WORLD WIDE JOURNAL OF
MULTIDISCIPLINARY RESEARCH AND
DEVELOPMENT

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Solar cell Modeling Based Matlab-Software

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Abstract
Due to the large demand and the need to use energy to meet the requirements of life and since the sources of energy available such as coal and oil are disappearing soon, attention, studies and research are moving towards renewable and alternative energies such as wind power, hydro, thermal, and solar energies etc… as renewable sources in the future.
This research is related to solar energy as an assistant to researchers and designers who design solar cell systems. Instead of much time, effort and expense in designing and building a solar cell system, this program helps to design these systems by knowing the specifications of the solar cell which help the designers to improve their systems design. If the results are good, then you can start building the solar system, the software used is the Matlab Software, by this software the curves of power, current and voltages obtained which gives the specifications of the solar cell accurately.

Keywords: Matlab, Solar cell, modeling

Introduction

Energy is an essential element of social and economic development and it is crucial for reaching all development goals. Most of the energy produced is burning fossil fuels and therefore produces polluting pollutants that cause high environmental pollution, whether air, soil, or water [1]. The current trend towards alternative and renewable energies has become a foregone conclusion and most countries emphasize this trend to reduce the environmental risks of pollution such as global warming and climate change [2]. A standout amongst the most essential sustainable power sources is sun powered vitality.

One of the main important sources of energy that will not run out as it is environmentally friendly and clean is solar energy. The interest in solar energy and its diversified applications have increased by 20% to 25% over the past few years, and their prices are declining due to the diversity of solar technology and encouraging consumers to use solar energy.

There are many factors that affect the specifications of the solar cell such as heat, humidity, radiation intensity, wind speed and angle of the fall of the sun, these effects have a major role in the process of design and construction of the solar system, The specifications of the solar photovoltaic cell can be estimated by obtaining the cell's specifications curves, which are the curves that link the cell's power to its output volt and current of the cell, By studying these curves, the designer can know a lot of details related to the solar cell [3].

When designing solar cells system, the variables affecting the performance of the photovoltaic cell must be accurately identified and complete information on the effect of these variables can be processed from experimental data. So, researchers have developed different software to design the many types of solar cells that describe electrical cell behavior and simulate this behavior [4]. The reference (p) presented a simulated photovoltaic (PV) model consisting of a module and the model was executed using Matlab. Ref. [5] compared the simulation results conducted by them with standard PV module characteristics in test conditions (STC). The results of the study were well agreed with the data provided by the manufacturer. So the study concluded that the simulation used is very useful for students and engineers because of its speed and ease of use to determine the performance of any photovoltaic module.

Ref. [6] provided a simple model of two-diode for a photovoltaic (PV) system able to infer equations that translated the current and voltage. The study analyzed the accuracy of the

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model by comparing it to other studies. The experimental results also showed a good compatibility with the results of the voltage and current measured in practice. The simulations achieved resulted in a simplified and accurate model for use in low radiation conditions. The study recommended using equations performed using the MATLAB program.

Ref. [7] developed a numerical simulation using the Matlab program and transport matrices to solve optical equations. This method allowed for optical reflectivity, wavelength absorption, and layer thickness. The electrical cell performance was simulated using PC1D and Silvaco. The results showed a 0.3% increase in cell efficiency.

The present study aims to build and equip a simulation model using the Matlab language, through which we can obtain the PV cell performance specification curves. This simulation programming is used for the purpose to obtain these curves; the PV cell must be represented by an electronic circuit consisting of DC source, diode, Resistors, as shown in Figure (1). The current (I_{ph}) source is connected in parallel with the diode and R_{sh} resistor and all components connected respectively with R_s resistor [8].
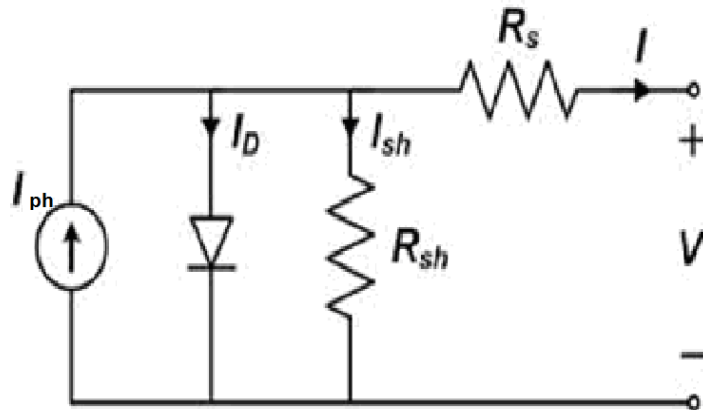

