Analysis of Photovoltaic Output and Current Density Through Photoelectric Effect at Low Insolation Level

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Abstract. Solar cells generate energy through a photoelectric process. The electrical energy is produced when electromagnetic waves in photons pass through the semiconductor layer. In real condition, it is often found that the problem of low solar insolation caused by weather and shading factors makes energy conversion unstable and has low efficiency. In this study, PV output and current density are analyzed under low insolation conditions. This research uses a solar cell simulation research tool, GUNT ET 250 (PV module capacity 400 Wp) and a light source from a halogen lamp. Data retrieval is taken by providing radiation on the surface of the PV array of halogen lamps. The radiation emitted from the halogen lamp is set at a radiation of 10 W/m2 to 300 W/m2 using a solar power meter instrumentation. Data from the results of the study are taken by experimental methods with quantitative data tests using PVsyst. From the results obtained for the analysis of PV output at low radiation levels, the lowest PV output is obtained with a current of 0.06 A and a voltage of 10.4 Volts. The linearity of the PV output shows a low error with a regression equation value close to one. The study finding of this research are as a reference for solar cell installation in environmental conditions with low insolation levels.

Keywords: Low Level Irradiance, Photoelectric, Photovoltaic System, Solar Power.

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1. Introduction

Solar energy is a type of renewable energy source generated by the sun. Solar energy can be converted to electrical energy through photoelectric processes on PV(Photovoltaic) modules[1]–[4]. PV modules absorb sunlight and knock electrons loose from its semiconductor layer [5], [6] These loose electrons are directed into one direction flow of electric current. Solar energy is considered as one of the most accessible renewable energy sources. Solar energy can be obtained in many parts of the globe. However, the energy generated by the sun through the PV module is not always constant [7]–[9].

The amount of energy that can be converted into electrical energy depends on the length of solar irradiation and the size of the power of a solar panel. The energy output can also be affected by environmental factors such as shading, solar intensity, and weather, of the area in which the module is installed [10]–[14].

Indonesia is a country with a tropical climate as it is located on the equator. The two main seasons of Indonesia are rainy and dry seasons. The main variable of Indonesia's climate is not temperature or air pressure, but rainfall. The nation's relative humidity ranges between 70% and 90% and average rainfall amounts to 218.4 milli meters (mm) per month. As weather conditions influence PV module voltage and power output, it is important to distinguish how the system responds to these changes, and, thus, research on PV modules outputs that reflects Indonesian weather conditions is highly needed [15]–[17]. The main focus of this research is to predict the

PV output at low solar irradiance level. There are many factors that cause the low level of irradiation, some of them are shading and weather [18]–[20]. Low irradiation level impacts the output of PV as the electromagnetic radiation on the surface of the PV Array is not optimal [21], [22]. The main purpose of this research is to find out the output value of PV in these conditions so that it is useful to determine the potential of PV installations in areas with low levels of irradiance.

The amount of solar energy per unit area that reaches the surface area of the PV array is called irradiation or insolation [23]. The average irradiation level in Indonesia is at the range of 800-900 W/m2 [24]. The low irradiation level is considered to range between 10-300 W/m2 [25]. Some areas with geographical conditions that have low irradiation levels need to be considered beforehand for PV installations.

In general, solar irradiation is measured using a pyranometer instrumentation tool. Previous studies also utilized the same instrumentation as in the study by Miguel C. Brito et.al. which discusses the measurement of photovoltaic potential in a case study on the Mediterranean. The use of a pyranometer is also evident in Daniel Tschopp's research which measures the level of irradiance in PV conditions with a certain angle [26], [27]. Meanwhile, the current research uses the GUNT ET 250 simulation tool and solar power meter instrumentation. Thus, the results of this paper can be useful for engineers or solar cell users to refer to for PV installations in low insolation level geographic conditions.

2. Method

2.1 Solar Irradince Measureament

Irradiance measurements were carried out using a solar power meter instrumentation [28]. The level of irradiation that fell on the surface of the PV array were measured by directing the pyranometer sensor at the halogen lamp [29]. The data taken were included in the PV simulation, PVsyst, so that the PV output can be predicted.

Table 1. Irradiance Input Data On Pvsyst.

