Matlab/Simulink Based Modeling and Simulation of Photovoltaic Array

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Abstract

This paper presents the Design and simulation of photovoltaic module and array. The Simulation is done in the MATLAB. It includes module BP SX 150S for a solar photovoltaic. This module provides a maximum power of 150 W. The current-voltage (I-V) & power-voltage (P-V) characteristics are obtained for various values of solar irradiance keeping the cell temperature constant and for varying temperature and constant irradiance.

1. Introduction

The growth of world energy demand and the environmental concerns lead to an increase of renewable energy production over the last decade. Energy sources such as solar, wind or hydro became more popular mainly because they produce no emission and are inexhaustible.

The realization that Solar Energy is both the heat as well as light, it would be imperative to harness both the thermal as well as the electric power from solar power plants of future to optimally utilize the Solar Energy. Photovoltaic energy is the fastest growing renewable source. Regardless of the intermittency of sun light solar energy is widely available and completely free of cost.

Photovoltaic Cells, commonly known as solar cells, when exposed to the sun, start generating electricity and continue to do so as long as the sun shines. A number of cells joined together to make a solar photovoltaic module. Output of the PV module is the function of solar radiation, cell temperature and output voltage of PV module.

In this paper a MATLAB/Simulink model of PV array considering the basic mathematical modeling of PV cell and module has been developed. P-V and V-I Characteristics are obtained for various irradiances and keeping temperature constant and for different temperatures and constant irradiance. Equation based mathematical modeling of PV module is presented. Next section deals with the detailed Simulink model of PV module and PV array. In last section results and discussions are presented.

2. Mathematical Modeling

Solar cell is a P-N junction diode. It converts solar energy to direct electrical energy. When a solar cell is exposed into sun light, electron holes pairs are generated, hence the current flows through the p-n junction. The ideal photovoltaic module consists of a single diode connected in parallel with a light generated current source (I_{sc}) as shown in Fig 1.
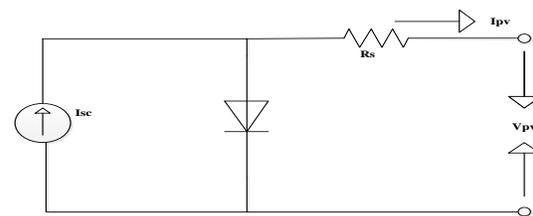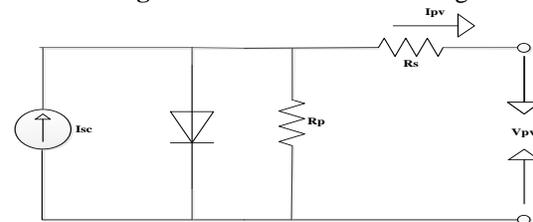

Fig: 1. PV Cell Basic circuit diagram

Figure: 2. Practical circuit for PV Cell

From Fig: 1 equation for the output current is given by:

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$$I = I_{SC} + I_D \qquad (1)$$

Where

$$I_D = I_{scref}\left[\exp\left(\frac{qVoc}{kAT}\right) - 1\right] \qquad (2)$$

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

Thus,

$$I_{sc} = [I_{scref} + K_i(T_k - T_{ref})] * S/1000 \qquad (3)$$

Where I_{sc} is the photocurrent in amperes which is the light-generated current at the nominal condition (25°C and $1000W/m^2$), Ki is the short-circuit current/temperature coefficient at I_{scref} (0.00065A/K), T_k and T_{ref} are the actual and reference temperature in Kelvin, S is the irradiation on the device surface, and $1000W/m^2$ is the nominal irradiation. Equation (2) does not adequately represent the behavior of the cell when subjected to environmental variations, especially at low voltage.

A more practical model is shown in Fig: 2, where R_s and R_p represents series and parallel resistance, respectively.

In this 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.

The equation that describes the I-V characteristic of the circuit in Figure 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:

$$I_{rs} = I_{scref} + \left[\exp\left(\frac{qVoc}{NskAT}\right) - 1\right] \qquad (6)$$

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

$$I_o = I_{rs}\left[\frac{\left(\frac{T}{T_{ref}}\right)^3 e^{qCg}}{Ak} * \left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right] \qquad (7)$$

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

Thus,

$$I_{PV} = I_{sc}N_p - N_sI_o\left[\exp\left\{\frac{q(V_{PV} + I_{PV}\,Rs)}{N_sAkT}\right\} - \right.$$
$$1VPV + IPVRsRp$$

$$(8)$$ Where k is the Boltzmann constant (1.38 x 10^{-23} J K^{-1}), 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 = 72. N_p is the number of cells connected in parallel = 1.