Fig. 1: PV cell model

Mathematical modeling of the PV cell

Depending on the circuit in fig. 1 and using Kirchhoff's law it is clear that:

$$I = I_{ph} - I_d - I_{sh} \tag{1}$$

Where:
I = Output current
I_{sh} = Shunt resistance current
I_d = Diode's current
I_{ph} = Current of photo cell
The current passes these segments are regulated by the voltage across finished them:

$$V_j = V + IR_s \tag{2}$$

Where
V = Terminals voltage (volt)
V_j = Voltages of the diode and resistor R_{sh} (volt)
R_s = Series resistance (Ω)
Using the Shockley diode condition, the current Transit of the diode is:

$$I_d = I_o \left\{ e^{\left[\frac{V_j}{n \times V_T} \right]} - 1 \right\} \tag{3}$$

Where:
I_o = Reverse saturation current of the diode.
Thermal voltage is:

$$V_T = \frac{k \times T}{q} \tag{4}$$

$V_T \cong 0.0259$ volt at 25° C
n = the diode's ideality factor (No units).
q = Charge of the electron = (1.602×10-19 C).
k = Boltizmann's constant (1.381×10-23 J/K).
T = Operating temperature (Kelvin).
Employing Ohm's law, the current passes in the parallel resistor is:

$$I_{sh} = \frac{V_j}{R_{sh}} = \frac{V + IR_s}{R_{sh}} \tag{5}$$

Where:
R_{sh} = Parallel resistance (Ω).
By compensating these values in Equation 1, these variables affect the solar cell and this effect is clearly reflected on the resulting current and voltages [8, 9, 10]:

$$I = I_{ph} - I_o \left\{ e^{\left(\frac{V+IR_s}{n \times V_T} \right)} - 1 \right\} - \frac{V + IR_s}{R_{sh}} \tag{6}$$

Photo current is managed and evaluated by the accompanying equation:

$$I_{ph} = \left[I_{sh} + K_c(T - 298) \right] \times \left(\frac{G}{1000} \right) \tag{7}$$

Where:
I_{sc} = Short circuit current.
K_i = Temperature coefficient of the solar cell short circuit = 0.0017
G = Radiance (mW/m^2) in this equation 7 is divided by 1000 to change units from mW/m^2 to W/m^2.

There are two important cases of the solar cell; the first is the open circuit while the second is the short circuit [11, 12]. In the case of the open circuit, there is no load on the cell, and the current will be at its minimum value (zero), and the cell voltage will be at its greatest value, known as the open circuit voltage of photovoltaic cells, or V_{oc}. In the second case, the photovoltaic cell is in short circuit conditions, as the cell's terminals are connected to each other. In this case, the cell voltage is zero, and the current is at its

greatest value, known as the short circuit of the photovoltaic cell [13, 14, 15].

The (I-V) curve of the solar cell ranges between the short circuit current (I_{sc}) when the return voltage is zero and the voltage of the open circuit (V_{oc}) where the highest voltage value and the current value is zero. The maximum voltage that can be achieved from the cell is in the open circle case at the end of the day, and the most extreme case is in the closed circuit. Obviously neither of these conditions produces any electrical energy, but there must be a point somewhere in the middle where the solar cell can generate its maximum energy [8, 16, 17].

