



Modeling and Simulation of Photovoltaic Module to Study the Effects of Variation in Irradiance and Temperature

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ABSTRACT: This paper proposes a simple and accurate modeling and simulation of photovoltaic (PV) module. The main aim is to find the unknown parameters of the nonlinear current-voltage ($I-V$) equations by adjusting the $I-V$ curve at three remarkable points when the circuit is open (open circuit), when circuit is delivering maximum power, and when it is short circuited. The data of these three studies are mentioned by all commercial PV module makers in their datasheets and with all these parameters of the adjusted $I-V$ equation, simulation of PV module is done in MATLAB/SIMULINK. In this paper the variation in $I-V$ and $P-V$ characteristic under varying irradiation and temperature is shown.

KEYWORDS: PV module, equivalent circuit, modeling, irradiance, temperature, I-V curve, simulation.

I. INTRODUCTION

With the increasing demand for electrical energy and increase in depletion rate of conventional sources. Need of renewable energy sources increases, therefore Photovoltaic (PV) generation is gaining significance, as a renewable source due to its various advantages like less running cost as there is no fuel required, no noise, less wear and tear due to absence of any rotating part, little maintenance etc. PV cell is a semiconductor diode which can convert light into direct current (DC). Some PV cells can even convert infrared (IR) and ultraviolet (UV) radiation into electricity. The DC current generated is dependent on intensity of solar radiation, due to which the $I-V$ characteristic of a PV cell is not linear [1]. Moreover, these characteristics changes with change in temperature [2]. The PV device efficiency depends on the solar radiation spectral distribution. To acknowledge the effect of solar radiation on PV module, study of various factor like changes in temperature of solar disc and how earth atmosphere mould solar radiation is described in [3].

In this paper, simulation of TATA make TP240 PV module is done. The datasheet of TP240 is taken from [4] and the unknown parameter that is the value of resistances is calculated under standard test condition (STC) using iterative method in which curve fitting is done using Newton-Raphson method. In literature, there are various equivalent circuit used for simulation of PV module. In [5], two diode model is used to interpret recombination effect of charge carriers. In [6], three-diode model is employed to quantitatively analyze output operation of multi-crystalline silicon solar cells with high leakage current through its periphery and its electrical properties. Single diode model is used in this paper for PV module modeling. As this model have well balance between simplicity and accuracy [7]. In single diode model, some have neglected series resistance R_s [8], [9] as it has very small value and some neglected parallel resistance R_p as it possess high value [10], [11]. Here effect of both R_s and R_p is considered

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II. MODELING OF PV MODULE

From the ideal equivalent circuit of PV cell (as shown in fig.1), equation of output current of PV cell is [12]:

$$I = I_{PVcell} - I_{Ocell} \left[\exp\left(\frac{qV_d}{akT}\right) - 1 \right] \quad (1)$$

Where q is charge of the electrons (1.602×10^{-19} C), k is Boltzmann constant (1.3806×10^{-23} J/K), T is junction temperature (K), V_d is voltage across diode, I_{Ocell} is diode saturation current, a is diode ideality constant, I_{PVcell} is light generated current in a PV cell, I is output current of a cell. The value of a is usually in between 1 and 1.5 in this paper the value of a is taken to be 1.3.

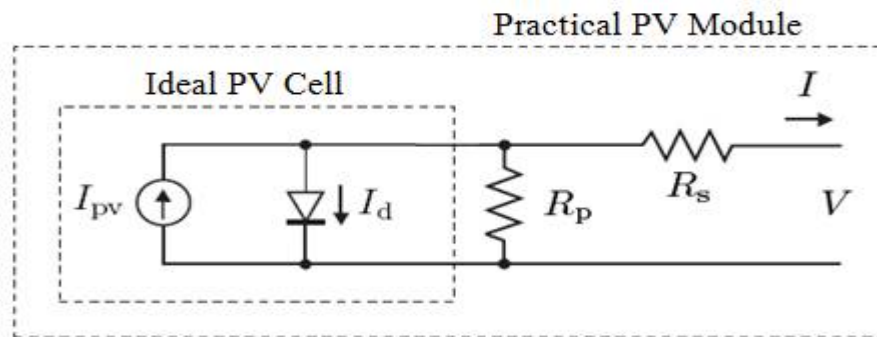


Figure: 1 Equivalent circuit [13]

