

## MODELING OF PHOTOVOLTAIC MODULE

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**Abstract** -This paper presents main characteristics and parameters that have to be considered for modeling a photovoltaic module. I-V and P-V characteristics of 50 W PV module are obtained at constant radiation and temperature level of module. The effect of varying environmental conditions is also taken into consideration. The proposed model is designed with a user-friendly icons using SimPowerSystem of Simulink block libraries. Detailed modeling procedure for the circuit model with numerical values is presented. The proposed model was found to be better and accurate for any irradiance and temperature variations and very useful for PV Engineers and expert who require a simple, fast and accurate PV simulator to design their systems.

**Key Words:** Matlab, PV Module, Modeling

### 1. INTRODUCTION

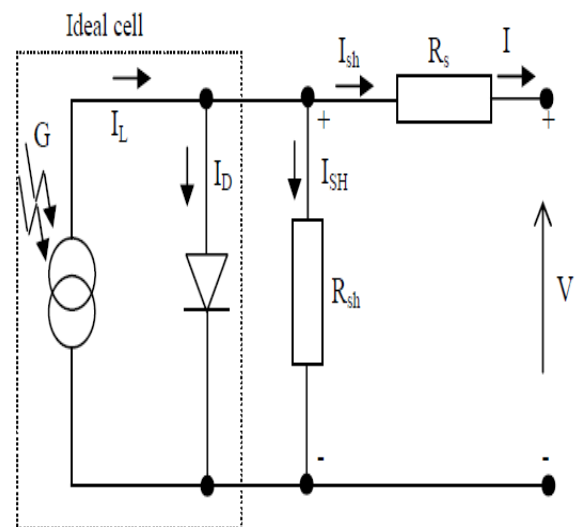
Energy exists in different forms and can be converted from one form to another. Solar energy, in terms of electromagnetic radiation, can be converted to another form of energy through various routes as solar thermal conversion, photovoltaic conversion and photochemical conversion. Solar energy can be converted to thermal energy, electrical energy or chemical energy depending on kind of interaction between solar radiation and matter. Energy conversion through photovoltaic route requires an increase in potential energy of the electrons. For this purpose material is required to possess energy levels. Energy difference between levels should be more than room temperature energy of electrons. A semiconductor device functions in similar way. P-N junction diode is essential for the generation of photovoltage. For collection of energy of photon in the form of electrical energy through solar cells it is required to increase potential energy of carriers i.e. electrons and holes and the separation of these carriers. Former is done by collection of photon energy by carriers due to which they remain in higher energy level and latter is achieved by asymmetry of P-N which provides built-in electric field at the junction [1]. When this P-N junction is exposed to light, photons are absorbed and an electron-hole pair is formed. These carriers are swept apart under the influence of the internal electric fields of the p-n junction and create a

current proportional to the incident radiation. When the cell is short circuited, this current flows in the external circuit; when open circuited, this current is shunted internally by the intrinsic p-n junction diode. Thus characteristics of PV cell are presented by diode characteristics [2].

In this paper the most important P-V and I-V characteristics of PV module are presented with Matlab Simulink tool and the nature of characteristics is verified with experimental evaluations. Mathematical formulations for basic PV module are considered and step by step procedure of Matlab model construction is presented.

### 2. MATHEMATICAL MODELING OF PV MODULE

An ideal solar cell can be considered as a current source with current produced directly proportional to solar radiations falling on it. The practical behavior of cell is deviated from ideal due to the optical and electrical losses. The single diode equivalent circuit of solar cell is represented in fig.1. The optical loss is represented by current source itself, where generated current is proportional to light input. The recombination losses are represented by diode connected parallel to current source, but in reverse direction as recombination current flows in the opposite direction to light generated current [1]. The ohmic losses in the cell occur due to the series and shunt resistance denoted by  $R_s$  and  $R_{sh}$  respectively. The series resistance is resistance offered by the solar cell in the path of current flow.