When the PV cell operates at open circuit case, the total current I = 0, the voltage between the two terminals represents the open-circuit voltage. Assuming that the bounded resistance between the two terminals in parallel is of sufficiently high value, and then the V_{OC} is:

$V_{oc} = V_T \times \ln [I_{ph}/I_o]$

At the second case (short circuit), this makes the entire current passes through this contact point between the two terminals, so I_{ph} is proportionate to I_{sc}.

$$I = I_{ph} - I_d$$

Where:

I_d = from equation 3 $I_d = I_o \left\{ e^{\left[\frac{V_j}{n \times V_T} \right]} - 1 \right\}$, so:

$$I = I_{sh} - I_o \left\{ e^{\left[\frac{V_j}{n \times V_T} \right]} - 1 \right\}$$

As mentioned above, the entire current passes through the diode due to the high shunt resistance value.

$$o = I_{ph} - I_o \times \left[e^{\frac{(q \times V)}{(N_s \times k \times n \times T)}} - 1 \right]$$

$$I_o = \frac{I_{sh}}{\left[e^{\frac{(q \times V)}{(N_s \times k \times n \times T)}} - 1 \right]} \quad (8)$$

The current passes through the shunt resistance can be obtained by:

$$I_{sh} = I_o \left(\frac{T}{T_{ref}} \right)^3 \times \left[e^{\left(\frac{q \times E_g \left(\frac{1}{T_{ref}} - \frac{1}{T} \right)}{k \times n} \right)} \right] \quad (9)$$

Where:
T_{ref} = Ref. temp. in (K).
E_g = Silicon band gap.

For a system of photovoltaic cells consists of a group of cells connected in series symbolized as Ns, while in the case of linking the cells in parallel their numbers symbolized as N_p.

$$I_{module} = N_p \times I_{cell} \text{ And } V_{module} = N_s \times V_{cell}$$

The final equation of the output current from a module's is:

$$I = (N_p \times I_{ph}) - N_p \times I_{sh} \left[e^{\left(\frac{q(V + (IR_s))}{(N_s \times n \times k \times T)} \right)} - 1 \right] - \frac{V + IR_s}{R_{sh}} \quad (10)$$

These above equations explain briefly the mathematical modeling of the solar cell in details, the next sections of this research is to write the software depending on these equations [8, 18, 19, 20].

Software parameters settings of the solar cell
In this research, Matlab programming was used to obtain solar cell properties by obtaining the I-V and P-V curves. These curves help designers to choose the type and specification of the solar cell. In the program shown below, the mathematical equations mentioned in the previous part of this section were used, which is a representation of the solar cell [8].

The specifications of this program, it is possible to change the variables affecting the specifications of the solar cell and several values at the same time such as temperature, radiation intensity, cell type used by changing the values of resistance etc….

For the purpose of completing the program used in this research, a number of variables (constants) were assumed in the equations mentioned in the previous section and as shown in Table 1 [21, 22, and 23].

Table 1: Photo cell Model Parameters

Variables	Variable Description	Variables Values
R_s	Series resistance	0.002 (Ω)
R_{sh}	Shunt resistance	100000 (Ω)
K_i	Short circuit solar cell Temperature coefficient	0.0017
I_{sh}	Shunt resistance current	3.8 (A)
N_s	Cell number in series	36
N_p	Cells number in parallel	1
E_g	Band gap for Silicon	1.1
n	Ideality factor of the diode	1.1
I_{sc}	Solar cell short circuit current	3.8 (Amp.)
T	Operating temperature	25 C^o (can be changed to any other value)
G	Irradiance	1000 mW/m^2 (can be changed to any other value)

