

# MATLAB/Simulink Model of Solar PV Module and MPPT Algorithm

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**Abstract**—The paper presents the simulation of the BP SX150S Solar Photovoltaic module using Matlab Simulink. The I-V & P-V characteristics are obtained for various values of solar insolation keeping the cell temperature constant. The Maximum Power Point Tracking (MPPT) algorithm, which is based on the incremental conductance method, is also described. The P-V characteristics are obtained for various insolarations using M-file showing MPP using Incremental conductance method. Also, the points indicating Module voltage  $V_{mp}$  and Current  $I_{mp}$  at maximum power  $P_{max}$  are obtained.

**Keywords**— Photovoltaic modules, MPPT, Matlab/Simulink, insolation, Incremental conductance Method

## I. INTRODUCTION

The entire world is facing a challenge to overcome the hurdle of energy crisis. The diminishing deposits of non renewable energy resources such as coal, natural gas, fossil fuels etc. have added to this worry. It is thus fairly evident that a need exist for developing alternative energy sources. The immediate need would be to vitiate the problems caused by depletion of oil and natural gas, while the long term need would be to develop means that can replace coal and fossil fuels. Rapid population growth and industrialization, demands for an increased amount of electrical energy.

Solar energy is a renewable, inexhaustible and ultimate source of energy. If used in a proper way, it has a capacity to fulfil numerous energy needs of the world. The power from the sun intercepted by earth is approximately  $1.8 \times 10^{11}$  MW [1]. This figure, being thousands of time larger than the present consumption rate enables more and more research in the field of solar energy so that the present and future energy needs of the world can be met. Thus Even though the PV system is posed to its high capital fabrication cost and low conversion efficiency, the skyrocketing oil prices make solar energy naturally viable energy supply with potentially long-term benefits.

PV module represents the fundamental power conversion unit of a PV generator system. The output characteristics of

PV module depends on the solar insolation, the cell temperature and output voltage of PV module. Since PV module has nonlinear characteristics, it is necessary to model it for the design and simulation of maximum power point tracking (MPPT) for PV system applications. The mathematical PV models used in computer simulation have been built. [2]- [3]. Almost all well-developed PV models describe the output characteristics mainly affected by the solar insolation, cell temperature, and load voltage. Recently, a number of powerful component-based electronics simulation software package have become popular in the design and development of power electronics applications. However, the Sim Power System tool in Matlab/Simulink package offers wind turbine models but no PV model to integrate with current electronics simulation technology. Thus, it is difficult to simulate and analyse in the generic modelling of PV power system. This motivates me to develop a model for PV cell, module, and array using Matlab/Simulink.

However, the solar energy is a dilute source of energy and its availability varies widely with time. So, it is very necessary to make a complete utilization of solar energy in available time. Many maximum power point tracking algorithms are available for a solar panel in order to produce maximum output. It is very necessary that it is operated consistently at the maximum power point. The Incremental Conductance Method of MPPT is described here with its maximum power point.

## II. PHOTOVOLTAIC MODULE AND ARRAY MODEL

Solar cell is basically a p-n junction fabricated in a thin wafer or layer of semiconductor. The electromagnetic radiation of solar energy can be directly converted to electricity through photovoltaic effect. Being exposed to the sunlight, photons with energy greater than the band-gap energy of the semiconductor are absorbed and create some electron-hole pairs proportional to the incident irradiation. Under the influence of the internal electric fields of the p-n junction, these carriers are swept apart and create a photocurrent which is directly proportional to solar insolation.

PV system naturally exhibits a nonlinear I-V and P-V characteristics which vary with the radiant intensity and cell temperature. Fig. 1 shows the equivalent circuit models of PV cell.

Since a typical PV cell produces less than 2W at 0.5V approximately, the cells must be connected in series-parallel configuration on a module to produce enough high power. A PV array is a group of several PV modules which are electrically connected in series and parallel circuits to generate the required current and voltage. The equivalent circuit for the solar module arranged in  $N_p$  parallel and  $N_s$  series is shown in Fig. 2. The terminal equation for the current and voltage of the array becomes as follows [5]-[8].

