



Experimental and Theoretical Analysis of a Mono PV Cell with Five Parameters, Simulation Model Compatible with Iraqi Climate

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Abstract— The present work included study of the effects of weather conditions such as solar radiation and ambient temperature on solar panels (monocrystalline 30 Watts) via proposed mathematical model, MATLAB_Simulation was used by scripts file to create a special code to solve the mathematical model, The latter is single –diode model (Five parameter), Where the effect of ambient temperature and solar radiation on the output of the solar panel was studied, the Newton Raphson method was used to find the output current of the solar panel and plot P-V, I-V curves, the performance of the PV was determined at Standard Test Condition (STC) (1000W/m²) and a comparison between theoretical and experimental results were done. The best efficiency ranging from 0.15 to 0.16. With a particularly, error about (-0.333) for experimental power (30 Watt) comparing with theoretical power (30.1), through these results it is concluded the validity of the proposed model. This model can be used for all types of photovoltaic panels and also with larger output power.

Keywords— Mono photo-voltaic (PV) cell, P-V curve, Matlab_Simulation, modelling; five-parameter PV model.

1. Introduction

The PV system can generate direct current electricity without environmental effect when it is subjected to solar radiation. Solar energy through the photovoltaic effect (PV) can be considered the most important renewable resources because of the availability of permanent and completely free of cost as in [5]. Based on Vergura [12] study, the performance of the photovoltaic (PV) system depends mainly on the solar irradiance and cell temperature, which is establishing toughly influences on the short-circuit current, finally on the open-circuit voltage. Therefore, the performance is influenced by the maximum power point (MPP), suggests that a reliable model of a PV system must take into account these parameters for any type of investigation monitoring of the performance, forecasting of the produced power, expansion and work out of maximum power point tracking algorithms and so on. The finite element approach is used for modelling some classes of defects in the PV cells [12]. Modelling is mandatory and necessary to study PV cells faulty. The photovoltaic (PV) cell performance is intrinsically affected by internally constraints PV

Parameters such as the series resistance (R_s) and shunt resistance (R_{sh}), the reverse saturation current (I_0) and the ideality factor (a). The changes on the ideality factor are very small, so it may be neglected with the weather clement changes and it is assumed constant for each PV model as given in table (1) [4] and [11]. Modelling is the primary factor that influences simulation results and accuracy in explaining the nonlinear characteristic of the PV system [10].

Emeksiz et al. [7] used a Matlab and Retscreen software to extract the model parameters. The simulation results take into account the effect of temperature and radiation in Tokat Region and they used three different methods (Manhattan, Euclidean and Minskowski) distance to extracted the distance of maximum power. The maximum distance of the results was calculated via Manhattan Distance.

Table 1: Ideality factor (a) [Liang Tsai,2008] [11].

Technology	Ideality factor
Si-mono	1.2
Si-poly	1.3
a-Si-H	1.8
a-Si-H tandem	3.3
a-Si-H triple	5
cdTe	1.5
CTs	1.5
AsGa	1.3

where as in presenting a simulation and modeling using Matlab_Simulink, considering the weather factors (temperature and solar radiation). Five parameter model, which are (I_{ph} , R_s , R_{sh} , a , I_0) is used in this model. The researchers concluded that they could use it as a tool to study all types of photovoltaic module available in markets under the influence of weather information history for standard test conditions [3]. This work Proposed a PV model to calculate the energy of different types of solar panels (monocrystalline, polycrystalline and thin film) by Matlab_Simlink for weather conditions of Istanbul. The energy of each solar panel was calculated under real condition and take into account the effect of temperature, radiation and wind speed. Results showed that the monocrystalline was more consistent with the model, where the proposed PV model has a deviation rate of 3.25%, 3.70% for thin-film panels, and 13.93% for polycrystalline silicon panels [2].

The aim of this work is to consider a simple, easy model, and fast tool for performance description of several types of solar cells, as well as, determines the environmental conditions which affect the operation of the proposed system. Therefore, we suggest a method of modeling and simulation of photovoltaic panels using Matlab_program. This method is based on the extraction the characteristic of PV panels and to study the effect of different values of solar radiation at different temperature values for weighing the optimum performance of PV cells. By considering the inspiration of solar radiation and cell temperature into consideration, the output current and power characteristic of photovoltaic module are simulated using the proposed model. Detailed modeling procedure for the circuit model is offered.

