84 V on irradiation of 500 W / m2. The best result c occurs when the commencement of variation at a temperature of 27 ºC and irradiation 1000 W / m^2. The decline in the value of the voltage it is consistent with the theory, due to the value of the band gap is decreased as a result of rising temperatures and the decrease of the value of band gap. This causes the distance between the valence band (n-type) and conduction (p-type) is narrowed, it allows more electrons to move towards the conduction band and it causes a rise in the diode saturation current (Io). Rising temperature also causes thermal excitation that makes intrinsic charge carriers increments so that the saturation current (Io) rides, when Io rises, it causes the open circuit voltage (Voc) to be lower.

Table 2. Result of open circuit voltage (Voc)

Temperature (°C)	Voc (V) at 1000W/m^2	Voc (V) at 750W/m^2	Voc (V) at 500W/m^2
27	21.16	20.81	20.08
30	20.89	20.52	19.78
35	20.53	20.1	19.41
40	20.14	19.7	18.89
45	19.76	19.33	18.66
50	19.38	18.93	18.28
55	18.96	18.55	17.87
60	18.52	18.12	17.42
65	18.06	17.73	17.07
70	17.73	17.31	16.65
75	17.29	16.89	16.25
80	16.95	16.51	15.84

Table 3. Result of short circuit current (Isc)

Temperature (°C)	Isc (V) at 1000W/m2	Isc (V) at 750W/m2	Isc (V) at 500W/m2
27	0.38	0.26	0.15
30	0.38	0.27	0.15
35	0.38	0.27	0.16
40	0.38	0.27	0.18
45	0.39	0.27	0.18
50	0.4	0.28	0.18
55	0.4	0.29	0.18
60	0.41	0.29	0.19
65	0.41	0.3	0.19
70	0.42	0.31	0.19
75	0.43	0.31	0.19
80	0.43	0.31	0.19

At the lowest temperature of 27 ºC, the current 0.38 A is obtained at irradiation of 1000 W / m^2, and 0.25 A at irradiation of 750 W / m^2 and 0,15 A at irradiation of 500 W / m^2. A current value rises with increments temperature value. At the highest temperature of 80 ºC, the value of short circuit is variable and follow the irradiance value i.e. 0.43 A on irradiation 1000 W / m^2, and 0.31 A at irradiation of 750 W / m^2, and 0.19 A at the irradiation of 500 W / m^2. The increment in current value it is consistent with the theory posed by a rise of temperature of the cell (Tc). By looking at the equation of equivalent circuit photovoltaic cells [10], it can be seen that the higher the temperature of the cell (Tc), the value of the current short circuit (Isc) also increase.

Table 4. Result of maximum power (Pm)

Temperature (°C)	Pm (W) at 1000W/m2	Pm (W) at 750W/m2	Pm (W) at 500W/m2
27	8.0408	5.4106	3.012
30	7.9382	5.5404	2.967
35	7.8014	5.427	3.1056
40	7.6532	5.319	3.4002
45	7.7064	5.2191	3.3588
50	7.752	5.3004	3.2904
55	7.584	5.3795	3.2166
60	7.5932	5.2548	3.3098
65	7.4046	5.319	3.2433
70	7.4466	5.3661	3.1635
75	7.4347	5.2359	3.0875
80	7.2885	5.1181	3.0096

Maximum power (Pm) is found by multiplying the open circuit voltage (Voc) and short circuit current (Isc). At maximum power, it is found that the higher the temperature, the power value will decrease. The highest point of maximum power produced at a temperature of 27 °C is 8.0408 W on the irradiation of 1000 W / m^2, then 5.4106 W on irradiation of 750 W / m^2, and 3.0120 W on irradiation of 500 W / m^2. At a temperature of 80 ºC generated power decreases, i.e. 7.2885 W on the irradiation of 1000 W / m^2, then 5.1181 W on irradiation of 750 W / m^2, and 3.0096 W on irradiation of 500 W / m^2. The power reduction due to the value of open circuit voltage (Voc) is decrease significantly than increment in short circuit current (Isc). The current is not too significant rise because it has a maximum value of 0.05 A, on the contratry the decline voltage is 4.21 V. Achieved maximum power has decreased to 0.7523 Watt at the lowest point T on the maximum irradiation (1000 W / m^2).

4. Conclusion

The output power of the photovoltaic cell type monocrystalline irradiation is affected by several factors. The higher the value of irradiation (1000 W / m^2) then the value of the power (P) generated become bigger at the same temperature. At the trial non-loaded and short circuit condition, open circuit voltage (Voc) will decrease with increment in temperature due to a decrease band gap. Furthermore, the diode saturation current (Io) increases, when the short circuit current (Isc) rises. The result of multiplying the Voc and Isc generates maximum power (Pm) and it decrease to 0.7523 Watt, due to a decrease in Voc at 4.21 V and Isc 0.05 A.

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