**Fig -1** Equivalent circuit for PV cell

The shunt resistance is referred as the leakage path of current in solar cell and therefore represented in parallel with current source. The equations describing I-V characteristics of PV cell are represented as below

$$I = I_L - I_0 \left( e^{\frac{q(V+IK_g)}{nkT}} - 1 \right) \tag{1}$$

$$I_L = I_{L(T_1)} (1 + K_0(T - T_1)) \tag{2}$$

$$I_{L(T_1)} = \frac{G}{G_{nom}} * I_{sc(T_1)} \tag{3}$$

$$K_0 = \frac{(I_{sc(T_2)} - I_{sc(T_1)})}{T_2 - T_1} \tag{4}$$

$$I_0 = I_{0(T_1)} * \left( \frac{T}{T_1} \right)^{3/n} * e^{\frac{-qV_g}{nk} * \left( \frac{1}{T} - \frac{1}{T_1} \right)} \tag{5}$$

$$I_{0(T_1)} = \frac{I_{sc(T_1)}}{\left( e^{\frac{qV_{oc(T_1)}}{nkT_1} - 1} \right)} \tag{6}$$

Where,

q = Charge of electron =  $1.6 * 10^{-19}C$

n = Diode ideality factor is 1.6

Eg = Band gap voltage for Si = 1.1eV

Isc = Short circuit current = 2.55A

k = boltzman constant =  $1.38 * 10^{-23} J/K$

G = Radiation in  $W/m^2$

$I_L$  = Photon current

I = Output current of PV cell

$I_0$  = Diode reverse saturation current

T = Temperature of module

T1 = Reference Temperature

Ko = Temperature coefficient of

Isc = 0.68mA

$I_{sc(T_1)}$  = Short circuit current at T1 = 2.94A

$I_{sc(T_2)}$  = Short circuit current at T2 = 3.22A

### 3. REFERENCE MODULE

For Matlab simulation purpose a 50 W (make BP solar) module is taken as reference module and important parameters required for Matlab simulation are taken from manufacturer datasheet as given in Table 1.

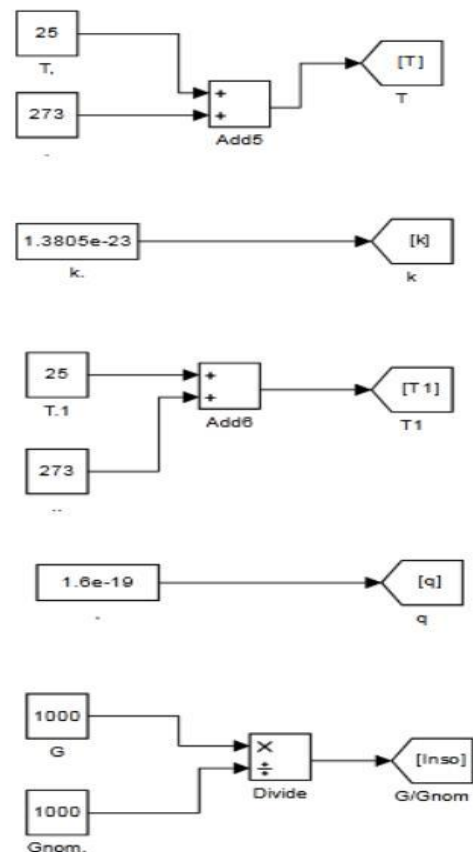
**Table -1:** Parameters of 50 W BP PV module

Parameters	Variables
Typical peak power (Pmax)	50 W
Voltage at Maximum power (Vmp)	17 V
Current at Maximum power (Imp)	2.94 A
Short Circuit Current (Isc)	3.22 A
Open circuit voltage (Voc)	21.2 V
Total number of cells in series (Ns)	36
Total number of cells in parallel (Np)	1

### 4. SIMULATION MODELING OF PV MODULE

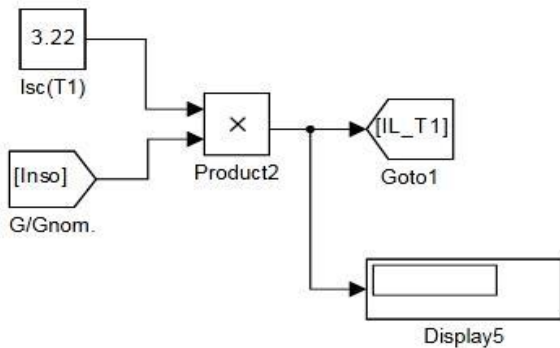
A model of PV module is constructed in Matlab/Simulink environment with the mathematical equations and parameters discussed in section 2 and 3.

