

SINGLE-DIODE AND TWO-DIODE PV CELL MODELING USING MATLAB FOR STUDYING CHARACTERISTICS OF SOLAR CELL UNDER VARYING CONDITIONS

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ABSTRACT

This paper presents a detailed explanation about various characteristics of ideal single diode, practical single diode and two diode equivalent circuit models realized for modeling of solar photovoltaic cell. Then it presents non-linear mathematical equations necessary for producing I-V and P-V characteristics from a single diode model. A flowchart has been made for estimation of solar cell output current, for single diode and two diode model, using Newton-Raphson iterative technique which is then programmed in MATLAB script file accordingly. A typical 120W polycrystalline solar module specifications have been used for model accuracy evaluation. The characteristic curves were obtained with the use of manufacturer's datasheet and it shows the precise correspondence to both the models.

KEYWORDS

Single Diode, Two Diode, I-V and P-V characteristics, solar irradiance, photovoltaic.

1. INTRODUCTION

A technology that directly converts free solar energy into electrical energy without causing any pollution to the environment is termed as photovoltaic power generation. The photovoltaic system consists of a group of solar cells connected in series and parallel. For simplicity in analyzing characteristics of solar cells, electrical equivalent circuits are realized and are hence modelled using simulation softwares. It helps in predicting behavior under various environmental conditions, and further in obtaining (I-V) and (P-V) characteristic curves.

The common approach is to utilize the electrical equivalent circuit, which is primarily based on a light generated current source connected in parallel to a p-n junction diode. Many models have been proposed for the simulation of a solar cell or for a complete photovoltaic (PV) system at various solar intensities and temperature conditions [1-4].

The key factor that affects the results of the simulation and accuracy in representing the nonlinear characteristics of the PV system is modeling [5]. There are different kinds of parametric models presented in various literatures in the past few decades, like single-diode model, two-diode model, three diode models, model with partial shading considerations and much more. The most commonly used models are single diode and two diode model, as they provide better relations with a practical solar cell keeping in mind the simplicity in implementation and the

iteration speed in the extracting parameters as well as I-V and P-V curves also gives minimum error with respect to characteristics of solar PV cell as per manufacturer`s datasheet.

In this paper a single diode also known as a five parameter model and a two diode model has been realized by formulating a flowchart with the help of schotkey equations, have been programmed in matlab using Newton-Raphson iteration method. In next section, different electrical equivalent circuits are discussed with their merits and demerits. In section III, the equaions necessary for calculating solar output current has been shown with flowchart. In section IV, both single diode and two diode models are implemented using matlab and respective curves are plotted. Then in section V, results are discussed and then conclusion.

I_{ph}	Photocurrent (A)
I_o	Diode saturation current (A)
q	Electron charge, 1.6021×10^{-19} C
k	Boltzmann constant, 1.3865×10^{-23} J/K
T	Operating Temperature (Kelvin)
n	Diode factor ($1 \leq n \leq 2$)
G	Irradiance (W/m^2)
R_s	Series resistance (Ω)
R_p	Shunt resistance (Ω)
n_s	Number of cells in series
V_{oc}	Open circuit voltage
I_{sc}	Short circuit current
V_{mp}	Voltage at the maximal power point
I_{mp}	Current at the maximal power point
I_d	Current through the diode
I	PV module current (A)
V	PV module voltage (V)
E_g	Silicon gap energy of semiconductor
v_T	Thermal voltage equivalent (V)
STC	Standard temperature condition

2. ELECTRICAL EQUIVALENT CIRCUITS

2.1. Ideal Single Diode Model

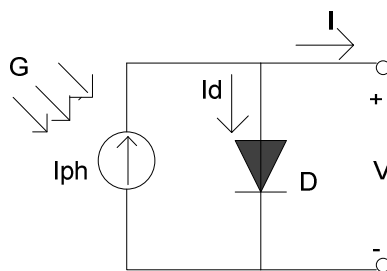


Figure 1. Ideal single diode model

This one is the most simplified form of an ideal PV cell through which the output voltage and current relations comes out to be,

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

$$I_d = I_o \left(e^{\frac{V}{n_s v_T}} - 1 \right) \quad (2)$$

$$v_T = \frac{nkT}{q} \quad (3)$$

But this model doesn't give accurate I-V and P-V curve characteristics.

