

A Simplified Matlab Based Simulation Of PV Module With Effect Of Temperature And Irradiation

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Abstract— This paper presents Matlab script based simulation model for a PV cell in order to allow estimate the electrical behavior of the cell with respect changes on environmental conditions of temperature and irradiance. An accurate PV module electrical model is presented based on the Shockley diode equation. The general model was implemented using Matlab script, and effect of irradiance and temperature as variable parameters and effect on outputs the I-V characteristic is studied. A particular typical 180W solar panel was used for model evaluation, and results was compare with points taken directly from the manufacturer’s published curves and show good correspondence to the model.

Index Terms— Photovoltaic, photocurrent, photovoltaic module, insolation.

I. INTRODUCTION

Nonconventional energy resources will be an increasingly important part of power generation in present case. Regardless of the intermittency of sunlight, solar energy is widely available and completely free of cost. Recently, photovoltaic array system is likely recognized and widely utilized as important source in electric power applications [1]. Besides assisting in the reduction of the emission of greenhouse gases, they add the much-needed flexibility to the energy resource mix by decreasing the dependence on fossil fuels. Photovoltaic (PV) systems produce DC electricity when sunlight shines on the PV array, without any emissions. The DC power is converted to AC power with an inverter and can be used to power local loads or fed back to the utility.

The PV application can be grouped depending the scheme of interaction with utility grid, grid connected, stand alone, and hybrid. PV systems consist of a PV generator (cell, module, array), energy storage devices (such as batteries), AC and DC consumers and elements for power conditioning. This paper is about a model for modeling and simulation of PV module based on Shockley diode equation.

II. IPV GENERATOR

Solar cell is basically a p-n junction fabricated in a thin wafer or layer of semiconductor. The electromagnetic radiation of solar energy can be directly converted electricity through photovoltaic effect. Being exposed to the sunlight, photons with energy greater than the band-gap energy of the semiconductor are absorbed and create some electron-hole pairs proportional to the incident irradiation. Under the

influence of the internal electric fields of the p-n junction, these carriers are swept apart and create a photocurrent which is directly proportional to solar insolation. PV system naturally exhibits a nonlinear I-V and P-V characteristics which vary with the radiant intensity and cell temperature.

III. MODELLING OF SOLAR CELL

Simple circuit having current source and parallel diode is used for modeling. The shunt resistance R_{sh} is neglected. A single shunt diode was used with the diode quality factor set to achieve the best curve match[2]. This model is a simplified version of the two diode model. The circuit diagram for the solar cell is shown in Figure 1.

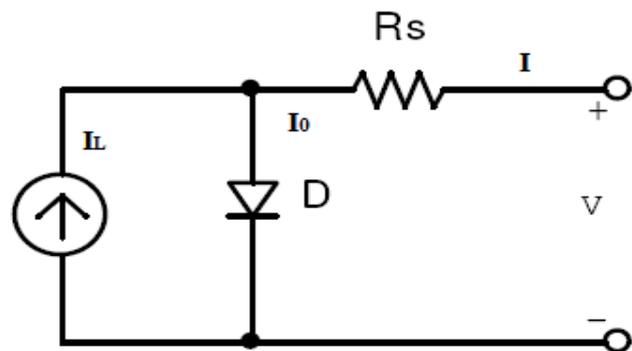


Fig.1 Circuit diagram of a PV cell model

- Shunt resistance R_{sh} , in parallel with the diode, this corresponds to the leakage current to the ground and it is neglected

$$I = I_L - I_0 \left(e^{\frac{q(V+IR_s)}{nkT}} - 1 \right) \quad (1)$$

(1)

I_0 =Diode saturation current,

I_L =Photocurrent

R_s =Series resistance

n = diode quality factor

Considering importance effect of temp and solar radiation can be introduced to the model by adding in turn

- Temperature dependence of the diode saturation current I_0 .
- Temperature dependence of the photo current I_L .
- Series resistance R_s , which gives a more accurate shape between the maximum power point and the open circuit voltage. This represents the internal losses due to the current flow

The model included temperature dependence of the photocurrent I_L and the saturation current of the diode I_0 [3].