Software modeling

The objective of this article is to write software by using Matlab to anticipate the performance and characteristics of the solar cell through different operating conditions and settings as shown in table (1) which can be changed according to the system designed in order to obtain performance maps as following so the software is general purpose [8, 24].
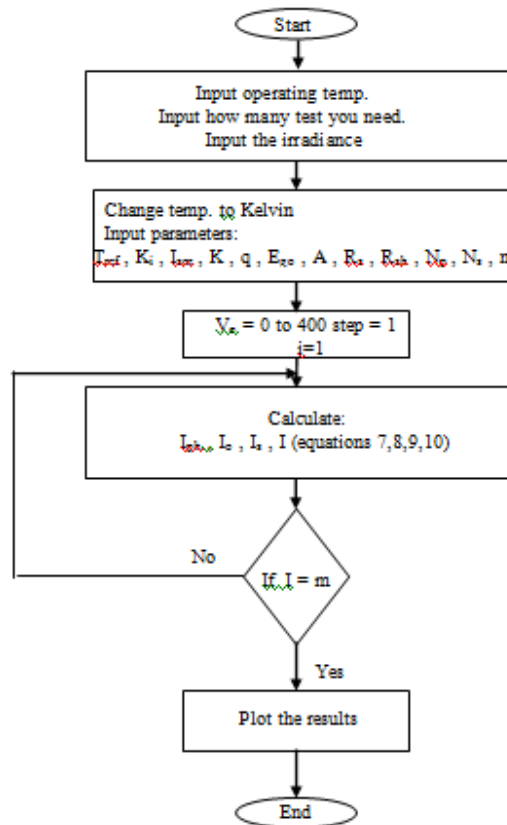
The software flowchart shown in figure 2 below:

Fig. 2: Solar cell modeling flowchart

From the above program flowchart, it will ask few questions to enter some parameters such as operating temperature, number of tests and irradiance of each one (test), the program can be improved or changed very easily by the same way by adding few steps to enter other parameters other than temperature and irradiance such as resistance values (series and shunt), short circuit current, diode ideality factor, cells of series and parallel number, shunt resistance current. In this program equation 7, 8, 9, 10 have been applied in order to get the results [25, 26].

Results and calculations

After running the program with setting described in table (1) with operating temperature equal to 25 C°, one get the results as appeared in figures (3, 4, 5).

Figure 3 demonstrates the connection between current and voltage of the photovoltaic cell for different irradiance, and from these curves the short circuit current increase when the irradiance increase and vise versa, same thing for open circuit voltage, it will increase for greater irradiance.
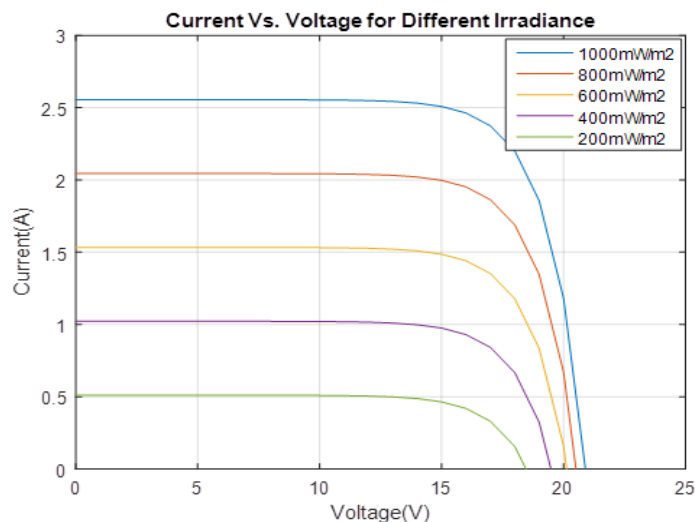

Fig. 3: Solar cell Current vs. Voltage for different irradiance.

