

SINGLE-DIODE PV CELL MODELING AND STUDY OF CHARACTERISTICS OF SINGLE AND TWO-DIODE EQUIVALENT CIRCUIT

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ABSTRACT

This paper presents characteristics of ideal single diode, practical single diode and two diode equivalent circuit models 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 cell current using Newton-Raphson iterative technique which is then programmed in MATLAB script file. A typical 120W polycrystalline solar module specifications have been used for model evaluation. The characteristic curves were obtained with the use of manufacturer's datasheet which shows the precise correspondence to the model.

KEYWORDS

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

1. INTRODUCTION

A large portion of energy is mainly extracted from the coal which is a limited source. Hence some alternate source of energy is required to compensate shortage of energy. A technology that directly converts free solar energy into electrical energy without causing any pollution to the environment is termed as photovoltaic power generation.

For the prediction of the behavior of a real solar cell under various environmental conditions and further to obtain its current-voltage (I-V) and power-voltage (P-V) characteristic curves, modeling of solar cell is necessarily required. 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 single solar cell or for a complete photovoltaic (PV) system at various solar intensities and temperature conditions [1-4].

Hence, modeling of solar cell is necessary for understanding its behavior under various atmospheric conditions. The key factor that affects the accuracy of the simulation and accurate representation of 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

and the speed in the extraction of parameters as well as I-V and P-V curves also gives minimum error with respect to characteristics of solar PV cell.

Now, there are various kinds of single diode models described in previous literatures in past decades. They have been briefly discussed with its properties and limitations in the succeeding segment.

With the help of datasheet given by manufacturers indicating specifications of solar cell module and from set of non-linear equations, various unknown parameters necessary for modeling are estimated and respective characteristics have been produced.

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

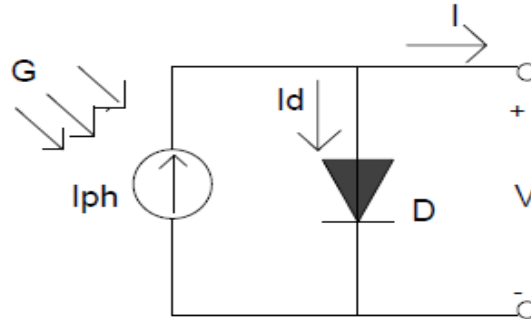


Figure 1. Ideal single diode model

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

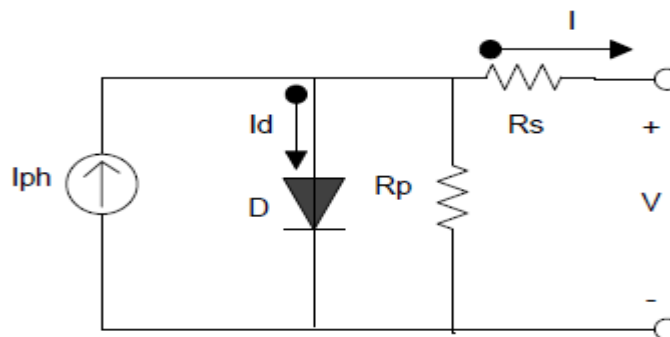


Figure 2. Practical single diode model

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

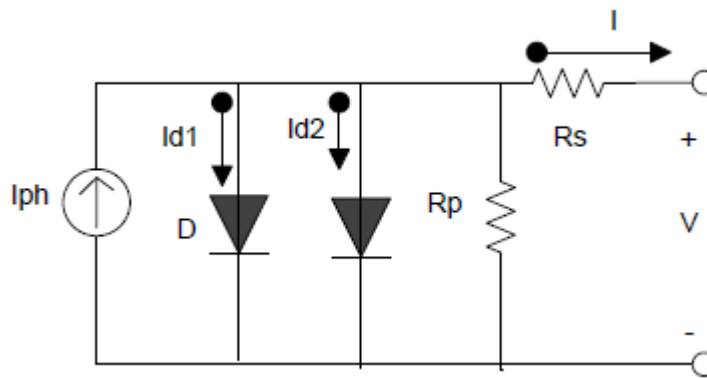


Figure 3. Two diode model

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 increases thereby making calculations 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. The single diode model can be suitably used for power system planning purposes.