Real operating conditions are always different from the standard conditions, and mismatch effects can also affect the real values of these parameters. 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 is generally high and hence neglected to simplify the model. 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.

The power produced by a single PV cell is not enough for general purpose. Series connection of PV cells in, gives higher voltage and parallel connection current gives higher current consequently higher power. Generally, a combined series and parallel connection of PV cells is known as a module. Mostly, commercial modules consist of 36 or 72 cells. The modules consist of transparent front side, encapsulated PV cells, and back side. Low-iron and tempered glass are used as front side material. A PV module has less efficiency than a PV cell due to the fact that some solar irradiation is reflected by the glass cover and frame shadowing.

3. Simulink Modeling

The complete model to study the different characteristics of PV module consists of 6 models inside it. Detail block diagram for each of these models are given in following sections.

3.1 Simulink modeling of PV Module and PV Array

Model for calculating the short circuit current of a PV module is shown in *Figure 2*. Basically Isc is the photon current at nominal conditions. Model given in *Figure 3* calculates the reference and operating temperature in Kelvin.
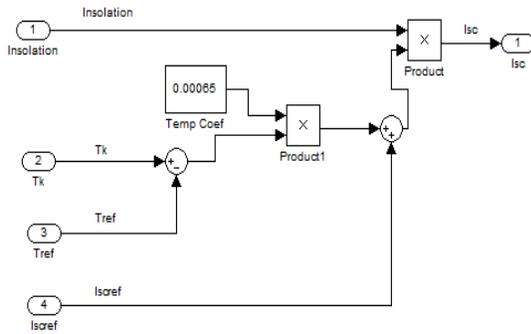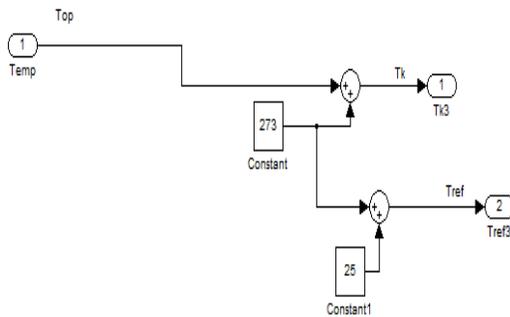
Fig: 2. Short circuit current calculation

Fig: 3. Temperature calculation in Kelvin

Figure 4 shows the model for calculation of reverse saturation current of diode using equation 6.
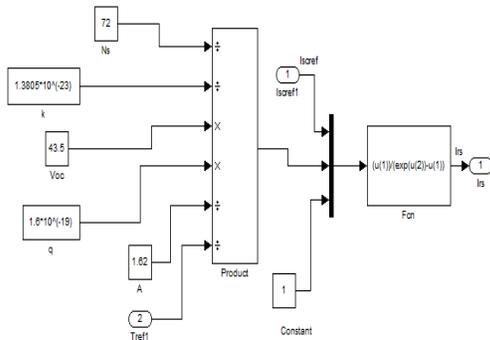

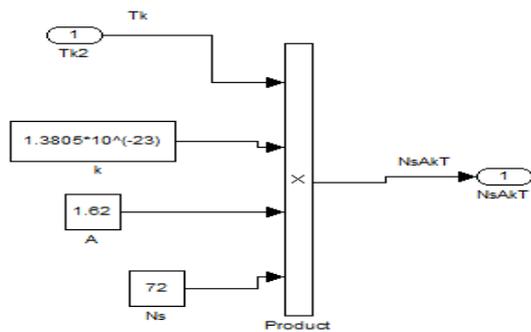**Fig: 4.** Reverse saturation current calculation

