A New Approach for Modeling the Photovoltaic Cell Using Orcad Comparing with the Model Done in Matlab

A. Blorfan, D. Flieller, P. Wira, G. Sturtzer, J. Merckle

Abstract – This paper represents two model of photovoltaic, the first uses the Matlab, it explains the Photovoltaic Cell I-V Characterization and how we can get the Maximum peak power tracking(MPPT), the other is done in Orcad(new version of Pspice), in Orcad we propose an electronic circuit to be realize easily, a newer technique will be discussed in the last one, it is a new geometric approach, it depends on the characteristic of the photovoltaic diode, this approach give an approximation reasonable to this model, more than the classical one. Copyright © 2010 Praise Worthy Prize S.r.l. - All rights reserved.

Keywords: Solar Cell, Photovoltaic, MPPT, Simulink, Orcad

Nomenclature

<table>
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<tr>
<th>Symbol</th>
<th>Description</th>
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<tr>
<td>I-V</td>
<td>Current-voltage characteristic</td>
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<td>MPPT</td>
<td>Maximum peak power tracking</td>
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<tr>
<td>ORCAD</td>
<td>A proprietary software tool suite used primarily for electronic design automation</td>
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<tr>
<td>WL, WV</td>
<td>Boundaries of valence and conductive bands</td>
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<tr>
<td>I</td>
<td>Overall current</td>
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<td>D</td>
<td>Diode dark current</td>
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<td>L</td>
<td>Light-induced current</td>
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<td>I_L</td>
<td>Saturation current</td>
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<td>I_0</td>
<td>Boltzmann’s constant</td>
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<td>I_SC</td>
<td>Short circuit current</td>
</tr>
<tr>
<td>V_OC</td>
<td>Open circuit voltage</td>
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<td>FF</td>
<td>Fill factor</td>
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<td>P_max</td>
<td>Maximum power</td>
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<td>V_out</td>
<td>Output voltage of the solar cell</td>
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<tr>
<td>I_out</td>
<td>Output current of the solar cell</td>
</tr>
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<td>η_ec</td>
<td>Solar cell efficiency</td>
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<tr>
<td>P_in</td>
<td>Input power</td>
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<tr>
<td>I(i)</td>
<td>Incident solar radiation</td>
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<tr>
<td>A_c</td>
<td>Area of solar cell</td>
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<tr>
<td>I_pv</td>
<td>Output current(solar cell)</td>
</tr>
<tr>
<td>V_pv</td>
<td>Output voltage(solar cell)</td>
</tr>
<tr>
<td>I_0</td>
<td>Reverse saturation current</td>
</tr>
<tr>
<td>V_T</td>
<td>Thermal voltage</td>
</tr>
<tr>
<td>P_pv</td>
<td>Output power</td>
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<tr>
<td>R_i</td>
<td>Resistance of diode number i</td>
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<tr>
<td>PWM</td>
<td>Pulse width modulation</td>
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</table>

I. Introduction

Solar cells are in fact large area semiconductor diodes. Due to photovoltaic effect energy of light (energy of photons) converts into electrical current [1]. At p-n junction, an electric field is built up which leads to the separation of the charge carriers (electrons and holes). At incidence of photon stream into semiconductor material the electrons are released, if the energy of photons is sufficient [2]. Contact to a solar cell is realized due to metal contacts. If the circuit is closed, meaning an electrical load is connected, then direct current flows. The energy of photons comes in "packages" which are called quants. The energy of each quantum depends on the wavelength of the visible light or electromagnetic waves. The electrons are released, however, the electric current flows only if the energy of each quantum is greater than WL - WV (boundaries of valence and conductive bands). The relation between frequency and incident photon energy is as follows:

\[ W = h \cdot v \]  

where there is: \( h \) - Planck constant \((6.626 \times 10^{-34} \text{Ws}^2)\), \( v \) - frequency (Hz).

II. Crystalline Silicon Solar Cells

Among all kinds of solar cells we describe silicon solar cells only, for they are the most widely used [3]. Their efficiency is limited due to several factors. The energy of photons decreases at higher wavelengths. The highest wavelength when the energy of photon is still big enough to produce free electrons is 1.15 µm (valid for silicon only). Radiation with higher wavelength causes only heating up of solar cell and does not produce any electrical current. Each photon can cause only production
of one electron-hole pair. So even at lower wavelengths many photons do not produce any electron-hole pairs, yet they effect on increasing solar cell temperature. The highest efficiency of silicon solar cell is around 23%, by some other semiconductor materials up to 30%, which is dependent on wavelength and semiconductor material. Self loses are caused by metal contacts on the upper side of a solar cell, solar cell resistance and due to solar radiation reflectance on the upper side (glass) of a solar cell. Crystalline solar cells are usually wafers, about 0.3 mm thick, sawn from Si ingot with diameter of 10 to 15 cm. They generate approximately 35 mA of current per cm² area (together up to 2 A/cell) at voltage of 550 mV at full illumination. Lab solar cells have the efficiency of up to 20%, and classically produced solar cells up to 15%.