$$I = N_p I_{PH} - N_p I_S \left[ \exp \left( \frac{q(V/N_s + IR_s)/N_p}{kT_C A} \right) - 1 \right] - (N_p V/N_s + IR_s)/R_{SH} \quad (1)$$

where,  $I_{PH}$  is a light-generated current or photocurrent,  $I_S$  is the cell saturation of dark current,  $q$  ( $= 1.6 \times 10^{-19}C$ ) is an electron charge,  $k$  ( $= 1.38 \times 10^{-23}J/K$ ) is a Boltzmann's constant,  $T_C$  is the cell's working temperature,  $A$  is an ideal factor,  $R_{SH}$  is a shunt resistance, and  $R_S$  is a series resistance. The photocurrent mainly depends on the solar insolation and cell's working temperature, which is described as

$$I_{PH} = [I_{SC} + K_I (T_C - T_{ref})] \lambda \quad (2)$$

where  $I_{SC}$  is the cell's short-circuit current at a  $25^\circ C$  and  $1kW/m^2$ ,  $K_I$  is the cell's short-circuit current temperature coefficient,  $T_{ref}$  is the cell's reference temperature, and  $\lambda$  is the solar insolation in  $kW/m^2$ . On the other hand, the cell's saturation current varies with the cell temperature, which is described as

$$I_S = I_{RS} (T_C / T_{ref})^3 \exp \left[ -\frac{qE_G \left( \frac{1}{T_{ref}} - \frac{1}{T_C} \right)}{kA} \right] \quad (3)$$

where  $I_{RS}$  is the cell's reverse saturation current at a reference temperature and a solar radiation,  $E_G$  is the bang-gap energy of the semiconductor used in the cell. The ideal factor  $A$  is dependent on PV technology [4] and is listed in Table I.

TABLE I  
FACTOR A DEPENDENCE ON PV TECHNOLOGY [9]

Technology	A
Si Mono	1.2
Si-Poly	13
a-Si:H	18
a-Si:H tandem	3.3
a-Si:H triple	5
CdTe	1.5
CTS	1.5
AsGa	13

All of the model parameters can be determined by examining the manufacturer's specifications of PV products. The most important parameters widely used for describing the cell electrical performance is the open-circuit voltage  $V_{OC}$  and the short-circuit current  $I_{SC}$ . The aforementioned equations are implicit and nonlinear; therefore, it is difficult to arrive at an analytical solution for a set of model parameters at a specific temperature and irradiance.

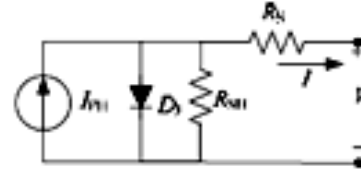


Fig. 1 Equivalent circuit model of PV cell

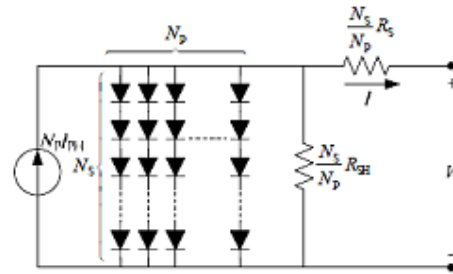


Fig. 2 Equivalent circuit model of generalized PV

Since normally  $I_{PH} \gg I_S$  and ignoring the small diode and ground-leakage currents under zero-terminal voltage, the short-circuit current  $I_{SC}$  is approximately equal to the photocurrent  $I_{PH}$ , i.e.,

$$I_{PH} = I_{SC} \quad (1)$$

On the other hand, the  $V_{OC}$  parameter is obtained by assuming the output current is zero. Given the PV open-circuit voltage  $V_{OC}$  at reference temperature and ignoring the shunt-leakage current, the reverse saturation current at reference temperature can be approximately obtained as

$$I_{RS} = I_{SC} / \left[ \exp \left( \frac{qV_{OC}}{N_s k T_C A} \right) - 1 \right] \quad (5)$$

In addition, the maximum power can be expressed as

$$P_{max} = V_{max} I_{max} = \gamma V_{OC} I_{SC} \quad (6)$$

where  $V_{max}$  and  $I_{max}$  are terminal voltage and output current of PV module at maximum power point (MPP), and  $\gamma$  is the cell fill factor which is a measure of cell quality.

### III. SIMULATION OF SOLAR PV MODULE IN MATLAB

In this section the characteristic equations (1), (2), (3) & (5) for the PV module is implemented in MatLab Simulink as shown in Fig. 3.

The parameters chosen for modeling corresponds to the BP SX150S module as listed in Table II. The voltage  $V$  is considered varying from 0 to open circuit voltage  $V_{oc}$  corresponding to the variation in current from short circuit current  $I_{sc}$  to 0. Fig.4 & 5 shows the V-I & P-V characteristics with the variation in solar insolation level at a constant cell temperature of 25 degrees respectively. It can be seen that the short circuit current as well as the power increases with the increase in insolation level, while very little change in the open-circuit voltage.

