

# “PV Module Design and Modelling using Maximum Power Point Tracking Technique”

Nilesh P. Mendhe<sup>1</sup> and Deepak Shahakar<sup>2</sup>

<sup>1</sup>Student M.E. 2<sup>nd</sup> Year (EPS) P. R. Pote College of Engineering, Amravati

<sup>2</sup>P. R. Pote College of Engineering, Amravati

E-mail: <sup>1</sup>mendhe\_np@yahoo.co.in, <sup>2</sup>deepakshahakar@gmail.com

**Abstract**—The paper proposes the design and MATLAB simulation based modelling of photovoltaic modules using maximum power point techniques. High initial investment and limited life span of photovoltaic array makes it necessary for the user to extract maximum power from the PV system. The performance of a Photovoltaic module is affected by irradiance and module temperature. It is important to understand the relationship between these effects and the output power of the PV module. The efficiency of a solar cell is very low. In order to increase the efficiency, methods are to be undertaken to match the source and load properly. One such method is the Maximum Power Point Tracking (MPPT). This is a technique used to obtain the maximum possible power from a varying source. In photovoltaic systems the I-V curve is non-linear, thereby making it difficult to be used to power a certain load. This is done by utilizing a boost converter whose duty cycle is varied by using a maximum power point tracking algorithm. An accurate PV module electrical model is presented based on the Shockley diode equation. A MATLAB Simulink based PV module model is developed and a Perturb and Observe method is used for finding maximum power point (MPP) of a solar PV cell. The model is used to investigate the variation of maximum power point with temperature and insolation levels. The results obtained shows that the proposed model has good predictability in the general behavior of MPPT under the conditions of both nonuniform and uniform irradiance.

## 1. INTRODUCTION

A PV cell is a thin semiconductor wafer made of two layers generally made of highly purified silicon. The layers have been doped with boron on one side and phosphorous on the other side, producing surplus of electrons on one side and a deficit of electrons on the other side. When the wafer is bombarded by sunlight, photons in the sunlight knock off some of excess electrons; this makes a voltage difference between the two sides as the excess electrons try to move to the deficit side.

Maximum Power Point Tracking regulates voltage & current parameters to produce maximum power. Surplus power obtained from the module is then used to charge battery.

## 2. EQUIVALENT CIRCUIT FOR A PHOTOVOLTAIC CELL

A simplest equivalent circuit model for a photovoltaic cell consists of a real diode in parallel with an ideal current source. The magnitude of the ideal current source must be equal to short-circuit current  $I_{sc}$ .

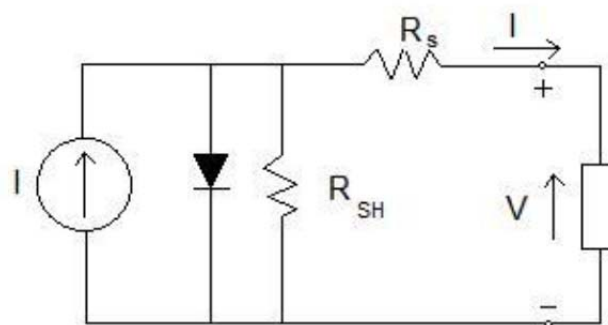


Fig. 1: Single diode model of a PV cell

The current equation for the PV cell is

$$I = I_{sc} - I_d \quad (1)$$

The voltage current characteristics a diode is given by a Shockley diode equation, hence

$$I = I_{sc} - I_d = I_{sc} - I_0 \left( e^{\frac{qV_d}{AKT}} - 1 \right) \quad (2)$$

Where

q = charge of an electron ( $1.6 \times 10^{-9}C$ );

K = Boltzman's constant ( $1.38 \times 10^{-23}J/^{\circ}K$ );

A = diode ideality factor (1.92);

T = cell temperature;

$V_d$  = Diode voltage

The open circuit voltage  $V_{oc}$ :

In these equations,  $I_{sc}$  is directly proportional to solar insolation.