2. Experimental setup

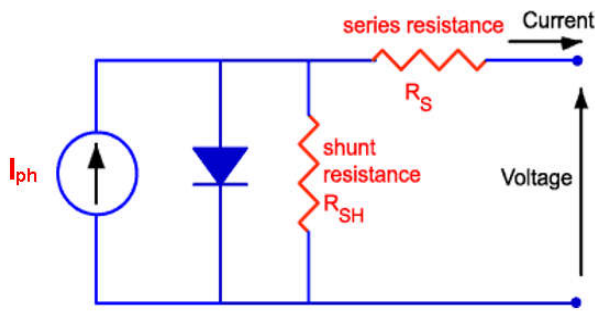
The experimental system adopted for this work, consists of a PV panel monocrystalline (0-60°C, Biao Di) fixed frame used with tilt angle 33° (local latitude of Baghdad city) towards the south and a solar module analyzer (0 °C ~ 50 °C, 85% RH, prova) is a connect of PV panel electrodes with computer for data transfer and, solar meter (0.1 W/m², 0.1 Btu/ (ft² x h), 400 ~ 1000nm, TES instruments) used to measure solar radiation, weather station (-40 to 65°C,0.5°C) for measure the (ambient temperature, wind speed, humidity) and sensor temperature (-50~70 °C, ±1 °C (-20 °C~+80°C); ±2°F (-4°F~+176°F) to measure the cell temperature as shown in

Figure 1 and Figure 2, experiment was conducted on the system for four months from October 2017 to January 2018 at time from 8 a.m. to 2 p.m., The PV module specifications of the manufacturer are given under standard conditions in Table.2.

**Figure 1:** Experimental setup**Figure 2:** Measuring apparatus from right to left: digital thermometer, Solar Power meter, solar module analyzer, and Weather station vantage prova2

Table 2: Module specifications at STC as presented by the manufacturer.

Rated power	30 W
Voltage At Maximum Power (Vmax)	17 V
Current At Maximum Power (Imax)	1.76 A
Open Circuit Voltage (Voc)	22 V
Short Circuit Current (Isc)	1.9 A
Normal Operation Cell Temperature	25 °C
Modulweight	3.5 Kg
Area	0.282 m ²
no. of cells (ns)	36

**Figure 3:** Electrical Device of Solar Cell with One-Diode

3. Mathematical model of a PV cell

In this work using Single_diode model (five parameter) is shown in figure.3 where (I_{ph}) is photo current in (A), D a single_diode, R_{sh} and R_s parallel and series resistance (Ω), respectively. I output current of a PV module in (A) and V output cell's voltage in (V) [12], [7] and [3].

This parameter is described by equation:

$$I = I_{ph} - I_o \left(\exp \left(\frac{V + R_s I}{a V_t} \right) - 1 \right) - \frac{V + R_s I}{R_{sh}} \quad (1)$$

Equation (1) is a nonlinear expression because I is a function of I and V in order to get a linear expression of (I) Newton Raphson's method is used to solve nonlinear equations as [6].

$$X_{n+1} = X_n + 1 \frac{f(X_n)}{f'(X_n)} \quad (2)$$

where $X_n = I$. consider $f = f(I, V)$

From the Equation (1), it shows that the solar cell Parameter extraction refer of the five parameters (R_{sh} , R_s , a , I_{ph} , I_o).

3.1 Equations for Determine Cell Parameters

The cell temperature can be calculated by using Equation (3). This equation depends on Weather conditions like ambient temperature, solar radiation and wind speed [9].

$$T = T_a + W \left[\frac{0.32}{8.91 + 2 \frac{v_w}{0.67}} \right] G \quad (3)$$

The change of these parameters according to the solar radiation and/or cell temperature is given below [12].

$$I_{ph} = G_{pu} \cdot [I_{sc}^{\circ} + \alpha_{Isc} \cdot (T_c - 25)] \quad (4)$$

$$I_{mmp} = G_{pu} \cdot [I_{mmp}^{\circ} + \alpha_{Isc} \cdot (T_c - 25)] \quad (5)$$

$$V_{oc} = V_{oc}^{\circ} - \alpha_{Voc} \cdot \Delta T \quad (6)$$

$$V_{mmp} = V_{mmp}^{\circ} - \alpha_{Voc} \cdot \Delta T \quad (7)$$

$$I_{sc} = \rho \cdot [G_{pu} \cdot (I_{sc}^{\circ} + \alpha_{Isc} \cdot \Delta T)] \quad (8)$$

$$R_{sh} = \frac{V_{mmp}^{\circ} - \alpha_{Voc} \cdot \Delta T}{G_{pu} \cdot \left(\frac{I_{sc}^{\circ} - I_{mmp}^{\circ}}{2} \right)} \quad (9)$$

$$R_s = \frac{\left(\frac{V_{oc}^{\circ} - V_{mmp}^{\circ}}{4} \right)}{G_{pu} \cdot (I_{mmp}^{\circ} + \alpha_{Isc} \cdot \Delta T)} \quad (10)$$

$$\rho = \frac{R_{sh}}{R_{sh} + R_s} \quad (11)$$

Thermal voltage depended on cell temperature is given by [8].

$$V_t = \frac{K T_{ns}}{q} \quad (12)$$

where K Boltzmann constant (1.3806×10^{-23} J/K). ns number of the series-connected cells in a PV module equal 36 and q electron charge (1.602×10^{-19} C), so it is depending on T .

