

Modeling and Simulation of Silicon Solar Cell in MATLAB/SIMULINK for Optimization

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Abstract

One of the most significant current discussions in life is solar energy and has been in use since the beginning of time. Increasingly, man is learning how to yoke this important resource and use it to replace traditional energy sources. Recent developments in the field of solar energy have led to a renewed interest in Solar cells to store this energy and reproduce electricity. Unfortunately the amount of energy converted is very less, that is the efficiency of conversion is poor. The major problem is to improve the efficiency so that the losses can be minimized. In this project the Maximum Power Points are found and the Fill Factor is calculated. In this paper using MATLAB and SIMULINK model the comparison of silicon solar cell and type of panels is done.

Keywords: maximum power point, Photoelectric, solar radiation, solar cell model, photovoltaic

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1. Introduction

Studies of photovoltaic generation systems are actively being promoted in order to cope with environment issues such as the green house effect and air pollution. In particular, the use of natural energy, especially the solar energy is increasingly emphasized and regarded as an important resource of power energy in the future. By definition, solar energy is that beaming light and heat that is generated from the sun [1].

2. Research Method

2.1. The Photoelectric Effect

A solar cell or photovoltaic cell is a simple PN junction photodiode that can absorb sun's radiation. The photovoltaic effect shown in Figure 1 is the basic physical process through which a PV cell converts sunlight into electricity. Sunlight is composed of photons--packets of solar energy. When photons strike a PV cell, they may be reflected or absorbed, or they may pass right through [2]. The absorbed photons generate electricity. The energy of a photon is transferred to an electron in an atom of the semiconductor device. An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity.

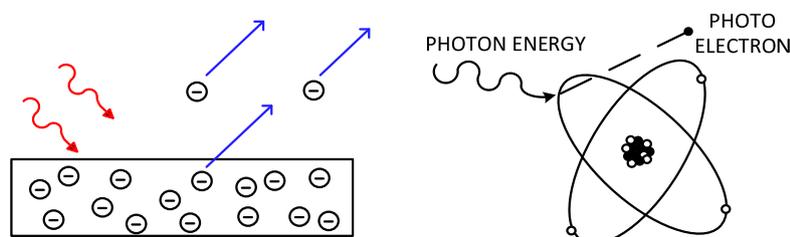


Figure 1. The Photoelectric Effect

Different materials have a tendency to absorb different amounts of light energy depending upon the band gap of each material. Silicon has a band gap of 1.1 eV, so it absorbs light energy of

minimum 1.1eV but it gives out energy that is less than 1.1eV. Similarly, Gallium arsenide which has band gap of 1.43eV absorbs energy more than 1.43eV but delivers energy less than 1.43eV.

2.2. One Diode Solar Cell Model

Solar cell is a PN junction diode and can be modeled as a diode with a photo generated current source in parallel [3, 8]. The diode itself has shunt and series resistance as shown in Figure 2.

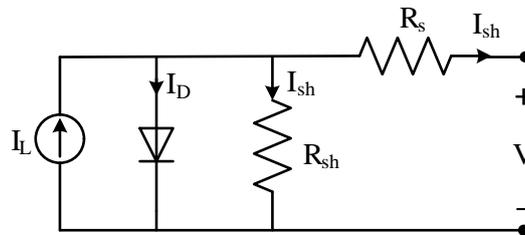


Figure 1. Solar Cell Electrical Equivalent Circuit

To understand the electronic behavior of a solar cell, it is useful to create a model which is electrically equivalent. An ideal solar cell may be modeled by a current source in parallel with a diode. In practice no solar cell is ideal, so a shunt resistance and a series resistance component are added to the model.

2.3. Solar Parameters

Irradiance (S): The amount of solar energy reaching the cell is irradiance given in Watts per meter square (W/m^2)

Open Circuit Voltage (V_{OC}): It is the maximum voltage available from a solar cell at zero current.

Short Circuit Current (I_{SC}): It is the current through the solar cell when the voltage across the cell is zero.