A PV equivalent circuit includes some parallel leakage resistance  $R_{sh}$ . The ideal current source  $I_{sc}$  in this case delivers current to the diode, the parallel resistance, and the load:

$$I = (I_{sc} - I_d) - \frac{V}{R_{sh}} \quad (3)$$

So, at any given voltage, the parallel leakage resistance

$$R_{sh} > \frac{100V_{oc}}{I_{sc}} \quad (4)$$

To analyze the impact of  $R_s$ , consider the original equivalent circuit equation

$$I = I_{sc} - I_d = I_{sc} - I_0 \left( e^{\frac{qV_d}{KT}} - 1 \right) \quad (5)$$

and then add the impact of  $R_s$

$$V_d = V + I R_s \quad (6)$$

to give

$$I = I_{sc} - I_0 \left\{ \exp \left[ \frac{q(V + I R_s)}{KT} \right] - 1 \right\} \quad (7)$$

For a cell to have less than 1% losses due to series resistance,

$$R_s < \frac{0.01V_{oc}}{I_{sc}} \quad (8)$$

Finally, we can write the following equation for current and voltage:

$$I = I_{sc} - I_0 \left\{ \exp \left[ \frac{q(V + I R_s)}{KT} \right] - 1 \right\} - \left( \frac{V + I R_s}{R_{sh}} \right) \quad (9)$$

### 3. MODEL OF A PV MODULE

If a solar cell type tends to have an  $I-V$  curve in which the slope at short circuit is almost zero, the value of  $R_{sh}$  assumed to be infinite .

$$I = I_{sc} - I_0 \left( e^{\frac{q(V + R_s I)}{AKT}} - 1 \right) \quad (10)$$

where  $I_{sc}$  is the short-circuit current.

Equation (11) is valid for a solar cell.

For the accurate application of this equation for a PV module, the term of  $q(V + R_s I)/AKT$  is changed to

$$q(V + R_s I)/NsAKT \quad (11)$$

in which  $N_s$  is the number of series-connected solar cells in a PV module.

Then, (10) will become

$$I = I_{sc} - I_0 \left( e^{\frac{q(V + R_s I)}{NsAKT}} - 1 \right) \quad (12)$$

When a PV module is in an open-circuit situation,  $I = 0$  and the item  $q/NsAKT$  in (12) will be solved as follows:

$$\frac{q}{NsAKT} = \frac{\ln \left( \frac{I_{sc}}{I_0} + 1 \right)}{V_{oc}} \quad (13)$$

where  $V_{oc}$  is the open-circuit voltage of a PV module.

Substituting (13) into (12), we get

$$I = I_{sc} \left[ I - \frac{I_0}{I_{sc}} \left( e^{\ln \left( \frac{I_{sc}}{I_0} + 1 \right) \frac{(V + R_s I)}{V_{oc}}} - 1 \right) \right] \quad (14)$$

Defining  $k = I_{sc}/I_0$  and simplifying (14), we get

$$I = I_{sc} \left[ 1 - \frac{1}{k} \left( k + 1 \right)^{\frac{V + R_s I}{V_{oc}}} + \frac{1}{k} \right] \quad (15)$$

Normally, the value of  $k$  is very large because  $I_0$  is far less than  $I_{sc}$ .

Therefore

$$I = I_{sc} \left( 1 - k^{\frac{V + R_s I}{V_{oc}}} - 1 \right) \quad (16)$$

Under standard test condition (STC), which consists of a PV module temperature of  $25^{\circ}C$  and an in-plane irradiance of  $1000 \text{ W/m}^2$  with spectral distribution, (16) could be rewritten as follows:

$$I_{ref} = I_{sc,ref} \left( 1 - k_{ref}^{\frac{V_{ref} + R_s I_{ref}}{V_{oc,ref}}} - 1 \right) \quad (17)$$

Where

$I_{ref}$  is the output current under STC,

$I_{sc,ref}$  is the short circuit current under STC,

$V_{ref}$  is the output voltage under STC,

$V_{oc,ref}$  is the open-circuit voltage under STC, and

$k_{ref}$  is the coefficient of  $k$  under STC.

