MODELING AND SIMULATION BASED APPROACH OF PHOTOVOLTAIC SYSTEM IN SIMULINK MODEL

M. Abdulkadir, A. S. Samosir and A. H. M. Yatim
Department of Energy Conversion, Faculty of Electrical Engineering, University Teknologi Malaysia, Skudai, Johor Bahru, Malaysia
E-Mail: musa.abdulkadir@fkegraduate.utm.my

ABSTRACT

This paper presents the modeling and simulation of photovoltaic model using MATLAB/Simulink software package. The proposed model is design with a user-friendly icon using Simpower of Simulink block libraries. Taking the effect of irradiance and temperature into consideration, the output current and power characteristic of PV model are simulated using the proposed model. Detailed modeling procedure for the circuit model with numerical values is presented. The simulator is verified by applying the model to 36 W PV modules. The proposed model was found to be better and accurate for any irradiance and temperature variations. The proposed model can be very useful for PV Engineers and expert who require a simple, fast and accurate PV simulator to design their systems.

Keywords: modeling, photovoltaic module, Simulink model.

INTRODUCTION

Photovoltaic energy is a source of interesting energy. It is renewable, inexhaustible and nonpolluting, and that it is more and more intensively used as energy sources in various applications. Photovoltaic systems have been the worldwide fast growing energy source because of the increase in energy demand and the fact that fossil energy sources are finite, and that they are expensive. Furthermore, the impacts that the energy technology has on the environment which make the photovoltaic become a mature technology in used (Jung H. J. and Ahmed S., 2010). The increase in a number of Photovoltaic system installed all over the world brought the need for proper supervision and control algorithms as well as modeling and simulation tool for researcher and practitioners involved in its application is very necessary.

The modeling and simulation of photovoltaic (PV) have made a great transition and form an important part of power generation in this present age. The modeling of PV module generally involves the approximation of the non-linear I-V curve. Many researchers used circuit based approach to characterize the PV module of which the simplest model is the current source in parallel to a diode (Da Silva R. M. *et al*., 2010; Altas H. I. *et al*., 2007; Nena S. *et al*., 2010 and Gradella Marcelo *et al*., 2007). In a PV system, peak power point changes continuously due to environmental variations, sometime substantial drop in power especially during partial shading conditions. Several computational methods are proposed by several researchers (Ishaque K, Zainal Salam, 2011, Dell R. V. *et al*., 2010, Da Silva R. M. *et al*., 2010; Jung J. H. and Ahmed S., 2010 and Walker G., 2001; Dell Aquila R. V., 2010; Ebrahim M., 2007). Simple circuit-based photovoltaic model has proposed in (Da Silva R. M. *et al*., 2010; Jung J. H. and Ahmed S., 2010; Walker G., 2001; Yushaizad Yusof, *et al*., 2004 and Jung Jee-Hoon, Ahmed S., 2010). Indirect methods have also been proposed by some researchers where the, I-V curve is adjusted through artificial intelligence techniques (Veerachary M., 2005; Chowdhury S., Chowdhury S.P., 2008; Zegaoui A., 2011; Ramaprabha R. and Mathur B. L., 2011). Although some of these methods are impractical, complicated and require high computational effort, and some of these modeling was limited to simulation of photovoltaic module characteristics. Thus, because of the numerous challenges, an accurate and comprehensive design of PV system using the detailed circuit model in MATLAB Simulink model was proposed.

In section II, the circuit model of the PV module system is shown. Section III, the mathematical equations of the PV module (cells) and the Simulink model for these equations of the PV module is presented. In section IV, the numerical results for different temperature and irradiance conditions is presented. Section V presents the discussion and conclusion of the modeling process. Detailed of the circuit model of the PV cell is discussed in the next section.

THE CIRCUIT MODELS OF THE PV MODULES

Photovoltaic cell models have long been a source for the description of photovoltaic cell behaviors for researchers and professionals. The most common model used to predict energy production in photovoltaic cell modeling is the single diode circuit model (Ishaque K, Zainal Salam, 2011; Dell R. V. *et al*., 2010; Da Silva R. M. *et al*., 2010; Jung J. H. and Ahmed S., 2010 and Walker G., 2001) shown in Figure-1.