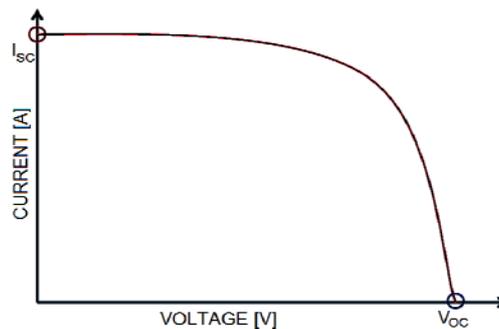


Figure 2. IV curve by joining I_{SC} and V_{OC}

The I-V curve of the solar cell follows the same shape as it is in Figure. 3 by making a curve joining I_{SC} and V_{OC} .

Input Power (P_{in}): The input to a solar cell is the radiation from sun. Thus the input power to a solar cell depends upon its effective area (A_e) and the radiation (S). The input power is given by ($A_e \times S$).

Output Power (P_0): The output power of a solar cell is the given by the product of the output voltage and output current.

Maximum Power Point (MPP): The voltage at which the highest power is observed as shown in Figure 4

Fill Factor (FF): This is the available power at the maximum power point (MPP) divided by the product of open circuit voltage (V_{OC}) and the short circuit current (I_{SC}) Typical commercial solar cells have a fill factor >0.70 . Cells with high fill factor have less current dissipated as internal loss.

Efficiency (η): The efficiency of a solar cell is determined as the fraction of incident power which is converted to electricity and is defined as [4, 7]:

$$\eta = \frac{P_o}{P_{in}} \times 100\% \quad (1)$$

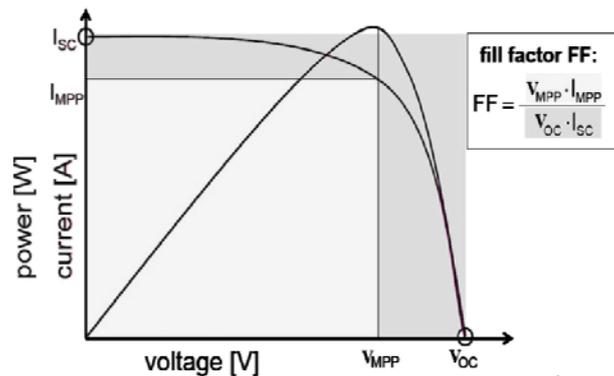


Figure 3. Maximum Power Point and Fill Factor

2.4. Solar Cell Simulation in MATLAB

As discussed earlier, a solar cell is nothing but a simple PN junction diode along with a photocurrent source, a series and shunt resistor. The entire energy conversion system has been designed in MATLAB environment. MATLAB® is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numerical computation [5].

For calculating the total current / Equation (2) is used:

$$I = I_{ph} - I_s \left(\exp \frac{qVt}{nkT} - 1 \right) \quad (2)$$

In this equation, I_{ph} is the photocurrent, I_s is the reverse saturation current of the diode, q is the electron charge, V_t is the thermal voltage, k is the Boltzmann's constant, T is the junction temperature, n is the ideality factor of the diode, and R_s and R_{sh} are the series and shunt resistors of the cell, respectively. As a result, the complete physical behaviour of the PV cell is in relation with I_{ph} , I_s , R_s and R_{sh} from one hand and with two environmental parameters as the temperature and the solar radiation from the other hand.

2.5. Effects of Solar Radiation Variation

The most important parameter on which the output of a solar cell depends is the solar radiation which is its only input. The change in radiation varies the output parameters of solar cell [5, 7]. The radiation dependency on solar cell is given by:

$$I_{ph} = \left[I_{sc} + K(T - 298) \right] \frac{\beta}{100} \quad (3)$$

Where, K_i is the cell's short circuit current temperature coefficient ($A/^{\circ}C$), β is the solar radiation (W/m^2) and I_{ph} is the photocurrent.

