MODELING AND SIMULATION OF A PV MODULE BASED POWER USING MATLAB

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Abstract— This paper describes how a simple one-diode model was used to develop a mathematical model and how simulation is carried out on the developed model to estimate the electrical characteristic and the power output of a photovoltaic (PV) panel and predict how the current- voltage (I-V) characteristic changes with environmental parameters such as temperature and irradiance. This work also shows the I-V characteristic at a constant temperature and different irradiation and I-V characteristics at a constant irradiation and different temperature. The simulation result at different levels of temperature and irradiation is used in estimating the maximum power output.

Index Terms - Photovoltaic, PV Model, Maximum Power Point, Simulation Model, MATLAB

1 Introduction

Electricity production by renewable energy sources is actually promoted in many countries worldwide and is considered a strategic objective for most of the developing countries. Many founding programmes also support projects that provide potential utilities with access to renewable energy solutions and increase familiarity with renewable energy technologies. For these reasons, it is mandatory to improve the know-how and skills in this field. Nowadays there are lots of concerns about photovoltaic systems because they can generate electricity onsite where it is needed, avoiding transport losses and complete reduction in CO2 emission [1]. Solar energy is a renewable energy resource and is converted to electrical energy in two ways thus using a photovoltaic material which generates an electrical potential when exposed to light or using a thermal process which uses the energy from the sun to heat a working fluid in an electricity generating cycle [2]. There are number of different types of solar panels, from an ever increasing range of manufacturers. Each manufacturer claims that they are best for one reason or another; with different sales people all giving different information [3]. Knowledge of the characteristic of a PV panel is a prerequisite for designing and dimensioning a PV power supply. This is the reason for the development of PV panel models useful for electrical generation and applications. This approach allows the development of new high-performances conversion systems balancing system-components and permitting the evaluation of the behavior of the entire system in various scenarios. Generally speaking, mathematical descriptions of the I-V characteristics of PV cells are available since many years and are derived from the physics of the p-n semiconductor junction. In the dark state, the I-V characteristic curve of this diode corresponds to the one of a normal p-n junction diode and it produces neither a voltage nor a current [4]. Illumination of the PV cell creates free charge carriers, which allow current to flow through a connected load. If the circuit is open the photocurrent is shunted internally by the p-n junction diode. PV devices (solar panels, inverters and loads) should be placed in a controlled-condition environment to test the performances of the whole system. Alternatively, it is possible to develop simulations based on models of the PV panel. After the model has been estimated in given experimental conditions, it can be used to predict the PV panel operation under different working conditions (i.e. surface temperature of the PV panel, irradiance and weather conditions).

2 Mathematical Modeling of a PV cell

Using a single silicon diode model, the PV cell may be represented in its simplest way as in Figure 2. The single diode model consists of a current source in parallel to a diode. The parameters required are short circuit current (Isc), open circuit voltage (Voc) and the diode ideality factor (A) which depends on the semiconductor material used. The ideality factor of a diode is a measure of how closely the diode follows the ideal diode equation. Series resistance Rs and parallel (shunt) Rsh that limit the performance of the cell are added to the model to take into account the dissipative phenomena at the cell internal losses.

From Figure 1, Rs: is series resistance mainly due to losses by Joule effect through grid collection and to the specific resistance of the semiconductor, as well as bad contact (semi conductor electrode).

Rsh: Parallel resistance, called shunt comes from the recombination losses mainly due to the thickness, the surface effects and the non-ideality of the junction. Now the values of Rs and Rsh modify shunt circuit current of the cell in photo generated Iph.

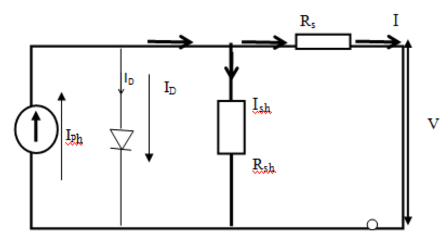

Figure 1: single diode model diagram

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Applying Kirchhoff law to the nodes of the circuit of Figure 1 it becomes:

$$I = I_{ph} - I_D - I_{sh} \text{ [5]} \qquad (3.1)$$

Where:
I= Load current
Ish= Shunt resistance current
ID= Diode current
IPh is the photo generated current. And Iph is given by (3.2)

$$I_{ph} = [I_{scr} + K_i (T - T_{ref})]\frac{G}{1000} \text{ [6]} \qquad (3.2)$$