The output power of the PV panel is given in the simplest form as:

$$P = IV = \left[I_{ph} - I_o \left(\exp \left(\frac{V + R_s I}{a V_t} \right) - 1 \right) - \frac{V + R_s I}{R_{sh}} \right] V \quad (13)$$

All of these previous equations can be solved by a MATLAB program. The flow chart of the program is shown in figure .4.

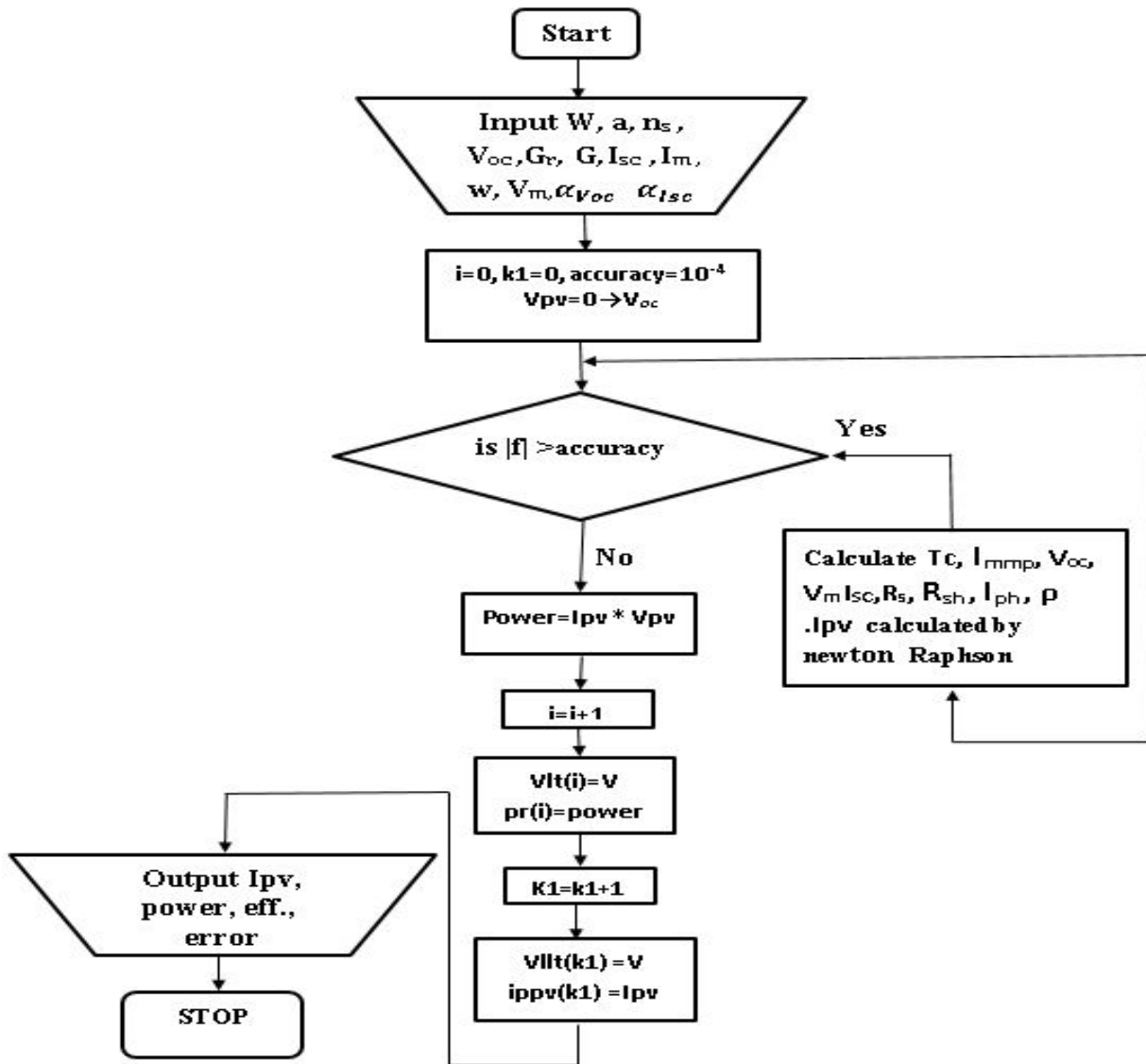


Figure 4: flow chart of Matlab program

4. Results and Discussions

In this section, single-diode five parameter model had been solved by simulation in Matlab. In this model, two variables are entered solar radiation and temperature of the cell (module). These inputs have been measured in normal conditions of those measurements were conducted in three months (October, November and December). For each of these input values there are output powers. The output power of one diode five parameter model and measured via experimental work for different levels of solar radiation like (500,750 and 1000 W/m²) and variable temperature are given in table (3). Figure 5, figure 6 and figure 7 show the comparison between the P-V curve obtained from the proposed model five parameters and the conforming three results of experimental work for solar radiation (500,750 and 1000W/m²) respectively in October. Figure 8 and 9 show the comparison between the experimental and modeling

results at different level of solar radiation (500,750 and 1000 W/m²) in December. Figure 10 shows P-V curves for the monocrystalline module predicted by the five – parameter model and experimental at STC. From table.3 comparing the theoretical, experimental results and calculating the error ratio, it was found that the lowest rate of error in radiation 500 W/m² at low temperature module, this indicate that the higher temperature of the module increases the ratio of error. Table 4 shows the comparison between our results and other previous studies for different radiation values, temperature, maximum power and maximum efficiency in November and December, it was found that increment in the power and efficiency indicated with decreasing module temperature. The error is calculated by the equation below:

$$error = \frac{Laboratory\ measurments - Matlab\ results}{Laboratory\ measurments} \times 100\% \quad (14)$$