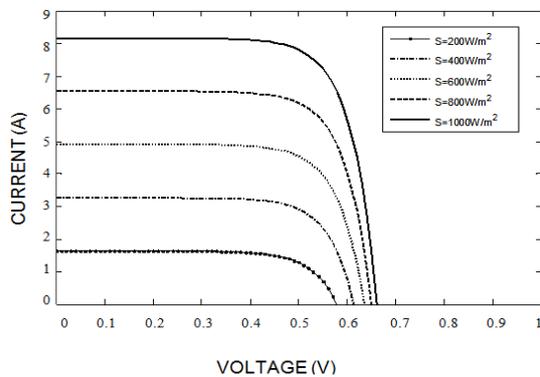


Figure 4. Solar Cell I-V Curve for Variation in Radiation

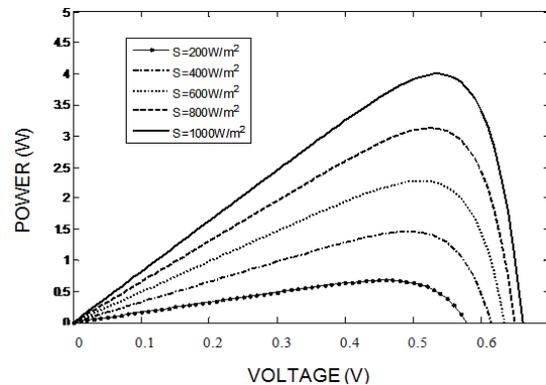


Figure 5. Solar Cell P-V Curve for Variation in Radiation

The output results for variation in solar radiation is given in Figure 5 for voltage versus current where it is observed that for the increase in radiation, the current of the solar cell is also increasing. With respect to the Equation (3), it is clear that the current is directly proportional to the radiation. The characteristic I-V curve tells that there are two regions in the curve: one is the current source region and another is the voltage source region. In the voltage source region (in the right side of the curve), the internal impedance is low and in the current source region (in the left side of the curve), the impedance is high. Irradiance temperature plays an important role in predicting the I-V characteristic, and effects of both factors have to be considered while designing the PV system. Whereas the irradiance affects the output, temperature mainly affects the terminal voltage. Figure 6 which shows voltage versus power curve is used to find the maximum power point that is the voltage at which the maximum power observed. From the I-V, it is observed that the short circuit current increases with increase in irradiance at a fixed temperature. Moreover, from the I-V and P-V curves at a fixed irradiance, it is observed that the open circuit voltage decreases with increase in temperature. In Figure 7 the current versus power curve is plot.

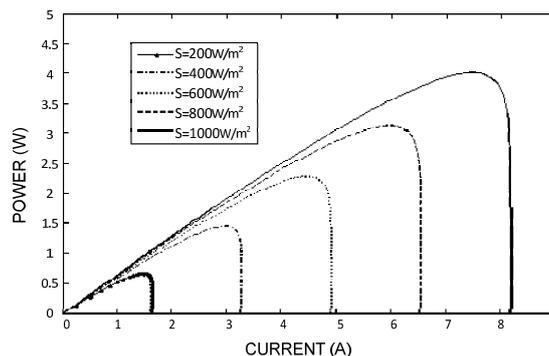


Figure 6. Solar Cell P-I Curve for Variation in Radiation

2.6. Effects of Temperature Variation

The solar radiation is the only input for the solar cell, but the other indirect input that changes the output characteristics of the solar cell is the temperature. Equation (3) shows the relation between the temperature and the photocurrent [5]. The change in photocurrent changes

the output voltage and current. The Figure 8, Figure 9 and Figure 10 give the I-V, P-V and P-I characteristics for various temperatures at a fixed irradiance at 1000W/m².