The ideal photovoltaic module consists of a single diode connected in parallel with a light generated current source (I_{SC}) as shown in Figure-1. The equation for the output current is given by:

$$I = I_{SC} - I_D \tag{1}$$

Where

$$I_D = I_{SCref}\left[\exp\left(\frac{qV_{oc}}{kAT}\right) - 1\right] \tag{2}$$

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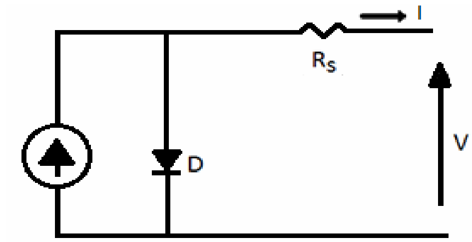

Figure-1. Solar cell model using single diode

The light current depends on both irradiance and temperature. It is measured at some reference conditions. Thus,

$$I_{SC} = [[I]_{SCref} + K_i(T_k - T_{ref})] * {}^{\sigma}/_{1000} \qquad (3)$$

Where I_{SC} is the photocurrent in (A) which is the light-generated current at the nominal condition (25°C and 1000W/m^2), K_i is the short-circuit current/temperature co-efficient at I_{SCref} (0.0017A/K), T_k and T_{ref} are the actual and reference temperature in K, is the irraiation on the device surface, and 1000W/m^2 is the nominal irradiation (Pandiarajan N. *et al*., 2011). Equation **(2)** does not adequately represent the behavior of the cell when subjected to environmental variations, especially at low voltage (Ishaque K., 2011; Chowdhury S. *et al*., 2008; Nishioka K. *et al*., 2007; Issam Houssamo, 2010). A more practical model is shown in Figure-2, where R_S and R_P represents trepresentent series and parallel resistance, respectively.

In this propose model, a current source I_{SC} which depends on solar radiation and cell temperature; a diode in which the inverse saturation current I_O depends mainly on the operating temperature; a series resistance R_S and a shunt resistance R_P which takes into account the resistive losses.

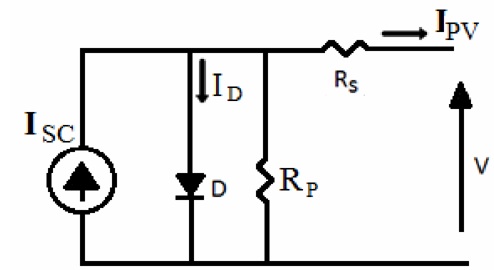

Figure-2. Solar cell model using single diode with R_S **and** R_P .

The equation that describes the I-V characteristic of the circuit in Figure-2 is given by;

$$I_{SC} - I_D - \frac{V_D}{R_P} - I_{PV} = 0 \qquad (4)$$

Thus,

$$I_{PV} = I_{SC} - I_D - \frac{V_D}{R_P} \qquad (5)$$

And the reverse saturation current I_{rs} is given as:

$$I_{rs} = I_{SCref}\left[\exp\left(\frac{qV_{oc}}{N_s kAT}\right) - 1\right] \qquad (6)$$

The module saturation current I_O varies with the cell temperature which is given by;

$$I_O = I_{rs}\left[\left({}^{T}/_{T_{ref}}\right)^3 e^{{}^{qC_g}/_{Ak} * \left({}^{1}/_{T_{ref}} - {}^{1}/_{T}\right)}\right] \qquad (7)$$

Where I_O is the diode saturation current (A). The basic equation that describes the current output of the photovoltaic (PV) module I_{PV} of the single-diode model is as given in equation **(8).**

Thus,

$$I_{PV} = N_P I_{SC} - N_S I_O\left\{\exp\left(\frac{q(V_{PV} + I_{PV}R_S)}{N_S AkT}\right) - 1\right\} - V_{PV} + \left(\frac{I_{PV}R_S}{R_P}\right) \qquad (8)$$