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.

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

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

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 an array 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,

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

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,

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

By using above equations solar PV cell characteristics can be produced.

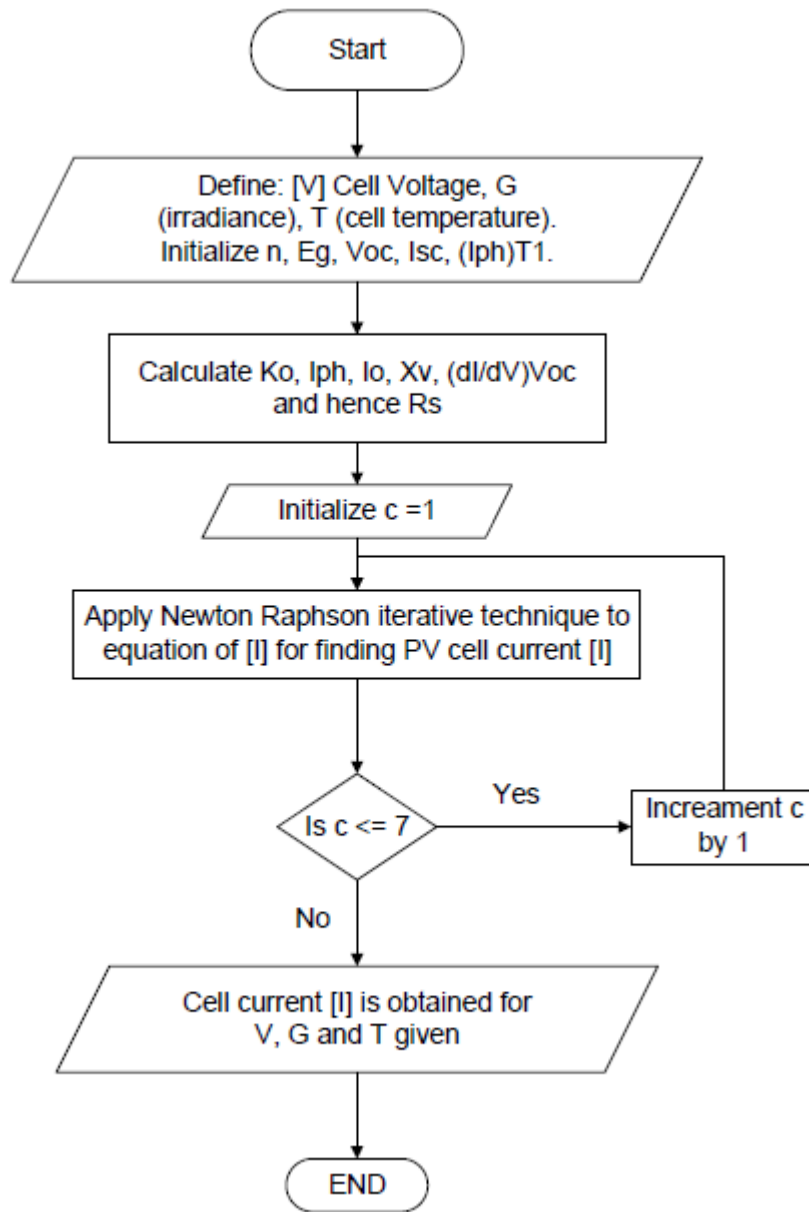


Figure 4. Flowchart for cell current calculation

4. MODELING OF THE PV MODULE

The BP Solarex MSX-120 polycrystalline PV module was 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.

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.