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$$I_L = I_L(T_1) + K_0(T - T_1) \quad (2)$$

$$I_L(T_1) = I_{SC}(T_{1,nom}) \frac{G}{G(nom)} \quad (3)$$

$$K_0 = \frac{I_{SC}(T_2) - I_{SC}(T_1)}{(T_2 - T_1)} \quad (4)$$

$$I_0 = I_0(T_1) \times \left(\frac{T}{T_1}\right)^{\frac{3}{n}} e^{-\frac{qV_q(T_1)}{nk\left(\frac{1}{T} - \frac{1}{T_1}\right)}} \quad (5)$$

$$I_0(T_1) = \frac{I_{SC}(T_1)}{\left(e^{\frac{qV_{oc}(T_1)}{nkT_1}} - 1\right)} \quad (6)$$

A series resistance R_s was included; which represents the resistance inside each cell in the connection between cells.

$$R_s = -\frac{dV}{dV_{oc}} - \frac{1}{X_v} \quad (7)$$

$$X_v = I_0(T_1) \frac{q}{nkT} e^{\frac{qV_{oc}(T_1)}{nkT_1}} - \frac{1}{X_v} \quad (8)$$

IV. I-V AND P-V CHARACTERISTICS OF SOLAR MODULE

A typical I-V characteristic of the solar cell for certain ambient irradiation G and a certain fixed cell temperature T_{ac} is obtained using script fig.2. For a resistive load, the load characteristic is a straight line with slope $I/V=1/R$. It should be pointed out that the power delivered to the load depends on the value of the resistance only.

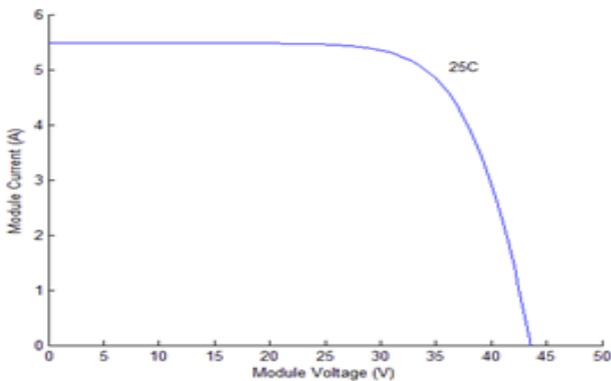


Fig.2 A typical current-voltage characteristics of PV module

Maximum power point is the operating point $A(P_{max}, I_{max})$ in Fig 3, at which the power dissipated in the resistive load is maximum: $P_{max} = V_{max} I_{max}$

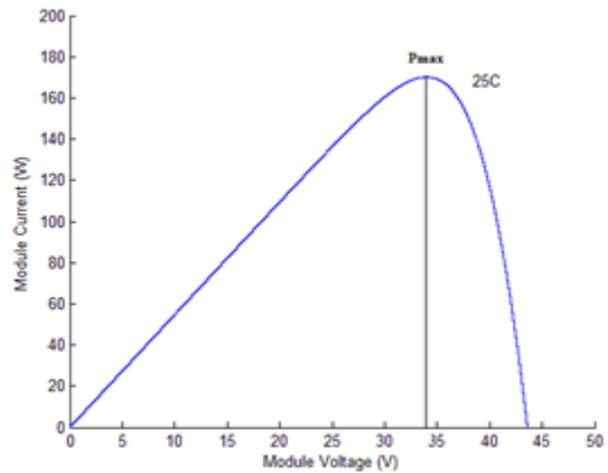


Fig.3 P-V Characteristics of PV module at 25°C

Fill factor is the ratio of the maximum power that can be delivered to the load and the product of I_{sc} and V_{oc} :

$$FF = \frac{P_{max}}{V_{oc} I_{sc}} = \frac{I_{max} V_{max}}{V_{oc} I_{sc}} \quad (9)$$

The fill factor is a measure of the real $I-V$ characteristic. Its value is higher than 0.7 for good cells. The fill factor diminishes as the cell temperature is increased. The open circuit voltage increases logarithmically with the ambient irradiation, while the short circuit current is a linear function of the ambient irradiation. The dominant effect with increasing cell's temperature is the linear decrease of the open circuit voltage, the cell being thus less efficient. The short circuit current slightly increases with the cell temperature.