Where k is the Boltzmann constant (1.38 x 10^{-23} J K^{-1}), (Pandiarajan N. *et al*., 2011) q is the electronic charge (1.602 x 10^{-19} C), T is the cell temperature (K); A is the diode ideality factor, R_S the series resistance (Ω) and R_P is the shunt resistance (Ω). N_S is the number of cells connected in series = 36. N_p is the numbr of cells connected in parallel = 1, $V_{PV} = V_{OC} = 21.06V.$ The nonlinear and implicit equation given by Equation (4) depend on the incident solar irradiance, the cell temperature, and on their reference values (Ishaque K, Zainal Salam, 2011; Dell R. V. *et al*., 2010; Da Silva R. M. *et al*., 2010; Jung J. H. and Ahmed S., 2010 and Walker G., 2001). These reference values are generally provided by manufacturers of PV modules for specified operating condition such as STC (Standard Test Conditions) for which the irradiance is 1000 W/m^2 and the cell temperature is 25°C. Real operating conditions are always different from the standard conditions, and mismatch effects can also affect the real values of these meatoparameters (Yushaizad Yusof, *et al*., 2004; Ishaque K. *et al*., 2011).

The use of the simplified circuit model for this work makes it suitable for power electronics designers to have an easy and effective model for the simulation of photovoltaic devices with power converters. The value of the parallel resistance R_P is generally high and hence neglected to simplify the model (Villalva M. G. *et al*., 2009; Nishioka K. *et al*., 2007). A procedure based on Simulink model to determine the values to these parameters is proposed. The evaluation of these model parameters at real condition of irradiance and temperature of the target PV modules are then determined according to their initial values.

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The detailed steps to this procedure for the Simulink model are given in the next section.

SIMULINK MODELING FOR PV MODULE

MXS 60 PV Module is taken as the reference module for simulation and the data sheet details are given in **Table-1**. A block diagram of the stage by stage model based upon the equations of PV model is represented in Simulink environment as given in Figures 3 to 9. These models are developed in moderate complexity to include the temperature dependence of the photo current source, the saturation current through the diode, and a series resistance is considered based upon the shackle diode equation as in (1)-(8) (Ishaque K, Zainal Salam, 2011; Dell R. V. *et al*., 2010; Da Silva R. M. *et al*., 2010; Jung J. H. and Ahmed S., 2010 and Walker G., 2001; Pandiarajan N. *et al*., 2011). Since the main objective is to develop a functional PV model for the Simulink environment, the system is modeled to supply power to the load.

Table-1 Parameter specification of MXS 60 PV module (Pandiarajan N. *et al*., 2011).

Parameter	Variable	Value
Maximum power	P_m	60W
Maximum voltage	V_m	17. 1V
Current at max power	I_m	3. 5A
Open cct voltage	V_{oc}	21. 06V
Short cct current	I_{sc}	3.74
Total No. of cells in series	N_s	36
Total No. of cells in parallel	N_p	1

Stage A:

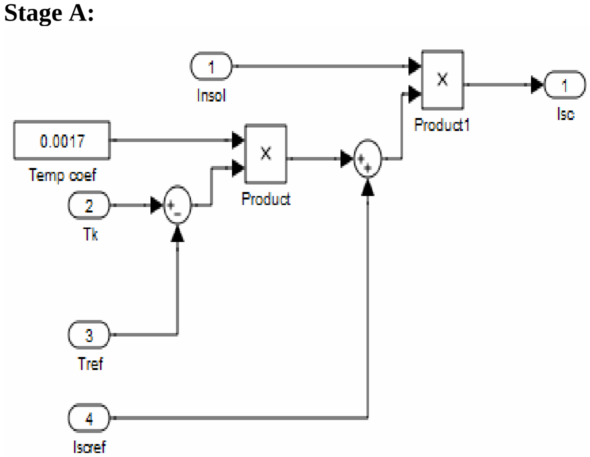

Figure-3. This model calculates the short circuit current I_{SC} at given operating temperature.