Month	Global horizontal radiation (W/m2)	Horizontal diffuse irradiation(W/m2)	Temperature (°C)
January	226.6	114.9	25.8
February	223.6	124.4	26.1
March	241.5	116.6	26.3
April	253.0	109.3	25.8
Mei	237.0	99.3	25.8
June	218.9	103.9	24.2
July	223.4	107.5	24.6
August	230.8	116.0	25.3
September	239.8	112.9	25.0
October	255.0	102.7	24.9
November	239.0	103.9	24.3

Fig. 1. Solar Power Meter (SPM).

2.2 Data Collection Media

The media used in collecting data is PV simulation GUNT ET 250. The tools used in this research are as follows:

Table 2. Data Instrumentation Tools

No.	Component	Amount
1	Solar PV module	2
2	SCC	1
3	Inverter	1
4	Battery	1
5	Measurement system	1
6	Thermal Camera	1
7	Solar power meter	1
8	Illuminance sensor	1

GUNT ET 250 is also equipped with sensors such as illuminance, irradiance, and temperature. Then, the specifications of the tools used are as follows:

a) Solar module:
- Cell type : Monocrystalline
- Module capacity : 400 Wp
- Power (Pmax) : 100 W
- Voltage at Power (Vmp) : 17.6 V
- Current at Power (Imp) : 5.68 A
- Open circuit voltage (Voc) : 21.6 V
- Short circuit current (Isc) : 6.14 A

b) Solar Charge Controller

- Nominal : 12 VDC
- Maximum Charging : 20 A
- Mode : MPPT

c) Inverter

- Input Voltage
  Nominal Voltage : 12 VDC
- Output (Mode Inverter)
  Power Continuous : 50 W
  Voltage : 230 VAC $\pm$ 5%
  Frequency : 50/60 Hz
  Wave Form : Sin Wave

2.3 PV Simulation Block Diagram

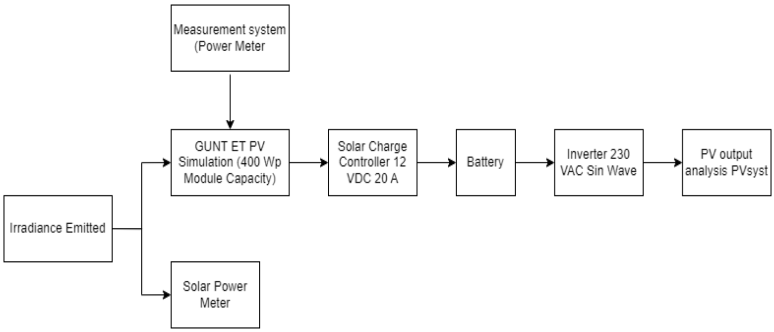

Fig. 1. PV simulation block diagram.

The block diagram explains about the research mechanism using a PV simulation tool, GUNT ET 250. The diagram also explains about data collection and analysis.

2.4 Photovoltaic Effect

The conversion of solar energy into electrical energy occurs in the photovoltaic semiconductor materials through a photoelectric process [30], [31].

$$Ek = W - Wo$$

Where w is the photon energy and Wo is the material threshold energy obtained from:

$$h\,c/\lambda \text{ or } hf$$

Where:
C : Speed of light ($3x$ 108 m/s)
λ : Wavelength (meter) F : Wave frequency (Hz)

2.5 Current Density

The total amount of current that is flowing through one unit value a cross-sectional area is known as current density. On uniform current flow, the amount of current that is flowing through a conductor is the same at all points of the conductor even though the conductor area differs. The amount of current in some specific area can be determined with the help of current density formula.

Current density can be determined by

$$J = \mathrm{I/A}$$

Where J is the current density, I is the total amount of current, and A is the cross section area.

2.6 Illuminance Factor

The solar panel that we use does not always be hit by the sun horizontally and the illuminance that is received by the solar panel differs depending on the illuminance angle that hit the solar panel. Thus, we need to calculate how much is the illuminance measured directly in the sun direction and it can be determined by:

$$R_{dir} = R_{hor}.\frac{\cos(\theta_D)}{\sin(\gamma_s)} = R_{hor}.\frac{\cos(\gamma_s - (90 - \theta_{hor}))}{\sin(\gamma_s)} = \frac{R_{gen}}{\cos(\theta_D)}$$

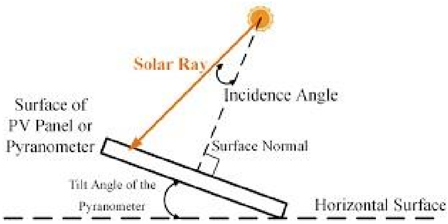

Fig. 3. Measurement of angle irradiance.