The peak value of the product of  $V$  and  $I$  represent the maximum power point (MPP)  $P_{max}$  of the solar module. The current and voltage of PV module at the MPP are denoted by  $I_{mp}$  and  $V_{mp}$ , respectively. The solar module should always be operated in this region so as to extract the maximum power for a given input conditions. For this purpose various maximum power point algorithms can be used.

TABLE II  
PARAMETERS OF BP SX150S SOLAR MODULE

Parameter	Value
Maximum Power ( $P_{max}$ )	150 W
Voltage at Pmax ( $V_{mp}$ )	34.5 V
Current at Pmax ( $I_{mp}$ )	4.35 A
Warranted minimum $P_{max}$	140 W
Short circuit current ( $I_{sc}$ )	4.75 A
Open-circuit voltage ( $V_{oc}$ )	43.5 V
Maximum System Voltage	600 V
Temp. Co-efficient of $I_{sc}$	(0.065+0.015)%/C
Temp. Co-efficient of $V_{oc}$	-(160+-20) mv/C
Temp. Co-efficient of Power	-(0.5+-0.05) %/C
NOCT	47+-2 °C

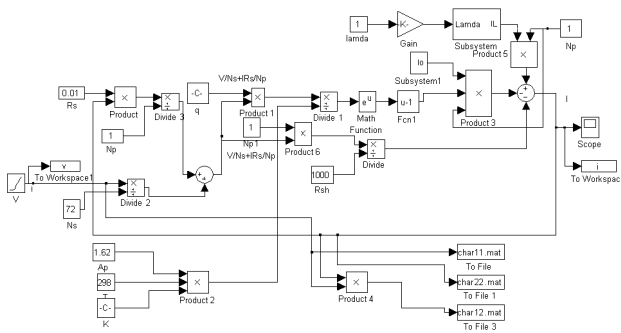


Fig. 3 Matlab Simulation of PV Module

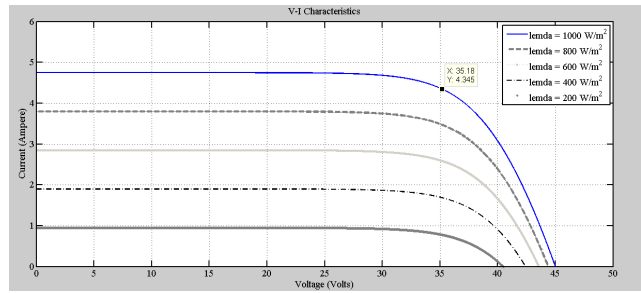


Fig.4 V-I Characteristics for different insolation

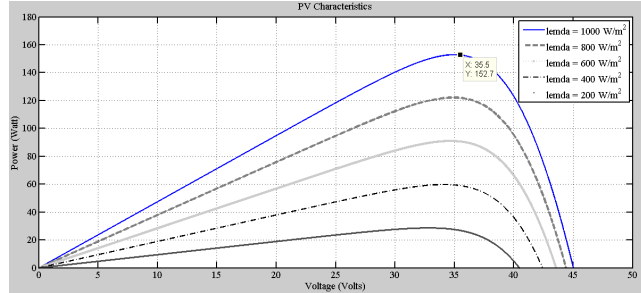


Fig.5 P-V Characteristics for different insolation

### IV. MAXIMUM POWER POINT TRACKING

The output power of the solar PV module changes with change in direction of the sun, change in solar insolation level and change in temperature. Also there is a single maximum power point in the PV characteristics of the PV module for a particular operating condition. It is desired that the PV module operates close to this point, i.e., output of the PV module approaches near to MPP. The process of operating PV module at this condition is called as maximum power point tracking (MPPT). Maximization of PV power improves the utilization of the solar PV module.[11]

Many MPPT algorithms had been proposed in the past. Two comparatives between them are included in the works presented in [8]. The most common algorithms nowadays are the P& O and the incremental conductance method [8]. Also the Hill climbing method is described in [10].The Incremental conductance method offers the main advantage of providing high efficiency under rapidly changing atmospheric conditions, so it has been employed in the proposed model. Nevertheless another MPPT algorithm could be used if it was required in the simulations. The MPPT implemented algorithm is depicted in Fig. 6. The algorithm basis is the PV array output current, which is constantly adjusted to reach the voltage in the maximum power point (MPP).

Fig. 7 shows the P-V characteristic for the BP SX150S module obtained using incremental conductance method. The Algorithm is implemented using M-file in MATLAB. Fig. 8 and Fig. 9 show the module voltage  $V_{mp}$  and Current  $I_{mp}$  at the maximum power  $P_{max}$ .