2.2. Practical Single Diode Model

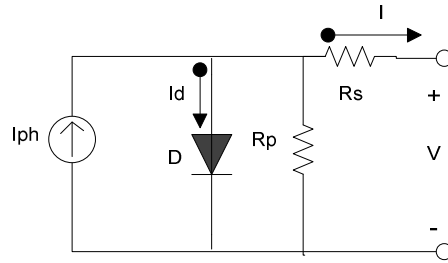


Figure 2. Practical single diode model

This one is an equivalent circuit of a practical PV cell. In many literatures it is also termed as a five parameter model (I_o, n, R_s, R_p, I_{ph}). It takes into account different properties of solar cell as:

- R_s is introduced as to consider the voltage drops and internal losses in due to flow of current.
- R_p takes into account the leakage current to the ground when diode is in reverse biased.
- But this model has neglected recombination effect of diode, which is why it is still not the most accurate model.

$$I = I_{ph} - I_o \left(e^{\frac{V+IR_s}{n_s v_T}} - 1 \right) - \frac{V+IR_s}{R_p} \quad (4)$$

2.3. Two Diode Model

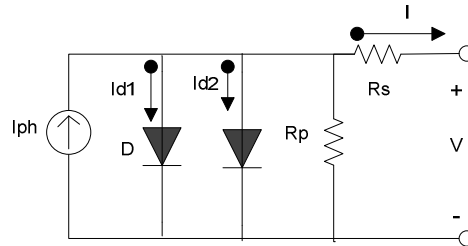


Figure 3. Two diode model

This is the modified form of single diode circuit which takes into account the effect of recombination by introducing another diode in parallel.

$$I = I_{ph} - I_{o1} \left(e^{\frac{V+IR_s}{n_{s1}v_T}} - 1 \right) - I_{o2} \left(e^{\frac{V+IR_s}{n_{s2}v_T}} - 1 \right) - \frac{V+IR_s}{R_p} \quad (5)$$

But now there will be two unknown diode quality factors. Hence no. of equations and unknown parameters increases to two thereby making calculations little bit more complex.

At lower values of irradiance and low temperatures, two diode model gives much more accurate curve characteristics as compared to single diode model.

So taking all aspects into consideration, as far as mathematical computation and number of iterations are concerned, single diode model turns out to be fast results due to less complex equation and also computational errors are less unlike in case of two-diode model. But two diode model gives more sharp and accurate characteristics under varying weather conditions with longer iterations and parameter calculations.

3. MATHEMATICAL EQUATIONS FOR PLOTTING I-V AND P-V CURVES

As current through R_p is very less compared to other currents, value of R_p has been assumed to be negligible for sake of simplicity in calculation.

Now, photocurrent and reverse saturation current are temperature dependent parameters as,

$$I_{ph} = (I_{ph})_{T_1} + K_o(T - T_1) \quad (6)$$

Where, T_1 is a normal standard temperature.

$$(I_{ph})_{T_1} = (I_{sc})_{T_1} \frac{G}{G_{STC}} \quad (7)$$

$$K_o = \frac{(I_{sc})_{T_2} - (I_{sc})_{T_1}}{T_2 - T_1} \quad (8)$$

The cell photocurrent is directly proportional to irradiance. Although cell performance does not degrade significantly but PV cell efficiency depends on incident solar energy.

$$I_o = (I_o)_{T_1} \times \left(\frac{T}{T_1} \right)^{3/n} \times e^{\frac{q(E_g)T_1}{nk} \left(\frac{1}{T} - \frac{1}{T_1} \right)} \quad (9)$$

$$(I_o)_{T_1} = \frac{(I_{sc})_{T_1}}{\left(e^{\frac{q(V_{oc})_{T_1}}{nkT_1}} - 1 \right)} \quad (10)$$

In case of two diode model, both diodes have different diode quality factors (n_1 & n_2) hence, different reverse saturation currents as I_{o1} & I_{o2} .