Where $Rdir$ is the illuminance measured directly in the sun direction, $Rhor$= is the illuminance hitting on a horizontal surface, and $Rgen$ is the illuminance falling on the solar panel [32].

2.7 Light Conversion and Effeciency

$$P_{max} = V_{OC} I_{sc} FF$$

The efficiency of solar cells can be seen from their light conversion efficiency which is the percentage of electricity converted from incident power by solar cells. The light conversion energy can be determined by

$$\eta = \frac{P_{max}}{P_{in}}$$

Where η is the efficiency of the solar cells, Pin is the total amount of the energy that solar cells take, and $Pmax$ is the power which is converted to electricity obtained from

Where Voc is the open-circuit voltage, Isc is the short- circuit current, and FF is the fill factor.

3. Results and Discussions

This section describes the experiment's result of the PV output at a low insolation level. The experiment resulted current and voltage values of the PV output by varying its irradiation. In addition, this section explains the energy produced by PV and its losses. Current density is another result of this research where it shows how the output current affects the PV performance ratio.

Fig. 4. Instrments for testing

Fig. 4 describes the instrumentation used in data collection for PV output at low insolation level. The general specifications of the tools used are using two PV modules each worth 200 Wp.

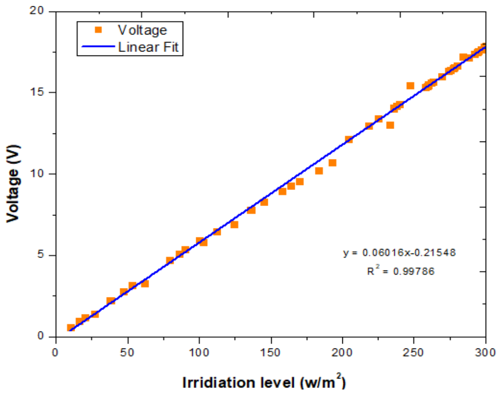

Fig. 5. Correlation between voltage output with irridiation

Fig. 5 describes the correlation between the irradiation level given to the PV array and the resulting voltage current. The following results are the output of the GUNT ET 250 instrumentation tool. The graph shows a fairly good linearity with a regression value of 0.06016x-0.21548

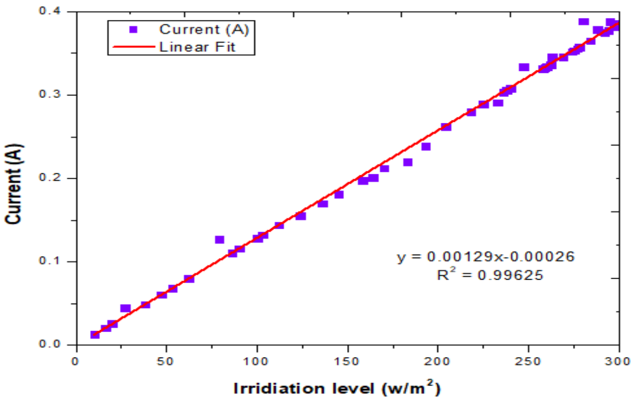

Fig. 6. Correlation between current output with irridiation

Fig. 6 explains the correlation between the irradiation level given to the PV array and the output current generated. In these results, the linearity of the results is quite good with a regression value of 0.00129x-0.00026.

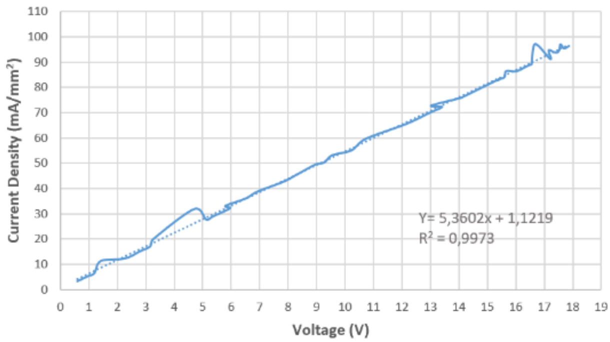

Fig. 7. Current density at low insolation level.

Current density is one of the results in the PV output analysis. Current density describes the amount of current flowing in a certain area (cable).