Table 3: Shows the sample result of experimental and theoretical at different radiation.

Temperature module	Radiation (W/m ²)	Power simulation (W)	Power measured (W)	Error %	Eff. simulation	Eff. measured
October 32°C	500	14.2	14.4	1.4	0.1	0.102
41°C	750	21	19.6	-7.1	0.099	0.092
48°C	1000	27	25.3	-9.3	0.095	0.089
November 33°C	500	15	22.1	32	0.105	0.156
39°C	750	21.5	22.3	3.6	0.101	0.104
44°C	1000	27.7	27	-2.6	0.098	0.096
December 12°C	500	16	16.2	1.2	0.113	0.114
18°C	750	23	22.3	-3.1	0.108	0.105
24°C	1000	30.1	29	-3.8	0.106	0.102
1.366667		Total average of error %				

Table 4: Maximum power and efficiency for experimental work comparison with other previous studies.

Radiation (W/m ²)	Our results			AbdAl-whaed, 2016[1]		
	Temperature module°C	Power max.(w)	Eff. max	Temperature module°C	Power max.(W)	Eff. max
November 500	33	22.1	0.156	38.2	17.34	0.10
750	39	22.3	0.104	44.1	21.57	0.102
1000	44	27	0.096	48.1	26.88	0.095
December 500	12	16.2	0.114	19.1	14.19	0.123
750	18	22.3	0.105	23.1	21.06	0.099
1000	24	29	0.102	30.3	25.22	0.089

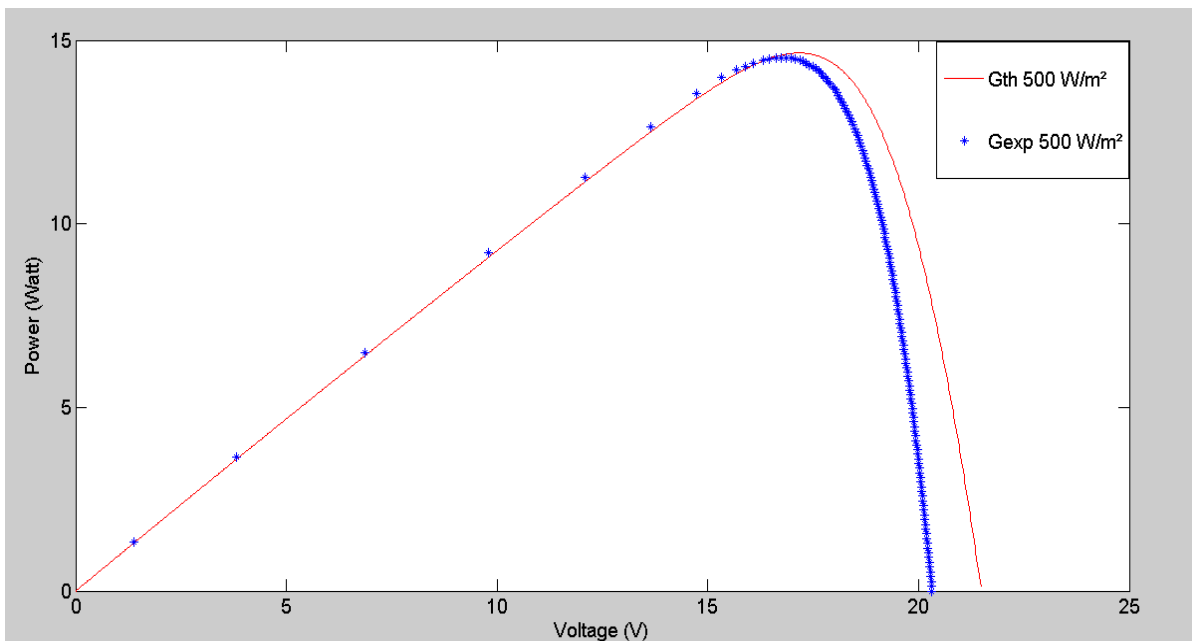


Figure 5: P-V curves for the monocrystalline module predicted by the five –parameter model and experimental measured result in Oct of radiation 500 W/m²