Stage B:

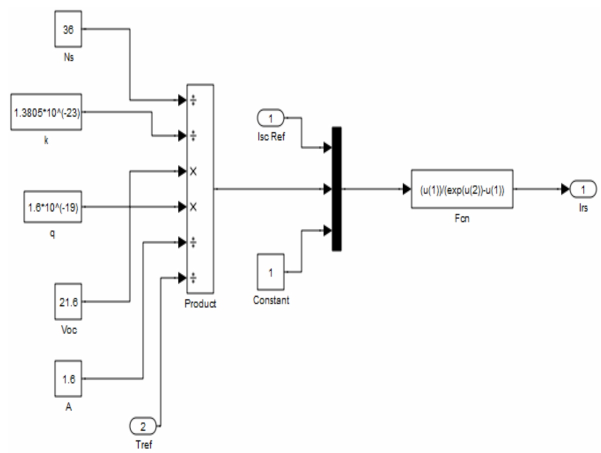

Figure-4. This model calculates the reverse saturation current through the diode using equation 6.

Stage C:

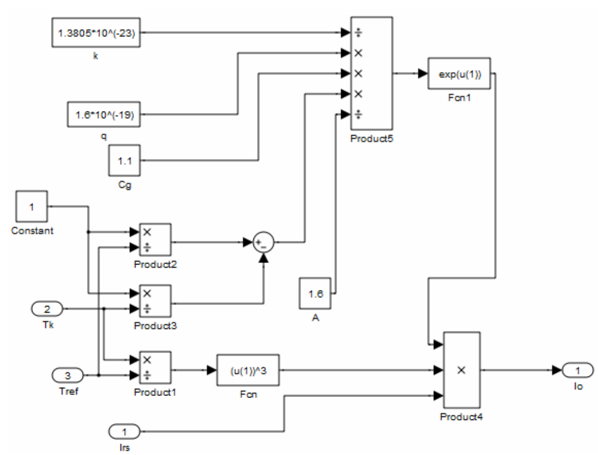

Figure-5. This model takes reverse saturation current, module reference temperature and the module operating temperature as input and calculates module saturation current.

Stage D:

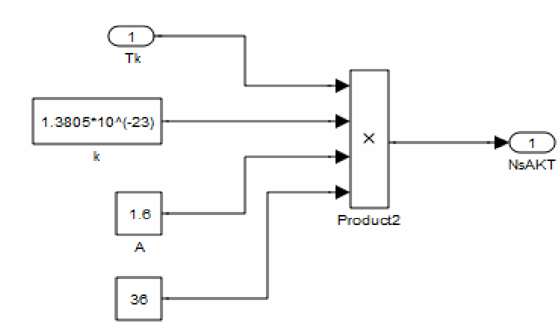

Figure-6. This model takes operating temperature in Kelvin and calculates the product NsAkT.

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Stage E:

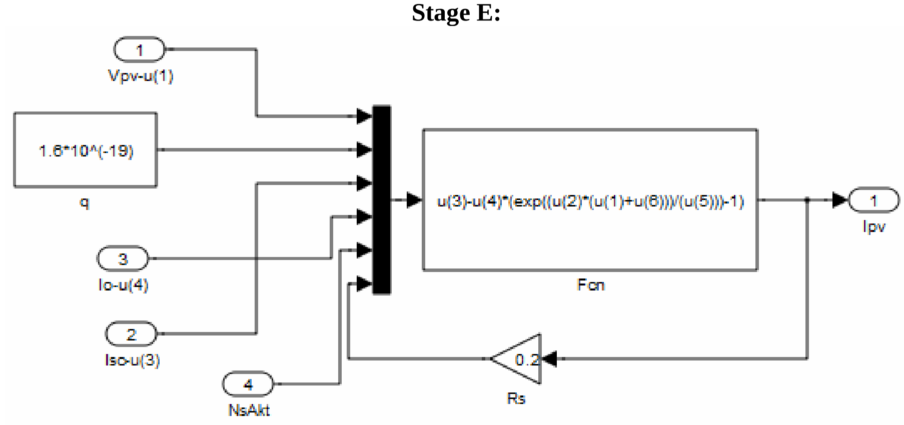

Figure-7. This model executes the function given by equation 8.

