Analysis of Partial shading Effect on Solar Panel Power Output

Andhika Giyantara¹,a *, Wisyahyadi ²,b, Rifqi Bagja Rizqullah³,c, and Yun Tonce
Kusuma Priyanto⁴,d

¹,4Jl. Soekarno Hatta, Balikpapan Selatan, East Kalimantan Indonesia
²Jl. Marsma R. Iswahyudi No 58, Balikpapan Selatan, East Kalimantan Indonesia
³Perum Sambutan Permai Ariesco AE No.10, Samarinda, East Kalimantan, Indonesia
⁴dhika@lecturer.itk.ac.id, bwisah.yadi06@gmail.com, crr4you@gmail.com,
dyuntonce@lecturer.itk.ac.id

ABSTRACT

Enlarging solar power plants are increasing. This increase is to reduce compatibility with the use of fossil fuel electricity. Utilization of solar power plants is mostly used for street lighting and home industries. Solar power plants must rely on solar irradiation received on solar panels. The output power is also changed by large values from external factors such as partial shading. Partial shading is a condition that is closed / blocked by some cells in the solar panel. The application of partial shading is mostly only used with simulation software. However, in this final project research is carried out the implementation of partial shading and analysis to determine the effect on the output power that occurs in solar panels in actual environmental conditions. The application is made to know the output power during normal and partial shading conditions and to know the partial effect on the solar panel output power. The maximum value of the power produced in solar panels is 298.50 W. The maximum power value that can be obtained when a partial shade occurs is 141.13 W and the partial shade that occurs in the solar panel causes the power to increase under normal conditions.

Keywords: Decrease, Normal Condition, Maximum Power, Partial Shading, Solar Irradiation, Solar Panel,

Introduction

Fossil fuels currently meeting all global energy demands, and it needs to reach a certain limit. Excessive consumption of fossil fuels in every human activity will lead to undesirable phenomena. This phenomenon is in the form of pollution to the atmosphere and the environment, the result of the pollution are global warming, greenhouse effect, extreme climate change, ozone layer depletion, and acid rain. Since 1970, science has proven that natural phenomena are related to the use of fossil fuels. The foundation of fossil fuels become the reason of these natural phenomena, is due to greenhouse gases in the form of carbon dioxide (CO2) and methane (CH4). The impact of this phenomenon can be avoided by two alternatives, specifically improving the quality and efficiency of fossil fuels or replacing fossil fuel with environmentally friendly, clean and renewable energy. Seeing from all energy sources, solar energy is in the first choice because of its quantity and equitable distribution in nature better than other renewable energy sources such as wind, geothermal, and water pressure [1]. These improvements aim to reduce dependency on fossil fuel power plants. Solar power plants in Indonesia are currently only used as public and household street lighting. Solar power generation is very reliant on solar irradiation received by solar cells. The irradiation can affect the value of the output power generated from solar cells [2]

The sun transmits energy in the form of electromagnetic radiation. The radiation can change in value based on the type of beam. The types of beams are divided into two types namely direct and diffuse. Direct radiation is solar radiation that comes directly taken by the earth without flattening on the surface of the atmosphere. Diffuse radiation is a type of solar radiation through the process of spreading to the atmosphere. The spread prompts the amount of irradiation that reaches the earth to be diminished. Illustration of the type of radiation in the sun is shown in Figure 1 [3]
Changes in irradiation values are determined by weather conditions experienced by the earth. In sunny conditions, there is direct radiation from the sun so that the amount of irradiation reaching the earth is > 900 W/m². In cloudy conditions, diffuse radiation occurs, which causes the value of irradiation taken by the earth to decrease in the range of 400-800 W/m². In cloudy conditions, there is a diffusion of sunlight in the form of direct irradiation. The transmission undergoes a spread of irradiation on the surface of the atmosphere so that the obtained irradiation value decreases. The reduction encountered in this condition is worth 50% of the cloudy conditions [4].

Solar irradiation given to the earth changes every time. These variations are caused by the position of the sun, based on the earth revolution that occurred. In this position, the sun can transmit maximum irradiation based on the irradiation time. The maximum optimal irradiation is during the daytime. The aforementioned happens due to the position of the sun perpendicular to the surface of the earth so that the irradiation value reaches > 1000 W/m². The optimal irradiation is found on the actual irradiation curve of the sun as shown in Figure 2 [3].