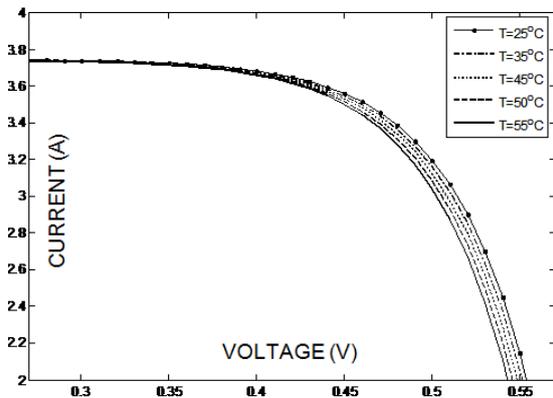


Figure 7. Solar Cell I-V Curve for Variation in Temperature

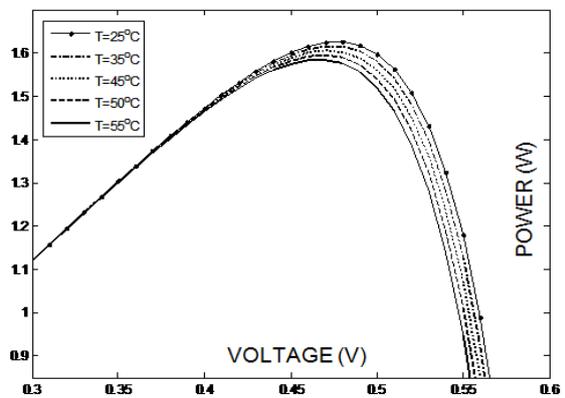


Figure 8. Solar Cell P-V Curve for Variation in Temperature

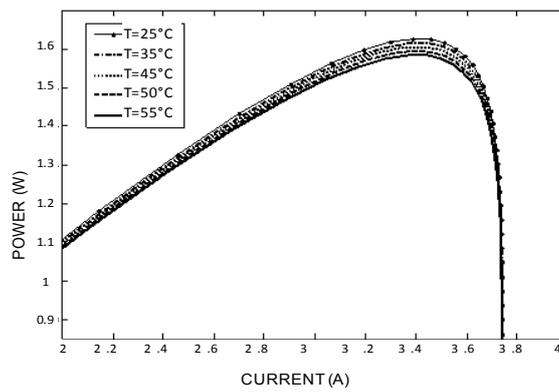


Figure 9. Solar Cell P-I Curve for Variation in Temperature

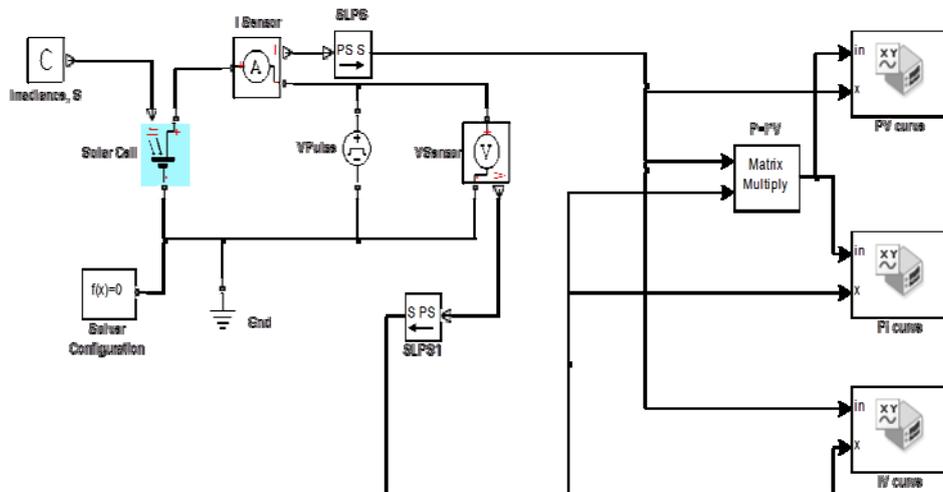


Figure 10. Simulated Model

2.7. PV Cell Model in SIMULINK

The MATLAB/SIMULINK [6] model of a Solar cell to measure the output voltage, current, power is shown in Figure 11. This model uses the main block "Solar Cell" in which the values are predefined. For V_{OC} the default value is 0.6V. The I_{SC} is set to 7.34A. The values can be changed once a model is created and place the block in it. The terminals of the block are Incident irradiance (I_r), Positive electrical voltage (+) and Negative electrical voltage(-). The I_r terminal is connected to the Irradiance block (C) where a constant value of radiance from sun in W/m^2 