Cloud Publications
International Journal of Advanced Electrical Engineering
2019, Volume 2, Issue 1, pp. 11-18
Crossref: 10.23953/cloud.ijaee.426

Research Article

Analysis of Electrical Characteristics of Solar Cell Employing Matlab/Simulink

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Publication Date: 7 August 2019

DOI: https://doi.org/10.23953/cloud.ijaee.426

Abstract The main objective of this paper is to find out the various electrical characteristics of solar cell. The main characteristics of solar cell are I-V and P-V characteristics, these two characteristics we are going to find by employing Matlab/Simulink. The exact curve of I-V and P-V are quite difficult to get manually; however, it is possible through the Matlab/Simulink. There are many approaches to find out the electrical characteristics of solar cell in Matlab/Simulink. In that we followed one circuit which is designed by us, shown and discussed below and the required curves are plotted with the help of Matlab/Simulink.

Keywords *Matlab/Simulink Software; Maximum power point; Mathematical model; Solar cell*

1. Introduction

Solar energy technologies supply a renewable, pollution free, and domestic energy supply. The world receives an implausible provide of solar power. The sun, a mean star, may be a nuclear reactor that has been burning over 4 billion years. It provides enough energy in few minutes to provide the world's energy desires for a year. In one day, it provides additional energy than our current population would consume in three decades. In fact, "The quantity of radiation hanging the world over a three-day amount is akin to the energy keep all told fossil energy sources.

Solar energy might have had nice potential; however, it had been left on the backburner whenever fossil fuels were more cost-effective and out there. "Only within the previous few decades once growing energy demands, increasing environmental issues and declining fuel resources created North American nation reminisce to energy choices have we tend to centered our attention on really exploiting this tremendous resource".

2. Working and Modeling of Solar Cell

The light incident on the semiconductor material might go or reflected through it. The PV cell is made of the semiconductor material which is neither a total conductor nor an insulator. This property of semiconductor material makes it progressively proficient for changing over the light energy into electric energy. At the point when the semiconductor materials retain the light, the electrons of the semiconductor materials begin emanating. This happens on the grounds that the light comprises little empower particles called photons.

At the point when the electrons ingest the photons, they progress toward becoming empowered and begin moving into the material. In view of the impact of an electric field, the particles move just in the one bearing and create flow. The semiconductor materials have the metallic cathodes through which the current leaves it. Consider the Figure 1 underneath demonstrates the PV cell made of silicon and the resistive load is connected across it. The PV cell comprises the P and N-type layer of semiconductor material. These layers are combined to frame the PN junction. The junction is the interface between the p-type and n-type material. At the point when the light falls on the junction, the electrons begin moving from one region to another.

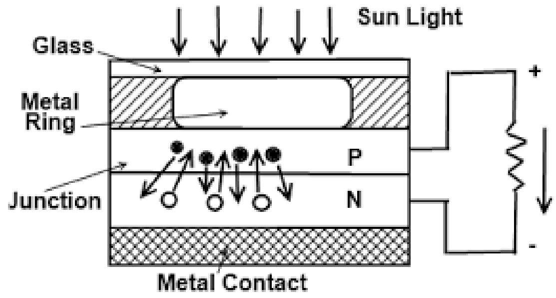

Figure 1: *PN junction solar cell with resistive load*

Equivalent Circuit of Solar Cell

The below equivalent circuit is a circuit of a solar cell, which helps us to find the electrical characteristics of solar cell. This also helps us to find the various mathematical equations like voltage and current for all parameters, which is directly or indirectly very helpful for modeling the solar system and these equations may lead to find the better efficiency of solar cell. This equivalent circuit consists diode, shunt resistor, series resistor and the supply source; the all parameters of this proportional circuit will investigate and find out the important equations for various parameters in the next section of mathematical model of solar cell.

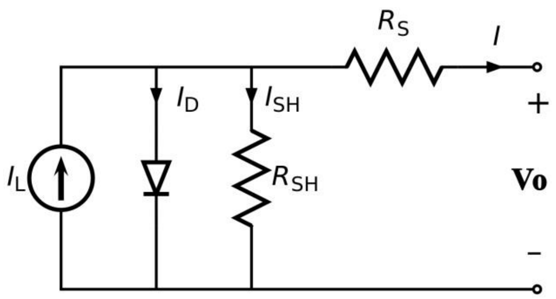

Figure 2: *Equivalent circuit of solar cell*

Mathematical Model of Solar Cell

The mathematical model is done by the help of equivalent circuit, which is shown in Figure 2. In this mathematical modeling, we are going to find different-different parameters like load current (I), photocurrent (I_L or I_{ph}), diode current (I_D), shunt current (I_{sh}), shunt voltage (V_{sh}), short circuit current (I_{sc}), open circuit voltage (V_{oc}) and output voltage (V_o).