In the morning and evening, the position of the sun changes by having a declination angle. Declination angle causes the value of solar irradiation received by the earth's surface to be decreased. The value of solar irradiation at intervals of 800-1000 W/m² could be received by the earth's surface at 9 AM & 2 PM. Irradiation values with intervals of 600-800 W/m² are available at 8 AM & 3 PM. Irradiation values between 400-600 W/m² are located at 7 AM & 4 PM [3].

Solar cells are highly dependent on the amount of solar irradiation. The quantity is proportional to the value of the output current that could be generated from solar cells. At one time, the cost of solar radiation received reached a maximum based on a standard condition test of 1000 W/m². This value could produce high current value if the value decreased causing the output current value to drop. The effect of irradiation can be seen in Figure 3 [5].
The temperature of the environment presented to these solar cells can also affect the value of the output voltage. The amount of the heat is inversely proportional to the value of the output voltage produced by solar cells. The higher the temperature value, the smaller the voltage produced. Every 1°C rise in temperature can lessen the output voltage by 0.04-1 V, as shown in Figure 4 [5].

Partial shading is the condition of the closed parts of the surface of a solar cell from sun exposure. The condition was caused by the presence of an object that is blocking the solar cells (Belhaouas, et al., 2017). By blocking the solar cells will result in a decrease in the power produced by solar cells. The decrease is affected by solar irradiation received by solar cells, thereby reducing the value of the output current generated, as shown in Figure 5 [6].

Partial shading can be prevented by giving a bypass diode to the module/array. The bypass serves to prevent the reverse flow that occurs in solar cells that experience partial shading. The bypass effect used by deactivating all cells connected to the bypass, as in Figure 6 [7].
The installation of solar cells in an area has a high cost. Consequently, the efficiency of the plant is exceptionally considerate when choosing a generator location. The location must have a very high solar irradiation and have the right temperature. The irradiation and temperature of the environment become due to the angle of the sun’s light on the earth. The angle of sunlight can vary with the rotation of the earth or at any time change. Experiments were carried out in the Electrical Engineering Laboratory of the Kalimantan Institute of Technology to determine the effect of solar irradiation and temperature on solar panels in normal condition and partial shading condition [8].

**Methodology**

The research was conducted at the Institut Teknologi Kalimantan. Data is collected from 12.00-13.00 midday. The time interval for each data collection is per minute. Data were also taken only on eight days, four days for the normal condition and the other four for partial shading condition. The timing is done because Balikpapan only has 2 seasons particularly the rainy season and the dry season. This indicates that the weather in the city of Balikpapan did not experience significant changes so that the time could represent the situation in the city of Balikpapan.

This research was conducted using a solar panel with a capacity of 250 Watt peak. The solar panel consists of 72 cells connected in series and 3 bypass diodes connected in parallel. Every 24 cells connected in series will be connected in parallel with 1 bypass diode. so that it can be illustrated as shown in Figures 7 and 8.

Besides, solar panels use 3 bypass diodes. Each bypass diode is connected in parallel with 24 solar cells. Bypass diode serves to prevent backflow during shading conditions experienced by one or more cells. The solar panels used are of the polycrystalline type with the specifications on the nameplate in Table 1.

**Table 1 Solar Panel Nameplate**

| SHINYOKU |
|----------|
| **Maximum Power** | $P_{\text{max}}$ | 250W |
| **Maximum Power Voltage** | $V_{\text{mp}}$ | 35V |
Solar cells are a semiconductor component that functions to convert solar energy into electrical energy. The conversion of energy is done by releasing electrons when receiving stimulation from sunlight. The semiconductor material used in solar cells to convert energy into silicon. The material consists of two layers namely the negatively charged layer (N) and the positively charged layer (P) [9]. Solar cells have an ideal equivalent circuit that functions to get the characteristic curve of I-V. The circuit consists of 1 diode and one current source so that it can be seen in Figure 9.

![Figure 9 Ideal Equivalent Circuit of Solar Panel](image.png)

As seen in Figure 11, a current and voltage Equation from the solar cell can be obtained as in Equations 1 and 2.

\[
I = I_{ph} - I_d \left( \frac{qV}{k_B T} - 1 \right) 
\]

(1)

\[
V = \frac{k_B T}{q} \ln \left( 1 + \frac{I_{ph}}{I_d} \right) 
\]

(2)

The information from Figure 9 is, Iph indicates the current generated from sunlight (A), Id is the current flowing at the diode (A), I is the current of the solar cell (A), V is the voltage generated by the solar cell (V), KB is a constant. Boltzmann (J.K^{-1}), T is the actual temperature (°C), q is the electron charge (Coulomb). Based on Figure 11 we get the same output current and output voltage from the solar panel. The Equation is obtained by using the Kirchhoff current law principle so that it can be formulated in Equations 3 and 4 [10].

