

# MATLAB Simulation of Photovoltaic and Photovoltaic/Thermal Systems Performance

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**Abstract.** The efficiency of the photovoltaic reduces when the photovoltaic cell temperature increased due to solar irradiance. One solution is come up with the cooling system photovoltaic system. This combination is forming the photovoltaic-thermal (PV/T) system. Not only will it generate electricity also heat at the same time. The aim of this research is to focus on the modeling and simulation of photovoltaic (PV) and photovoltaic-thermal (PV/T) electrical performance by using single-diode equivalent circuit model. Both PV and PV/T models are developed in Matlab/Simulink. By providing the cooling system in PV/T, the efficiency of the system can be increased by decreasing the PV cell temperature. The maximum thermal, electrical and total efficiency values of PV/T in the present research are 35.18%, 15.56% and 50.74% at solar irradiance of 400 W/m<sup>2</sup>, mass flow rate of 0.05kgs-1 and inlet temperature of 25 °C respectively has been obtained. The photovoltaic-thermal shows that the higher efficiency performance compared to the photovoltaic system.

## 1. Introduction

Renewable energy is defined as the energy that is generated from natural resources that can continually be recharge. There are various types of renewable energy, one most important are solar energy. The photovoltaic system is one of the renewable electric power generations. It can generate direct current electricity without contamination and environmental impact when exposed to solar radiation. To improve the performance of the photovoltaic system, it was brought to recover the heat dissipated by convection and conduction, this system use of photovoltaic-thermal in order to operate thermal and electrical performance for both occupied the same space.

The photovoltaic or known as PV cells or solar cells, are the semiconductor pn-junction that consists of p-type and n-type [1]. When sunlight is exposed, photons with energy greater than band gap energy is absorbed to create an electron-hole pair to the incident irradiation is produced [2]. While, the photovoltaic-thermal (PV/T) is a combination of a photovoltaic panel that integrates to a solar thermal collector to removes waste heat from the Photovoltaic module for water heating and cooling system [3]. The photovoltaic-thermal (PV/T) system studied in this research is Solar PV, a rectangle tunnels, an absorber, and an insulator. The rectangle tunnel was placed below PV cells as the heat conductor to increase the efficiency of thermal [3] . The purpose of the absorber plate is to cool the PV module and to improve its electrical performance at the same time to collect the thermal energy produced. The absorber plate was covered with PV cells and hence constituted the combined photovoltaic/thermal (PV/T) absorber.



PV and PVT system have been investigated and discussed by many researchers. For the photovoltaic module, many researchers used simplest the equivalent circuit PV cell to characterize the I-V and P-V characterization [1], [2], [5]–[8]. The software that uses to model the simulation of equivalent circuit PV module are Matlab/Simulink and PSIM software. While for thermal modeling, has been developed in COMSOL Multiphysics [9]–[10]. A block diagram of the stage by stage model for Simulink modeling of PV module was developed by other researchers [5]–[7]. Two important parameters which are solar irradiation and temperature are discussed of PV simulation study [6]–[7].

From the other researchers, the PV results show the I-V and P-V output characteristics with varying irradiance at the constant temperatures and constant irradiance with varying temperature [5]–[7]. Effects of an increase in solar irradiance, the open circuit voltage also increased. While, effects of varying temperature increase, the open circuit voltage drop and short circuit current will increase [5]–[7]. Besides that, the PV results in effects of varying series resistance,  $R_S$  and shunt resistance,  $R_{SH}$ . The value of  $R_{SH}$  must higher than the value of  $R_S$  to reduce the power output of PV cell [8]. The output power reduces when the temperature increase and efficiency increase depends on the weather conditions [1].

Thermal/Electrical of a PV module to enhanced cooling system has been studied by earlier researchers to investigate the electrical and thermal performance [11]. The result shows that the performance PV/T with cooling influenced of increasing irradiance (200–1000 W/m<sup>2</sup>) at constant temperature (25°C) and increasing temperature (0–50°C) at absorbed radiation of 800W/m<sup>2</sup>.

Another research has been carried out by evaluation Single-pass Photovoltaic-Thermal (PV/T) air collector with absorber is to increase its electrical efficiency and to produce heat energy [4]. The efficiency will increase with the increase of mass flow rate. At a mass flow rate of 0.0754 kg sec<sup>-1</sup>, electrical and thermal efficiency can achieve 10.06% and 75.16% respectively shows that the PV/T system has the higher performance in efficiency of thermal and electrical.

