Modeling and verification of solar panel measurement for Household scale

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Abstract. This research aims to build a modeling of solar panels that will be verified with the results of experiment. The measurements of the implementation of solar panels that have been installed at the household scale. Solar photovoltaic (PV) produces power that is affected by solar irradiation and ambient temperature. These two parameters have been the input values in solar panel modeling. Modeling PV cell simulation was using Simulink Matlab. This modeling used two solar panels with a total capacity of 200 W which are installed in parallel and share the same voltage. This model is able to simulate the I-V characteristic curve and the P-V characteristic curve. Based on the results of measurements of the implementation of solar panels that have been installed in Sukoharjo, Central Java at the longitude location point 10.870902 and latitude -7.603960 with the capacity and electrical characteristics data of the solar panels that were the same as the modeling, the Root Mean Square (RMSE) results of 0.13784 and 0.31305.

1. Introduction

The global electricity demand increases is faster than energy consumption, a serious problem due to the necessary investment to replace obsolete infrastructure in the electricity sector. Breakthroughs and the search for energy sources for electricity are needed. There are various sources of electrical energy such as water, geothermal, sunlight and so forth. The solar radition is a renewable energy source that has great potential to meet the needs of human life. The choice of solar energy as a renewable energy source is given that the energy supply generated from solar radiation reaching the earth's surface reaches 3 x 1024 J. Indonesia is a tropical climate country that has great solar energy potential with an average daily insulation of 4.5- 4.8 KWh / m² / day \cite{1}, \cite{2}.

The potential of solar energy Utilizing in the form of solar or PV (photovoltaic) modules needs to be maximized \cite{1}. PV output is affected by many factors such as solar radiation, temperature, humidity, dust, rain, and so on. Solar radiation and temperature are the main factors, so are the power output of the PV systems a stochastic random process. Moreover, the PV power fluctuation due to the solar radiation and temperature fluctuations also affects the PV system capital and operation costs. The uncertainty of the PV system's power output is the major drawback of these systems \cite{1}, \cite{3}. To get the PV (photovoltaic) efficiency profile, it cannot be separated from the study of parameter identification and PV modeling. Research on the identification of PV has been carried out by many researchers previously through analytic approaches. Analytical approach is a method of solving
mathematical models with standard algebraic formulas, therefore we need a mathematical approach model that is accurate in the PV module. The research using analytic methods has been conducted by several researchers. Research on solar panel modeling that depends on input variables such as radiation and temperature [4], [5], [6].

Related research has also been carried out aimed at finding the parameters of the nonlinear I – V equation by adjusting the curve at three points: open circuit, maximum power, and short circuit. The method finds the best I – V equation for the single-diode photovoltaic (PV) model including the effects of the series and parallel resistance [7], [8]. Research related to modeling and simulation of solar panels with the maximum power point tracker (MPPT) technique has also been conducted with the result that MPPT can significantly increase the efficiency of solar panels compared to without MPPT [9], [10].

This research has studied solar panel modeling with an analytical approach that is simulated with Simulink Matlab. The result of modeling were compared with the results of solar panel experiments that have been implemented with the same solar panel electrical data. The solar panels used are two modules of a house with a total capacity of 200 W photovoltaic model

1.1. Input parameter and specification of the module

This solar panel modeling used Simulink Matlab. The solar panels used amount to two modules with each solar panel module having a capacity of 100W. The parameters in solar panel modeling and simulation that are of constant value are:

| Parameter                                    | Nilai            |
|----------------------------------------------|------------------|
| The reference temperature (Tr)               | 298 K            |
| Ideality factor = 1.6 (A = B)                | 1.6              |
| Boltzman constant (k)                        | 1.3805 × 10-23 J/K |
| Electron charge (q)                          | 1.6 × 10-19 C    |
| The series resistance of a PV module (Rs)    | 0.221            |
| PV module short-circuit current at 25 oC and 1000W/m2 (ISCr) | 2.55A           |
| The short-circuit current temperature co-efficient at ISCr (Ki) | 0.0017A / oC |
| The band gap for silicon (Ego)               | 1.1 eV           |

The following is a table of electrical characteristics data from the VISERO Module PV 100W:

| Karakteristik                                      | Nilai     |
|---------------------------------------------------|-----------|
| Rated Maximum Power (Pmax)                        | 100W      |
| Voltage at Maximum Power (Vmp)                     | 17.6 V    |
| Current at Maximum Power (Imp)                     | 5.71 A    |
| Open Circuit Voltage (Voc)                         | 21 V      |
| Short Circuit Current (Isc)                        | 6.4 A     |
| Maximum System Voltage                             | 1000 V    |

Note: The electrical specifications are under test conditions of irradiance of 1 kW/m², spectrum of 1.5 air mass and cell temperature of 25°C.