III. Basic Parameters of Solar Cells

There are certain parameters to be mentioned in the I-V characteristics of a solar cell [4].

III.1. Overall Current $I$

Overall current is determined by subtracting the light-induced current from the diode dark current and can be expressed as:

$$I = I_D - I_L$$  

where $I_D$ is the diode dark current, $I_L$ is the light-induced current, and $I_0$ is the saturation current, which is also known as the leakage or diffusion current; $e$ is the charge on an electron and hole and $K$ is Boltzmann’s constant. Both $I_L$ and $I_0$ depend on the structure of solar cells.

III.2. Short Circuit Current $I_{SC}$

Short circuit current is the light-generated current or photo current, $I_L$. It is the current in the circuit when the load is zero in the circuit. It can be achieved by connecting the positive and negative terminals by copper wire.

III.3. Open Circuit Voltage $V_{oc}$

Open circuit voltage is obtained by setting $I = 0$ in the expression for overall current i.e. $I = 0$ when $V = V_{oc}$:

$$V_{oc} = \frac{kT}{e} \ln \left( \frac{I}{I_0} + 1 \right)$$  

The open circuit voltage is the voltage for maximum load in the circuit.

III.4. Fill Factor (FF)

The fill factor, also known as the curve factor (Fig. 2), is a measure of sharpness of the knee in an I-V curve. It indicates how well a junction was made in the cell and how low the series resistance has been made. It can be lowered by the presence of series resistance and tends to be higher whenever the open circuit voltage is high. The maximum value of the fill factor is one, which is not possible. Its maximum value in Si is 0.88:

$$FF = \frac{P_{max}}{V_{oc} \cdot I_{SC}} = \frac{V_{max} \cdot I_{max}}{V_{oc} \cdot I_{SC}}$$

III.5. Maximum Power $P_{max}$

No power is generated under short or open circuit. The power output is defined as:

$$P_{out} = V_{out} \cdot I_{out}$$

The maximum power $P_{max}$ provided by the device is achieved at a point on the characteristics, where the
product IV is maximum. Thus:

$$P_{\text{max}} = V_{\text{max}} \cdot I_{\text{max}}$$  \hspace{1cm} (6)$$

The maximum possible output can also be given as

$$P_{\text{max}} = V_{oc} \cdot I_{SC} \cdot FF$$  \hspace{1cm} (7)$$

where FF is the fill factor given by eqn (4).

### III.6. Solar Cell Efficiency $\eta_{ec}$

The solar cell power conversion efficiency can be given as:

$$\eta_{ec} = \frac{P_{\text{max}}}{P_{in}} = \frac{V_{\text{max}} \cdot I_{\text{max}}}{\text{IncidentSolarRadiation} \cdot \text{AreaOfSolarCell}}$$  \hspace{1cm} (8)$$

where $I_{\text{max}}$ and $V_{\text{max}}$ are the current and voltage for maximum power, corresponding to solar intensity $I(t)$.

### IV. Solar Cell Model Using Matlab

The simplest solar cell model consists of diode and current source connected parallel [5]. Current source current is directly proportional to the solar radiation. Diode represents PN junction of a solar cell. Equation of ideal solar cell, which represents the ideal solar cell model, is:

$$i_{PV} = I_{SC} - i_D$$

$$i = I_0 \left( e^{\frac{v}{v_T}} - 1 \right) - I_L \Rightarrow$$  \hspace{1cm} (9)$$

where:

- $I_{SC}$ - photocurrent (A),
- $I_0$ - reverse saturation current (A) (approximately range 10^-9 m^2/s),
- $v_D$ - diode voltage (V),
- $v_T$ - thermal voltage (see equation below),
- $v_T = 25.7$ mV at 25°C,
- $m$ - diode ideality factor = 1.5 x $v_T$ (-) (m = 1 for ideal diode).

The simple model of the solar cell is shown in the Fig. 3 [6, 7].

Output power $P_{PV}$ (i.e. the product of $i_{PV}$ and $v_{PV}$) as a function of $v_{PV}$ is immediately displayed in a X-Y (Fig. 5).

Output current $i_{PV}$ as a function of $v_{PV}$ is immediately displayed in another X-Y Plot window.

The Fig. 6 shows this characteristic as a function of $v_{PV}$. Output power $P_{PV}$, current $i_{PV}$, voltage $v_{PV}$, and simulation time are stored in a "structure" variable PV, which is made available (using the "To Workspace" block) for further processing in the MATLAB Command Window [8].

As a result of the last model done using Simulink we could get the power and the current for the solar cell as a function of the its voltage.
Fig. 6. $i_{pv} = f(v_{pv})$

But the question here could we find another model using another utilities more accurate and elastic to transfer towards the electronic circuit easily.

This paper uses the Orcad such as a new software to modulate the photovoltaic and using Orcad we shall propose a new approach depends on the characteristic of the photovoltaic diode.

