

Simulation of photovoltaic module in Matlab/Simulink

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Abstract—This paper presents the implementation of a generalized photovoltaic model using Matlab/Simulink software package, which can be representative of PV cell, module, and array for easy use on simulation platform. Taking the effect of sunlight irradiance and cell temperature into consideration, the output current and power characteristics of PV model are simulated. The experimental results, provided by the author validate the accuracy of the computational simulation results.

Keywords: simulation, photovoltaic, solar power

Solar power is a renewable energy source that has great potential when compared to other renewable energies and might one day soon replace fossil fuel dependent energy sources. However, for that to happen, solar power cost per kilowatt-hour has to be competitive with fossil fuel energy sources. Currently, solar panels are not very efficient with only about 17% efficiency in their ability to convert sunlight to electrical power [1]. The efficiency can drop further due to other factors such as solar panel temperature and load conditions. Although irradiance is an important factor in determining the I-V characteristic of a solar panel, temperature also plays an important role in predicting the I-V characteristic, and the effects of both factors have to be considered when designing a PV system.

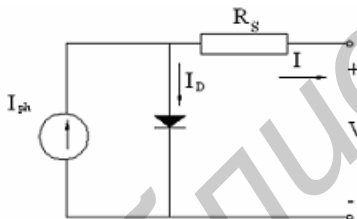


Fig.1. Model of a single solar cell

This work presents the development of MATLAB/SIMULINK model for simulation of photovoltaic module. A typical 120W solar panel was used to evaluate the model, and the results are compare with manufacturer’s published curves and showed excellent correspondence to the model.

Simulink offers the advantage of building hierarchical models, namely to have the possibility to view the system at different levels. Simulink provides also the possibility to build modular models, which have the advantage that in this way the models can be easily connected together in order to simulate a certain system. Fig. 2 shows the Solar Panel Block and inputs as: 800-Solar irradiance block; 20-temperature block; Ramp-block of voltage/temperature dependence.

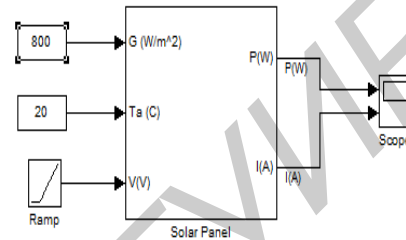


Fig.2. Simulink implementation of the PV module.

The relationship between the output current I and the voltage V of the equivalent circuit [1] can be found by equating the light current I_{ph} , diode current I_D , to the operation current I as follows:

$$I = I_{ph} - I_D = I_{ph} - I_{sat} [\exp q(V + IR_s)/nkT - 1] \quad (1)$$

where T -Junction temperature in Kelvin;
 R_s - the series resistance [Ω];
 T =Junction temperature in Kelvin. Other parameters are given in [1].

The open circuit voltage under given environmental conditions is calculated as follows:

$$V_{oc}(G, T) = V_{ocs} + \beta_{ocT}(T - T_s) + \frac{kT}{q} \ln(I_{mpp}/I_{scs}) \quad (2)$$

Where:

- V_{ocs} — Open-circuit voltage at standard test condition;
- β_{ocT} - Temperature coefficient of open-circuit voltage.
- I_{mpp} - Current at MPP

The energy output in the form of current is directly proportional to the energy input in the form of solar irradiation. There is a small temperature coefficient, on the order of a few milliamps per degree Celsius to account for temperature differences recognized empirically.

$$I_{ph} = (G, T) = I_{scs} \cdot \frac{G_a}{G_{as}} + \alpha_{scT}(T - T_s) \quad (3)$$

Where:

I_{scs} — Short circuit current at standard test condition

G_a – Solar irradiance (W/m²)
 G_{as} – Solar irradiance at standard test condition (1000W/m²)
 α_{scT} – Temperature coefficient of short-circuit current
 T - Cell temperature (oC)
 T_s – Cell temperature at standard test conditions (25 oC)

The open circuit voltage under given environmental conditions is calculated as follows:

$$V_{oc}(G, T) = V_{ocs} + \beta_{ocT}(T - T_s) + \frac{kT}{q} \ln\left(\frac{I_{mpp}}{I_{scs}}\right) \quad (4)$$

Where:

V_{ocs} – Open-circuit voltage at standard test condition.
 β_{ocT} – Temperature coefficient of open-circuit voltage.