Practical PV module I - V characteristic equation, in which N_s number of cells is connected in series, is

$$I = I_{SC} - \left\{ I_o \exp\left[\frac{q(V + IR_s)}{kTN_s}\right] - 1 \right\} - \left(\frac{V + IR_s}{R_p} \right) \quad (2)$$

All PV module manufacturer mention three remarkable points regarding module in their datasheets which is nominal open-circuit voltage (V_{OCn}) when the module is open circuited in STC, the nominal short-circuit current (I_{SCn}) when the output terminal of module is shorted under STC, the voltage and current at MPP when the module is delivering maximum power (as shown in Figure 2). Temperature coefficient of voltage (i.e. represent by K_V) and of current (represent by K_I) and max peak output power of PV module (represent by P_{MAXm}) and the number of cells (represent by N_s) in a module, these information are also presented in datasheet of a PV module. In practical PV module series resistance R_s have more impact when device is operating in region where it acts as a voltage source and parallel resistance R_p have more impact in current source region.

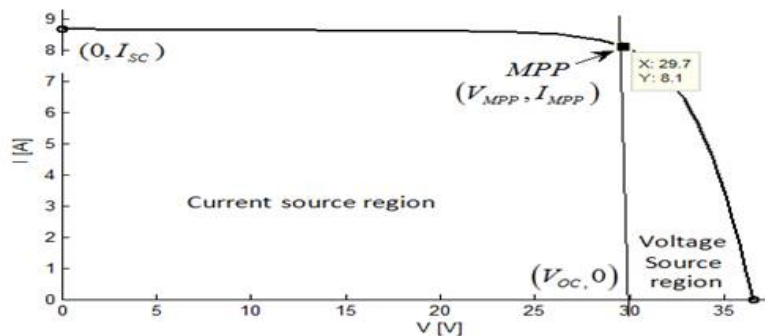


Figure: 2 I - V characteristic curve of practical PV module

For modeling of PV module I_{SC} is take approximately equal to I_{PV} (Where I_{PV} is current generated by PV module) because generally value of the series resistance is low and of parallel resistance is high. But in this paper. The current generated in module due to sunlight is linearly depends on the solar irradiation and also have temperature influence given by following equation [14]



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$$I_{PV} = (I_{PVn} + K_I \Delta T) \frac{G}{G_n} \quad (3)$$

Where: I_{PVn} is the current generated due to sunlight at STC (usually 25°C and 1000W/m^2), $\Delta T = T - T_n$ (where T is actual temperature and T_n is temperature at STC), G is actual irradiation and G_n is irradiance at STC. The influence of temperature on diode saturation current is expressed as [15].

$$I_O = I_{On} \left(\frac{T_n}{T} \right)^3 \exp \left[\frac{qE_g}{ak} \left(\frac{1}{T_n} - \frac{1}{T} \right) \right] \quad (4)$$

where E_g represent bandgap energy of the semiconductor material (For the polycrystalline Si $E_g \approx 1.12\text{ eV}$ at 25°C [16]), Now we consider the effect of temperature coefficient of current (K_I) and voltage (K_V) on saturation current so that open circuit voltages match with the experimental data for a wide range [12].

$$I_O = \frac{I_{SCn} + K_I \Delta T}{\exp \left(\frac{V_{OCn} + K_V \Delta T}{aV_T} \right) - 1} \quad (5)$$

Where V_T is thermal voltage of N_S series connected cells and $V_T = N_S kT/q$.