By applying KCL in above equivalent circuit, we get below equation of photocurrent (I_{ph}):

$$I_{ph} = I_D + I_{sh} + I \qquad (A)$$

Here, photocurrent is linearly relying upon solar radiation (G) and insolation of sun. From equivalent circuit, it is very clear that the photocurrent is splitting in three directions and the equation of that is given in equation (A). To examine the effect of temperature and solar radiation we have to developed and implement some basic equations corresponding to solar PV cell which shows dependence of these parameters. From the equivalent circuit we can see the direction of diode current. We know very basic science about diode which varies with varying temperature. The diode current is given by the below equation:

$$ID = I_s[\exp(V_D/V_T)-1] \qquad (B)$$

Where,

I_s - reverse saturation current,
V_D - voltage across the diode,
V_T - the thermal voltage.

The thermal voltage causes here due to semiconductor properties which follow heat for the science behind the PN junction interference to produce current and the equation is given by:

$$VT = nkTc/q \qquad (C)$$

Where,

n = diode ideality factor,
k = Boltzmann constant (1.3806503 × 10-23 J/K)
q = charge on electron (1.602× 10 -19 C)

By applying KVL in Figure 2 we can observe that:

$$V_D = V_o + IR_s \qquad (D)$$

Now, substituting the value of V_D in equation (B) and we get the diode current as below:

$$I_D = I_S[\exp(V_o + IR_s)/V_T\text{-}1] \qquad (E)$$

From Figure 2, Shunt current can be given by following equation:

$$I_{sh} = V_{sh}/R_{sh} \qquad (F)$$

In equivalent circuit, shunt resistance and the diode of solar cell is parallel and the terminals of these shunt resistance and diode are connected with the supply and ground respectively. Here ground is used to feed leakage current through the diode. Due to parallel connection of shunt resistance and diode the voltage will be same, so the V_D=V_{sh}.

So now we can rewrite the equation (D) as following:

$$V_{sh} = V_o + IR_s \qquad (G)$$

By substituting the value of V_{sh} in equation (F), we get:

$$I_{sh} = (V_o + IR_s)/R_{sh} \qquad \text{(H)}$$

If we operate the diode in reverse bias region then reverse saturation current will be *ISO*. This current mainly depends on open circuit voltage, short circuit current and thermal voltage.

$$I_{SO} = I_{sc}/[\exp(V_{oc}/(N_s V_T))-1] \qquad \text{(I)}$$

Where,

Ns represent the number of photovoltaic cells connected in series.
As we know that, diode reverse bias saturation current can be changed by the variation of temperature. Hence the saturation current is:

$$I_s = I_{so}(T_o/T_c)^{\wedge}3{*}\exp[(qEg/nk)\ ((1/T_o)-(1/T_c))] \qquad \text{(J)}$$

Where,

E_g is band gap energy.

Photocurrent is basically relying upon sunlight and its radiation, which is denoted by 'G'. The output of the photocurrent is directly proportional to the solar radiation and insolation of sun. The equation of photocurrent based on insolation and solar radiation is given by the equation (K):

$$I_{ph} = [I_{sc} + K_{sc}(T_c - T_o)]{*}(G/G_s) \qquad \text{(K)}$$

Where,

Ksc is short circuit current temperature coefficient,
Gs is solar radiation at nominal temperature in w/m^2,
G is solar radiation at operating temperature in w/m^2.
By substituting the value of I_D, I_{ph} and I_{sh} in equation (A), we get:

$$I = I_{ph} - I_s[\exp\{(V_o+IR_s)/V_T\}-1]-\{(V_o+IR_s)/R_{sh}\} \text{ (L)}$$

$$I = N_p I_{ph} - I_s[\exp\{(q/nkT_o)\ (V_o/N_s)\}-1]-(V_o/R_{sh}) \text{ (M)}$$

Where,

T_c is nominal temperature;
T_o is operating solar cell temperature.