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 from flowchart implemented in MATLAB script file. Fig. 5 describes I-V characteristic for varying solar irradiance value G (at STC 1000 W/m^2). On observing the curve we see that with increase in irradiance values cell current value also increases proportionally but cell voltage increases very less. Fig. 6 describes I-V characteristics for varying temperature T . It is observed that as temperature increases cell current also increases slightly and cell voltage shows significant decrease in its value. Likewise in Fig. 7 and Fig. 8 diode quality factor and series resistance is varied respectively. The reverse saturation current is temperature dependent parameter and also depends on quality factor of diode. There are two more plots in Fig. 9 and Fig. 10 are showing P-V characteristics of solar cell through which 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.

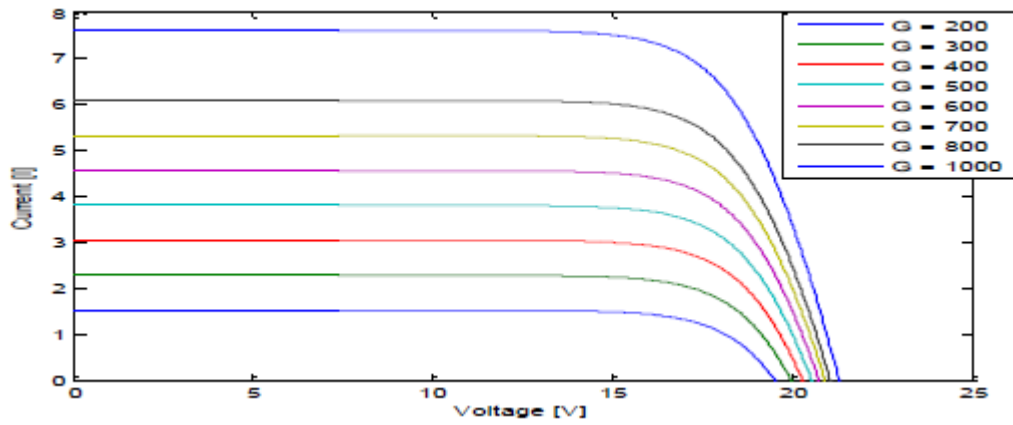


Figure 5. I-V characteristics for varying irradiance G (W/m²)

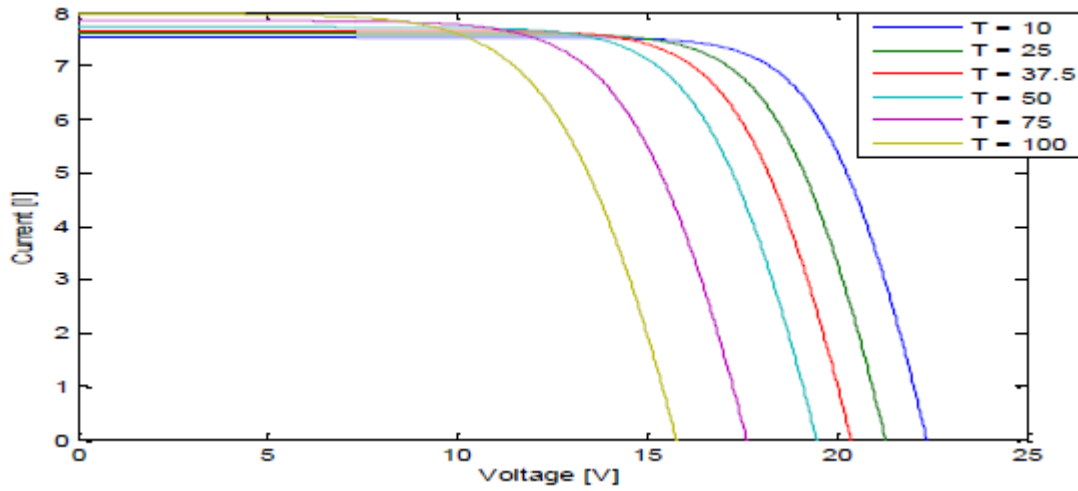


Figure 6. I-V characteristics for varying temperature T(Celsius)