Iscr is the short circuit current at (Standard Test Condition) STC
Ki is the shunt circuit current/temperature co-efficient of the cell
T and Tref are the working temperature of cell and reference temperature respectively in Kelvin.
G is the solar radiation on the cell surface (1000W/M2 is the nominal radiation).
For PV with n cells in series and m cells in parallel and n = m, ID is given by (3.3)

$$I_D = I_O\left(e^{\frac{qV}{AKT}} - 1\right) \text{ [7]} \qquad (3.3)$$

Where:
q = Electron charge 1.6x10-19C
K = Boltzmann's constant 1.386503x10-23J/K
T = Cell Temperature in Kelvin
Io = Reverse saturation current of the diode and is given as
A = Diode ideality constant (A= 2 for Si, 1 for Ge)
N = Number of PV cells in series.

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$$I_o = I_{rs}\left[\frac{T}{T_{ref}}\right]^3 \exp\left[\left(\frac{q\ E_{gap}}{AK}\right)\left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right] \qquad (3.4)$$

Irs is the Diode saturation current is given as

$$I_{rs} = \frac{I_{scr}}{\left[exp\left(\frac{qVoc}{KAT} - 1\right)\right]} \text{ [8]} \qquad (3.5)$$

Then the Ish is the current through the shunt resistance and using current division rule Ish becomes

$$I_{sh} = \frac{V_D}{R_{sh}} = \frac{V + I\,R_s}{R_{sh}} \qquad (3.6)$$

Substituting (3.3) and (3.6) into (3.1), then by approximation (3.1) becomes

$$I = I_{ph} - I_o\left(e^{\frac{q(V + IR_s)}{AnKT}} - 1\right) - \frac{V + IR_s}{R_{sh}} \qquad (3.7)$$

2.1. Assumption and Approximation

Using Single Silicon Diode Model, for n-cell PV with Rsh very large and Rs very small, Ish will tend to zero and therefore (3.7) can be rewritten as in (3.8).

$$I = I_{ph} - I_o\left(e^{\frac{qV}{2nKT}} - 1\right) \qquad (3.8)$$

The expression in (3.8) can be further simplified as shown in (3.9)

$$I = I_{ph} - I_o\left(e^{\frac{qV}{2nKT}}\right) \qquad (3.9)$$

2.2. Estimation of Maximum Parameters

At open circuit I= zero and $\frac{V + IR_s}{R_{sh}}$ also tends to zero and therefore (3.9) becomes

$$I_{ph} = I_o\left(e^{\frac{qV_{oc}}{AnKT}}\right) \qquad (3.10)$$

Therefore the open circuit voltage is given by (3.11)

$$V_{oc} = \frac{2nKT}{q}\left(Log\left[\frac{I_{ph}}{I_o}\right]\right) \qquad (3.11)$$

At short circuit V=0, and Iph= I, rewriting (3.7), (3.12) is obtained at:

$$I_o\left(e^{\frac{qIsc\,R_s}{2nKT}}\right) = \left|\frac{IR_s}{R_{sh}}\right| \qquad (3.12)$$

From (3.12), therefore

$$e^{\frac{qIsc\,R_s}{2nKT}} = \frac{1}{I_o} * \left|\frac{IR_s}{R_{sh}}\right| = e^{\frac{q\,IR_s}{2nKT}} = \frac{1}{I_o}\left|\frac{IR_s}{R_p}\right|$$

Assuming $\left|\frac{IR_s}{R_{sh}}\right| = \alpha$, $e^{\frac{qIsc\,R_s}{2nRT}} = \alpha/I_o$

where $\alpha = I_o + \delta$ and $0 < \delta < 0.01$, therefore

$$I_{sc} = \frac{2nKT}{qR_s}\ln\left(1 + \frac{\delta}{I_o}\right) \qquad (3.13)$$

3 Simulation and Results

3.1. Simulation Parameters

V	is the module voltage [V].
I	is the module current [A].
Iph	Photocurrent [A], proportional to the irradiance [ϕ]
Io	is the Diode saturation current, Io= 0.07Amps depends on temperature [K]
Rs	is the Series resistance =[0.008Ω]
A	is the Diode ideality factor (A= 2 for Silicon and 1 for Germanium)
η	is the number of PV cell in series and it is 100 cells in this work.
P	is the maximum power
Voc	is the open circuit voltage
q	is the Electron charge =1.602*10-19 coulomb.
K	is the Boltzmann's constant = 1.381*10-23J/K
Tref.	is the reference temperature= [283K]
T	is the working temperature of the system= [353K]

Fig.2 shows the simulation result characteristics of a PV module at different level of temperature and at constant solar irradiation of 1000W/M2. The behaviour of the characteristic shows that as the temperature levels of the PV model increases, the open circuit current increases. And the short circuit voltage tends to decrease as the temperature rises this could be observed well if the trend of the graph is followed well. The effect of temperature variation is more on short circuit current than on open circuit voltage which has a very small increment.