In preparing the component, system design is very influential with the desired result. The components are chosen in making this Solar Panel Research implementation included current sensors, voltage sensors, irradiation sensors, ambient temperature sensors, and temporary data storage.

\[
I_{out} = I_{ph} - I_s (e^{\frac{qV_d}{k_B T}} - 1) 
\]

(3)

\[
V_{out} = \frac{k_B T}{q} \ln (\frac{I_{ph}}{I_s} + 1) 
\]

(4)
The solar panel used consists of 72 cells, so at the time of partial shading, the number of active cells in the solar panel will be reduced from 72 cells to 48 cells. The partial shading Equation then obtains the reduction in the number of cells in Equation 5 and 6.

\[
V_{\text{partial}} = 48 \times V_{\text{out}}
\]  
\[
P_{\text{partial}} = V_{\text{partial}} \times I_{\text{out}} \times FF
\]  

The design of solar panel simulation is done by dividing the panels into 3 parts. Distribution of panels is seen based on the number of cells in the solar panel.

![Figure 10 Solar Panel Simulation Circuit](image)

Besides, cell division is also seen based on the number of bypass diodes used in solar panels. Each panel used consists of 24 cells connected in series and one bypass diode connected in parallel the design of solar panel simulation using Matlab Simulink software. The solar panel simulation circuit results are based on the construction of the nameplate. There are two external factors, namely the irradiation of exposed sun and ambient temperature. These two factors are used as input parameter values from the simulation that has been made. These parameters are obtained from the solar panel nameplate in a standard condition test [5].

The voltage sensor used is the voltage divider sensor. The voltage will be reduced so that it can be received by the microcontroller, the input limit of the microcontroller is 0V ≤ V ≤ 5V. The voltage will be received by the microcontroller in analog form. The analog data will be converted into digital data by a microcontroller. The current sensor used is the ACS 712 sensor. The input signal from the sensor is a voltage that will be converted by a microcontroller into a current signal. The temperature sensor used is DHT 11. The DHT 11 sensor has a temperature reading capability from 0º-50ºC with an error tolerance of 2ºC. Solar irradiation sensor uses LDR (Light-dependent resistor). The reading of the sun's irradiation value is based on the value of the resistance given, if the irradiation is very large there will be very little resistance produced.

Figure 11 is a block diagram of the system in the implementation that has been made. Based on the picture, solar panels that are exposed to sunlight with certain irradiation can activate solar cells arranged in series in solar panels. The cells are activated by the process of generating an output voltage value that is influenced by environmental temperature.

![Figure 11 Block Diagram System](image)
Experiment of testing the solar panels under normal conditions and partial shading conditions is carried out by providing input parameter values. Input parameters are obtained based on data obtained in hardware testing. The results of the data obtained in the test in the form of output voltage, output current, output power, solar irradiation and ambient temperature. From these data the input parameters in this simulation test are solar irradiation and ambient temperature. An illustration of normal conditions and partial shading conditions can be seen in Figure 12 and Figure 13. The results of the simulation obtained the characteristic curve of I-V under normal circumstances. The curve is then merged with the sampling data obtained. From the results of the merger was analyzed. The analysis was done by comparing the simulation results with the hardware.

![Figure 12 Normal Condition](image1)

![Figure 13 Partial Shading Condition](image2)

**Result and Discussion**

Analysis of the effect of changes in solar irradiation can be done by simulating a standard condition test on solar panels. The condition of the solar panel is without shading. The results obtained are based on simulations in the form of solar panel I-V characteristic curves as in Figure 14.

![Figure 14 Characteristic Curve I-V with Changes in Solar Irradiation Based on Nameplate](image3)

Changes in the characteristic curve of I-V in Figure 14 are influenced by the value of solar irradiation input parameters that are exposed to solar panels. The output current seen in Figure 14 has decreased significantly based on the value of the solar irradiation input given to the solar panel. This decrease affects the value of the output power produced by solar panels.

Analysis of the effect of changes in environmental temperature can be done by simulating a standard condition test on solar panels. The condition of the solar panel is without shading. The results obtained are based on simulation in the form of solar panel I-V characteristic curves as shown in Figure 15. Changes in the characteristic curve of I-V in Figure 15 are affected by the input values of the environmental temperature parameters exposed to solar panels.
Figure 15 Characteristic Curve I-V with Changes in Environmental Temperature

The output voltage seen in Figure 15 has decreased significantly based on the value of the input temperature given to the solar panel. The output voltage of the solar panel is affected by changes in the temperature value of the environment. The greater the value of the solar panel environment temperature, the smaller the value of the output voltage. This decrease influences the value of the output power generated by solar panels.