The analysis of a practical single diode equivalent circuit PV model was implemented by using Matlab/Simulink. I-V and P-V output characteristics with a constant temperature (25°C) and solar irradiation (1000 W/m<sup>2</sup>) were observed for the PV module. Then, another observation was done for different surrounding conditions by the varying the solar irradiation (200 W/m<sup>2</sup> and 600 W/m<sup>2</sup>) and temperature (50°C and 75°C).

In this project, the aim is to develop the model for photovoltaic (PV) and photovoltaic-thermal (PV/T) using Script Editor Matlab. The main objective is to investigate I-V and P-V output characteristics by using the equivalent circuit for the PV cell in order to calculate the total efficiency. In addition to that is to investigate the PV/T and characterize their thermal and electrical performances.

## 2. Methodology

### 2.1. Photovoltaic system modeling

The equivalent circuit of PV cell as shown in figure 3 where  $R_s$  is the series resistance,  $R_{sh}$  is the shunt resistance,  $I_{ph}$  is the photocurrent source which is dependent on the irradiation and temperature and  $D$  is the p-n diode. Voltage,  $V$  and current,  $I$  represent the output voltage and current respectively.

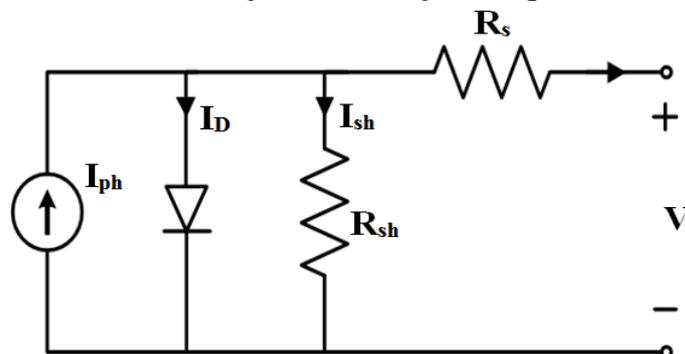


Figure 1 A practical single diode equivalent circuit of PV cell

The mathematical equations of equivalent circuit PV cell shown in figure 1 can be expressed as follow (1)-(5) [1], [2], [5]–[9].

$$I = I_{ph} - I_d \quad (1)$$

$$I_d = I_s \left( \exp\left(\frac{q(V + IR_s)}{N_s A k T}\right) + \frac{V + IR_s}{R_{sh}} \right) \quad (2)$$

$$I_{ph} = I_{sc} + k_i(T - 298) \times \left(\frac{G}{1000}\right) \quad (3)$$

Voltage  $V$  is open circuit voltage,  $V_{oc}$ . The generated photo-current  $I_{ph}$  is the light generated current at specific temperature and irradiance condition ( $25^\circ\text{C}$  and  $1000 \text{ W/m}^2$ ). While  $I_s$  represents the reverse current. The electron charge  $q$  is a constant at  $1.602 \times 10^{-19}$ . In this model, the series and shunt resistance,  $R_s$  and  $R_{sh}$  are to represent the real internal voltage drop voltage drops and internal losses due to flow of current and any leakage current to the ground when diode is in reverse biased [4]. The value of shunt resistance,  $R_{sh}$  is very large than the value of series resistance,  $R_s$ . Boltzmann constant,  $k$  is  $1.38 \times 10^{-23} \text{ J/K}$ . The ideality factor  $A$  is assumed to be 1 and  $N_s$  are the number of cells connected in series.  $I_{sc}$  is the short circuit current,  $k_i$  is the temperature coefficient the short circuit current (0.017),  $T$  is the surface temperature of PV cell and  $G$  is the solar radiation ( $\text{W/m}^2$ ). The saturation current,  $I_o$  varies with temperature, which is given by:

$$I_o = I_{rs} \times \left(\frac{T_n}{T}\right)^3 \exp\left(\frac{qE_g}{Ak}\right) \left(\frac{1}{T_n} - \frac{1}{T}\right) \quad (4)$$

where, the reverse saturation current,  $I_{rs}$ ;

$$I_{rs} = \frac{I_{sc}}{\exp\left(\frac{qV_{oc}}{N_s k A T}\right) - 1} \quad (5)$$

In (4) and (5),  $V_{oc}$  represents the open circuit voltage,  $E_g$  is the energy band gap for silicon ( $E_g=1.12$ ) and  $T_n$  is the reference temperature of PV cell. The reference values are generally provided by manufacturers of PV cells for specified operating condition (Standard Test Conditions, STC).