Table 1: Table showing voltage- current at different temperatures

V_1(V)	V2(V)	V3(V)	V_4(V)	V_5(V)	I_1(A) T=(273k)	I_2(A) T=(283K)	I_3(A) T=(293K)	I_4(A) T=(303K)	I_5(A) T=(313K)
0	0	0	0	0	45.51	47.18	48.85	50.52	52.18
3	3	3	3	3	45.45	47.12	48.79	50.46	52.13
6	6	6	6	6	45.33	47.01	48.69	50.37	52.04
9	9	9	9	9	45.11	46.81	48.5	50.2	51.89
12	12	12	12	12	44.7	46.45	48.17	49.9	51.62
15	15	15	15	15	43.92	45.76	47.57	49.37	51.14
18	18	18	18	18	42.44	44.5	46.49	48.43	50.32
21	21	21	21	21	39.66	42.18	44.54	46.77	48.9
24	24	24	24	24	34.41	37.91	41.02	43.82	46.41
27	27	27	27	27	24.52	30.04	34.65	38.62	42.1
30	30	30	30	30	5.88	15.52	23.17	29.4	34.6
33	33	33	33	33	-29.25	-11.24	2.43	13.07	21.56

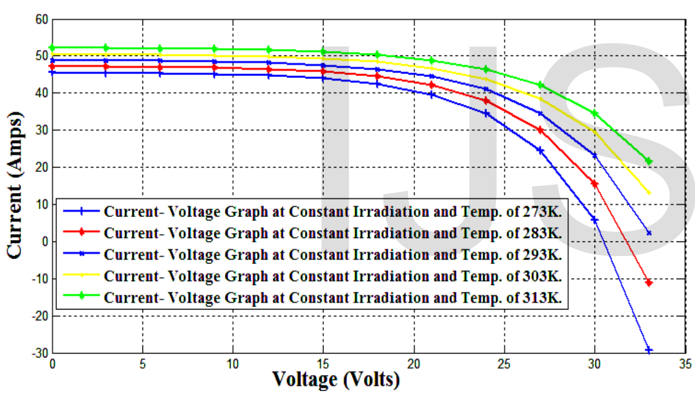

Figure 2: I-V graph at different temp. & constant irradiation.

Table 2: Voltage- Current at different irradiation.

V_1(V)	V2(V)	V3(V)	V_4(V)	V_5(V)	I_1(A) G=1kw/m^2	I_2(A) G=0.8kw/m^2	I_3(A) G=0.6kw/m^2	I_4(A) G=0.4kw/m^2	I_5(A) G=0.2kw/m^2
0	0	0	0	0	58.85	47.08	35.31	23.54	11.77
3	3	3	3	3	58.81	47.04	35.27	23.48	11.72
6	6	6	6	6	58.74	46.97	35.2	23.43	11.65
9	9	9	9	9	58.62	46.85	35.08	23.31	11.53
12	12	12	12	12	58.42	46.66	34.89	23.11	11.34
15	15	15	15	15	58.11	45.34	34.57	22.8	11.02
18	18	18	18	18	57.59	45.83	34.06	22.28	10.51
21	21	21	21	21	56.96	44.98	33.22	21.44	9.67
24	24	24	24	24	55.38	43.61	31.85	20.07	8.3
27	27	27	27	27	53.15	41.37	29.61	17.83	6.06
30	30	30	30	30	49.5	37.72	25.95	14.18	2.4
33	33	33	33	33	43.52	31.75	19.98	8.21	-3.56
36	36	36	36	36	33.77	22	10.23	-1.54	-13.31
39	39	39	39	39	17.85	6.07	-5.69	-17.46	-29.23

Figure 3 shows the current voltage relationship at constant temperature and variation of irradiance. The short circuit current and open circuit voltage of the simulation results increases as the irradiation varies. Under high irradiation and constant temperature there is a drastic increase in short circuit current and a very little change in the open circuit voltage. Therefore the irradiation variation has a strong effect on the short circuit current compare to the open circuit voltage.