Parameters at maximum output power point (MPP) under STC could be given to solve the coefficient of  $k_{ref}$

$$k_{ref} = \left( \frac{V_{MPP,ref} + R_s I_{MPP,ref}}{V_{oc,ref}} - 1 \right) \sqrt{1 - \frac{I_{MPP,ref}}{I_{sc,ref}}} \quad (18)$$

where

$V_{MPP,ref}$  is the output voltage at MPP under STC and

$I_{MPP,ref}$  is the output current at MPP under STC.

The open-circuit voltage of the PV module has a negative temperature coefficient and the output current of the PV module has a characteristic of positive temperature coefficient.

It is clear that the output voltage and current of a PV module change with irradiance . Hence, the effect of changes of temperature and irradiance should be considered in the PV module model. To achieve electrical characteristic of a PV module in various temperature and irradiance, the mathematical expressions for correction of current and voltage are

$$I_{sc} = I_{sc,ref} [1 + \alpha (T - T_{ref})] \frac{S}{S_{ref}} \quad (19)$$

$$V_{oc} = V_{oc,ref} \left[ 1 + a \ln \frac{S}{S_{ref}} + \beta (T - T_{ref}) \right] \quad (20)$$

where

$T$  is the PV module temperature,

$T_{ref}$  is the reference PV module temperature under STC,

$S$  is the in-plane solar irradiance,

$S_{ref}$  is the reference irradiance under STC,

$\alpha$  is the temperature coefficient of  $I_{sc}$ ,

$\beta$  is the temperature coefficient of  $V_{oc}$ , and

$a$  is the irradiance correction factor of  $V_{oc}$ .

The translation equations in this method are

$$I = I_{ref} \frac{I_{sc}}{I_{sc,ref}} \quad (21)$$

$$V = V_{ref} + (V_{oc} - V_{oc,ref}) + R_s(I_{ref} - I) \quad (22)$$

To simplify, (21) and (22) are substituted into (17) to get a new expression of  $I_{ref}$

$$I_{ref} = I_{sc,ref} \left( 1 - k_{ref} \frac{V - V_{oc} + R_s I_{ref} \frac{I_{sc}}{I_{sc,ref}}}{V_{oc,ref}} \right) \quad (23)$$

A PV module, TP240, produced by Tata Power Solar with 60 series-connected multi crystalline cells, is chosen to evaluate the proposed model. in this project. The electrical characteristics specifications under STC and NOTC from manufacturer are shown in Table I & Table II respectively.

**Table 1 Electrical Parameters of PV module TP240 at standard test conditions (STC).**

Nominal power output (W)	240
Module efficiency ( $\eta\%$ )	14.4
Voltage at $P_{MAX}$ , $V_{MPP}$ (V)	29.7
Current at $P_{MAX}$ , $I_{MPP}$ (A)	8.10
Open-circuit voltage $V_{oc}$ (V)	36.5
Short-circuit current $I_{sc}$ (A)	8.68

**Table 2: Electrical parameters of PV module TP240 at Nominal Operating Cell Temperature**

Power output $P_{MAX}$ (W)	172.8
Voltage at $P_{MAX}$ , $V_{MPP}$ (V)	26.3
Current at $P_{MAX}$ , $I_{MPP}$ (A)	6.58
Open-circuit voltage $V_{oc}$ (V)	32.5
Short-circuit current $I_{sc}$ (A)	7.17

The following formula can be obtained at MPP:

$$\left. \frac{dI}{dV} \right|_V = V_{MPP} = - \frac{I_{MPP}}{V_{MPP}} \quad (24)$$

On the other hand, the derivative of (16) with respect to  $V$  brings

$$\frac{dI}{dV} = -I_{sc} \frac{1+R_s \frac{dI}{dV}}{V_{oc}} k^{\frac{V+R_s I}{V_{oc}} - 1} \ln k \quad (25)$$