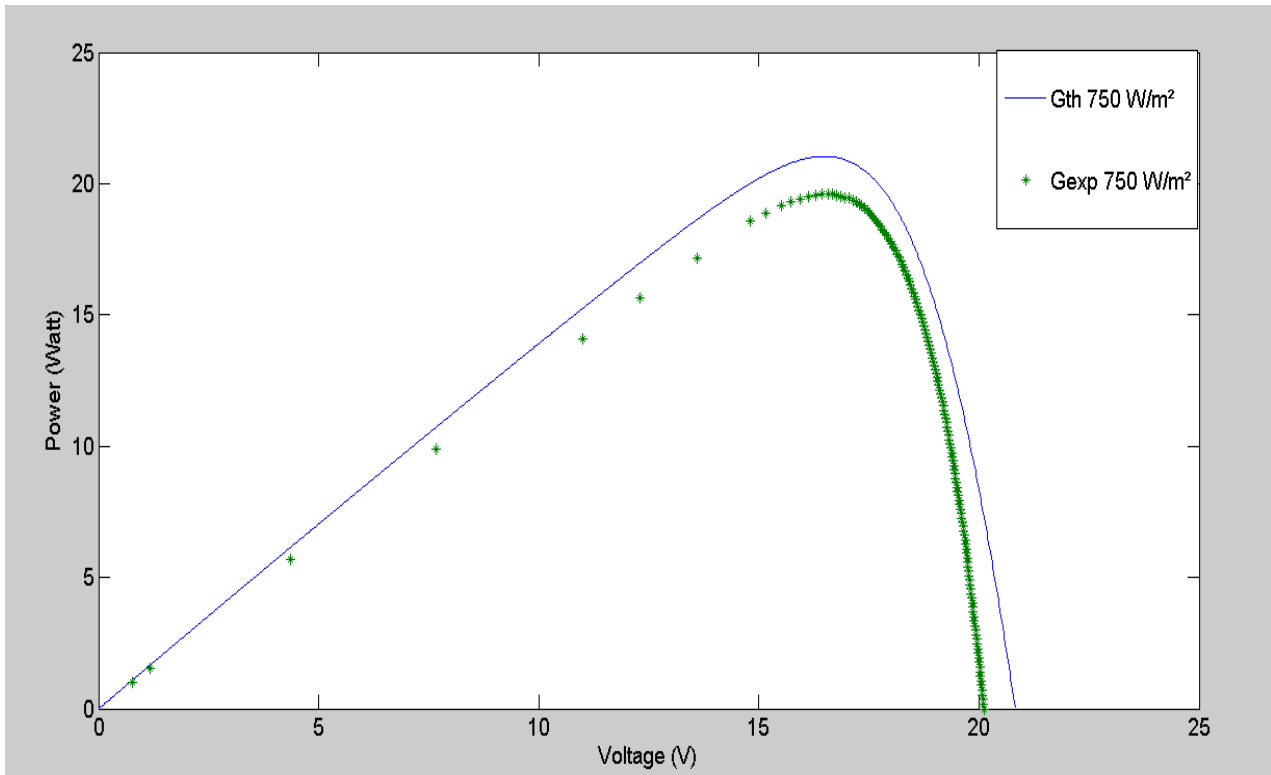


Figure 6: P-V curves for the monocrystalline module predicted by the five –parameter model and experimental measured result in October of radiation 750 W/m^2