3. Experimental Analysis of Solar Cell

In this segment we will dissect the trial physically. We have made a circuit diagram which is appeared in Figure 3. We have given connection according to the circuit diagram and observe the perusing by shifting the rheostat from max to min/min to max position. Alongside this, some readings are taken for different loads which were noted down in tabulation.

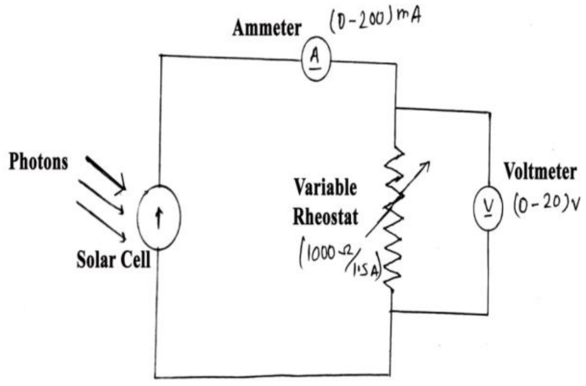

Figure 3: *Circuit diagram of solar cell with resistive load*

Table 1: *Solar cell in light@11:30 am on 5th Nov, 2018 (Rheostat at max-min)*

S. No.	Voltage (V)	Current (mA)	Power (V*mA)
1	5.56	12.7	70.612
2	5.55	19.8	109.89
3	5.53	23.7	131.061
4	5.52	28.6	157.872
5	5.47	40.2	219.894
6	5.33	57.8	308.074
7	2.58	76.4	197.112
8	0.17	79.5	13.515
9	0	80	0

The electrical characteristics of solar cell are drawn with the help of above table. The I-V curve is plotted between voltage and current. The I-V curve based on the above circuit diagram is shown below in Figure 4.

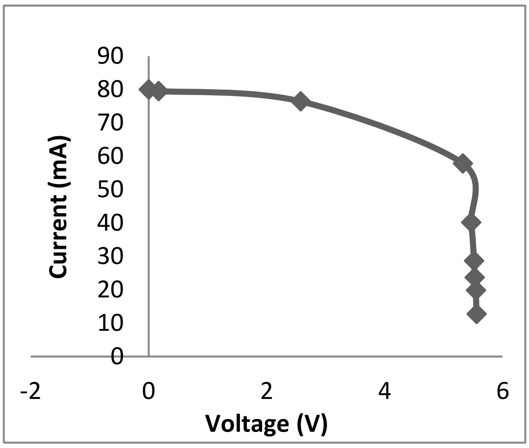

Figure 4: *I-V curve of solar cell*

Here the P-V curve is plotted between power and voltage. The unit of power is watts and the unit of voltage is volts. The P-V curve based on the above circuit diagram (Figure 3) is shown below in Figure 5.

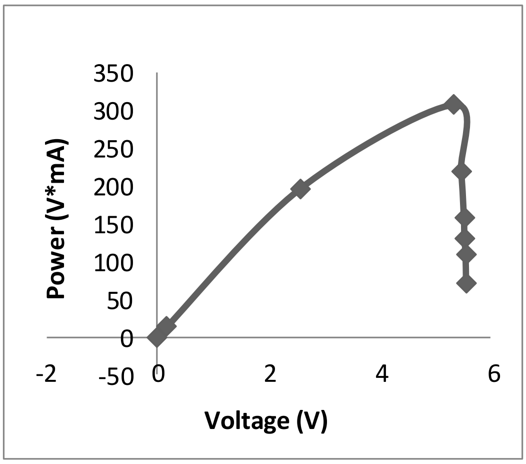

Figure 5: *P-V curve of solar cell*

4. Analysis of PV Model using Matlab

MATLAB is an incredible language for some applications as it has abnormal state usefulness for science and building applications combined with the adaptability of a comprehensively valuable programming condition. All through this investigation, we principally use MATLAB for simulating solar cell and its model and the examination and perception of experimental information.