Retrieval of data that has been done by two types of testing, normal condition testing, and partial shading condition. The first experiment carried under normal data conditions obtained in the form of voltage, current, irradiation, temperature, and power. The output voltage and temperature received by PV can be seen in Table 2. The output current from PV and irradiation received by PV could be seen in Table 3.

Table 2 Output Voltage and Temperature Received by Solar Panel in Normal Condition

| Date      | Time | Voltage | Measurement | Microcontroller | Error |
|-----------|------|---------|-------------|-----------------|-------|
| 11-Feb-19 | 12:00| 37.19   | 38.47       | 3.32            | 35.70 |
| 12-Feb-19 |      | 34.13   | 34.24       | 0.32            | 37.30 |
| 1-Mar-19  |      | 36.57   | 37.60       | 0.20            | 32.10 |
| 2-Mar-19  |      | 34.03   | 33.76       | 0.82            | 36.60 |
| Mean      |      | 35.48   | 36.02       | 1.17            | 35.43 |

The output voltage values listed in Table 2, experiencing changes caused by weather changes at the time of data collection. The output interval at noon is the highest output voltage due to irradiation and the temperature at noon reaches its maximum point. At noon the maximum output voltage that can be generated by solar panels under normal conditions is 37.19 Volts and the minimum voltage obtained is 34.13 Volts. While the maximum temperature obtained by solar panels under normal conditions is 38.70°C and the minimum temperature obtained is 32.10°C.

Table 3 Output Current and Irradiation Received by Solar Panel in Normal Condition

| Date      | Time | Current | Measurement | Microcontroller | Error |
|-----------|------|---------|-------------|-----------------|-------|
| 11-Feb-19 | 12:00| 7.88    | 7.76        | 1.58            | 1461.80 |
| 12-Feb-19 |      | 2.50    | 2.63        | 4.65            | 362.80 |
| 1-Mar-19  |      | 3.61    | 3.48        | 3.94            | 615.00 |
| 2-Mar-19  |      | 1.55    | 1.61        | 3.93            | 229.50 |
| Mean      |      | 3.89    | 3.87        | 3.53            | 667.28 |

The value of the output current listed in Table 3, experiencing changes caused by weather changes at the time of data collection. The output current at noon is the highest output current due to irradiation and the temperature at noon reaches its maximum point. At noon the maximum output current that can be produced by solar panels in normal conditions is 7.88 Amperes and the minimum
current obtained is 1.55 Amperes. While the irradiation received by solar panels under normal conditions is 1461.80 W / m² and the minimum irradiation received is 229.50 W / m².

In the experiments that have been carried out, it can be seen that data Table 3. generated power exceeds the limit of the PV. Analysts obtained were that the current generated by PV was very high on February 11 at noon. It states that there is an influence on the parameters of the PV power output. Input of high solar irradiation will cause high output current, while high ambient temperature can cause lower output voltage.

The second experiment was conducted with partial shading data obtained in the form of voltage, current, irradiation, temperature and power. The output voltage and temperature received by PV can be seen in Table 4. The output current from PV and irradiation received by PV can be seen in Table 5.

Table 4 Output Voltage and Temperature Received by Solar Panel in Partial Shading Condition

| Date      | Time | Voltage | Error | Temperature | Error |
|-----------|------|---------|-------|-------------|-------|
| Measurement | Microcontroller | Measurement | Microcontroller |
| 13-Feb-19 12:00 | 25.10 | 26.15 | 4.02 | 34.00 | 34.00 | 0.00 |
| 14-Feb-19 12:00 | 23.97 | 24.13 | 0.68 | 44.60 | 42.00 | 6.19 |
| 3-Mar-19 12:00 | 25.17 | 25.53 | 1.43 | 33.80 | 33.00 | 2.42 |
| 4-Mar-19 12:00 | 24.60 | 24.68 | 0.78 | 34.00 | 35.00 | 2.86 |
| Mean       | 24.71 | 25.12 | 1.73 | 36.60 | 36.00 | 2.87 |

The output voltage values listed in Table 4 experiencing changes caused by weather changes at the time of data collection. The decrease in voltage value is also caused by the number of active cells, in the partial shading condition 1/3 solar panels are closed so that only 48 cells are active. The output interval at noon is the highest output voltage due to irradiation and the temperature at noon reaches its maximum point. At noon the maximum output voltage that can be generated by solar panels under normal conditions is 26.15 volts and the minimum voltage obtained is 24.13 volts. While the maximum temperature obtained by solar panels under normal conditions is 42°C and the minimum temperature obtained is 33°C. The amount of voltage that has been generated by PV can be seen in Figure 23. The amount of temperature that has been received by PV can be seen in Figure 24.