1.2. Photovoltaic model in Matlab Simulink

Solar panel modeling and simulation used are 2 solar panel modules and arranged in parallel. Figure 1 is a block of a solar panel modeling system with a total capacity of 200 W arranged in parallel.
This solar panel modeling has 5 subsystems namely current photo sub-system, sub-system, sub-system, sub-system, sub-system. The following will explain the modeling of each sub-system:

1) Sub Sistem of Photo Current

Formula of photo-current yang was produced by modul PV - $I_{ph}$ is [6]:

$$I_{ph} = [I_{SCr} + K_i(T - 298)]*G/1000$$

Furthermore, the formula is made using simulink as shown in Figure 2. The parameters T and G are input systems, while the parameters $I_{SCr}$ are based on the characteristics of the type of PV.

![Figure 2. The Simulink Sub Program of Photo-Current](image)

2) Sub Sistem of Saturation Current

The formula of electrical current saturation PV - $I_0$ is [6]:

$$I_0 = I_0 + \frac{q}{nk} \exp\left(\frac{q\cdot E_{oc}}{nk}\right) \left(\frac{1}{T} - \frac{1}{T_r}\right)$$

Furthermore, the formula is made using simulink as shown in Figure 3.

![Figure 3. The Simulink Electrical Current Saturation of PV](image)

3) Sub Sistem Reserve Saturation Currents

Formula reserve saturation current - $I_{rs}$ is [6]:

$$I_{rs} = I_{SCr}/[\exp(q\cdot E_{oc}/N_{ks}kT)-1]$$

Furthermore, the formula is made using simulink as shown in Figure 4.
4) **Sub Sistem Shunt Current**

Formula shunt electrical current \( I_{sh} \), is \[6\] :

\[
I_{sh} = \frac{V + I_{ph} R_s}{R_{sh}} \tag{4}
\]

Furthermore, the formula is made using simulink as shown in Figure 5.

5) **Sub Sistem PV**

Formula of current output frommodul PV \( I_{pv} \) [6]

\[
I_{pv} = N_p * I_{ph} - N_p * I_0 \left[ \exp \left( \frac{q (V_{pv} + I_{pv} R_s)}{N_S n k T} \right) - 1 \right] \tag{5}
\]

Where \( V_{pv} = V_{oc}, N_p = 1 \) and \( N_S = 20 \)

Furthermore, the formula is made in series using simulink which can be seen in Figure 6. While Figure 7 is a PV Module Simulink which combines the five sub-programs which include Photo-Current sub-programs, PV Current Saturation sub-programs, Reserve Saturation Current sub-programs, sub-programs Shunt Current, and the Output Flow sub program of the PV module.
2. Experimental Method

The experiment was done in the Sukoharjo, Central Java Java at the point of longitude 10.870902 and latitude -7.603960. The stages of the research are the installation of solar panel sets and their supporting components, PV performance testing, data measurement and retrieval and data analysis.

Measurements were made two days, namely on 28 and 29 September 2019. Ambient temperature fluctuates in the range of 25°C to 37°C. Solar panels are tested and parameters such as Voc, Isc and P. What is needed for system evaluation is measured at one hour intervals between 07.00 until 16:00 WIB. Voc and Isc parameters are measured using an intelligent solar charge controller as shown in Figure 8. Figure 9 shows the installation of solar panel modules on the roof of the house.
3. Results and Discussions

3.1. Modeling Result
The parameters that determine solar cell operations are reflected in curves I-V and V-P. Input data used are temperature and solar irradiation. Temperature data are obtained from http://www.weather.com. While the solar irradiation data varies, i.e. 1000 Watt/m², 900 Watt/m², 800 Watt/m² and 700 Watt/m² [6].

1). Curve I-V
Fotocurrent depends on the irradiation of the moment. The higher the irradiation, the greater the current. While the voltage will be almost constant even though irradiation increases or decreases. Figure 11 are the results of modeling for the characteristics of the I-V curve with a constant temperature of 25°C.

![Figure 11. The I-V curve for Constant Temperature at 25°C](image)

2). Curve of P-V
The effect of irradiation variations, at a constant temperature, is the basis for calculating the maximum power point. The higher the irradiation, the main maximum power point will be obtained in the solar pane module. Figure 12 are the results of modeling for the characteristics of the V-P curve with a constant temperature of 25°C.
3.2. Experimental Study Result

**Figure 12.** V-P Curve for Contant Temperature at 25 °C

**Table 3.** Comparison Results Modeling and Experiment on 28-9-2019

| Time   | T (°C) | I (Ampere) | V (Volt) | P (Watt) | I (Ampere) | V (Volt) | P (Watt) |
|--------|--------|------------|----------|----------|------------|----------|----------|
| 07.00  | 25     | 7.14       | 13.6     | 97.11    | 6.1        | 13.6     | 82.96    |
| 08.00  | 28     | 7.29       | 14.0     | 102.08   | 7.5        | 14.1     | 105.75   |
| 09.00  | 31     | 8.31       | 14.1     | 117.20   | 9.3        | 14.1     | 131.13   |
| 10.00  | 34     | 6.86       | 14.0     | 96.06    | 9.4        | 14.1     | 132.54   |
| 11.00  | 35     | 6.25       | 14.0     | 87.49    | 9.2        | 14.0     | 128.80   |
| 12.00  | 36     | 6.41       | 13.5     | 86.48    | 8.8        | 13.9     | 122.32   |
| 13.00  | 36     | 6.06       | 13.0     | 78.75    | 5.6        | 13.1     | 73.36    |
| 14.00  | 35     | 6.58       | 13.0     | 85.57    | 5.6        | 13.0     | 72.80    |
| 15.00  | 33     | 5.32       | 12.9     | 68.67    | 5.1        | 12.9     | 65.79    |
| 16.00  | 31     | 5.07       | 12.7     | 63.57    | 5.0        | 12.7     | 63.50    |