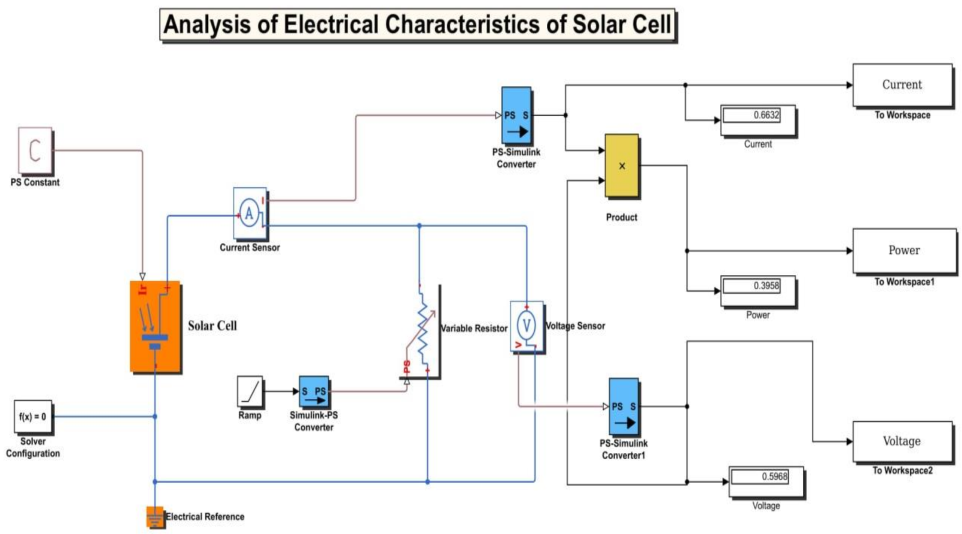

Figure 6: *PV model using Matlab/Simulink*

The above model of solar cell is simulated with the help of Matlab and the required electrical characteristics are obtained and compared with the manually characteristics of the solar cell. The I-V and P-V curves are obtained with the solar radiation, G=1000 w/m^2. We can change the different - different solar radiation and can get various curves of solar cell.

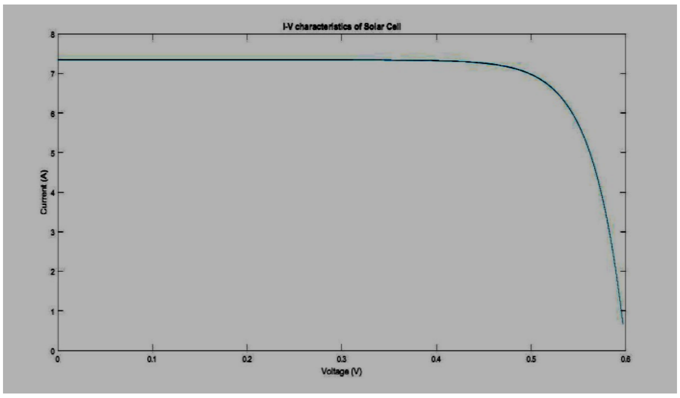

Figure 7: *I-V curve of solar cell using Matlab*

PV cell current is immovably subject to solar radiation. That impact can be appreciated from the Figure 7 of I-V attributes with the variety of radiation. The I-V characteristics of solar cell thinking about the impact of saturated current. It will in general be seen from the below characteristics that saturated current shows reverse association with the open circuit voltage.

The power of PV cell is also unequivocally subject to solar radiation. The impact can be comprehended from the Figure 8 of P-V curve with the fixed solar radiation, G = 1000 w/m^2.

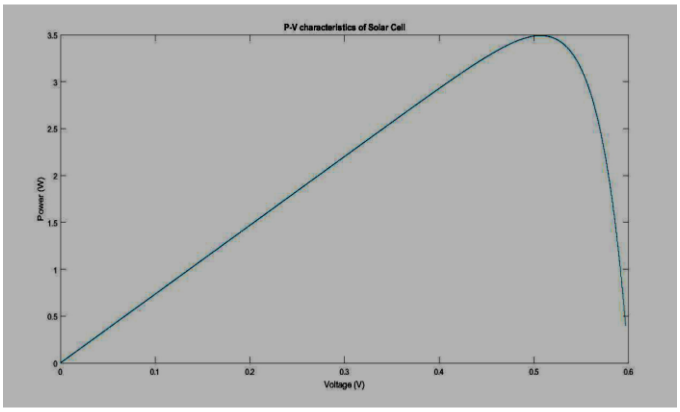

Figure 8: *P-V curve of solar cell using Matlab*

5. Conclusion

This paper describes with detailed study of the photovoltaic system which includes model description of solar cell, simulation diagram, different characteristics equation depending upon which, I-V and P-V curves were obtained.

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