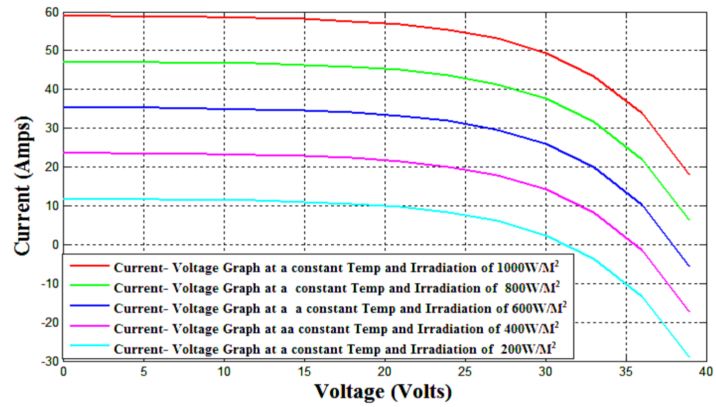

Figure 3: I-V graph at constant temp. & different irradiation.

Table 3: Power - Voltage at constant irradiation table

V_1(V)	V2(V)	V3(V)	V_4(V)	V_5(V)	P_1(W) T=(273k)	P_2(W) T=(283K)	P_3(W) T=(293K)	P_4(W) T=(303K)	P_5(W) T=(313K)
0	0	0	0	0	0	0	0	0	0
3	3	3	3	3	136.36	141.37	146.38	150	160
6	6	6	6	6	272.02	282.09	292.16	300	310
9	9	9	9	9	406.06	421.34	436.58	450	460
12	12	12	12	12	536.43	557.35	578.14	600	620
15	15	15	15	15	658.8	686.46	713.68	740	770
18	18	18	18	18	763.99	801.12	836.95	870	900
21	21	21	21	21	832.9	885.98	935.45	980	1030
24	24	24	24	24	826.02	910.02	984.5	1050	1110
27	27	27	27	27	662.3	811.14	935.76	1040	1140
30	30	30	30	30	176.67	465.73	695.1	880	1040
33	33	33	33	33	-965.36	-370.87	80.19	430	710

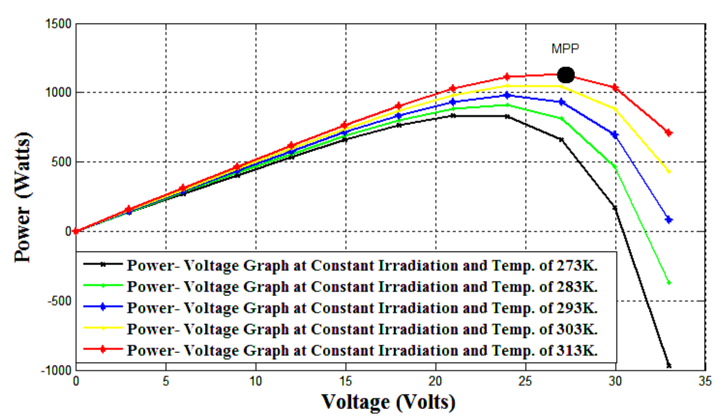

Figure 4: Power- Voltage graph at constant irradiation and different temperature.

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The simulation result of Figure 4 has clearly shown that a PV system delivers maximum power at high temperature and under the irradiation condition of 1KW/M2. Here simulation has been carried out for a set of temperature and irradiation levels, result obtained can be used to demonstrate the behavioural characteristics of any PV module or array under different irradiation and temperature variation. From the Figure 4 the point marked is the maximum power of 1.2KW obtained at the highest level of temperature and irradiation condition using 100 cells.

4 Conclusion and Recommendation

Considering the analysis carried out on the developed model, simulation result obtained has shown that the irradiation and temperature variations have very strong effect on the short circuit voltage and open circuit current. Since simulation has been performed on the model, at a certain temperature and irradiation condition, it can be said that this developed model could be used to test any PV module power system under some irradiation and temperature conditions.

In conclusion, the proposed model is a useful tool for PV cell design, PV module and array system testing. The model performed efficiently from the simulation result which means, this could used to test run any PV model or an array system.

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