can be set. The current sensor and voltage sensors are used to measure current and voltage respectively. Further, to plot the curve of voltage versus current XY plotter block is used. The plots of output characteristics can be seen in below figures which are tested at Standard Test Conditions (STC). The STC has $S=1000W/m^2$, $T=25^\circ C$ and Air Mass (AM) = 1.5.

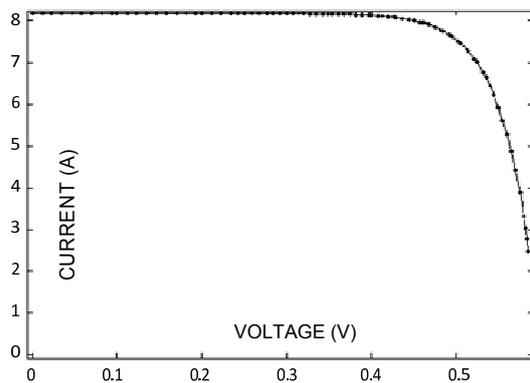


Figure 11. Solar I-V Curve in SIMULINK

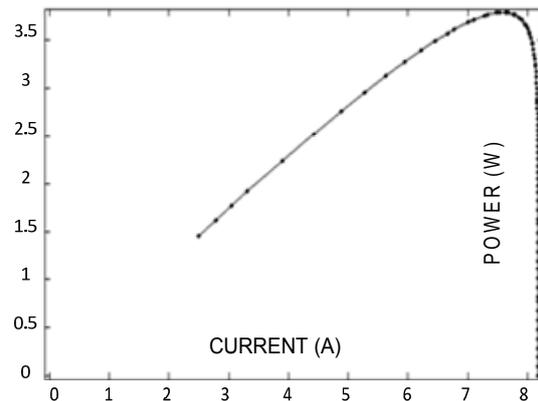


Figure 12. Solar P-I Curve in SIMULINK

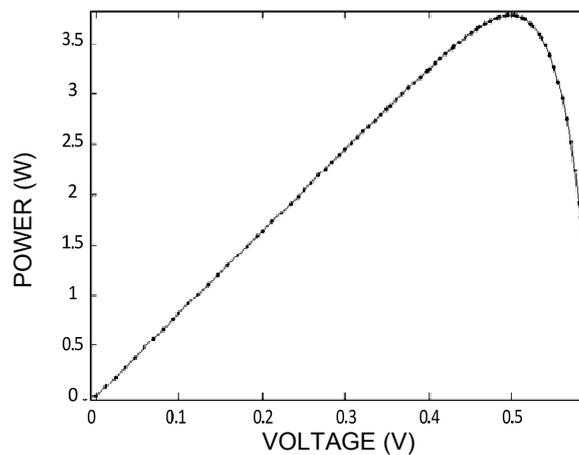


Figure 13. Solar P-V Curve in SIMULINK

2.8. Efficiency of Solar Cell

The efficiency of solar cell is given in Equation (1). The output power and input power are calculated. Since power is directly proportional to radiance, the efficiency will increase as the radiance increases. Figure 15 shows the curve of efficiency versus the radiance. The efficiency at STC of the solar cell is found out to be 14.185%