The value of series resistance can be estimated by,

$$R_s = - \left(\frac{dV}{dI} \right)_{V_{oc}} - \frac{1}{x_v} \quad (11)$$

$$X_v = (I_o)_{T_1} \frac{q}{nkT_1} e^{\frac{q(V_{oc})_{T_1}}{nkT_1}} - \frac{1}{X_v} \quad (12)$$

The flowchart for estimation of cell current with irradiance, temperature and cell voltage as input parameters is as shown in Fig. 4. The cell voltage must be a row vector whose range should cover all possible values PV cell is able to produce under specified conditions from manufacturers.

The ratio of the maximum power that can be delivered to the load and the product of I_{sc} , V_{oc} is termed as fill factor. It is a measure of the real I-V characteristics. For value of 0.7 or higher are considered as good cells. FF increases with decrease in temperature.

$$FF = \frac{P_{max}}{V_{oc}I_{sc}} = \frac{V_{mp}I_{mp}}{V_{oc}I_{sc}} \quad (13)$$

From I-V characteristics of PV cell, at extreme points, from (4), it changes to,

At open circuit condition,

$$0 = I_{ph} - I_o \left(e^{\frac{V_{oc} + I_{sc}R_s}{n_s v_T}} - 1 \right) - \frac{V_{oc} + I_{sc}R_s}{R_p} \quad (14)$$

At short circuit condition,

$$I_{sc} = I_{ph} - I_o \left(e^{\frac{I_{sc}R_s}{n_s v_T}} - 1 \right) - \frac{I_{sc}R_s}{R_p} \quad (15)$$

At maximum power point condition,

$$I_{mp} = I_{ph} - I_o \left(e^{\frac{V_{mp} + I_{mp}R_s}{n_s v_T}} - 1 \right) - \frac{V_{mp} + I_{mp}R_s}{R_p} \quad (16)$$

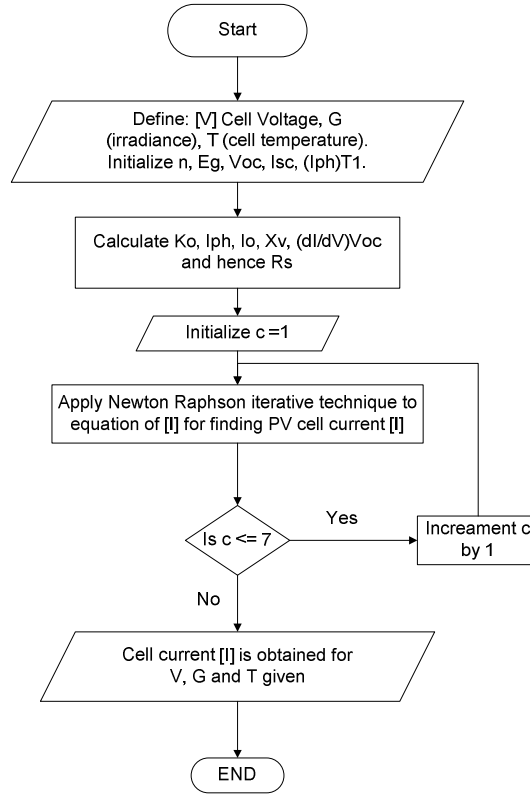


Figure 4. Flowchart for cell current calculation

4. MODELING OF THE PV MODULE

The Specifications of BP Solarex MSX-120 polycrystalline PV module is chosen for modeling. It provides 120 Watt of nominal maximum power and consists of 36 series connected Cr-Si type PV cells. Its specifications are shown in Table 1. By using matlab program the PV module was implemented using flowchart for both single diode and two diode equivalent circuit models. For simplicity, R_p has been considered as infinite.

Table 1.

Electrical Parameters	BP MSX-120W
Voltage Configurations	12 or 24 V
Nominal power rating (P_m)	120 W
V_{mp}	17.1 V
I_{mp}	7.0 A
I_{sc}	7.6 A
V_{oc}	21.3 V
Number of cells in series	36
Weight	14.0 Kg

The necessary parameters are evaluated and assumptions have been made during execution of equations listed in previous section. This program takes irradiance, cell temperature and PV module voltage as inputs and with the help of equations it returns output current value of PV module for all values of voltage vector so applied in the program.