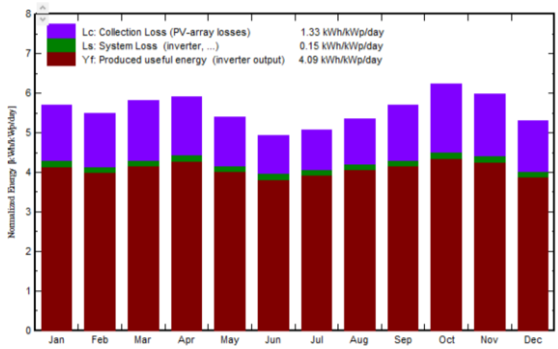

Fig. 8. PV output at low insolation level.

Fig. 8 describes the energy that can be produced by PV at a low insolation level. The PV module with a capacity of 400 Wp converts solar energy into electrical energy on the graph shown in red. While the losses that arise are 1.33 kWh/kWp/day. This value is rather large because the intensity of the sun is low and unstable so that it affects the PV output.

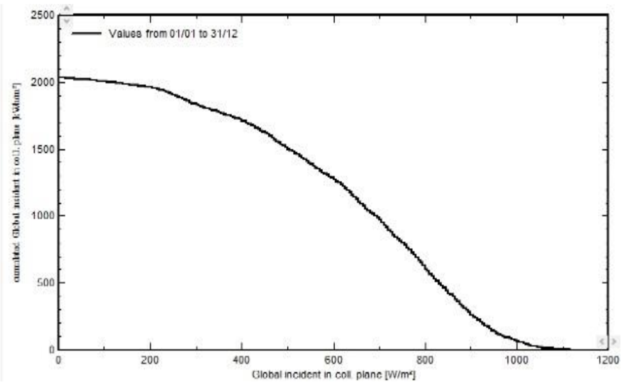

Fig 9. Incident Irradiation Tail Distribution.

Fig. 9 describes the incident irradiation tail distribution. The graph shows the correlation between the cumulative global incident in coll. plane (kWh/m2) and the global incident in coll. Planes (W/m2).

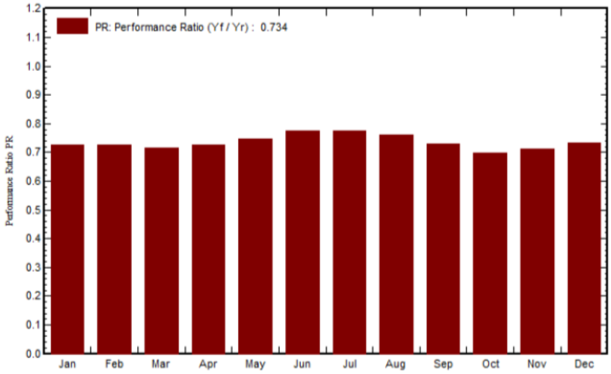

Fig. 10. Performance ratio

Fig. 10 is the value of the performance ratio. The value of the performance ratio at low insolation level gets a lower result, namely 0.734 (average value for a year) than the value of the performance ratio at the normal insolation level of 0.85. The value of the performance ratio can be used as a benchmark in solar PV installations. With these results, it can be a reference for regions with low irradiation levels in considering the development of PV mini-grid in their area.

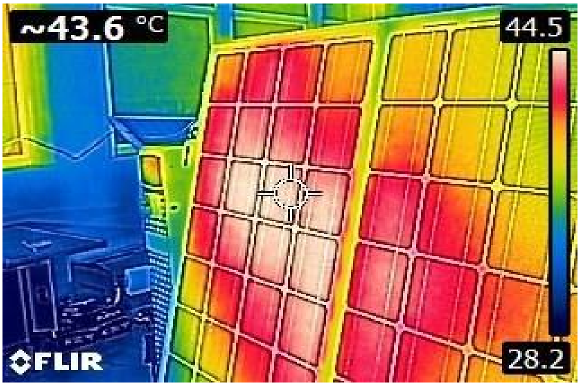

Fig. 11. Surface temperature test.

Figure 11 shows the test for PV surface temperature conducted with FLIR E4 thermal camera. Temperature used in the performance test is about 44.5 ºC. the result of the test shows the PV modules still generate power efficiently at higher temperature than normal.

4. Conclusion

In this study, the topic of PV output and current density at low insolation level is raised. Solar irradiation is not always ideal. The installation of solar cells must be balanced between the expenditure of costs and the energy produced. Thus, the solar cell installation must be in an area that has good sunlight. There are several conditions that cause low levels of solar intensity and should be avoided by solar cell users. This research can be utilized as a reference for solar PV engineers and users to analyze the feasibility of solar cell installations.

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