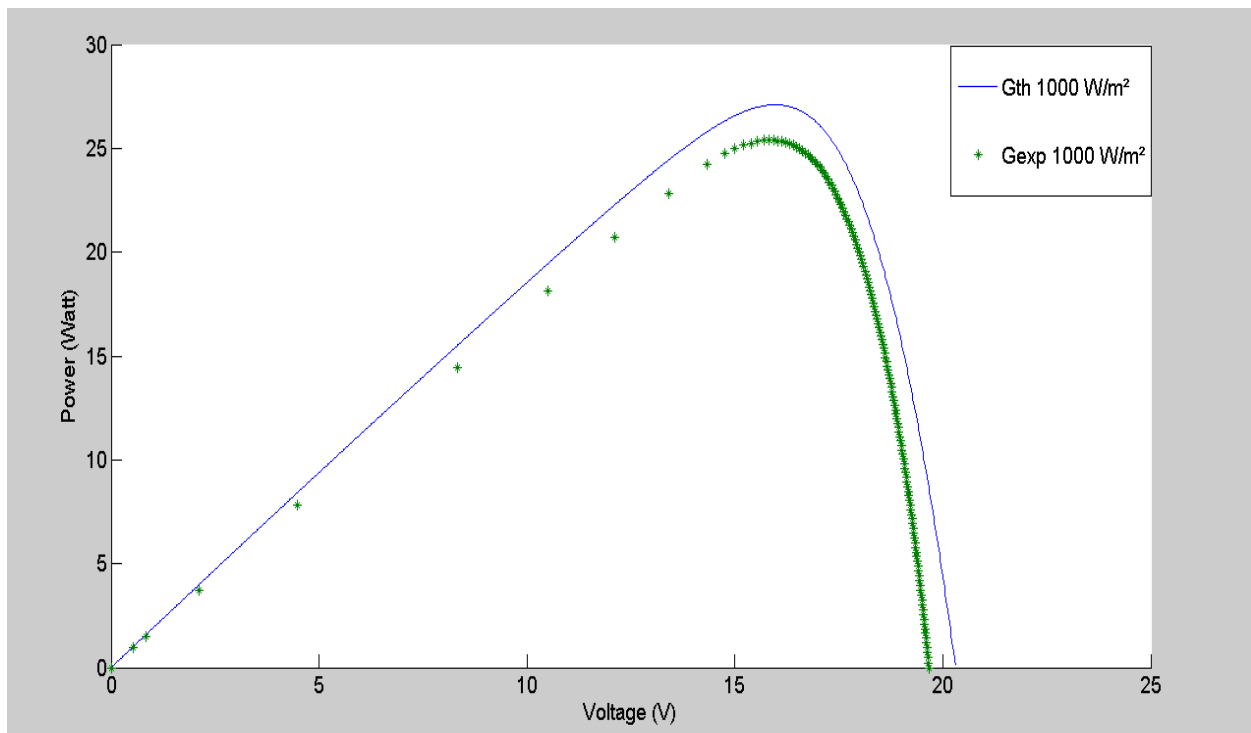


Figure 7: P-V curves for the monocrystalline module predicted by the five –parameter model and experimental measured result in October of radiation 1000 W/m^2

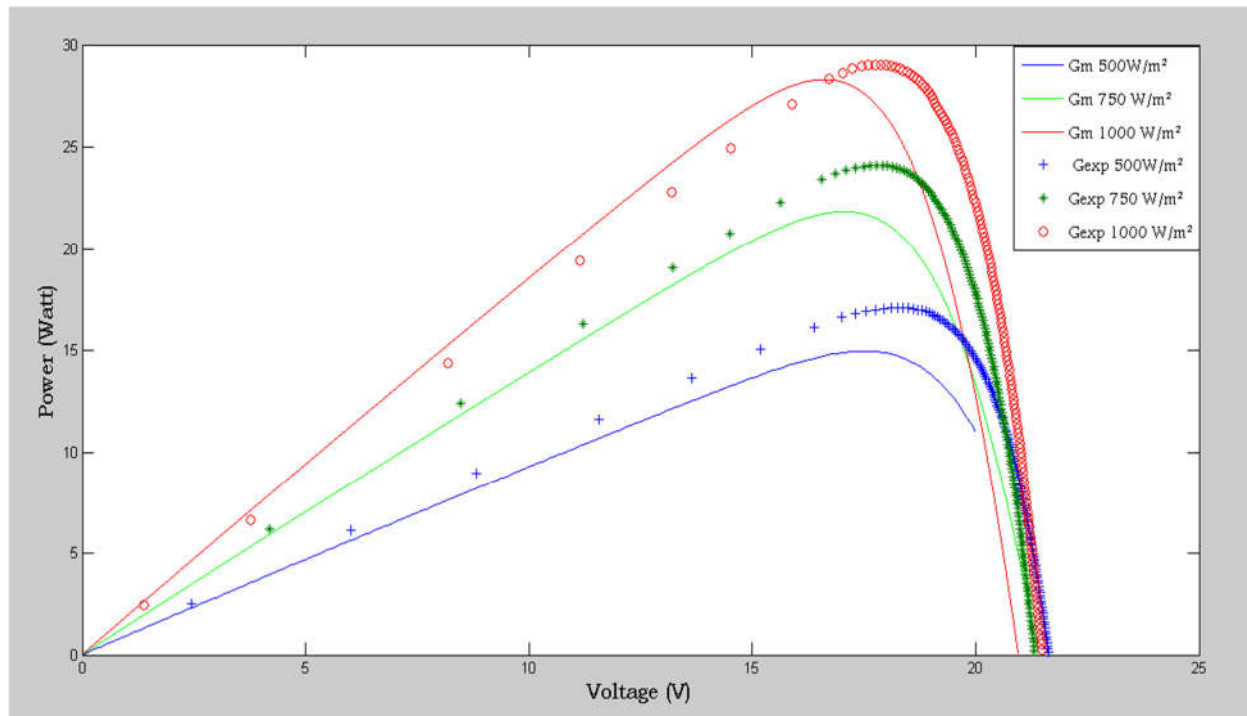


Figure 8: P-V curves for the monocrystalline module predicted by the five –parameter model and experimental measured result in December