Equation (25) could be rewritten at MPP as follows:

$$\left. \frac{dI}{dV} \right|_V = V_{MPP} = -I_{sc} \frac{1+R_s \left. \frac{dI}{dV} \right|_{V=V_{MPP}}}{V_{oc}} k^{\frac{V_{MPP}+R_s I_{MPP}}{V_{oc}} - 1} \ln k \quad (26)$$

An expression of  $R_s$  obtained as follows:

$$R_s = \frac{V_{MPP,ref} + \frac{I_{MPP,ref}(V_{oc,ref} - V_{MPP,ref})}{(I_{sc,ref} - I_{MPP,ref}) \ln(1 - \frac{I_{MPP,ref}}{I_{sc,ref}})}}{I_{MPP,ref} + \frac{I_{MPP,ref}^2}{(I_{sc,ref} - I_{MPP,ref}) \ln(1 - \frac{I_{MPP,ref}}{I_{sc,ref}})}} \quad (27)$$

$R_s$  of a PV module TP240 is 0.0605  $\Omega$  by substituting the parameters in Table I into (27) and the coefficient  $k_{ref}$  is 0.2198 by using (18).  $R_s$  is assumed to be a constant at its reference value under STC , the irradiance correction factor for selected PV module is 0.2433.

By using data from datasheet, current, voltage and power for PV module TP240 is calculated and studied for varying temperature and irradiance as shown in Table 3 and Table 4.

**Table 3: Effect of variation in Temperature on PV module output at irradiance of 800 W/m<sup>2</sup>**

T( <sup>0</sup> C)	I <sub>sc</sub> (A)	V <sub>oc</sub> (V)	I (A)	V (V)	P (W)
25	6.94	35.96	6.48	29.16	188.98
30	6.96	35.43	6.49	28.63	185.92
35	6.97	34.89	6.51	28.09	182.85
40	6.99	34.36	6.52	27.56	179.77
45	7.01	33.82	6.54	27.02	176.66
50	7.02	33.29	6.55	26.49	173.55
75	7.10	30.61	6.62	23.81	157.73

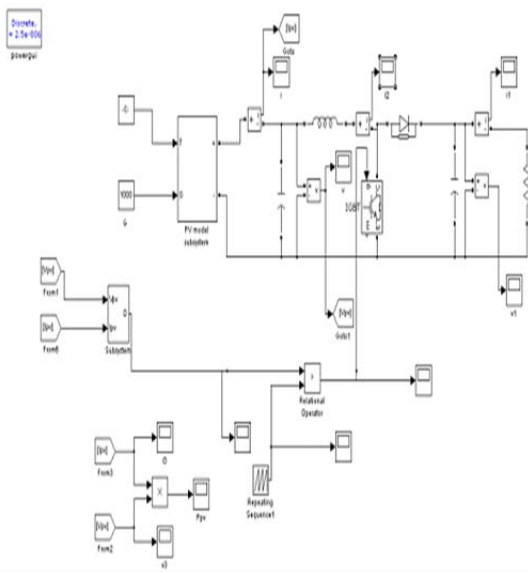
**Table 4: Effect of variation in irradiance on PV module output at temperature of 25<sup>0</sup>C.**

S (W/m <sup>2</sup> )	I <sub>sc</sub> (A)	V <sub>oc</sub> (V)	I (A)	V (V)	P (W)
1000	8.68	36.50	8.10	29.70	240.57
950	8.25	36.38	7.70	29.58	227.59
900	7.81	36.25	7.29	29.45	214.67