Stage F:

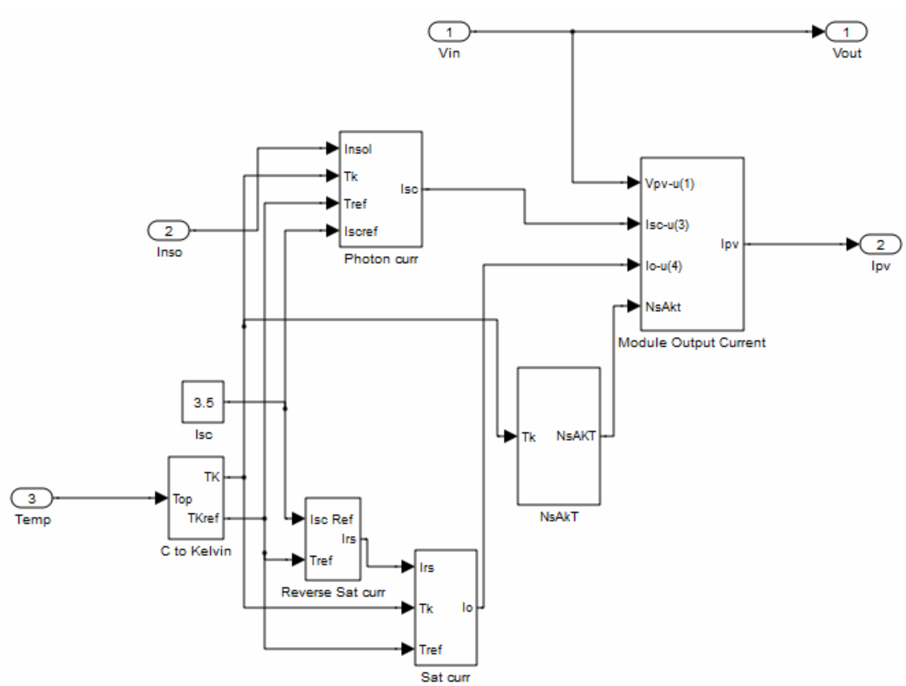

Figure-8. This model contains all the six model interconnected together.

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Stage G:

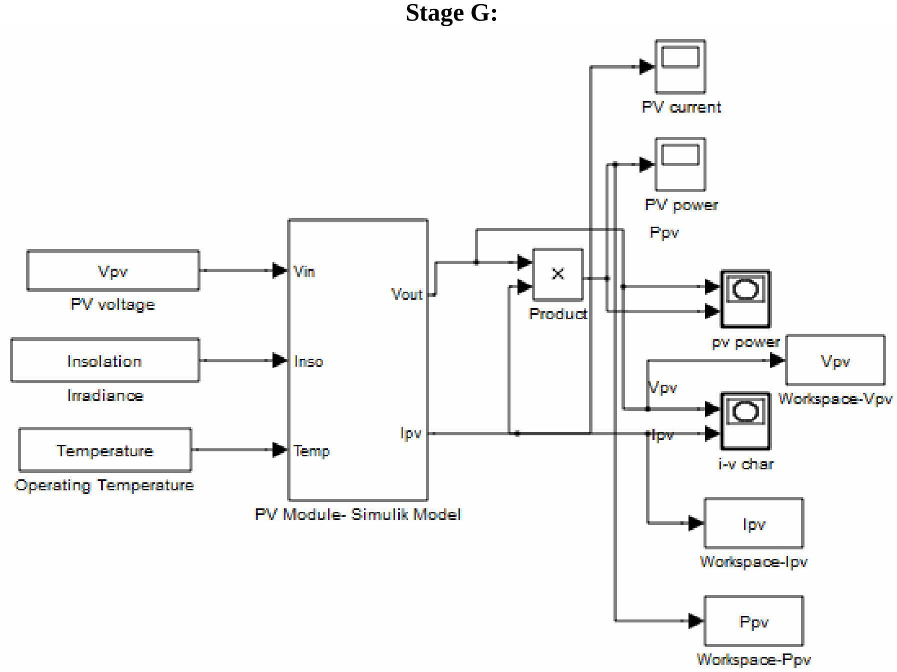

Figure-9. This is the final model which takes irradiation, operating temperature and Module voltage as input and gives the output current I_{PV} and output voltage V_{PV}.