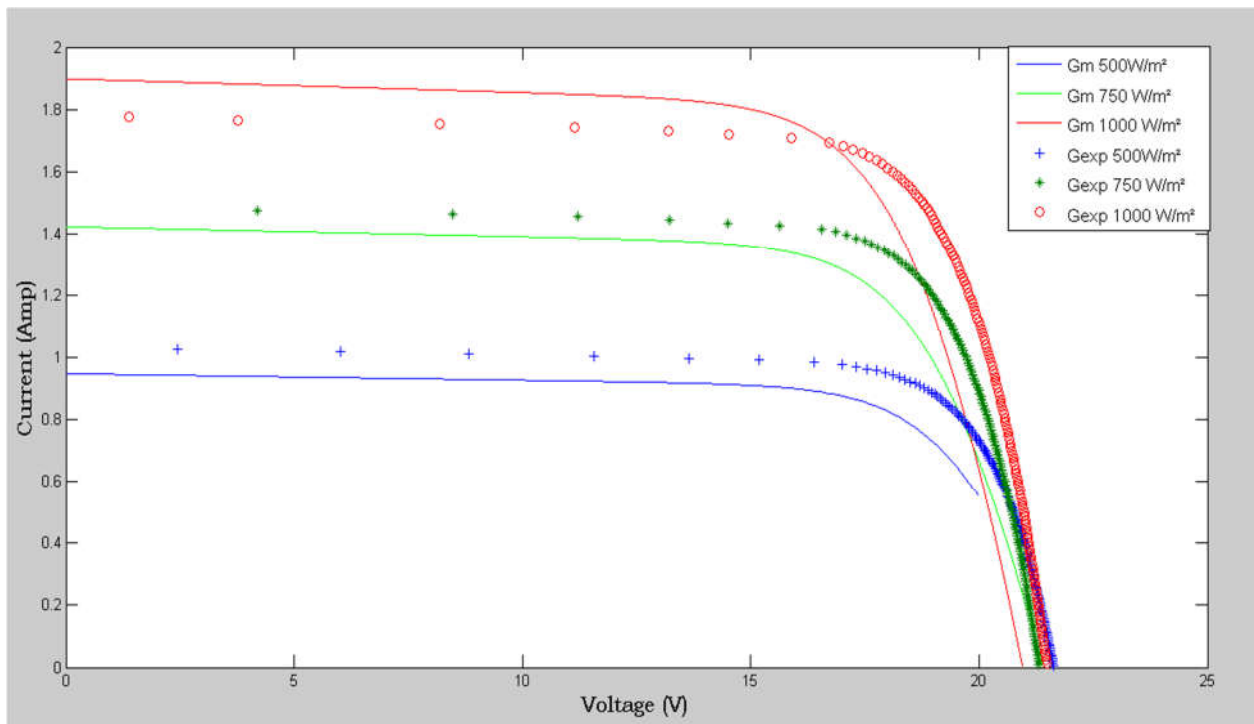


Figure 9: I-V curves for the monocrystalline module predicted by the five –parameter model and experimental measured result in December

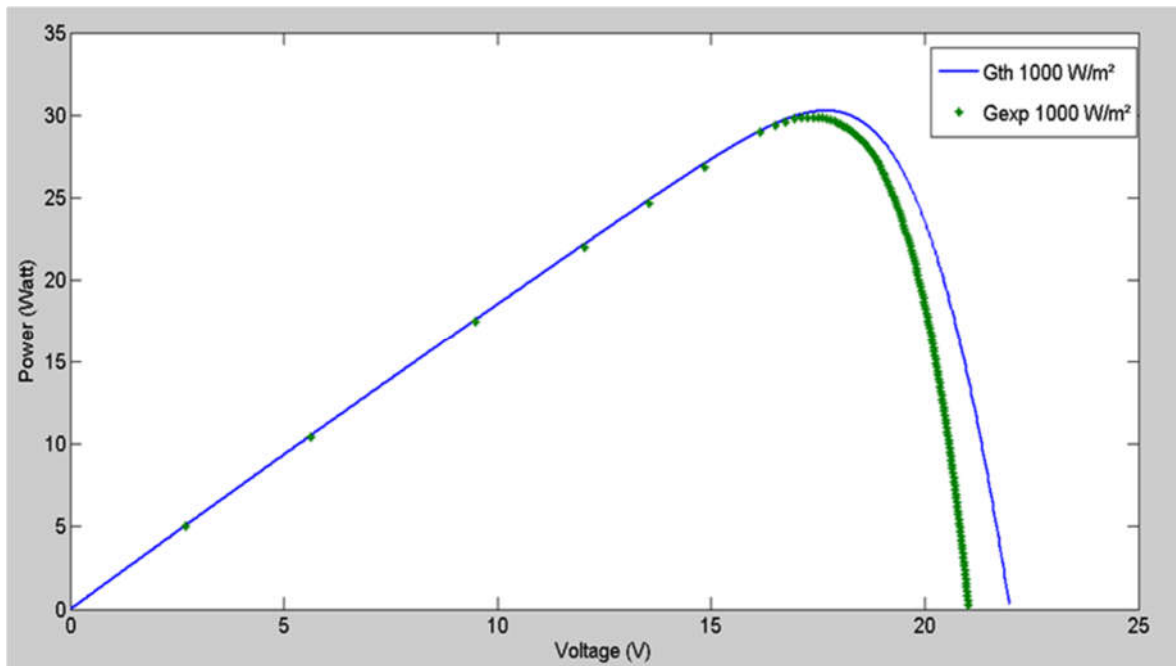


Figure 10: P-V curves for the monocrystalline module predicted by the five-parameter model and experimental at STC