Fig: 5. N_sAkT Calculation

Model given in Figure 6 takes reverse saturation current, module reference temperature and the module operating temperature as input and calculates module saturation current. I_{pv} is calculated by executing the function given by equation 8 using Figure 8. Final model which takes irradiation, operating temperature and Module voltage as input and gives the output current and output voltage is shown in Figure 7. This model is used to find the PV and IV characteristics of PV Module under different Temp and irradiation conditions. The model is built as indicated above starting from model 1 to the final model.
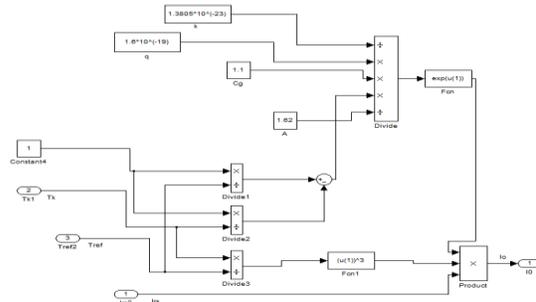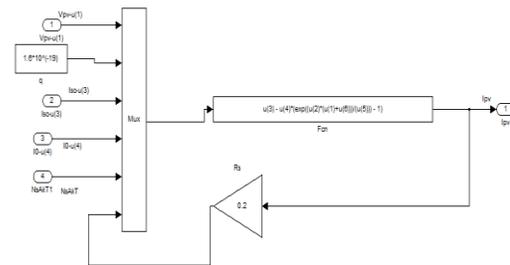

Fig: 6. Io Calculations

Fig: 7. Ipv Calculation

PV modules can be interconnected in series and/or parallel to form a PV panel. In case these modules are connected in series, their voltages are added with the same current. Nevertheless, when they are connected in parallel, their currents are added while the voltage is the same. Model shown in *Figure 9* consists of 3 PV modules. All are connected in series
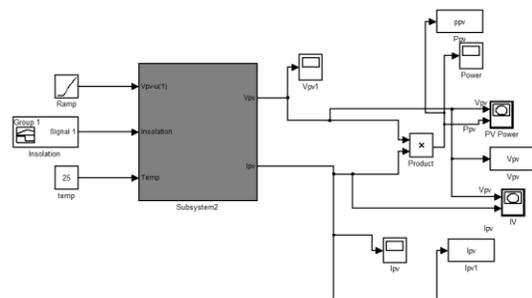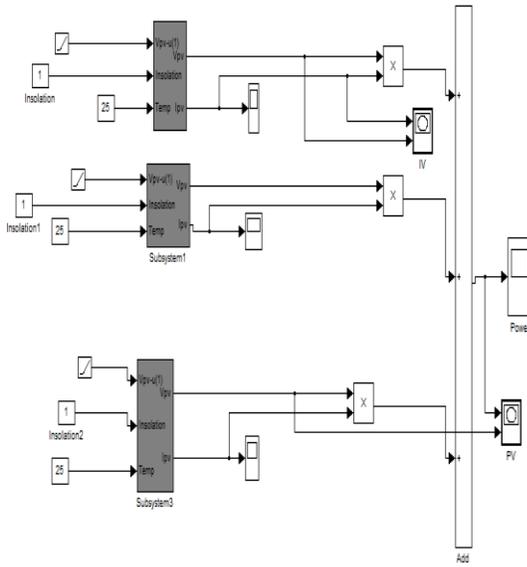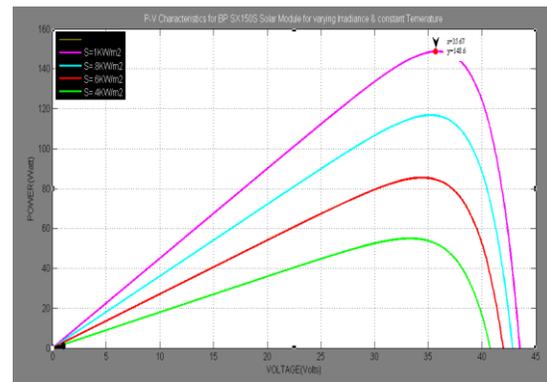