Table 5 Output Current and Irradiation Received by Solar Panel in Partial Shading Condition

| Date      | Time | Current | Error | Irradiation | Error |
|-----------|------|---------|-------|-------------|-------|
| Measurement | Microcontroller | Measurement | Microcontroller |
| 13-Feb-19 12:00 | 2.97 | 2.77 | 7.28 | 788.50 | 764.55 | 3.13 |
| 14-Feb-19 12:00 | 1.70 | 1.65 | 2.57 | 618.80 | 631.27 | 1.97 |
| 3-Mar-19 12:00 | 5.52 | 5.53 | 0.20 | 1499.90 | 1595.00 | 5.96 |
| 4-Mar-19 12:00 | 1.56 | 1.67 | 6.56 | 454.90 | 470.00 | 3.21 |
| Mean       | 2.93 | 2.90 | 4.15 | 840.53 | 865.20 | 3.57 |

The output current values listed in Table 5 experiencing changes caused by weather changes at the time of data collection. The decrease in current value is also caused by the number of active cells, in the partial shading condition 1/3 solar panels are closed so that only 48 cells are active. The output current at noon is the highest output current due to irradiation and the temperature at noon reaches its maximum point. At noon the maximum output current that can be produced by solar panels under normal conditions is 5.53 amperes and the minimum current obtained is 1.65 amperes. While the irradiation received by solar panels under normal conditions is 1595 W / m² and the minimum irradiation received by 470 W / m².

Table 6 Table Output Power from Solar Panel in Partial Shading Condition

| Date      | Time | Power | Error |
|-----------|------|-------|-------|
| Measurement | Microcontroller |
| 13-Feb-19 12:00 | 74.49 | 72.34 | 2.97 |
The output power values listed in table 6, have changed due to weather changes at the time of data collection. The output power at noon is the highest output power due to irradiation and the temperature at noon reaches its maximum point. At noon the maximum output power that can be produced by solar panels in normal conditions is 298.5 Watt and the minimum power obtained is 54.34 Watt.

Based on the results of the analysis that has been done then a characteristic curve formed from the solar panel. The formation of I-V characteristic curve for solar panels is based on testing. In the test solar panel input parameter values based on measurement data obtained. The simulation results can be obtained by a characteristic curve I-V from solar panels. The curves were obtained as many as 4 pieces based on sampling data collection. The normal condition characteristic curve can be seen in Figure 16 and he partial shading condition characteristic curve can be seen in Figure 17.

The four curves obtained have the difference. The difference is caused by the value of the input parameters of solar irradiation and different ambient temperatures. The greater the value of the irradiation input parameters, the higher the value of the output current produced by solar panels. The greater the input temperature parameter of the environment causes the output voltage produced by solar panels to be low.

| 14-Feb-19 | 40.67 | 39.92 | 1.88 |
| 3-Mar-19  | 138.85| 141.13| 1.62 |
| 4-Mar-19  | 38.31 | 41.14 | 7.29 |
| Mean      | 73.08 | 73.63 | 3.44 |

![Figure 16 The Characteristic Curve of The I-V Solar Panel under Normal Condition](image)
In Figure 17 the output voltage and current data generated by solar panels has decreased. The decrease was caused by partial shading that occurred. Partial shading reduces the number of active cells in the solar panel. The reduction of active cells causes the cell output power produced by solar panels to be lower.

Figure 16 and figure 17 have shown that the experiment result is within the scope of the simulation result. This is proof that the data is valid. The validation is obtained with an equation of the solar panel model. Thus the result in calculation and experiment is the same.

**Conclusion**

Based on the analysis conducted on solar panels under normal conditions and partial shading it can be concluded. The output power produced by solar panels under normal conditions for all sampling is 298.50 W, 89.93 W, 130.73 W and 54.34 W. The output power produced by solar panels in partial shading conditions is 72.34 W, 39.92 W, 141.13 W and 41.14 W. The result have shown that partial shading can reduce the value of the output power produced by solar panels from normal conditions.

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