

Design and Modelling Of PV Module Using Maximum Power Point Tracking Technique

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Abstract – The proposed work proposes the design and simulation based modelling of photovoltaic modules using maximum power point tracking 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 efficiency of a solar cell is very low and can be increased by using Maximum Power Point Tracking (MPPT). This is a technique used to obtain the maximum possible power from a varying source. The I-V curve is non-linear, so it is difficult to power a certain load. This is achieved by using a boost converter with variation of duty cycle using a maximum power point tracking algorithm.

Index Terms – PV cell, modelling, MPPT, MATLAB-simulink model.

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. RESEARCH OBJECTIVES

PV generation systems have two major problems - the conversion efficiency in electric power generation is low under low irradiation conditions, and the amount of electric power generated by solar arrays changes continuously with weather conditions. There is a point on the V-I or V-P curve, called the Maximum Power Point (MPP), at which the entire PV system operates with maximum efficiency and produces its maximum output power.

3. SOLAR CELL

A solar cell is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect. It is a form of photoelectric cell which, when exposed to light,

generate and constitute an electric current without being attached to any external voltage source, but do require an external load for power consumption.

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} .

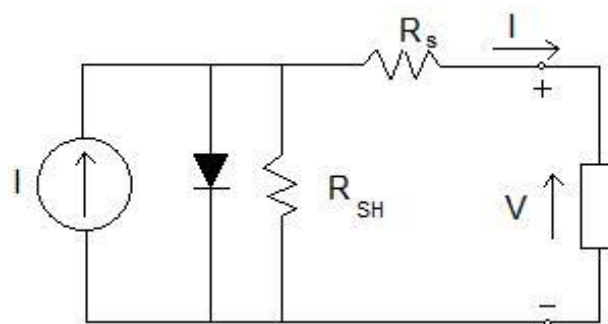


Fig.1: Single diode model of a PV cell

The current equation for the PV cell is $I = I_{sc} - I_d$ (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 Voc:

In these equations, Isc is directly proportional to solar insolation.

A PV equivalent circuit includes some parallel leakage resistance Rsh. The ideal current source ISC in this case delivers current to the diode, the parallel resistance, and the load:

$$I = (I_{sc} - I_d) - \frac{V}{R_{sh}} \quad (4)$$

So, at any given voltage, the parallel leakage resistance

$$R_{sh} > \frac{100V_{oc}}{I_{sc}} \quad (5)$$

To analyze the impact of Rs, consider the original equivalent circuit equation

$$I = I_{sc} - I_d = I_{sc} - I_0 \left(e^{\frac{qV_d}{KT}} - 1 \right) \quad (6)$$

and then add the impact of Rs

$$V_d = V + IR_s \quad (7) \text{ to give}$$

$$I = I_{sc} - I_0 \left\{ \exp \left[\frac{q(V + IR_s)}{KT} \right] - 1 \right\} \quad (8)$$

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

$$R_s < \frac{0.01V_{oc}}{I_{sc}} \quad (9)$$

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

$$I = I_{sc} - I_0 \left\{ \exp \left[\frac{q(V + IR_s)}{KT} \right] - 1 \right\} - \frac{V + IR_s}{R_{sh}} \quad (10)$$

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 Rsh assumed to be infinite .

$$I = I_{sc} - I_0 \left(e^{\frac{q(V + RsI)}{AKT}} - 1 \right) \quad (11)$$

where Isc 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 + Rs I)/AKT is changed to q(V + Rs I)/NsAKT, in which Ns is the number of series-connected solar cells in a PV module.

Then, (11) will become

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

When a PV module is in a 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 VOC is the open-circuit voltage of a PV module.

Substituting (13) into (12), we get

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

Defining k = Isc/I0 and simplifying (14), we get

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

Normally, the value of k is very large because I0 is far less than Isc.

Therefore

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

Under standard test condition (STC), which consists of a PV module temperature of 25°C and an in-plane irradiance of 1000 W/m² with spectral distribution, (16) could be rewritten as follows:

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

Where

Iref is the output current under STC,

Isc,ref is the short circuit current under STC,

Vref is the output voltage under STC,

Voc,ref is the open-circuit voltage under STC, and

kref is the coefficient of k under STC.

Parameters at maximum output power point (MPP) under STC could be given to solve the coefficient of kref

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

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

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

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

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,

α is the temperature coefficient of I_{sc} ,

β 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.

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

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

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

The following formula can be obtained at MPP:

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

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:

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

An expression of R_s obtained as follows:

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

R_s of a PV module TP240 is 0.0605 Ω 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.

T(°C)	Isc (A)	Voc (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 3: Effect of variation in Temperature on PV module output at irradiance of 800 W/m²

S (W/m ²)	Isc (A)	Voc (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

Table 4: Effect of variation in irradiance on PV module output at temperature of 25°C.