**Step-1:** In order to reduce complexity of Matlab model basic blocks as goto and from are used for various terms as temperature of module T, T<sub>1</sub>, boltzman constant k, charge on electron q as shown in fig.2. Rather than using these blocks repeatedly goto and from blocks are used. Interrelation between these blocks can be interpreted by assigning same tag names.



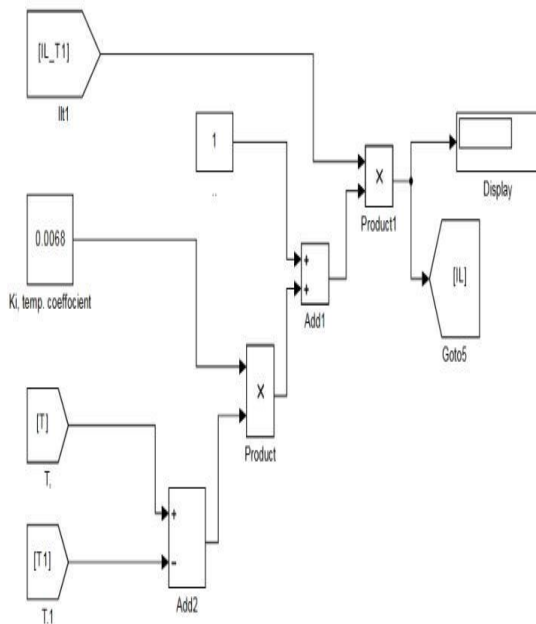
**Fig -2** Goto and from blocks in Matlab

**Step 2** Design model for  $I_{L(T1)}$  as given in equation (3) is shown in fig. 3.



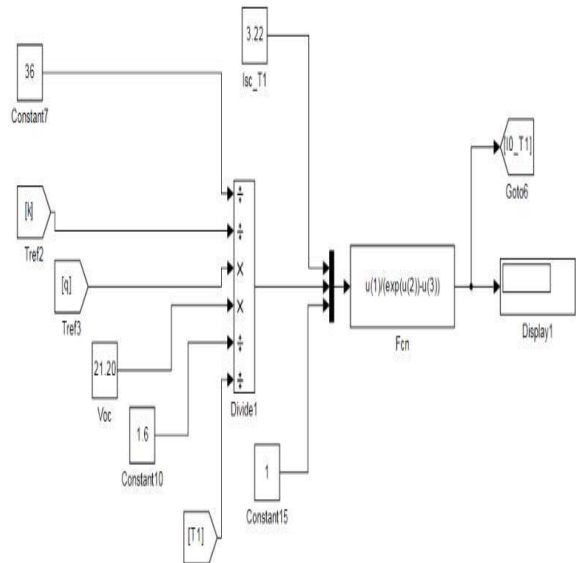
**Fig -3** Model for current  $I_{L(T1)}$

**Step-3:** The design model for  $I_L$  based on equation (2) is shown in figure 4. The value of  $K_0$  is mentioned in manufacturer datasheet. Thus the equation (4) of  $K_0$  is not taken into considerations.