V. Solar Cell Model Using Orcad

The characteristic of the photo diode is performance by the producer of the photovoltaic array.

The Fig. 7 shows the characteristic of the photo diode given with the array of photovoltaic.

If we stare at the last figure we conclude that an geometric approximation represented by four segments will be satisfied to our need, so the new model will be shown in the Fig. 8.

The values of the resistance are calculated using the equation (10)[9]:

$$R_i = \frac{1}{m_i - m_{i-1}}$$

$$m_0 = 0$$

$$V_i = E_i$$

(10)

The new approach is modulated using the Orcad 15.7 which is considered as a new version of the Pspice with a high ability to produce an electronic board from the circuit simulated.

The Fig. 8 shows this new model with four branches parallel.

The characteristic of the photovoltaic is represented by the two graph, first graph is the current($i_{pv}$) as a function of the voltage of the Photovoltaic($v_{pv}$) and the second is the power($P$) as a function of the same variable($v_{pv}$).

The I-V curve of an illuminated PV cell has the shape shown in Fig. 9 as the voltage across the measuring load is swept from zero to $V_0$, and many performance parameters for the cell can be determined from this data, as described in the sections below.

The power produced by the cell in Watts can be easily calculated along the I-V sweep by the equation $P=IV$. At the $I_0$ and $V_0$ points, the power will be zero and the maximum value for power will occur between the two. The voltage and current at this maximum power point are denoted as $V_{mp}$ and $I_{mp}$ respectively.

Fig. 7. $I_d = f(V_d)$

Fig. 8. Real Model of the photovoltaic

Fig. 9. $i_{pv} = f(v_{pv})$
The above arc shape (Fig. 10) is obtained by making use of different resistance, starting from lower resistance say $1 \Omega$ and increasing in 5 units up to 5 or 10 K $\Omega$. The below figure depicts how to take voltage and current measurement for varying resistance.

VI. Maximum Power Point Tracking

Power output of a Solar PV module changes with change in direction of sun, changes in solar insolation level and with varying temperature [10].

Hence maximization of power improves the utilization of the solar PV module. A maximum power point tracker (MPPT) is used for extracting the maximum power from the solar PV module and transferring that power to the load. A dc/dc converter (step up/step down) serves the purpose of transferring maximum power from the solar PV module to the load.

We choose the Hill Climbing method, which consists of observing the current and voltage at the output of the generator (PV). Multiply these data we shall get the power, then we use two montages integrators to save this power and to make a delay between two values of the power the actual value and the new value. Both montages have different time constants.

By comparing these two signals, we could know the derivation of the power, and thus if it increases or it decreases. Then, using a toggle JK, a third integrator and a triangular signal we will create the PWM control to be sent to the driver of the transistor (here we used P-channel Mosfet).

The Fig. 11 shows the diagram of this technique.

However, for most orders MPPT, to achieve convergence in good conditions, whatever the algorithm, it is necessary that the power curves issued by the generator are constant or slowly varying. If this assumption is not respected (abrupt changes in operating conditions) the system can diverge.

The principle of MPPT controllers is often based on the "elbow" of the P-V characteristics. It's more or less a trial and error, as shown in the following figure.

It is located in an area of the curve ($X_1$) and if you look at the value of the next item is higher or not. If so, we move to the next point ($X_2$), until the next term ($X_n$) will be lower than the previous ($X_{n-1}$). At this time, we take an interval value between every point lower, and repeat from ($X_{n-1}$) to obtain MPP ($X$).

The Fig. 12 is shown this technique of MPPT.

The controller type of MPPT consists of two distinct parts:
1. Control part whose purpose is to determine the operating point, where the solar cell can transfer the power towards the batteries.
2. The power part which transfers energy between the solar panels and batteries.

These two parts are shown in Fig. 13.
Now it is easy to get the electronic schematic from the Orcad’s library, it is shown in the Fig. 14.

![Fig. 14. Proposed controller circuit diagram](image)

**VII. Simulation Results**

The simulation of this method using Orcad shows that the control pulses PWM changes according to the voltage of the generator, the PWM and the output voltage are shown in the Fig. 15.

![Fig. 15. Control pulses for the DC-DC converter](image)

**VIII. Conclusion**

This paper explained to us the classical module of the photovoltaic, the first is done in Matlab, and the second using Orcad, the two modules are shown the same characteristic of the I-V but the second module is more nearest to the solar cell itself, because it is depends on the characteristic of the photo diode, it is shown the real model of the solar cell, by using it we could determine the exact value of the $P_{max}$, our objective is to conserve the power about its maximum values, we estimate the value of the power by tracking the maximum value of this power, where the old technique is not accurate so it could not give us high efficiency such as this new method.

Then we discussed the flow chart of the maximum point power tracking (MPPT) technique, The role of the MPPT is to place the operating point of the assembly at the top of this bell, and how could be realized the prototype using an electronic components.

The efficiency of the photovoltaic is very important especially nowadays where all the world is seeking for the renewal energy.

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**References**


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