Figure 4 shows the relationship of power and voltage of the solar cell for different irradiance, from these curves the maximum output power increase when the irradiance increase and vise versa, same thing for open circuit voltage, it will increase for greater irradiance.
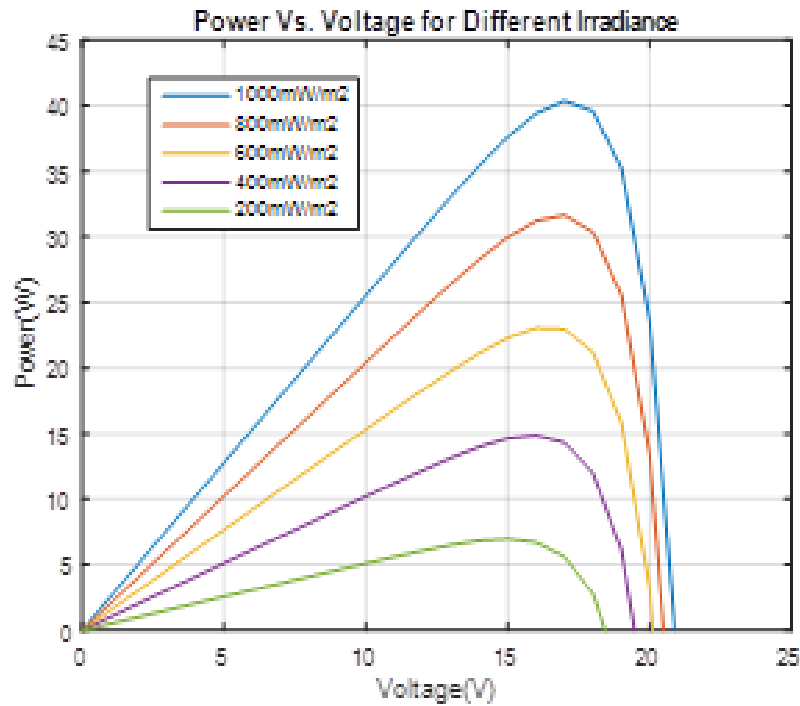

Fig. 4: Solar cell power Vs. Voltage for different irradiance.

Figure 5 shows the relationship of power and current of the solar cell for different irradiance, from these curves the maximum output power increase when the irradiance increase and vise versa, same thing for short circuit current, it will increase for greater irradiance.
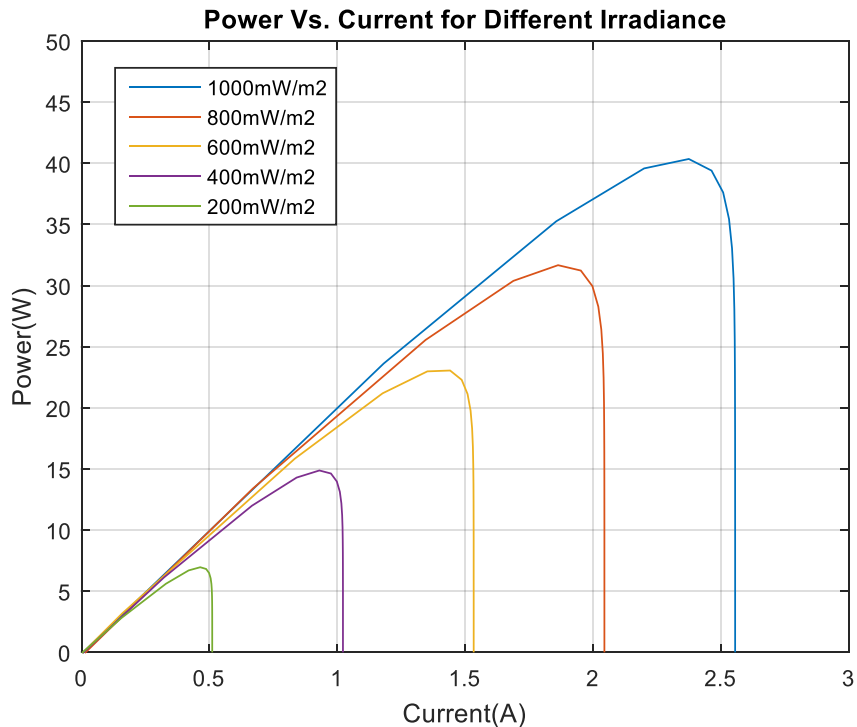

Fig. 5: Solar cell power Vs. Current for different irradiance.