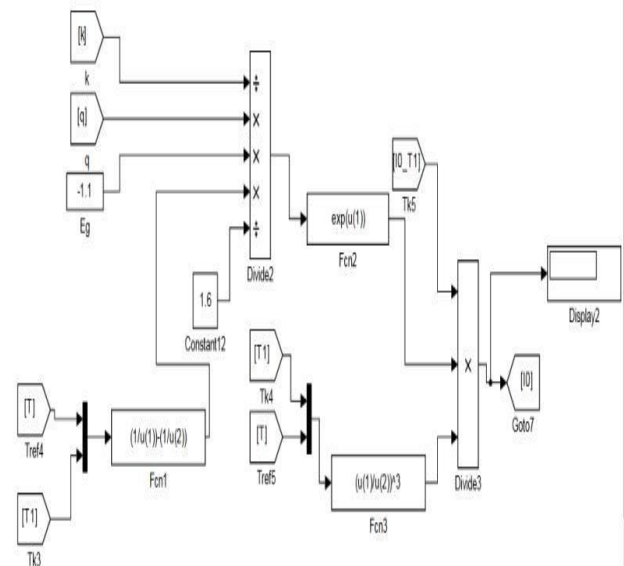
**Fig. 4** Photon Current

**Step 4:-** Looking at equation (1), (5) and (6), it is important to model for equation (6) first as other two are dependent on it. Design model for equation (6) is shown in fig. 5.



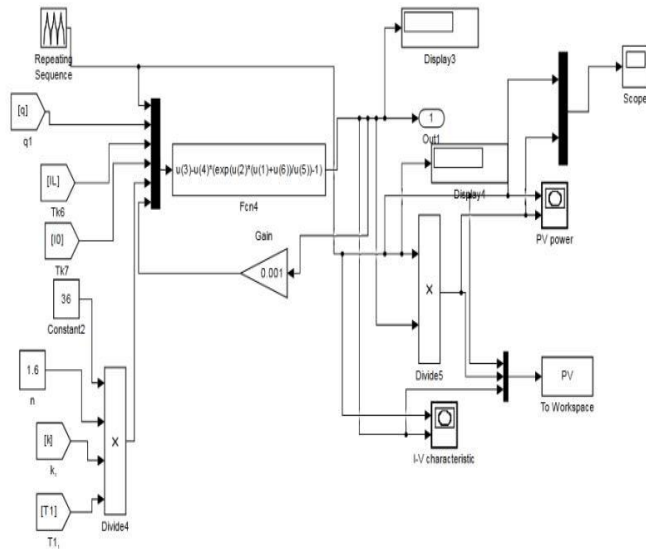
**Fig -5** Model for current  $I_{0(T1)}$