THE SIMULATION RESULTS

The model of the PV module was implemented using a Matlab Simulink model. The model parameters are evaluated during execution using the equations listed as in the previous section. The PV module chosen for this simulation is MXS60, which provides 60W nominal maximum power and has 36 series connected cells (Pandiarajan N. *et al*., 2011; Aissa Chouder, 2011). The parameter specification of the module is as shown in Table-1. The model was built in stages as indicated above starting from stage A to the final model. The subsystem contains all the mathematical equations of every stage model block.

Figure-10 shows the I-V output characteristics of PV module with varying irradiance at the constant temperatures. It is depicted that the PV output current varies drastically with insulation conditions and there is an optimum operating point such that the PV system delivers its maximum possible power to the load. The optimum operating points changes with the solar insulation, temperature and load conditions.

Figure-11 shows the P-V out characteristics of the PV module with varying irradiance at the constant temperatures (Pandiarajan N. *et al*., 2011; Altas I.H. and Sharaf A.M., 2007; Yushaizad Yusof, 2004). From the graphs when the irradiance increases, the current and voltage output also increases. This result shows the net increase in power output with an increase in irradiance at the constant temperatures. Furthermore, it is well known that for a certain PV panel, the voltage-power characteristics are fixed for each insolation without intersection, as shown in Figure-11. Hence, for any given PV voltage and power, the corresponding insolation can be estimated (Nema S. *et al*., 2010).

The I-V and P-V characteristics under constant irradiance with varying temperature are presented in Figure 12 and 13, respectively. When the operating temperature increases, the current output increases marginally but the voltage output decreases drastically, which result in net reduction in power output with a rise in temperature.

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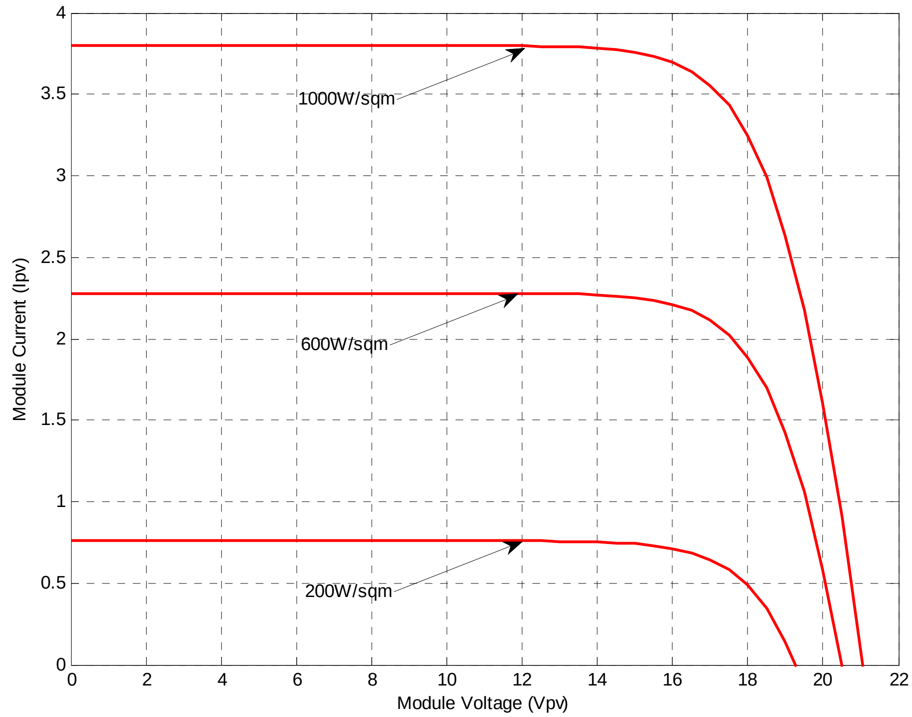

Figure-10. I-V characteristic-varying irradiance- constant temperature.