The above results show the impact of irradiance variation on the photovoltaic characteristics curve. Another test has been done to know the influence of temperature variation on the PV characteristics while irradiance is fixed at (1000 mW/m^2) as shown in Figures (6, 7, 8). It is clear that when temperature increases the short circuit current increase slightly (almost unaffected) but the open circuit voltage decrease, as a result the power decrease.
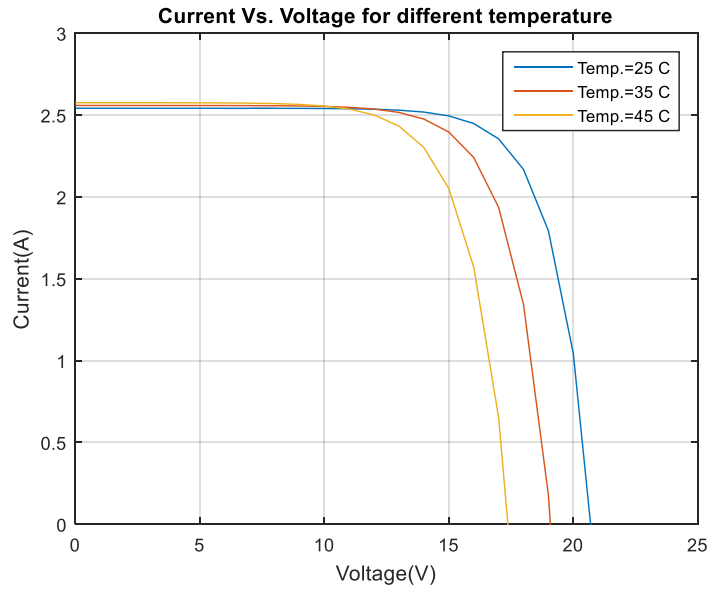
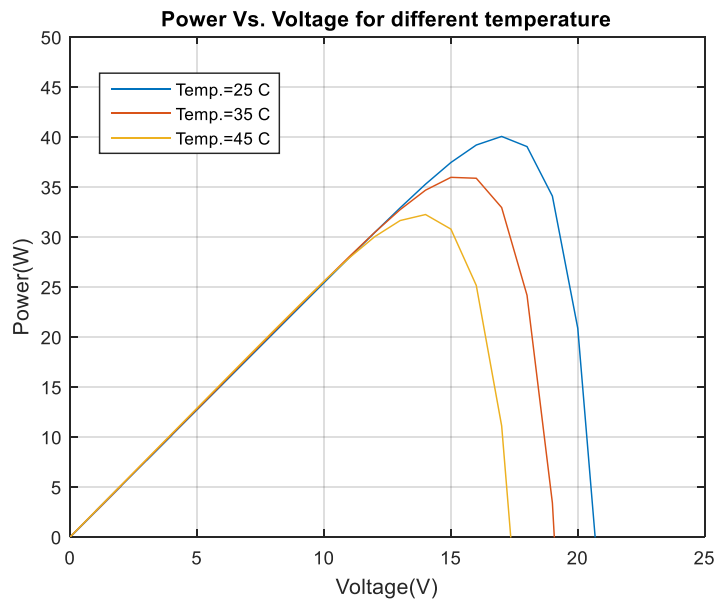**Fig. 6:** Solar cell current vs. voltage for different temp

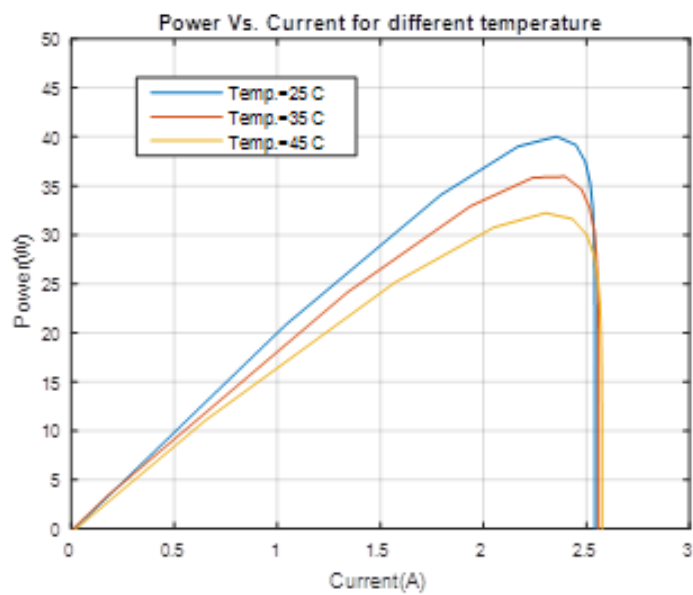**Fig. 7:** Solar cell power Vs. Voltage for different temp.