III. ADJUSTMENT MADE IN MODULE

Two parameter R_S and R_P are left unknown in eq. (2). In order to adjust R_S and R_P , such that maximum power that can be generated by module mentioned in datasheet should be equal to experimental power generated and both I - V and P - V curve should be match with experimental data. As we know the open circuit voltage and short circuit current, so the range of voltage and current is known we have to find such value of R_S and R_P so that all the points with mainly three remarkable point (which are open circuit voltage V_{OCn} , MPP, short circuit current I_{OCn}) must match. The relation between R_S and R_P constituted by equating $P_{MAXm} = P_{MAXe}$ and solving resulting equation for R_S (Where P_{MAXe} is experimental maximum output power of module)

$$P_{MAXm} = V_{MPP} \left\{ I_{PV} - I_O \left[\exp \left(\frac{q}{kT} \frac{V_{MPP} + R_S I_{MPP}}{aN_S} \right) - 1 \right] - \frac{V_{MPP} + R_S I_{MPP}}{R_P} \right\} = P_{MAXe} \quad (6)$$

$$R_P = V_{MPP} \frac{(V_{MPP} + I_{MPP} R_S)}{\left\{ V_{MPP} I_{PV} - V_{MPP} I_O \exp \left[\frac{(V_{MPP} + I_{MPP} R_S) q}{N_S a kT} \right] + V_{MPP} I_O - P_{MAXe} \right\}} \quad (7)$$

From eq. (7) we get value of R_P for any value of R_S such that the I - V curve touch the experimental maximum point (V_{MPP}, I_{MPP}). Before starting the iterative procedure to get the value of R_S and R_P initial guesses are good so that convergence rate increases. As R_S is practically have small value so initially we take it zero, Initial value of R_P is

$$R_{P,MIN} = \frac{V_{MPP}}{I_{SCn} - I_{MPP}} - \frac{V_{OCn} - V_{MPP}}{I_{MPP}} \quad (8)$$

This equation represents the slope of line between point $(0, I_{SCn})$ and (V_{MPP}, I_{MPP}) . This is a good initial guess for R_P . For modeling purpose TP240 data is used from [4].

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Table 1 Parameters of the TP240 PV module at STC as provided in its datasheet

I_{MPP}	8.10
V_{MPP}	29.7
P_{MAXe}	240
I_{SC}	8.68
V_{OC}	36.5
K_V	-0.2931
K_I	0.0442
N_S	60

Algorithm

Step1: Input the data of module TP240 which are available in datasheet.

Step 2: Input value of constants (like Boltzmann constant, value of electron charge etc) and those parameter whose value is not dependent on variable or unknown parameters

Step 3: Define the tolerance value of power, step increment in value of R_S and number of step for which we want to plot I-V characteristic and input initial guess of R_S and R_p and set error value to infinity

Step 4: Start the while loop till the absolute value of error ($P_{MAXe}-P_{MAXm}$) is less than tolerance

Step 5: Calculate the value of I_{pv} and I_{PV} as these values depend on R_S and R_p so with increment in R_S and R_p these value is updated with each iteration. Increments the values of R_S from 0 to some step increment value calculate value of R_p with the value of R_S using equation update the value of R_p .

Step 6: Solve the I-V equation for several (V,I) pairs (set in step 3) and for incremented value of R_S and R_p . This is done using Newton-Raphson method

Step 7: Plot the I-V and P-V curve. Update error value ($P_{MAXe}-P_{MAXm}$) end the loop and until the absolute of error value is not less than tolerance the loop is repeated (from step 4).

Step 8: Display the value of all parameter.