Fig: 8. Final Mode

Fig: 9. PV Array MATLAB/Simulink Model

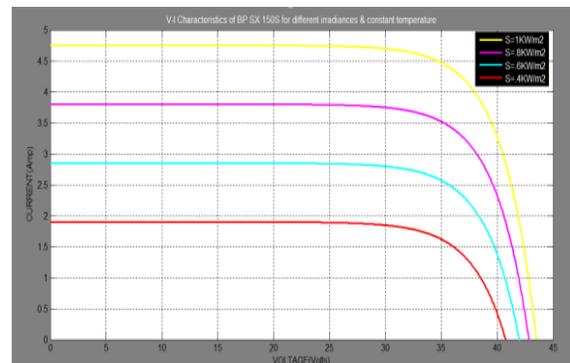## 4. Results

The PV module chosen for this simulation is BP SX 150S, which provides 150W nominal maximum power and has 72 series connected cells. The parameter specification of the module is as shown in Table-1.
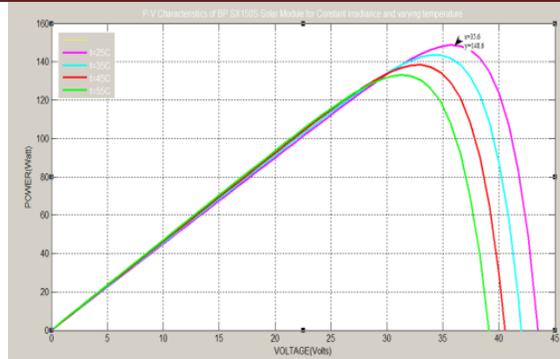
P-V characteristics of the PV module with varying irradiance at the constant temperatures are shown in *Figure 10*. If the amount of solar irradiance increases the output power of PV module increases at constant temperature. For a certain PV panel, the voltage-power characteristics are fixed for different irradiance without intersection. Hence, if the value of voltage and power is given then the value of required irradiance can be estimated. *Figure 11* shows the V-I characteristics of PV module with varying irradiance and constant temperature. It can be observed that the PV output current varies with irradiance. The operating point changes with the solar irradiance, temperature and load conditions. P-V characteristics under constant irradiance with varying temperature are presented in *Figure 12*.With the increase in operating temperature the output current increases but the value of voltage decreases drastically. This results in the reduction of the output power. In *Figure 13* output V-I characteristics are shown. Output P-V characteristics of PV array which consist three such PV modules in series are shown in *Figure 14*. It can be seen from the graph that the output power of PV array is 470 Watt. To increase the output voltage PV modules are connected in series.

Table: 1. Parameter specification of BP SX 150S PV module

| *Parameter*	*Variable*	*Value*
Maximum power	Pm	150 W
Voltage at maximum power	Vm	34.5 V
Current at maximum power	Im	4.35 A
Open circuit voltage	Voc	43.5 V
Short circuit current	Isc	4.75 A
Total No. of cells in Series	Ns	72
Total No. of cells in Parallel	Np	1
Temp. Coefficient of Isc	Ki	(0.065+0.015) %/C
Temp. Coefficient of Voc	Kv	160+-20)mV/C

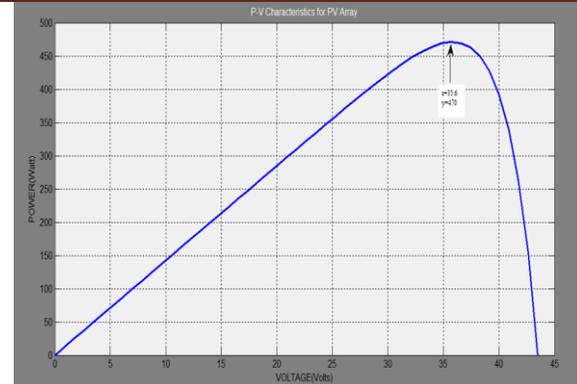**Fig: 10.** P-V Characteristics for different irradiances & constant temperature

Fig: 11. V-I Characteristics for different irradiances & constant temperature

Fig: 12. P-V Characteristics for different
temperatures & constant irradia
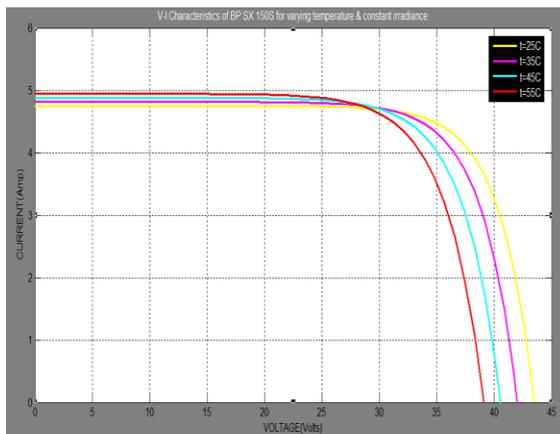
Fig: 12. P-V Characteristics of PV array for constant
temperatures & constant irradiance

5. Conclusions

Mathematical modeling of PV module in Matlab /Simulink is presented. The physical equations governing the PV cell are shown. These equations are also applicable to PV module. The given circuit model presents the relationship between module parameters and circuit performance. Detailed MATLAB/SIMULINK modeling of each block is presented. I-V and P-V characteristics of PV module and PV array are shown for different conditions such as constant temperature, varying irradiance and varying temperature, constant irradiance.

Fig: 12. V-I Characteristics for different temperatures
& constant irradiance

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