Fig. 8: Solar cell power Vs. current for different temp.

Fig. 9 represents the maximum power obtained from a solar cell; there is a specific value for both the voltage and current at which the maximum power can be obtained (V_{mp} and I_{mp}). At the end, the time when the PV cell generates its maximum power as shown in the upper right zone of the left rectangle. This point is the "maximum power point" or MPP. The intersection point of the blue curve with the vertical line falling from the maximum power shows the maximum power point (MPP). This point expresses the
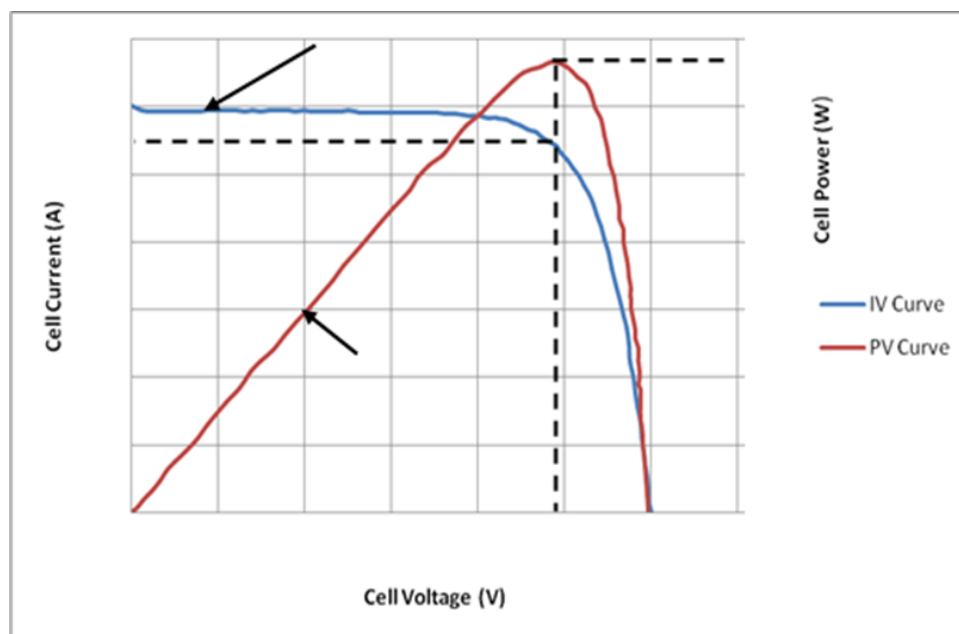
best specification and efficiency of the solar cell [8].

The PV Maximum power point (MPP) is situated close to the I-V characteristics curves. The comparing estimations of Vmp and Imp can be assessed from the V_{oc} and I_{sc}: V_{mp} is about (0.8–0.90) of V_{oc} and Imp almost (0.85–0.95) of I_{sc}. Since photovoltaic current and voltage affected by temperature variation, then the resulted power will vary with this variation [25, 26].

Fig. 9: Clarifying curve for Maximum power point calculation [27].

Conclusion

One can notice from this article that solar cell can be simulated by using Matlab-Software, also there are many other programs can be used but Matlab has the facilities that it is very easy and it have many functions can help to make changes for the parameters simply.

From this work solar cell characteristics curve obtained by the software mentioned above and by changing the hardware parameters such value of the resistances, connection of the cells, I_{sc}, V_{oc} and ideality factor, and environment parameters such as temperature and irradiance.

So this program help the manufacturer and designer to simulate the solar cell and make many changes till get the appropriate solar cell specification and after that they begin to manufacture it so it reduce coast and time spending.

The maximum efficiency of the solar cell is achieved at the maximum output power. The suggested software declared that this maximum power can be reached by changing the solar cell parameters as mentioned above.

The program is very easy, when the program run it ask few questions about the parameters and number of tests needed and by run the program the characteristic of the solar cell is obtained, the program can improved in the future to get other facilities of the solar cell properties by adding few simple steps.

From the output curves it is seen that when irradiance increase the output power and current increase while increasing temperature is reduce the output power and output voltage of the solar cell.

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