**Step 5:-** Design model for equation (5) is shown in fig.6. It shows modeling of current  $I_0$



**Fig -6** Model for current  $I_0$

**Step 6:-** The final Matlab model representing equation (1) is shown in fig.7

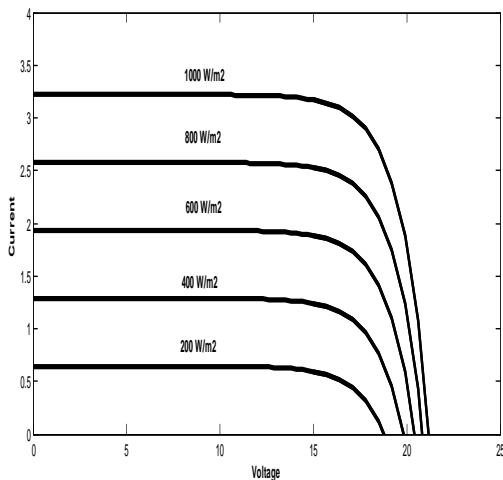


**Fig -7** Final Matlab model for I-V and P-V characteristics of PV module

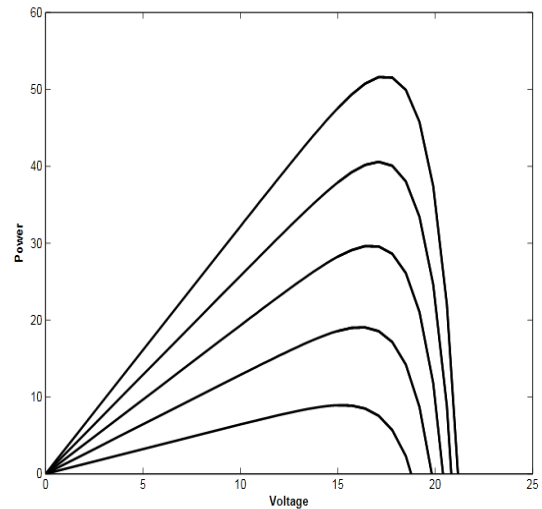
**5. RESULT ANALYSIS AND DISCUSSION**

**5.1 Effect of varying radiation**

The effect of variation of radiation on PV module is shown by I-V and P-V characteristics in fig. 8 and 9 respily. Model is run for various values of radiation levels as 1000W/m<sup>2</sup>, 800W/m<sup>2</sup>, 600W/m<sup>2</sup>, 400W/m<sup>2</sup>, 200 W/m<sup>2</sup>. As insolation drops, short-circuit current drops in direct proportion. Cutting insolation in half, for example, drops Isc by half. Decreasing insolation also reduces VOC, but it does so following a logarithmic relationship that results in relatively less changes in VOC. Also module output power decreases with decrease in solar radiations as shown in fig. 9.



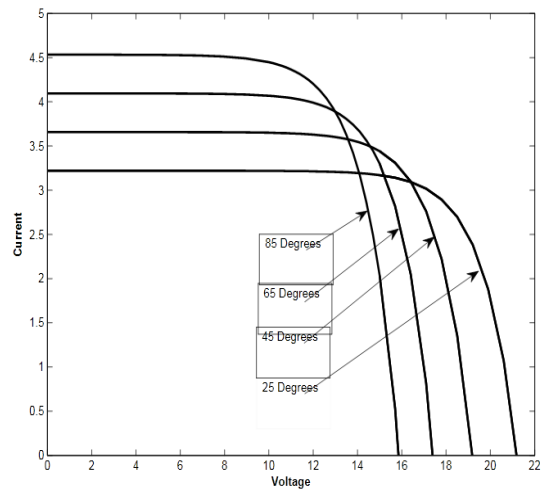
**Fig -8** I-V characteristics of PV module at varying radiation levels



**Fig -9** P-V characteristics of PV module at varying radiation levels

**5.2 Effect of varying temperature**

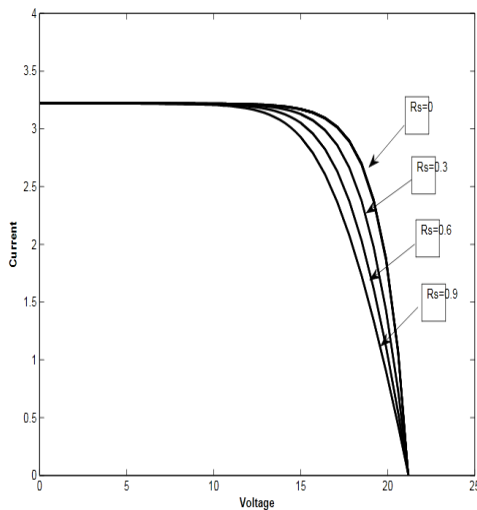
As cell temperature increases, the open-circuit voltage decreases substantially while the short-circuit current increases only slightly as shown in fig.10. Photovoltaic, perhaps surprisingly, therefore perform better on cold, clear days than hot ones.



**Fig -10** I-V characteristics of PV module at varying temperature levels

**5.3 Effect of varying series resistance Rs**

From the comparison shown in fig.11, it is seen that an increase in the series resistance causes an inward bending at the corners of the IV curve with no change in Isc or Voc. Thus area under curve decreases with increase in series resistance which results in less power output from PV module.



**Fig.11** I-V characteristics of PV module at varying series resistance  $R_s$

## 6. CONCLUSION

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. 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. When radiation increases, output voltage increases also current increases. If module operating temperature increases then the current output increases marginally. But the voltage output decreases drastically results in net reduction in power output with rise in temperature. Hence, this circuit model presents the relationship between module parameters and circuit performance.

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