**Table 4.** Comparison Results Modeling and Experiment on 28-9-2019

| Time   | T (°C) | I (Ampere) | V (Volt) | P (Watt) | I (Ampere) | V (Volt) | P (Watt) |
|--------|--------|------------|----------|----------|------------|----------|----------|
| 07.00  | 26     | 6.92       | 13.6     | 94.15    | 5.7        | 13.1     | 74.67    |
| 08.00  | 28     | 7.45       | 13.8     | 102.80   | 8.2        | 13.7     | 112.34   |
| 09.00  | 32     | 8.07       | 13.9     | 112.2    | 9.1        | 14.0     | 127.40   |
| 10.00  | 33     | 7.43       | 14.0     | 104.00   | 9.3        | 14.0     | 130.20   |
| 11.00  | 36     | 6.09       | 13.7     | 83.41    | 9.6        | 13.9     | 133.44   |
| 12.00  | 37     | 5.76       | 13.5     | 77.75    | 8.9        | 14.1     | 125.49   |
| 13.00  | 37     | 6.56       | 13.0     | 85.30    | 6.0        | 12.9     | 77.40    |
| 14.00  | 36     | 6.71       | 13.3     | 89.26    | 6.3        | 13.2     | 83.16    |
| 15.00  | 34     | 7.56       | 13.5     | 102.00   | 7.4        | 13.3     | 98.42    |
| 16.00  | 32     | 4.78       | 12.6     | 60.17    | 4.1        | 12.1     | 49.61    |
Figure 13. Voltage(V) Curve of Modeling and Experiment Result (28-9-2019)

Table 3 and Table 4 show the comparison results modeling and experiment values on 27 and 28-9-2019. Temperature data are based on data obtained from www.accuweather.com and is in accordance with research conducted by Nikhol [10]. The value Root Mean Square Error(RMSE) for Voltage (V) modeling and experimental results on 28-9-2019 is 0.13784.

Figure 14. Voltage(V) Curve of Modeling and Experiment Result(29-9-2019)

The value Root Mean Square Error(RMSE) for Voltage (V) modeling and experimental results on 29-9-2019 adalah 0.31305.

Figure 15. Current (I) Curve of Modeling and Experiment Result(28-9-2019)
The value Root Mean Square Error (RMSE) for Current \( I \) modeling and experimental results on 28-9-2019 adalah 1.556204.

**Figure 16. Current (I) Curve of Modeling and Experiment Result (29-9-2019)**

The value Root Mean Square Error (RMSE) for Current \( I \) modeling and experimental results on 29-9-2019 adalah 1.726104. If we compare the results of modeling with experiments it can be said that the values are in accordance. This is indicated by the value of RMSE (root mean square error). The RMSE value for voltage measurements on 28-9-2019 is the best, 0.13784. The largest value of RMSE on Electrical Current measurements on 29-9-2019. Weather factors influence measurement through experiments [1], [2], [7], [11]. In addition, it is also because the measurement tool intelligent solar charge controller has to add loads, which results in smaller measurement currents.

4. **Conclusion**
The performance of solar panels in generating electricity both modeling and experimentally produces almost the same value. The similarity of power is indicated by the RMSE value for measuring the amount of electric current and the electric voltage. The RMSE voltage measurements for 28-9-2019 and 29-9-2019 are 0.13784 and 0.31305. The RMSE values for the measurement of electric current for the date of 28-9-2019 and 29-9-2019 are 1.556204 and 1.726104.

5. **Nomenclature**
- \( V_{pv} \): output voltage of a PV module (V)
- \( I_{pv} \): output current of a PV module (A)
- \( T_r \): the reference temperature
- \( T \): the module operating temperature in Kelvin
- \( I_{ph} \): the light generated current in a PV module (A)
- \( I_0 \): the PV module saturation current (A)
- \( A = B \): an ideality factor
- \( k \): Boltzman constant
- \( q \): Electron charge
- \( R_s \): the series resistance of a PV module
- \( I_{SCr} \): the PV module short-circuit current at 25 °C and 1000W/m²
- \( K_i \): the short-circuit current temperature co-efficient at \( I_{SCr} \)
- \( \lambda \): the PV module illumination (W/m²) = 1000W/m²
- \( E_{go} \): the band gap for silicon
- \( N_s \): the number of cells connected in series
- \( N_p \): the number of cells connected in parallel
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