4. Conclusion

According to the results obtained and the previous discussion the following conclusion can be extracted:

1. Power output or wattage is an important factor to consider when comparing solar panel options.
2. The parameters of the Solar cell specification are also lectured in this study by using a parameter extraction technique. The arrangements of solar cell model parameters gotten by using the parameter extraction technique are capable to breed the behavior of the PV array in real conditions of work with high efficiency around 0.16.
3. The solar radiation variation in Iraq is enough to apply PV cell for generating electricity with good performance, so it is an optimized choice of using the solar energy as an alternate choic for providing energy instead of oil.
4. One can conclude that at minimum radiation (500 W/m^2) and minimum temperature lead to minimum percentage error and as radiation increased the PV cell temperature is increased and percentage error rise.

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Nomenclature

q	Electron charge (1.602×10^{-19} C).
k	Boltzmann constant (1.3806×10^{-23} J/K).
α	Diode ideality factor.
Tc	Temperature of the p-n junction (K).
I_{ph}	Photocurrent (A).
I_0	saturation current (A)
V_t	Thermal voltage (V).
R_s	Equivalent series resistance of the array (Ω).
R_{sh}	Equivalent parallel resistance of the array (Ω).
ρ	Proportion between R_s , R_{sh}
ns	Number of the series-connected cells in a PV module.
G	Solar irradiance (W/m^2).
G_{pu}	$G/1000$ (W/m^2).
I_{sc}^o	Short circuit current at STC (A).
α_{Isc}	Thermal coefficient of the short-circuit current ($A/^oC$).
α_{Voc}	Thermal coefficient of the open –circuit voltage ($V/^oC$).
V_{oc} , V_{oc}^o	Open-circuit voltage of a PV module and its voltage STC (V).
I_{sc} , I_{sc}^o	Short-circuit current of a PV module and its value at STC (A).
T_a	Ambient temperature in oC .
v_w	Local wind speed in m/s, will take the average 2.2 m/s.
W	Mounting affect.
I_{mmp} , I_{mmp}^o	Current at the maximum power point (MPP) and at STC (A).
V_{mmp} , V_{mmp}^o	Voltage of a PV module at the MPP and voltage under STC (V).
P	Output power of a PV module (W).
I	Output current of a PV module (A).
V	Output voltage of a PV module (V).
Gth	Theoretical radiation (W/m^2).
Gexp	Experimental radiation (W/m^2).
CdTe	Cadmium telluride.
Si-mono	Monocrystalline silicon.
Si-poly	Polycrystalline silicon.
AsGa	Arsenide Gallium.
a-Si-H	Hydrogenated amorphous silicon.
a-Si-H triple	Hydrogenated amorphous silicon triple.
a-Si-H tandem	Hydrogenated amorphous silicon tandem.
CTs	Copper Tin sulfide Cu_2SnS_3 .
STC	Standard test condition.

التحليل التجريبي والنظري للخلية الكهروضوئية الأحادية مع خمسة معلمات، نموذج محاكاة متلائم مع بيئة مناخ العراق

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الخلاصة اشتمل العمل الحالي على دراسة تأثيرات الظروف المناخية مثل الإشعاع الشمسي ودرجة حرارة المحيط على الألواح الشمسية (أحادي البلورة 30 واط) عبر نموذج رياضي مقترح ، واستخدم البرنامج الجاهز MATLAB_Simulation من خلال ملف النصوص البرمجية لإنشاء برنامج خاص لحل النموذج الرياضي ، الأخير هو نموذج أحادي - الدايمود (خمس متغيرات) ، حيث تم دراسة تأثير درجة الحرارة المحيط والإشعاع الشمسي على القدرة الخارجية للوح الشمسي، تم استخدام طريقة نيوتن رافسون لإيجاد التيار الناتج من الألواح الشمسية ورسم العلاقة بين منحنى I-V و P-V ، تم تحديد أداء الخلية الكهروضوئية في ظروف الاختبار القياسي (Tc=25°C, 1000W /) m² وتم إجراء مقارنة بين النتائج النظرية والتجريبية. أفضل كفاءة تتراوح من 0.15 إلى 0.16. مع وجود نسبة خطأ تقريبا (0.333) للقدرة التجريبية (30 وات) مقارنة مع القدرة النظرية (30.1)، من خلال هذه النتائج توصلنا إلى صحة النموذج المقترح. يمكن استخدام هذا النموذج لجميع أنواع الخلايا الضوئية وأيضاً مع طاقة إنتاج أكبر.

الكلمات الرئيسية -الخلية الكهروضوئية الاحادية، منحنى القدرة-الفولتية، محاكاة-الماتلاب، النمذجة، نموذج الكهروضوئية خمسة متغيرات.