V. EFFECT OF TEMPERATURE AND IRRADIATION ON OUTPUT OF PV MODULE

The influence of the ambient irradiation G and the cell temperature T_{ac} on the cell characteristics, can be obtained from the model equations. The PV cell photocurrent $I_L(A)$ is directly proportional to solar irradiance $G(W/m^2)$. When the solar cell is short circuited, negligible current flows in diode. Hence the proportionally constant in (3) is set to the rated short circuit current I_{SC} at is delivered under rated irradiation. Solar intensities are commonly normalized with respect to full solar radiation at sea level with average humidity and aerosol particulate concentration (1 Sun = 1000Watt/m²). Though somewhat contrary to intuition, PV cell performance does not degrade significantly between full sun and cloudy conditions. The power output decreases linearly with incident solar energy, but efficiency is nearly flat over the region of concern. The relationship between the photo-current and temperature is linear (eqn. 2) and is deduced by noting the change of photo-current with the change of temperature (eqn.4). When the cell is not illuminated, the relationship between the cell's terminal voltage and current is given by the Shockley equation. When the cell is open circuited and illuminated, the photo-current flows entirely in the diode. The I-V curve is offset from the origin by the photo generated current I_L (eqn. 1). The value of the saturation current I_0 at 25°C is calculated using the open circuit voltage and short circuit current at this temperature (eqn. 6). An estimate must be made of the unknown "ideality factor". The value of n is between 1 and 2,

being near one at high currents, rising towards two at low currents. A value of 1.3 is considered as typical in normal operation, and may be used initially, until a more accurate value is estimated later through curve fitting. The relationship of I_0 to temperature is complex, but fortunately contains no variables requiring evaluation (eqn.5). The series resistance of the panel has a large impact on the slope of the I-V curve at $V = V_{OC}$. [4]

The TP180 PV module was chosen for modeling, due to its well-suited to traditional applications of photovoltaic's. The TP180 module provides 180 watt of nominal maximum power, and has 72 series connected polycrystalline silicon cells. The key specifications are shown in Table 1. The model of the PV module was implemented using a Matlab program. The model parameters are evaluated during execution using the equations listed on the previous section. The program calculates the current I , using typical electrical parameters of the module (I_{SC} , V_{OC}), and the variables Voltage, Irradiation (G), and Temperature (TaC). The TP180, a typical 180W PV module, was chosen for modeling. The module has 72 series connected polycrystalline cells. The key specifications are shown in table 1 [5].

TABLE 1
TYPICAL ELECTRICAL PARAMETERS OF TP180 AT STP

Power Output $P_{MAX}(W)$	180
Power tolerance $P_{MAX}(W)$	[-0&+5]
Module efficiency $\eta(\%)$	14.4
Voltage at $P_{MAX}(V)$	35.8
Current at $P_{MAX}(A)$	5.03
Open circuit voltage $V_{OC}(V)$	43.6
Short circuit current $I_{SC}(A)$	5.48

The model was evaluated using Matlab. The model parameters are evaluated during execution using the equations listed in the previous section using the above data points contained in the script. The current I_a is then evaluated using these parameters, and the variables Voltage, Irradiation, and Temperature. If one of the input variables is a vector, the output variable (current) is also a vector. The inclusion of a series resistance in the model makes the solution for current a recurrent equation (refer to eqn. 1). A simple iterative technique initially tried only converged for positive currents. The Newton Raphson method used converges much more rapidly, and for both positive and negative currents. A listing of the Matlab script which implements the equations shown is given in Figure 4.

```
function I = TP_180(Va,G,TaC)
% Define constants
k = 1.381e-23; % Boltzmann's constant
q = 1.602e-19; % Electron charge
% curve fitting of I-V character (Use data for 1000W/m^2)
n = 1.62; % Diode ideality factor (n),
Eg = 1.12; % Band gap energy;
Ns = 72; % Series connected cells (TP180, 72 cells)
```

```
TrK = 298; % Reference temperature (25C) in Kelvin
Voc_TrK = 43.6/Ns; % Voc (open circuit voltage per cell) @
temp TrK
Isc_TrK = 5.48; % Isc (short circuit current per cell) @ temp
TrK
a = 0.65e-3; % Temperature coefficient of Isc (0.065%/C)
% Define variables
TaK = 273 + TaC; % Module temperature in Kelvin
Vc = Va / Ns; % Cell voltage
% Calculate short-circuit current for TaK
Isc = Isc_TrK * (1 + (a * (TaK - TrK)));
% Calculate photon generated current @ given irradiance
IL = G * Isc;
% Define thermal potential (Vt) at temp TrK
Vt_TrK = n * k * TrK / q;
% Define b = Eg * q/(n*k);
b = Eg * q / (n * k);
% Calculate reverse saturation current for given temperature
Ir_TrK = Isc_TrK / (exp(Voc_TrK / Vt_TrK) - 1);
Ir = Ir_TrK * (TaK / TrK)^(3/n) * exp(-b * (1 / TaK - 1 /
TrK));
% Calculate series resistance per cell (Rs = 5.1mOhm)
dVdI_Voc = -1.0/Ns; % Take dV/dI @ Voc from I-V curve of
datasheet
Xv = Ir_TrK / Vt_TrK * exp(Voc_TrK / Vt_TrK);
Rs = - dVdI_Voc - 1/Xv;
% Define thermal potential (Vt) at temp Ta
Vt-Ta = n * k * TaK / q;
% I = IL - Ir * (exp((Vc + I * Rs) / Vt-Ta) - 1)
% f(I) = IL - I - Ir * (exp((Vc + I * Rs) / Vt-Ta) - 1) = 0
% Solve for Ia by Newton's method: I2 = I1 - f(I1)/f'(I1)
Ia=zeros(size(Vc)); % Initialize I with zeros
% Perform 5 iterations
for j=1:5;
I = I - (IL - I - Ir .* (exp((Vc + I .* Rs) ./ Vt-Ta) - 1))...
./ (-1 - Ir .* (Rs ./ Vt-Ta) .* exp((Vc + I .* Rs) ./ Vt-Ta));
end
```