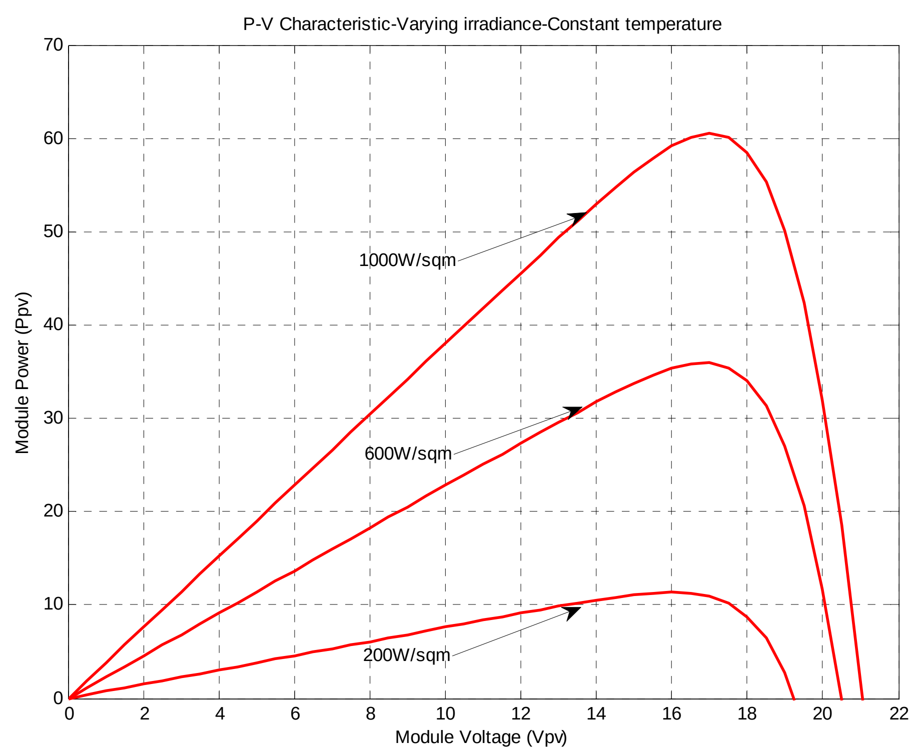

Figure-11. P-V characteristic-varying irradiance-constant temperature.

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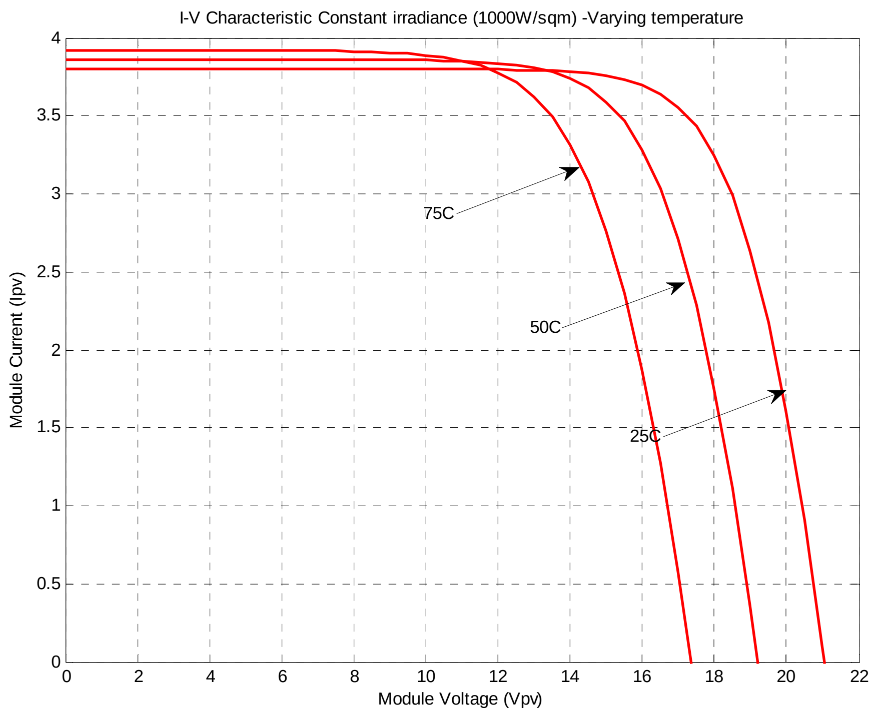

