Modelling of Photovoltaic Module Using Matlab Simulink

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Abstract. Photovoltaic (PV) module consists of numbers of photovoltaic cells that are connected in series and parallel used to generate electricity from solar energy. The characteristics of PV module are different based on the model and environment factors. In this paper, simulation of photovoltaic module using Matlab Simulink approach is presented. The method is used to determine the characteristics of PV module in various conditions especially in different level of irradiations and temperature. By having different values of irradiations and temperature, the results showed the output power, voltage and current of PV module can be determined. In addition, all results from Matlab Simulink are verified with theoretical calculation. This proposed model helps in better understanding of PV module characteristics in various environment conditions.

1. Introduction
Research on photovoltaic energy as energy source in various applications has increasing nowadays. It is clean, renewable and essential sustainable resources which make it suitable to be used as an alternative energy sources due to finite source of fossil fuels and coals. Malaysia solar radiation is high by world standard where in Kuala Lumpur, a PV system installed received more than 30% energy compared to an equivalent system in Germany [1]. Power output of PV module is directly proportional to solar radiation. Hence, in order to select the best location to install PV module, the strength of solar radiation need to be considered. Besides that, environmental factors and local climate such as humidity, temperature and wind also need to be considered as it will affect the output power of PV module [2]. These effects are shown clearly in this simulation result where the performances of PV module depend on the amount of solar radiation also the temperature of surrounding.

Modeling and simulation of PV module helps in better understanding in terms of the behavior and characteristics. These methods effectively used in predicting the behavior of PV module vary in environmental conditions [3]. Effective PV module is required in developing Maximum Power Point Tracking (MPPT) method as it relies on the behavior of the PV module to works accurately.

There are several methods in modelling PV cell characteristics. The methods are numerical methods, analytical techniques, artificial intelligence techniques and linearization and Thevenin...
equivalents [4]. As for this paper, analytical methods are used where PV cell is modelled as a single diode circuit that consists of photocurrent, diode, and series and shunt resistor. By using this method, characteristics of PV cell and module can be determined easily.

2. Mathematical Model of Photovoltaic Module

Photovoltaic module consists of photovoltaic cells that are connected in parallel. This cell basically is a p-n junction that is fabricated in thin film semiconductor such as silicon that enables to converts the light energy into electricity. As the cell exposed to light energy, the photon that hits the cells will be absorbed by semiconducting material as the electron will be flow and creating electricity.

An ideal PV cell is modeled as single diode circuit [4-9] as shown in figure 1.

![Figure 1. Equivalent circuit of PV cell.](image)

The current $I_{ph}$ represents the photocurrent of the cell. $I_o$ represents the PV saturation current and while $R_{sh}$ and $R_s$ both are intrinsic shut and series resistances of the cell respectively. Both value of $R_{sh}$ and $R_s$ are always neglected in order to simplify the analysis due to the value of $R_{sh}$ is very large and $R_s$ is very small.

To have high value of voltage and current, PV cells are connected together to form a module that are usually covered in glass and framed together. Then, when the modules are connected parallel-series configurations, they form a PV array. Equations (1) – (4) below shows the mathematical model of PV panel [5-9].

For PV photocurrent, $I_{ph}$

$$I_{ph} = [I_{SCR} + K_i(T - T_r)] \times \frac{S}{1000} \quad (1)$$

For PV reverse saturation, $I_{rs}$

$$I_{rs} = I_{SCR}/\left[\exp \left(\frac{qV_{oc}}{N_{sk}A}\right) - 1\right] \quad (2)$$

For PV saturation current, $I_s$

$$I_s = I_{rs}\left[\frac{T}{T_r}\right]^3 \exp \left[qE_g/Ak\left(\frac{1}{T_r} - \frac{1}{T}\right)\right] \quad (3)$$

For PV output current, $I_{pv}$

$$I_{pv} = N_p \times I_{ph} - N_p \times I_{ph}\left[\exp \left(\frac{qV_{pv} + I_{pv}R_s}{N_{sk}AT}\right) - 1\right] \quad (4)$$

Where $V_{pv} = V_{oc} = 37.191$ V, $N_p = 1$ and $N_s = 60$
Malaysian Solar Resources (MSR) PV mono-crystalline 245W module is chosen for both simulation and experimental model. Table 1 below shows the technical data of MSR 245W PV module.

| Type                                           | MYS-60M/B3/CL-245 |
|------------------------------------------------|-------------------|
| Rated power                                    | 245W              |
| Open circuit voltage ($V_{oc}$)                | 37.191V           |
| Short circuit current ($I_{sc}$)               | 8.449A            |
| Voltage at maximum power ($V_{mpp}$)           | 29.702V           |
| Current at maximum power ($I_{mpp}$)           | 8.107A            |
| Total number of cells in series ($N_s$)        | 60                |
| Total number of cells in parallel ($N_p$)      | 1                 |

The electrical characteristics are within $\pm 3\%$ of the indicated values under Standard Test Conditions. (1000W/m$^2$, 25°C, AM1.5)

3. Simulink Model of Photovoltaic Module

MSR 245W PV module has been chosen as a reference in simulation using Matlab Simulink. The model develop based on equations (1) – (4) including temperature dependence on photocurrent source, diode saturation current and a series resistance which is considered based on Shockley diode equation.

By depending on radiation of sunlight and the temperature, PV cells converts the energy directly into electricity which given both I-V and P-V output characteristics. Figure 2 to 9 below shows the modelling that been done in Simulink with steps that involved.