## 2.2. Photovoltaic system modelling

Heat transfer and thermal capacity are the important parameters of thermal because heat transferred to the PV/T by convection and removed from the PV module and PV/T. The performance of PV/T can be depicted by the combination of efficiency expression. It comprised of the electrical efficiency and thermal efficiency. The total of the efficiency is used to evaluate the performance of the system.

$$\eta_{total} = \eta_{th} + \eta_{elec} \quad (6)$$

The electrical efficiency is expressed in (7), where  $\eta_{T_{ref}}$  as the electrical efficiency at references conditions is 10%,  $T_{pv}$  is the PV module surface temperature and  $\beta_{ref}$  as thermal coefficient of PV module are 0.003 [12].

$$\eta_{elec} = \eta_{Tref} [1 - \beta(T_{pw} - T_{ref})] \quad (7)$$

The total amount of energy and the output thermal energy extracted by cooling water can be determined by the given equation in (8) and (9). Solar irradiation,  $Q$  is the energy in,  $\dot{m}$  is the mass flow rate and  $C_p$  is the specific heat capacity.  $T_{outlet}$  and  $T_{inlet}$  are the outlet and inlet temperature respectively. The thermal efficiency,  $\eta_{th}$  can be expressed by equation (10).

$$E_{in} = Q.A \quad (8)$$

$$E_{water} = \dot{m}C_p(T_{outlet} - T_{inlet}) \quad (9)$$

$$\eta_{th} = E_{water}/E_{in} \quad (10)$$

Hence, the quantity of the total input energy converted to electrical energy ( $E_{pv}$ ) is obtained by the total amount energy multiplying by electrical efficiency.

$$E_{pv} = \eta_{elec} E_{in} \quad (11)$$

By assuming that there are no energy losses, the total efficiency of the PV/T can be calculated by equation (12):

$$\eta_{total} = (E_{water} + E_{pv})/E_{in} \quad (12)$$

### 2.3. Comparison of PV and PV/T systems modeling

The models of photovoltaic and thermal systems are implemented by using Matlab/Simulink. The inputs for photovoltaic cell are the surface temperature and solar irradiation, while the output calculated and shown in the I-V and P-V characteristics. KC200GT is taken as the reference module for the simulation and parameters from the manufacturer's datasheet measured under standard test condition as shown in Table 1 [13].

Table 1 Parameter of KC200GT for Photovoltaic module

Parameter	Variable	Value
Open circuit Voltage	$V_{OC}$	32.9 V
Voltage at MPP	$V_{MPP}$	26.3V
Short circuit current	$I_{SC}$	8.21A
Current at MPP	$I_{MPP}$	7.61A
Voltage temperature coefficient	$A_V$	-0.123 V/K

Current temperature coefficient	$A_I$	$0.0032 \text{ A/K}$
Maximum power	$P_{MAX}$	$200.14 \text{ W}$

### 3. Results and Discussion

The model of the photovoltaic was implemented using Matlab script editor. The parameters of the model are evaluated using the equations listed in the methodology part. Figure 2– 7 illustrates the dependence of I-V and P-V characteristics on temperature and irradiance for a KC200GT model. Figure 4 and 5 display the I-V and P-V output characteristics of PV module with the constant temperature of 25°C and vary the irradiance from 200 W/m<sup>2</sup>, 600 W/m<sup>2</sup> and 1000 W/m<sup>2</sup> respectively.

From figure 2, the PV cell current is dependent on the solar irradiation. The open circuit voltage increase and also current and power output increases when the solar irradiation increased from 200 W/m<sup>2</sup> to 1000 W/m<sup>2</sup> at the constant temperature. This is in accordance to other papers that also proving that by increasing irradiance parameter, the output of current and voltage outputs also increase.

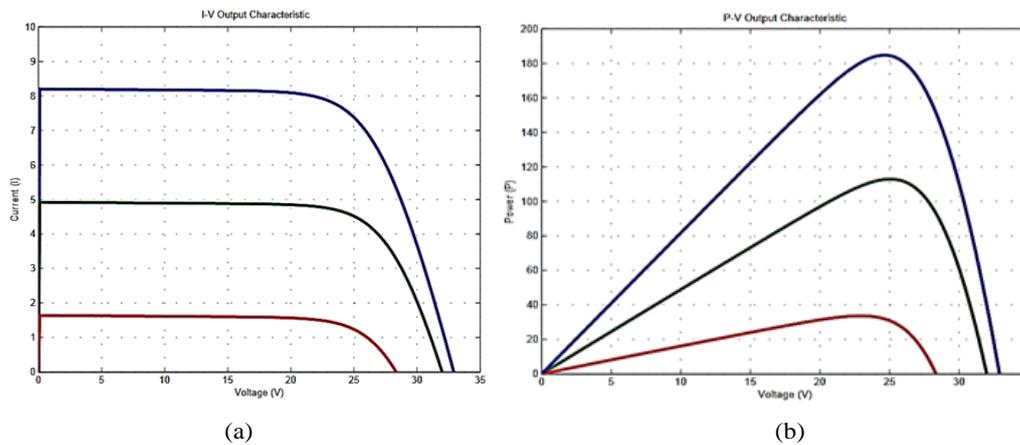


Figure 2 I-V and P-V characteristics with a constant temperature and varying irradiance