Figure-12. I-V characteristic-constant irradiance (1000W/sqm)-varying temperature.

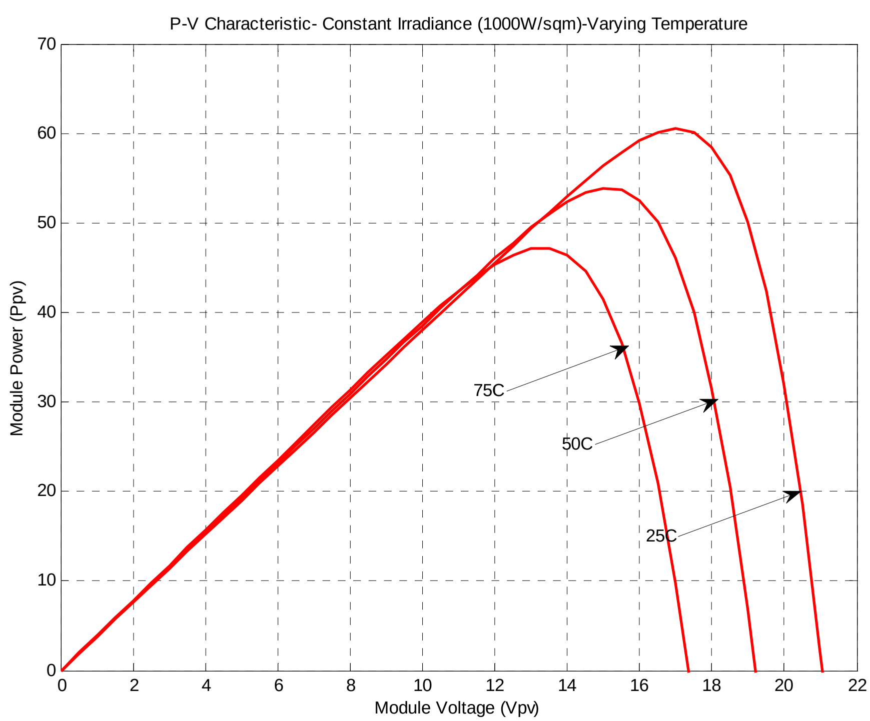

Figure-13. P-V characteristic-constant irradiance (1000W/sqm) varying temperature.

DISCUSSIONS AND CONCLUSIONS

An accurate PV module electrical model is presented and demonstrated in Matlab Simulink. In section II, in Equation (1) and Figure-2, it can be seen that the PV current Isc is a function of the solar irradiation and is the only energy conversion process in which light energy is converted to electrical energy. Equations, (6) and (7), indicate that PV voltage is a function of the junction voltage across the diode, which is the material property of the semiconductors, susceptible to failure at higher temperatures. The physical equations governing the PV module (also applicable to PV cell) is elaborately presented with numerical values of module saturation current at various temperatures. Hence, this circuit model presents the relationship between module parameters and circuit performance. This involves the step-by-step method for the PV modeling in Matlab Simulink. This paper provides a clear and concise understanding of the, I-V and P-V characteristics of PV module, which will serve as the model for researchers and expert in the field of PV modeling.

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