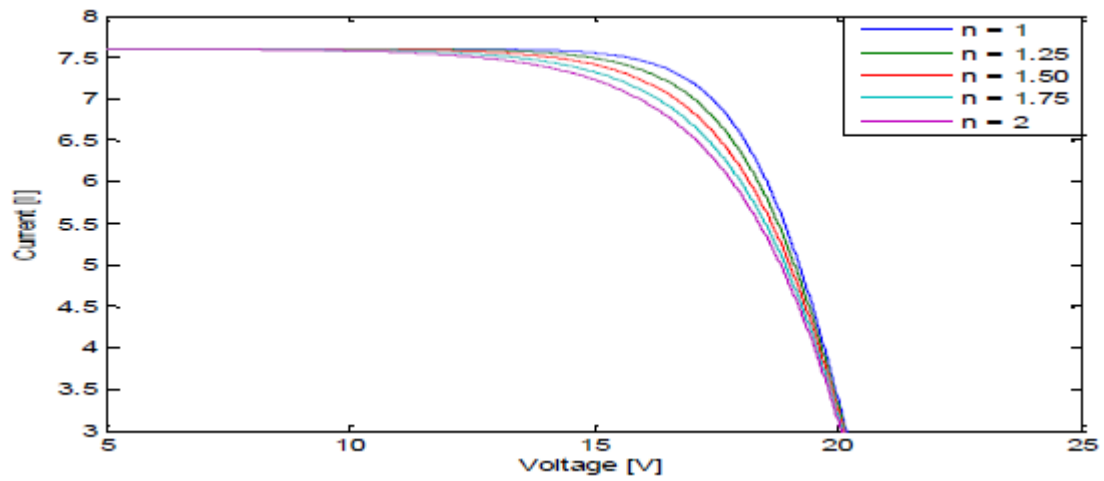


Figure 7. I-V characteristics for varying diode quality factor n

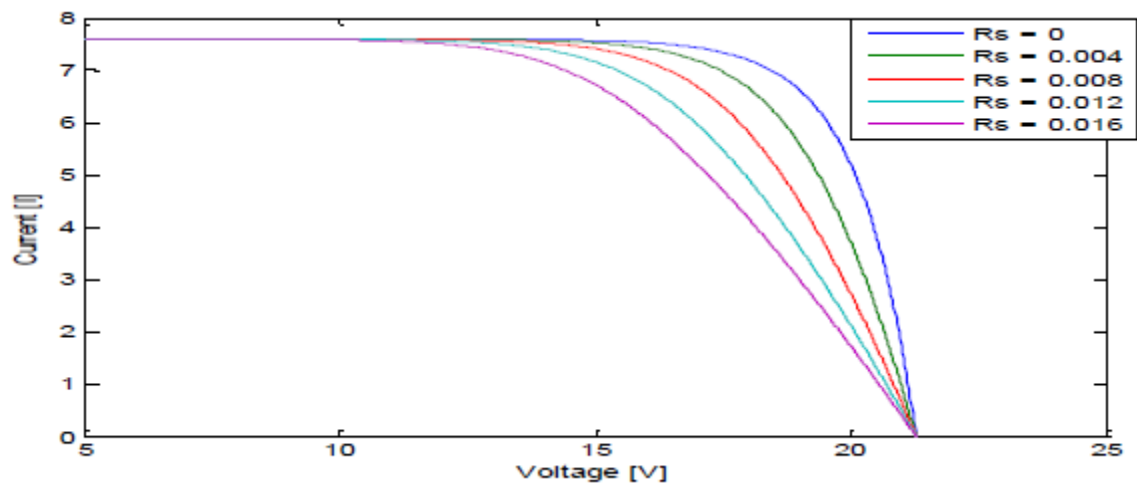


Figure 8. I-V characteristics for varying series resistance R_s (ohms)