The value of R_S and R_p obtained are 0.132Ω and 357.837Ω respectively

IV. SIMULATION OF PV MODULE

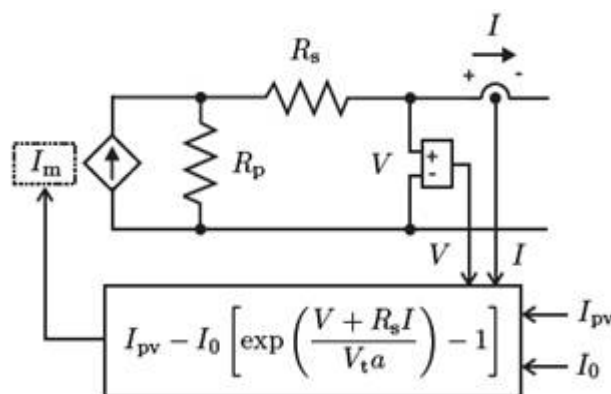


Figure: 3 PV module circuit for simulation [13]

Now using these parameter and the equations above one can simulate this module in MATLAB/SIMULINK. The photovoltaic module is simulated with an equivalent circuit model shown in Figure 3, in which a circuit model having one current source (I_m) and two resistors (R_p and R_S). The value of temperature and irradiance is provided externally. The value of the current I_m is

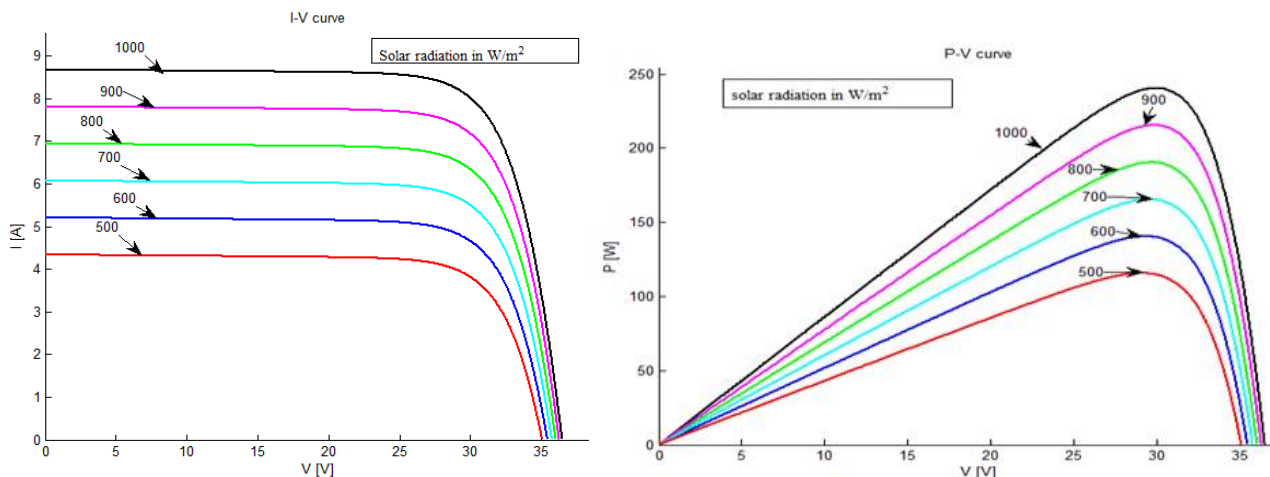
$$I_m = I_{PV} - I_o \left[\exp\left(\frac{V + R_s I}{aV_T}\right) - 1 \right] \quad (9)$$

Where I_{PV} and I_o is calculated using eq. (3) and (5). The voltage and current are given using voltage and current sensing. The value of I_{PV} , I_o and I_m is calculated from in MATLAB/SIMULINK using simple product, divide, addition and subtraction block and PV module output voltage and current(when load is applied) is obtain.

V. RESULT AND DISCUSSION

A. Irradiation Effect on TP240

PV module output power is dependent upon incident irradiation. As we know that the short circuit current (I_{sc}) is in direct proportion to irradiation and also with the increase of irradiation the maximum value of open circuit voltage (V_{oc}) increases exponentially. So with the increase in irradiation there is considerable increase in I_{sc} in comparison to V_{oc} . The effect of irradiation on TP240 is observed, the I - V characteristics under changing irradiance and at constant temperature (25°C) is plot as shown in Figure 4 and the effect of irradiation on P - V curve at constant at temperature (25°C) is shown in Figure 5.