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.

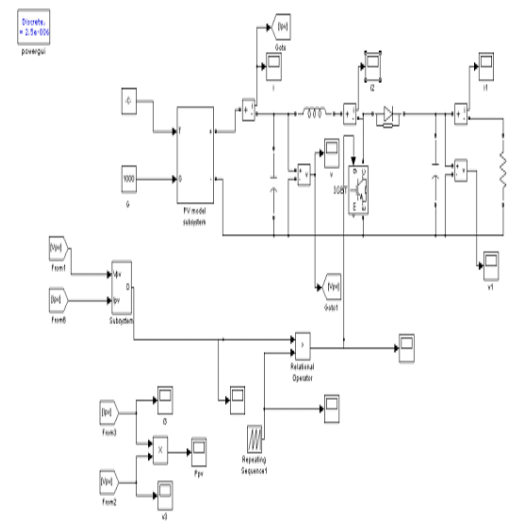


Fig. 2: MATLAB Simulink based PV module model

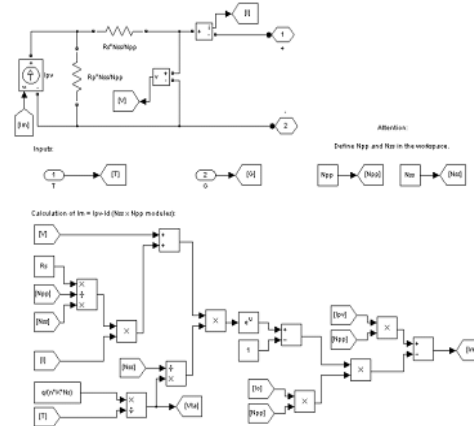
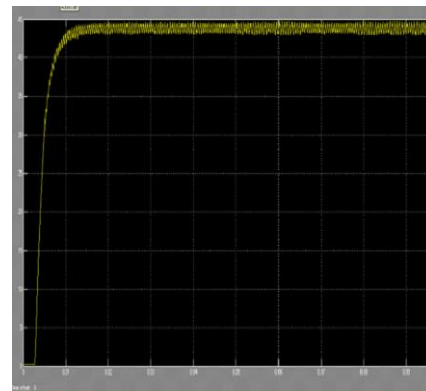
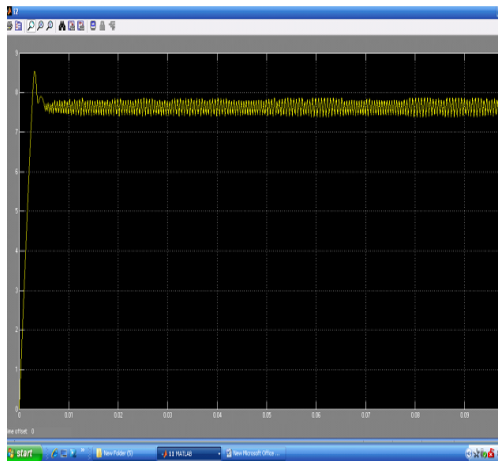


Fig. 3: MATLAB Simulink based PV module subsystem model

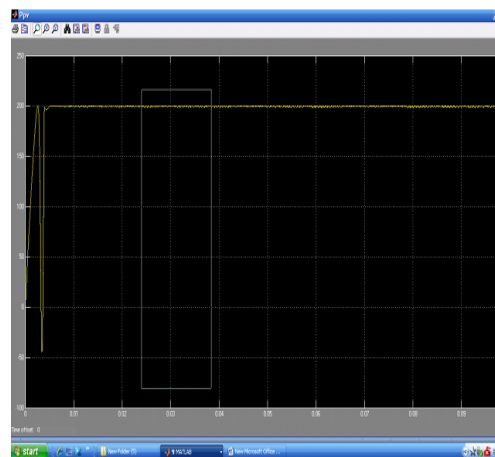
Fig. 4 shows the details of the screen shot of a MATLAB Simulink PV module model.



(a) Voltage



(b) Current



(c) Power

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

4. CONCLUSION

A mathematical model of a simple photovoltaic module model is designed and a simulation of PV module using MPPT technique using Perturb and Observe method is carried out and

then results are compared for different irradiance conditions and temperature changes according to weather change.

It is observed that Perturb and Observe method can improve the PV module efficiency by continuously keeping PV & IV curve at its maximum power point. A MATLAB-Simulink based PV module model includes a controlled current source. Various PV module simulation can be done by the Simulink model, and parameters of irradiance and temperature of PV module model can be set independently.

A PV module electrical model is presented and demonstrated in MATLAB for a typical TP240W solar PV module model.

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