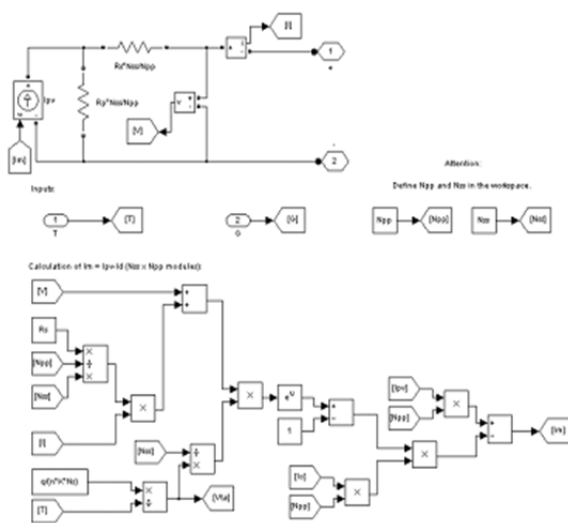
850	7.38	36.11	6.89	29.31	201.79
800	6.94	35.96	6.48	29.16	188.98
750	6.51	35.81	6.08	29.01	176.23
500	4.34	34.83	4.05	28.03	113.53

**4. PV MODULE MODEL IN MATLAB-SIMULINK**

The block diagram of the MATLAB-Simulink-based PV module model is shown in Fig. 2, The subsystem block in Fig. 3 will be a basic PV module mode of MATLAB-Simulink.

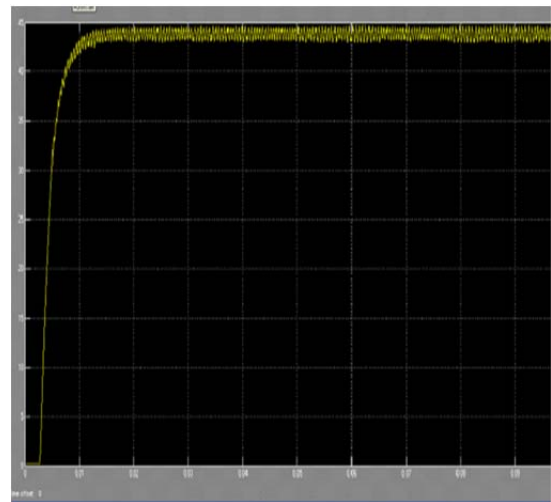


**Fig. 2: MATLAB Simulink based PV module model**

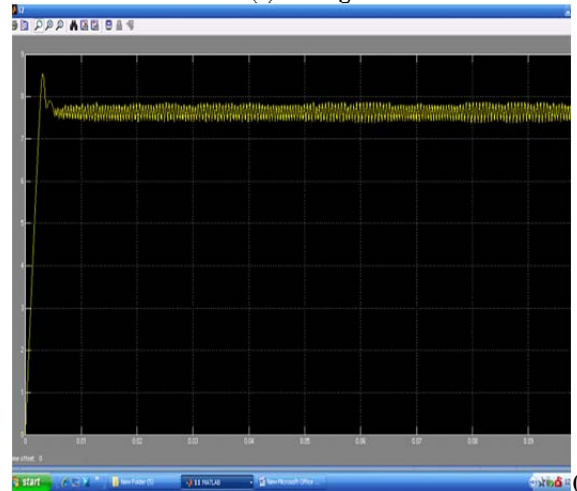


**Fig. 3: MATLAB Simulink based PV module subsystem model**

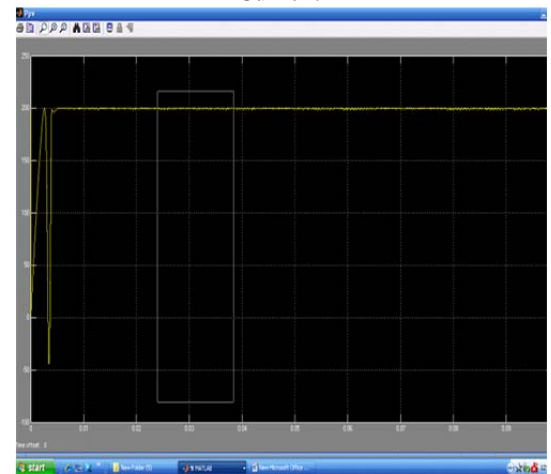
Fig. 4 shows the details of the screen shot of a MATLAB Simulink PV module model.