Fig. 4 Matlab scrip file for the PV module model

VI. RESULTS OF MATLAB™ PV MODULE MODEL

The output of the Matlab function is shown first for various temperatures (Fig.5) and then for various irradiation levels (Fig.6). These are points taken directly from the manufacturer's published curves, and show good correspondence to the model [6].

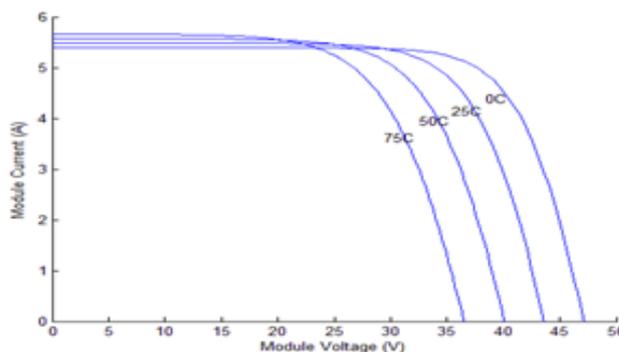


Fig.5 Effect of temperature in output of PV module

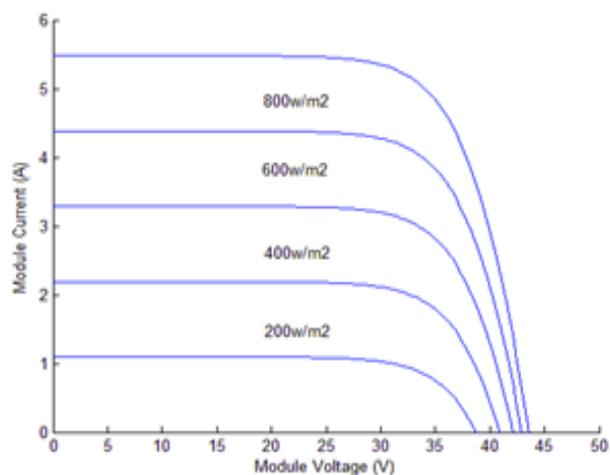


Fig.6 Effect of solar isolation on PV module

VII. CONCLUSIONS

In the present work a Matlab script file for simulation of the operation of a photovoltaic system. Software includes the models of the solar panel. A generalized PV model which is representative of the all PV cell, module, and array has been developed with Matlab script file and been verified with a PV cell and a commercial module. The proposed model takes sunlight irradiance and cell temperature as input parameters and outputs the I-V and P-V characteristics under various conditions. Such a generalized PV model is easy to be used for the implementation on Matlab/Simulink modeling and simulation platform. Especially, in the context of the Simulink tool, there is now a generalized PV model which can be used for the model and analysis in the field of solar PV power conversion system.

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