5. RESULTS AND DISCUSSIONS

The plots of I-V characteristic curves have been produced by varying certain parameters one at a time keeping other parameters constant at STC. In matlab script file, flowchart specified in this paper is implemented.

Fig. 5.a and Fig. 5.b describes I-V characteristics of single diode and two diode model for varying solar irradiance value G (at STC is $1000\text{W}/\text{m}^2$) respectively. On observing the curve we see that with increase in irradiance values cell current value also increases proportionally but cell voltage increases very less. On observing both curves closely we see that I-V curve of two diode model Fig. 5.b is more steeper as compared to single diode Fig. 5.a.

Fig. 6.a and Fig. 6.b describes I-V characteristics of single diode and two diode model for varying temperature T respectively. It is observed that as temperature increases cell current also increases slightly and cell voltage shows significant decrease in its value. Here on observation we see that slope of two diode model I-V curve Fig. 6.b is more when compared with single diode curve Fig. 6.a.

Fig. 7.a and Fig. 7.b describes P-V characteristics of single diode and two diode model for varying solar irradiance value G respectively. We can locate its peak i.e. maximum power point with respective voltages for varying irradiance and temperature respectively. And it is being observed that as irradiance increases output power also increases and reaches nominal power point at STC. Also, with increase in temperature, output power decreases. On observing P-V characteristics for both single diode and two diode models we figure out that maximum power occurs at slightly higher values of output voltage in case of single diode P-V curve Fig. 7.a with little bit higher maximum power as compared to two diode P-V curve Fig. 7.b. And when temperature is varied for P-V characteristics Fig. 8.a and 8.b we find out that in case of two diode curve Fig. 8.b maximum power is more and it occurs at slightly higher value of output voltage as compared to single diode curve Fig. 8.a.

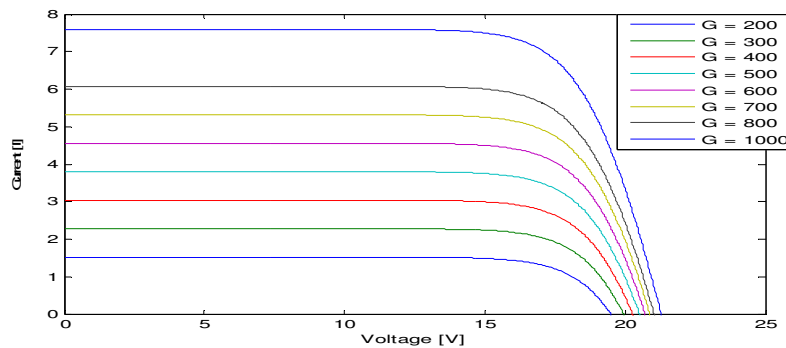


Figure 5.a I-V characteristics of single diode for varying irradiance $G(\text{W}/\text{m}^2)$

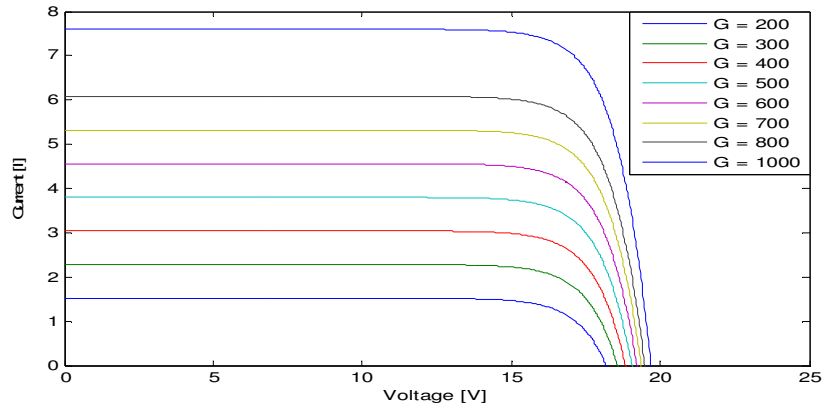


Figure 5.b I-V characteristics of two diode for varying Irradiance G (W/m²)