I_{mpp} – Current at MPP

Under open circuit condition; $I_{ph}(G, T) = I_D = (G, T)$

$$\text{But } I_{ph}(G, T) = I_{sat}(G, T) \cdot \left[e^{\frac{V_{oc}}{V_t}} - 1 \right]$$

Therefore

$$I_{sat}(G, T) = \frac{I_{ph}(G, T)}{\left[e^{\left(\frac{V_{oc} T}{V_t T} - 1\right)} - 1 \right]} \quad (5)$$

Where thermal voltage

$$V_t(T) = \frac{AKT}{q} \quad (6)$$

$$P = I \cdot V = V \cdot I_{ph} - I_{sat} [\exp q(V + IR_s)/nkT - 1] \quad (7)$$

The output of the Matlab/Simulink is shown first for various irradiation levels Fig. 4, and then for various temperatures Fig. 5. Fig. 4 shows how the I-V curve of the PV module is affected by irradiation, when the cell temperature is kept constant (T=25 oC). And Fig.5 shows the influence of the cell temperature on I-V curve, when the irradiation is kept constant (G_a =1000W/m²). The simulation results showed that an increase in irradiance generally caused an increase in the module's output current while an increase in operating temperature generally caused a drop in the module's terminal voltage. In fact, the results showed a linear relationship between the short circuit current and the irradiance level while there is a logarithmic relationship between the open circuit voltage and the operating temperature. Therefore it would seem that the output voltage should increase as the irradiation level increases. However this is not necessarily so, since the cell temperature is likely to rise as the irradiation level increases. An increase in cell temperature will generally lead to a reduction of the output voltage. This makes it imperative to consider the effect of temperature on the cell output voltage as illustrated in Fig. 5. Overall, there is a reduction of the voltage at higher irradiances due to the accompanying higher cell temperature.

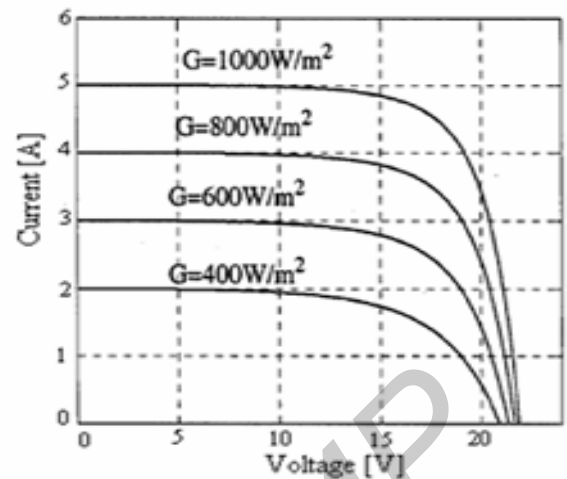


Fig. 4 I-V characteristics at constant solar cell temperature

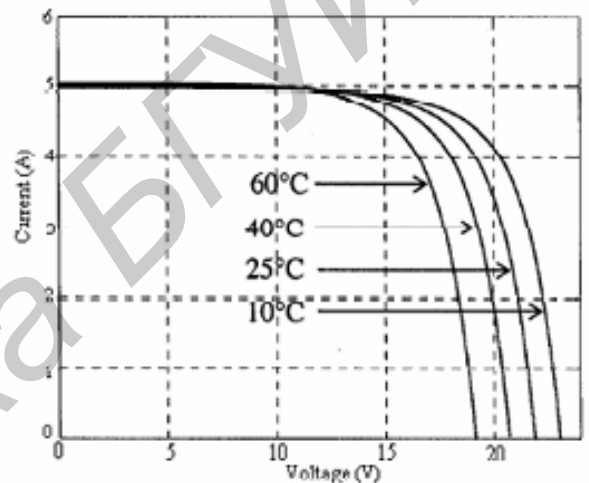


Fig. 5 I-V characteristics-constant Irradiance

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