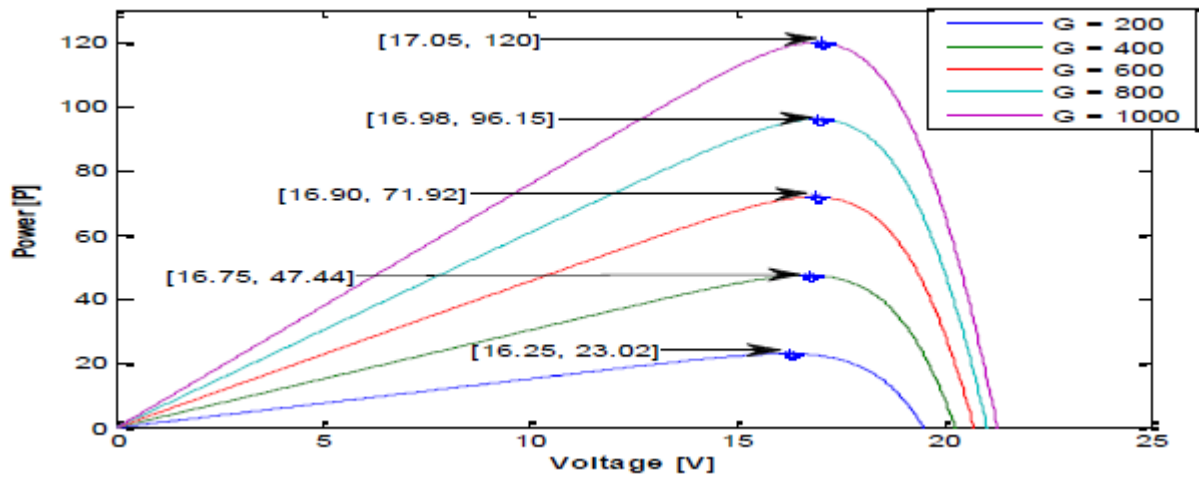


Figure 9. P-V characteristics for varying irradiance $G(W/m^2)$

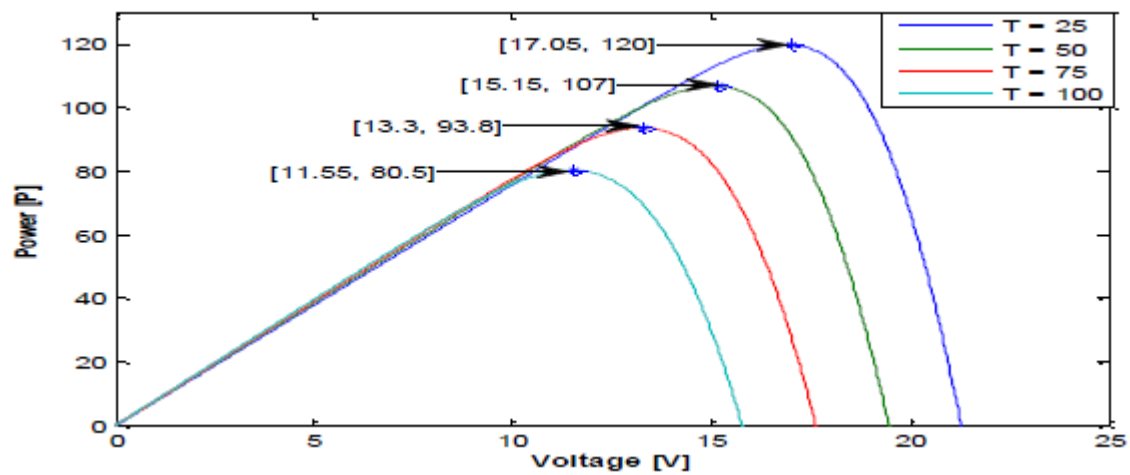


Figure 10. P-V characteristics for varying temperature $T(\text{celcius})$

5. CONCLUSIONS

The single diode model gives much acceptable results in various conditions within less iteration as demonstrated using a flowchart in Matlab for a typical BP solarex MSX-120W solar panel. For a given solar insolation and temperature, the program estimates the current for a given set of voltages. The results from the Matlab model shows excellent correspondence to manufacturer's data from datasheet. This model so developed was used to show effect in I-V characteristics of temperature, insolation, resistance, ideality factor and series resistances. The main objective of this paper was to show that single diode modeling is the most suitable model which can be used for simulating electrical behavior of PV module system for planning purposes in the field of power system.

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