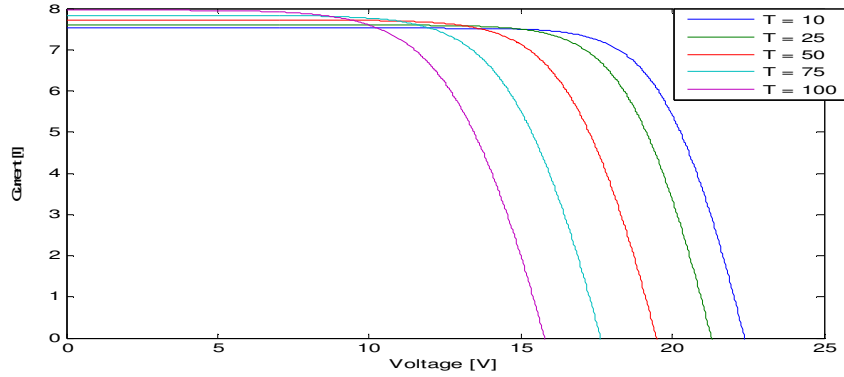


Figure 6.a. I-V characteristics of single diode for varying temperature T (C)

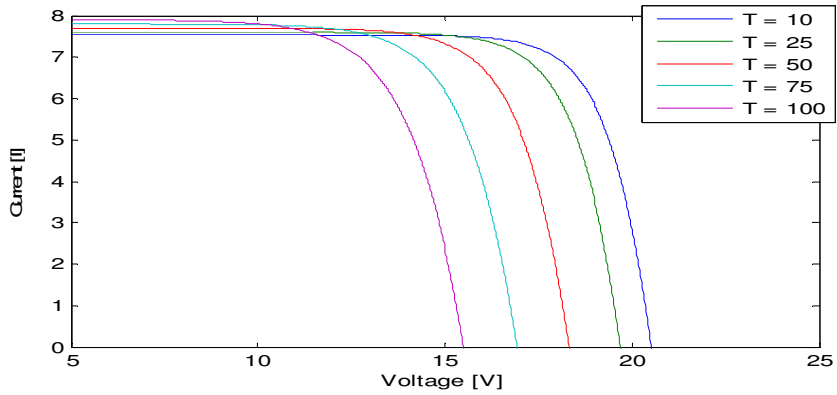


Figure 6.b.I-V characteristics of two diode for varying temperature T (C)

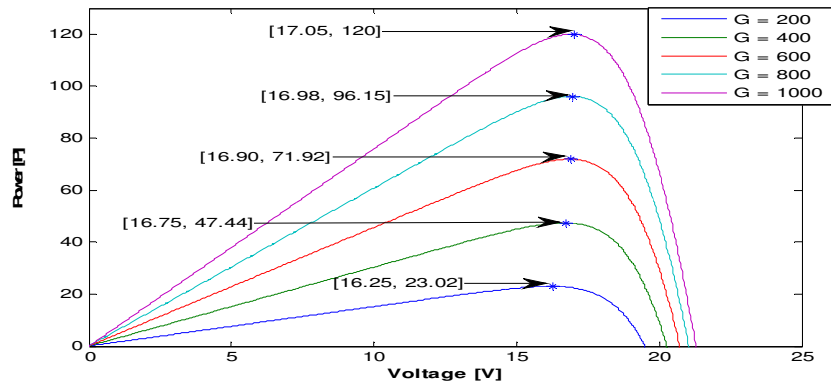


Figure 7.a P-V characteristics of single diode for varying irradiance $G(\text{W}/\text{m}^2)$