Step 1

Figure 2. Converting operating temperature from degree Celcius to Kelvin (K).

Step 2

Figure 3. This model calculates the value of $N_s kAT$ used in equation (2) and (4).
Step 3

![Diagram for Step 3]

**Figure 4.** This model calculates PV photocurrent, $I_{ph}$ based on equation (1).

Step 4

![Diagram for Step 4]

**Figure 5.** This model calculates PV reverse saturation current, $I_n$ based on equation (2).

Step 5

![Diagram for Step 5]

**Figure 6.** This model calculates PV saturation current, $I_s$ based on equation (3).
Step 6

![Figure 7](image1)

**Figure 7.** This model calculates PV output current, $I_{pv}$, based on equation (4).

Step 7

![Figure 8](image2)

**Figure 8.** This model includes all six model of subsystem above and connected together.
Step 8

As in figure 9 shows, the final model of PV model developed using Simulink includes irradiation and temperature as the input parameters and results in voltage output, $V_{pv}$, and current output, $I_{pv}$, as the results.

4. Result and Discussion

PV module is modelled by using Matlab Simulink. The parameters of the model are based on the equations mentioned above and technical data of PV module as shown in Table 1. The model built by following the sequences until the final model is presented.

The values of every calculation in Simulink model are verified with theoretical calculations that are based on the equations (1) until (4) shown in Table 2. This proves that the simulation is according to the characteristics and performances of the PV module.

|                   | Theoretical | Simulation |
|-------------------|-------------|------------|
| PV photocurrent, $I_{ph}$ | 8.449 A     | 8.449 A    |
| PV reverse saturation, $I_{rs}$ | 0.0001141 A | 0.0001141 A |
| PV saturation current, $I_{s}$       | 0.0001141 A | 0.0001141 A |
| PV output current, $I_{pv}$           | $-1.39 \times 10^{-3}$ A | $-1.39 \times 10^{-3}$ A |

4.1. Varying irradiation, fixed temperature

As the results based on the equations are proved, the I-V and P-V characteristics with vary in irradiation and temperatures are obtained.
Figure 10 and 11 below shows the I-V and P-V output characteristic of PV module. The inputs for irradiation are varied by three different values of irradiation which are 200 W/m², 600 W/m² and 1000 W/m² respectively. As for the temperature, it set following the value of PV panel reference temperature, $T_{pk} = 25^\circ$C.

Results above show that the voltage and current output both increases when the irradiations are increases. These increases lead to the increasing value in power output of PV panel.
4.2. Fixed irradiation, varying temperature
As for the inputs of fixed irradiation and varied in temperature, irradiation input is set to 1000 W/m² and the temperatures are set as 28°C, 50°C and 60°C. This is to observe the PV characteristics when varying the irradiation. Figure 12 and 13 below shows the I-V and P-V output characteristics of the PV module.

![Figure 12. I-V characteristics varying temperature, fixed irradiation.](image1)

![Figure 13. P-V characteristics varying temperature, fixed irradiation.](image2)
As for the increases in operating temperature, the output current increases while the voltage drops accordingly. This leads to decreasing value in PV power output.

5. Conclusion
Step by step method in modelling PV module was developed using Matlab Simulink and presented. This method also verified by theoretical calculations based on the equations involved for PV module. This paper presents a clear understanding on the behaviour and parameters involved in PV module especially on I-V and P-V characteristics. Hence, it will serve the researchers with better understanding of PV module.

References
[1] Energy, A.B.C.f.S., Renewable Energy in Asia: The Malaysia Report, in An overview of the energy systems, renewable energy options,initiatives, actors and opportunities in Malaysia. 2005.
[2] X. Gong and M. Kulkarni, “Design optimization of a large scale rooftop photovoltaic system,” Sol. Energy, vol. 78, no. 3, pp. 362–374, Mar. 2005.
[3] H. Patel and V. Agarwal, “Matlab-Based Modelling to Study the Effects of Partial Shading on PV Array Characteristics,” IEEE Transactions on Energy Conversion, vol. 23, pp. 302-310, 2008.
[4] S. Lyden, M. E. Haque, A. Gargoom, M. Negnevitsky, and P. I. Muoka, “Modelling and Parameter Estimation of Photovoltaic Cell,” in Universities Power Engineering Conference (AUPEC), 2012 22nd Australasian, 2012, pp. 1–6.
[5] N. Pandiarajan and R. Muthu, “Mathematical modeling of photovoltaic module with Simulink,” in 2011 1st International Conference on Electrical Energy Systems, ICEES 2011, 2011, no. Icees, pp. 258–263.
[6] M. Edouard and D. Njomo, “Mathematical Modeling and Digital Simulation of PV Solar Panel using MATLAB Software,” vol. 3, no. 9, pp. 24–32, 2013.
[7] M. Abdulkadir, A. S. Samosir and A. H. M. Yatim, “Modelling and simulation based approach of photovoltaic system in simulink model,” vol.7, no 5, pp. 616 - 623, May 2012.
[8] H. Mahamudul, M. Saad, and I. Henk, “A Modified Simulation Method of Photovoltaic Module in Simulink Environment,” no. 1, pp. 607–610, 2012.
[9] T. Marnoto, K. Sopian, W. A. N. Ramli, and W. A. N. Daud, “Mathematical model for determining the performance characteristics of multi-crystalline photovoltaic modules,” International Conference on Mathematical and Computational Methods in Science and Engineering, pp. 79–84, 2007.