Figure 3 display the I-V and P-V output characteristics of PV module with a constant irradiance of  $1000 \text{ W/m}^2$  with varying temperature at  $25^\circ\text{C}$ ,  $50^\circ\text{C}$  and  $75^\circ\text{C}$  respectively. From the figures, the open circuit voltage and power output decreases with rise of cell temperature at a constant irradiation. This results are validating the other researchers findings [6]-[7], where by varying the PV cell temperature, the output voltage drops at a faster rate while maintaining at the output current.

Figure 6 shows the efficiency of PV module effects by PV cell temperature. The results show that when the temperature is increased, the efficiency will drop slightly. When the PV cell temperature is increased from  $25^\circ\text{C}$  to  $75^\circ\text{C}$ , the electrical efficiency dropped from 17.8% to 15.5%. This condition is normal and the main reason of needs in the cooling system research for PV system.

Figure 7 and 8 are showing that the electrical, thermal and total efficiency by the effect of the mass flow rate at solar irradiation  $400 \text{ W/m}^2$  and  $600 \text{ W/m}^2$  respectively. The results shown that the efficiency (photovoltaic, thermal and total) was increasing with respect to solar radiation. The electrical efficiency varies from 9.82% to 15.5% at solar radiation of  $400 \text{ W/m}^2$  and inlet temperature of  $30^\circ\text{C}$ . The thermal efficiency varies from 21.10% to 35.18%. The combined efficiency varies from 40.92% to 46.86%. The results in Figure 8 show that the electrical efficiency varies from 9.56% to 11.46% at solar irradiation of

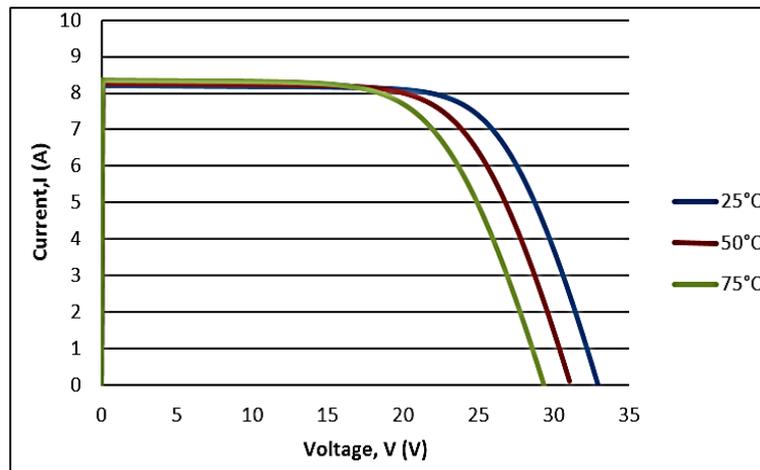


Figure 3 I-V characteristics with  $1000 \text{ W/m}^2$  irradiance across the PV surface temperature  $T$  at 25, 50 and 75 degree Celsius.

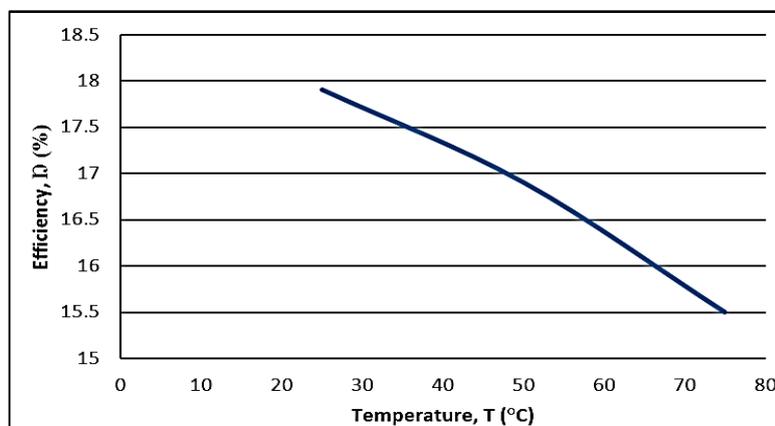


Figure 4 The efficiency of PV module decreases with the increase of PV surface cell temperature.