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B. Temperature Effect on TP240

Module temperature is changes with the change in ambient temperature. Short circuit current (I_{sc}) increases marginally with the increase of PV module temperature more than the nominal temperature, that is 25°C (298.15K) .But there is a considerable impact of PV module temperature on the open circuit voltage (V_{oc}) when module temperature increases above nominal temperature open circuit voltage reduces. Increase in current due to module temperature increase is much lower than decrease in voltage so that the overall output power is reduced. The effect of temperature on TP240 is observed, the P - V characteristics under varying temperature and at constant irradiance (1000W/m²) is plot as shown in Figure 6 and the effect of temperature on I - V curve at constant irradiance (1000W/m²) is shown in Figure 7.

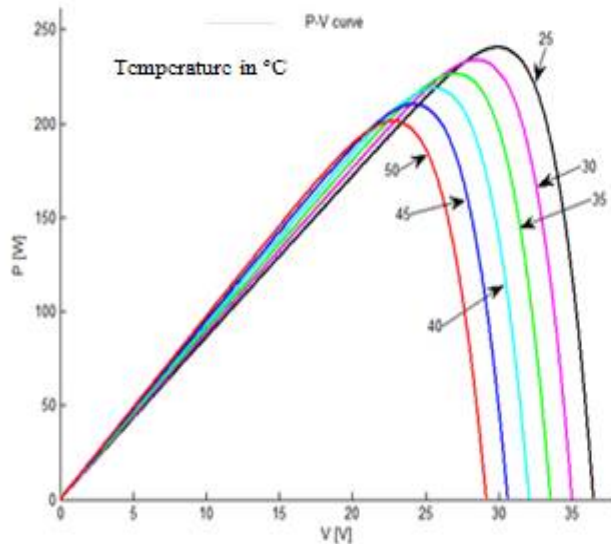


Figure 6 Temperature variation effect on P-V curve

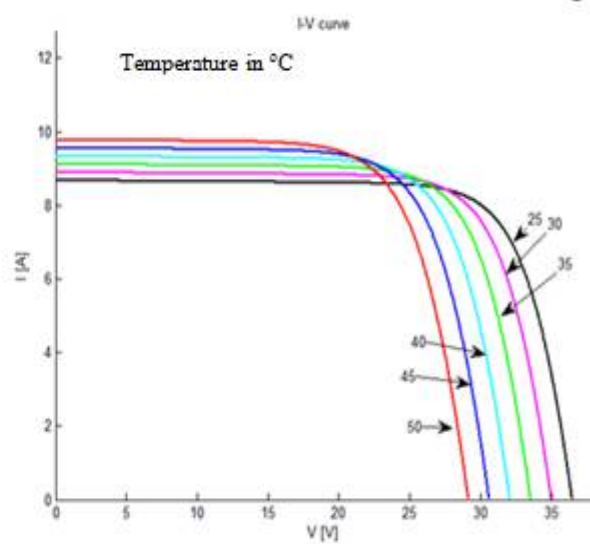


Figure 7 Temperature variation effect on I-V curve

VI. CONCLUSION

This paper has fulfilled the objective to fit the mathematical $I-V$ characteristic equation to the experimental noteworthy points of the $I-V$ curve of the practical PV module. The method obtains the known parameters of the $I-V$ characteristic equation by using the information provided in PV module datasheet: open circuit voltage (V_{OC}), short-circuit current (I_{OC}), maximum output power (P_{MAXm}), voltage and current at the MPP (V_{MPP} , I_{MPP}), and temperature coefficients of voltage and current (K_V and K_I). This paper provides the reader with all essential information to easily develop a single-diode PV module model for analyzing and simulating a PV module.

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