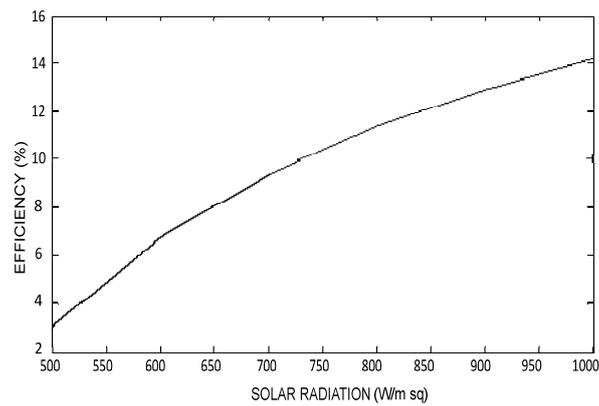


Figure 14. Efficiency versus Radiation Curve at STC

3. Results and Conclusion

3.1. Maximum Power Point and Fill Factor

For a solar cell, the more the Fill Factor, the more is the reliability. So it is one of the important factors after efficiency. For a good solar cell, the efficiency has to be greater than 70%. Table 1 shows the calculation of fill factor at different radiations. From this it is observed that the fill factor is constant for different radiation.

Table 1. Fill Factor

S (W/m ²)	V _{max} (V)	I _{max} (A)	V _{oc} (V)	I _{sc} (A)	V _{max} × I _{max} (W)	V _{oc} × I _{sc} (W)	Fill Factor
1000	0.53	7.5370	0.661	8.174	3.995	5.403	0.74
800	0.53	5.9020	0.650	6.539	3.128	4.248	0.74
600	0.51	4.4730	0.635	4.904	2.281	3.112	0.73
400	0.49	3.0610	0.614	3.270	1.500	2.007	0.75
200	0.45	1.5010	0.578	1.635	0.675	0.945	0.71

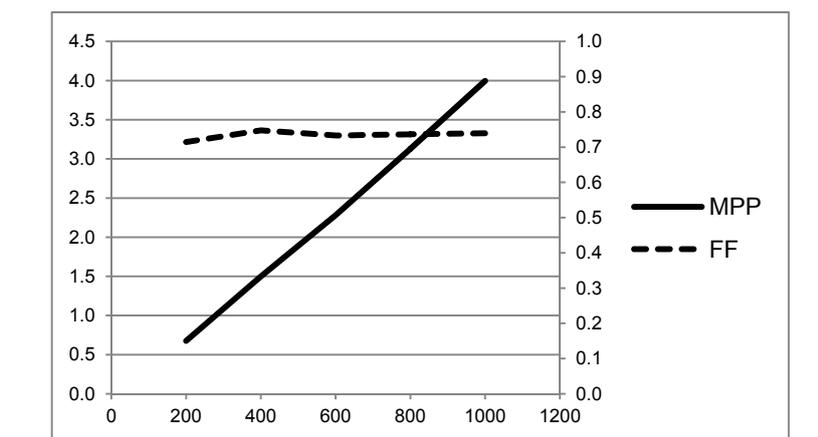


Figure 15. Plot for MPP and FF versus Radiation

The graph in Figure 16 which is plotted from the data in Table 1 shows that the MPP increases linearly and the FF remains constant for the variation in sun's radiation. The simulated fill factor is nearly same as the datasheet fill factor.

By the formula of fill factor, the FF for different methods is compared and is found to be nearly the same.

3.2. Efficiency

Efficiency being the main parameter of solar cell, it is necessary to try to have maximum efficiency for maximum energy conversion. Table 2 gives comparison of efficiency by all three methods and are nearly same.

parameter	MATLAB	SIMULINK
Output power	3.452W	3.6W
Input Power	24.336W	24.336W
Efficiency	14.185%	14.8%

The open circuit P-V, P-I, I-V curves were obtained from the simulation of the PV cell designed in MATLAB environment explains in detail its dependence on the irradiation levels and temperatures. The entire energy conversion system has been designed in MATLAB-SIMULINK environment. The various values of the voltage and current obtained have been plotted in the open circuit I-V curves of the PV cell at insolation levels ranging from 200W/m^2 to 1000W/m^2 . However the performance of the photovoltaic device depends on the spectral distribution of the solar radiation. The values for all the output parameters are found to be satisfactorily comparable.

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