**(a) Voltage**



**Current**



**(c) Power**

**Fig. 4: Screen shot of a MATLAB Simulink PV module model.**

## 5. CONCLUSION

Due to the nonlinear relationship between the current and the voltage of the PV cell, it can be observed that there is a unique Maximum Power Point (MPP) at a particular environment, and this peak power point keeps changing with solar illumination and ambient temperature. An important consideration in achieving high efficiency in PV power generation system is to match the PV source and load impedance properly for any weather conditions, thus obtaining maximum power generation. Therefore, the system needs a Maximum power point tracking (MPPT) which sets the system working point to the optimum and increases the system's output power.

The proposed MATLAB-Simulink model was tested to verify whether it could correctly simulate the behaviour combining with dc/dc converter. Fig.4 shows current and voltage curves in simulation which coincide with the curves in measurement. Fig. 4.(a) shows boosted voltage of boost converter and Fig. 4.(b) shows a reduced current level of boost converter output. The maximum possible output is shown in Fig. 4.(c). From the output obtained from simulink model, it is observed that Boost Converter step up the voltage level of output voltage of photovoltaic cell.

In Perturb and Observe (P&O) method the controller adjusts the voltage by a small amount from the array and measures power; if the power increases, further adjustments in that direction are tried until power no longer increases. This is called the perturb and observe method and can result in oscillations of power output. Perturb and observe method result in high efficiency.

## REFERENCES

- [1] G. D. Rai, "Non conventional Energy sources", *Khanna Publishers, fourth edition*, 2008
- [2] Y.A. Sadawarte, Rajashree T. Hiware, Prateek Pathak, SameekshaTripathi, "Non Conventional Sources of Energy", *International Journal of Computer Applications (IJCA)*, Pp. 1-11
- [3] Richard A. Cullen, "What is Maximum Power Point Tracking (MPPT) and How Does it Work?", [www.blueskyenergyinc.com](http://www.blueskyenergyinc.com).
- [4] Trishan Efram, Patrick L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques", *IEEE transactions on energy conversion*, vol. 22, no. 2, June 2007, Pp. 439-449.
- [5] A. Dolara, R. Faranda, S. Leva, "Energy Comparison of Seven MPPT Techniques for PV Systems", *J. Electromagnetic Analysis & Applications*, March 2009, Pp. 152-162.
- [6] Geoff Walker, "Evaluating MPPT converter topologies using a MATLAB PV model", *J. electr. Electron. Eng.*, vol. 21, no. 1, 2001, pp. 49-56.
- [7] <http://www.solardirect.com/pv/pvlist/pvlist.htm>
- [8] Raal Mandour, I. Elamvazuthi, "Optimization of Maximum Power Point Tracking (MPPT) of Photovoltaic System using Artificial Intelligence (AI) Algorithms", *Journal of Emerging Trends in Computing and Information Sciences*, Vol. 4, No. 8 Aug 2013, Pp. 662-669
- [9] Swati Singh, Lini Mathew, Shimi S.L., "Design and Simulation of Intelligent Control MPPT Technique for PV Module Using MATLAB/ SIMSCAPE", *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, Vol. 2, Issue 9, September 2013, Pp. 4554-4566
- [10] Sachin Jain and Vivek Agarwal, "A Single-Stage Grid Connected Inverter Topology for Solar PV Systems With Maximum Power Point Tracking", *IEEE transactions on Power Electronics*, Vol. 22, No. 5, Sept. 2007, Pp. 1928-1940
- [11] Eftichios Koutroulis, Kostas Kalaitzakis, Nicholas C. Voulgaris, "Development of a Microcontroller-Based, Photovoltaic Maximum Power Point Tracking Control System", *IEEE transactions on Power Electronics*, Vol. 16, No. 1, January 2001, Pp. 46-54
- [12] N. P. Mendhe, D. Shahakar, "Design and Modeling of PV module using Maximum Power Point Tracking Techniques" *Journal of Network Communications and Emerging Technologies (JNCET)*, Vol. 6, Dec. 2016