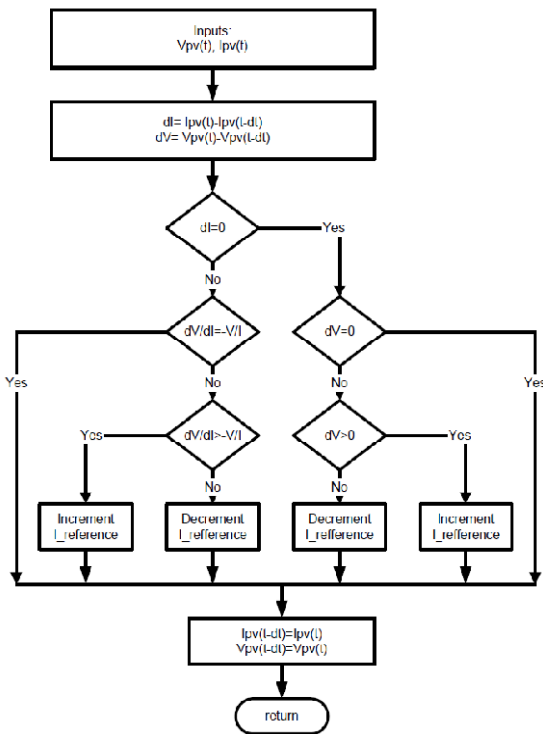


Fig. 6 Incremental conductance Method [12]

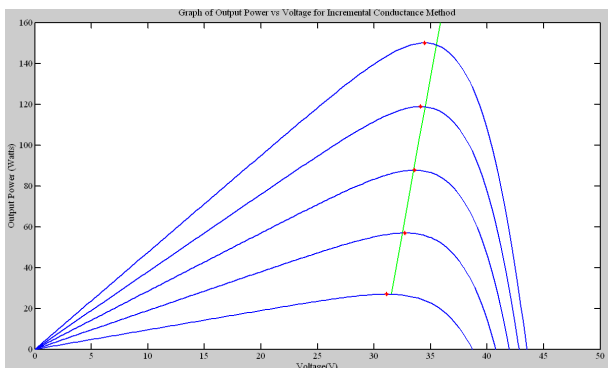


Fig. 7 PV curve for Incremental conductance Method

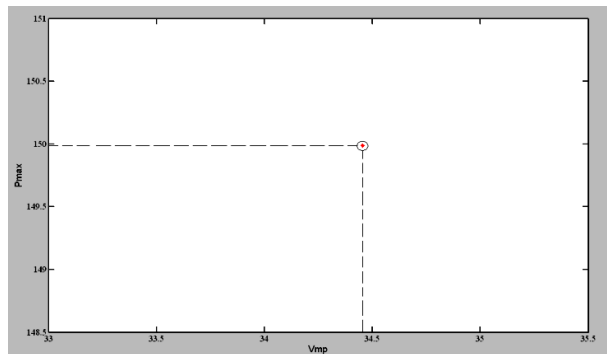


Fig. 8 Module Voltage at Maximum Power,  $V_{mp}$

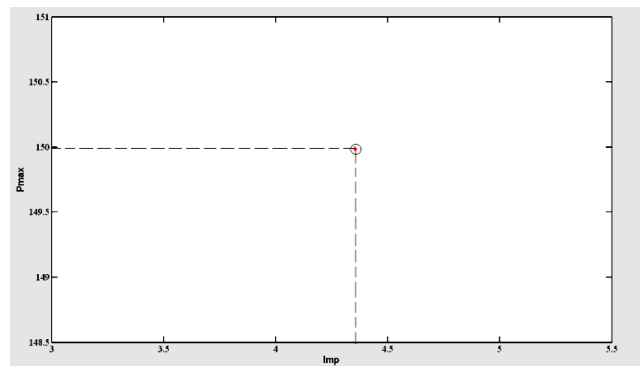


Fig. 9 Module Current at Maximum Power,  $I_{mp}$

## V. CONCLUSIONS

The I-V and P-V characteristics of BP SX150S solar module are obtained using the MATLAB/Simulink for different values of insolation. The P-V characteristics are also obtained using the M-file with Incremental Conductance method. It is observed that the characteristics obtained using both methods are matching with the theoretical Characteristics. Also the module voltage  $V_{mp}$  and Current  $I_{mp}$  at the maximum power  $P_{max}$  are obtained which are fairly same as indicated by the manufacturer of BP SX150S solar panel. Thus the proposed simulation model in conjunction with MPPT algorithm can be used with DC-DC Boost converter to obtain the required dc voltage to supply the dc load.

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