600 W/m<sup>2</sup>. The thermal efficiency varies from 9.89% to 48.5% and combined efficiency of PV/T varies from 18.98% to 58.9%. Figure 5 and 6 also show the comparison of two different values for solar irradiation (400 W/m<sup>2</sup> and 600 W/m<sup>2</sup>). The solar irradiation increase by increasing the effect of mass flow rate, but the efficiencies (electrical, thermal and total) is slightly decreased.

The Thermal efficiency reaches steady stage when the mass flow rate over 0.05 kg s<sup>-1</sup>, the thermal efficiency can increase about 20%. From the equation (9) and (10), the output thermal energy will increase

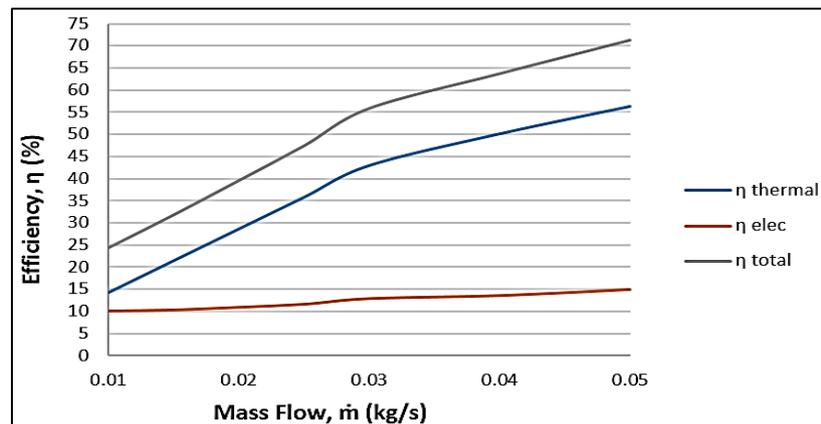


Figure 5 Electrical, thermal and total efficiencies for PV/T system with the effect of the mass flow rate at solar irradiation of 400 W/m<sup>2</sup>

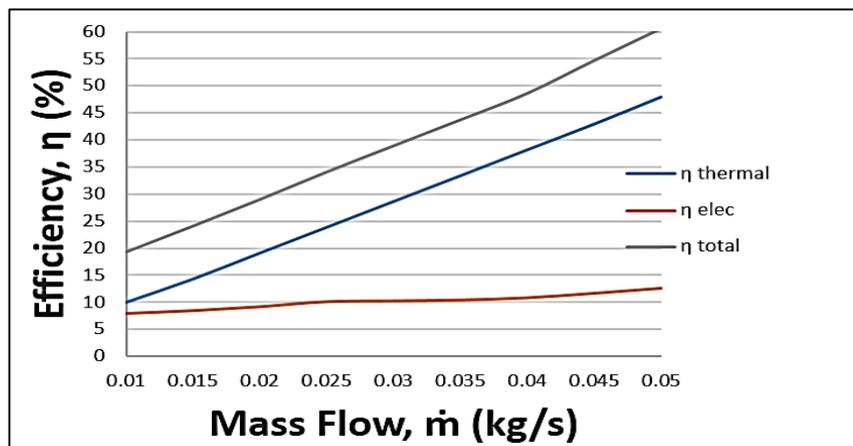


Figure 6 Electrical, thermal and total efficiencies for PV/T system with the effect of the mass flow rate at solar irradiation of 600 W/m<sup>2</sup>

and also input energy will increase. This is due to the fact that when the mass flow increases, the heat extracted from the air. The more the amount of heat extracted by the water, the lower the PV/T temperature and increases the electrical and thermal efficiency.

#### 4. Conclusion

The I-V and P-V output characteristics are studied and shown with effect of irradiance and PV cell temperature. At a constant solar irradiance, the PV cell temperature has become an important parameter to distinguish the output current, voltage and power. Fortunately, with a cooling system, PV cell

temperature can be at constant value. In this condition, an increase of solar irradiance can benefit the system by having an increasing output of current, voltage and power output. Thus, it is showing that the performance of PV cell can be increased and optimized by the integration of thermal module into the system. The maximum of thermal, electrical and total efficiency values of PV/T in the present research at the mass flow rate of  $0.05 \text{ kg s}^{-1}$  and solar irradiance ( $400 \text{ W/m}^2$ ) are 35.18%, 15.56% and 50.74% respectively.

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