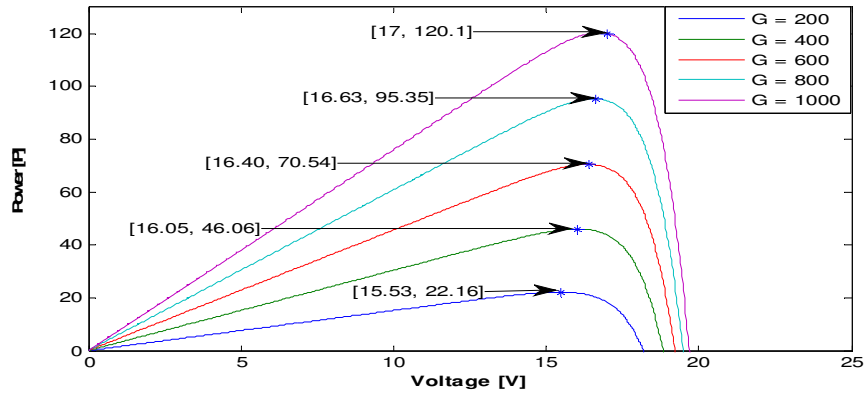


Figure 7.b P-V characteristics of two diode for varying irradiance $G(\text{W}/\text{m}^2)$

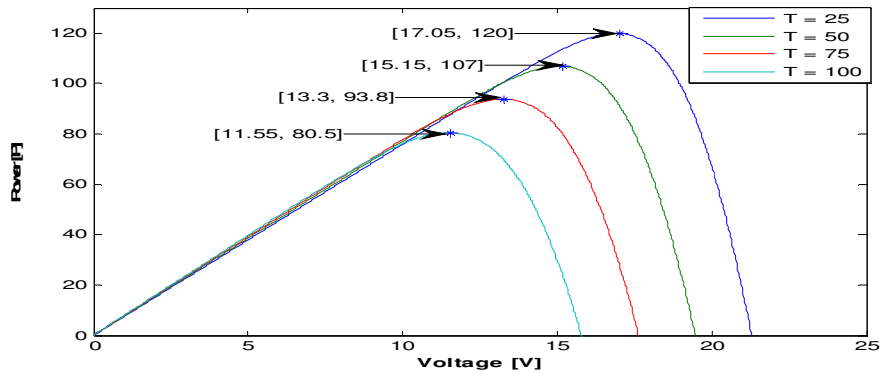


Figure 8.a P-V characteristics of single diode for varying temperature $T(\text{C})$

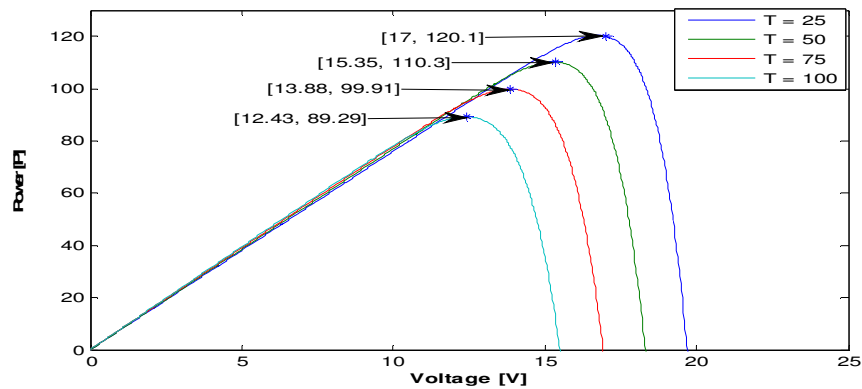


Figure 8. P-V characteristics of two diode for varying temperature T (C)

5. CONCLUSIONS

The main objective of this paper was to show the difference in I-V and P-V characteristics of single diode and two diode equivalent circuits, which were produced after implementation of these models in matlab through programming using a flowchart formulated as shown in Fig. 4. BP Solarex MSX-120 polycrystalline PV module datasheet has been used for verification of matlab program. Hence, after observing all characteristic curves by varying solar irradiance G and temperature T and plotting I-V and P-V curves, it can be concluded that two diode model gives more precise characteristics close to practical photovoltaic solar cell as compared to single diode model characteristics. But in two diode model implementation we face more complex equation and two more unknown parameters, also number of iterations increases accordingly in forming solar cell characteristics. So, choosing an electrical equivalent model between these two can be based on area in which we would like to realise for study of solar cell characteristics. Like for power system planning purpose, single diode model is better as it will save time. While for study of solar cell characteristics at critical points two diode is more preferable.

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