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Characterization Performance of Monocrystalline Silicon Photovoltaic Module Using Experimentally Measured Data

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ABSTRACT

Solar photovoltaic (PV) system has emerged as one of the most promising technology to generate clean energy. In this work, the performance of monocrystalline silicon photovoltaic module is studied through observing the effect of necessary parameters: solar irradiation and ambient temperature. The single diode model with series resistors is selected to find the characterization of current-voltage (I-V) and power-voltage (P-V) curves by determining the values of five parameters ($I_{Ph}, I_S, I_{rs}, R_{Sh}, A$). This model shows a high accuracy in modeling the solar PV module under various weather conditions. The modeling is simulated via using MATLAB/Simulink software. The performance of the selected solar PV module is tested experimentally for different weather data (solar irradiance and ambient temperature) that is gathered from October 2017 to April 2018 in the city of Baghdad. The collected data is recorded for the entire months during the time which is limited between 8:00 AM and 1:00 PM. This work demonstrates that the change in a cell temperature is directly proportional with the PV module current, while it is inversely proportional with the PV module voltage. Additionally, the output power of a PV module increases with decreasing the solar module temperature. Furthermore, the Simulink block diagram is used to evaluate the influence of weather factors on the PV module temperature by connecting to the MATLAB code. The best value from the results of this work was in March when the solar irradiance was equal to 1000 W/m^2 and the results were:

$I_{sc,exp}$=3.015, $I_{sc,mod}$=3.25 , RE=7.79 and $V_{oc,exp}$=19.67 ,$V_{oc,mod}$=19.9 ,RE=1.1

Keywords: solar PV, solar irradiance, monocrystalline silicon photovoltaic module, MATLAB/

دراسة توصيفية لأداء نموذج المعاملات الخمسة لوحدة الطاقة الشمسية الكهروضوئية أحادية البلورية باستخدام بيانات مقاسة تجريبياً

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الخلاصة

برز نظام الطاقة الشمسية الكهروضوئية كواحدة من أكثر التقنيات الواعدة لتوليد الطاقة النظيفة. تمت دراسة أداء الوحدة الشمسية الضوئية السليكونية أحادية البلورية في هذا العمل من خلال ملاحظة تأثير معاملين مهمين هما: إشعاع الشمسي ودرجة حرارة المحيط. يتم اختيار نموذج الصمام الثنائي مع المقاومات المربوطة بالتسلسل لإيجاد توصيف منحنيات الجهد-التيار و الجهد-الطاقة

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من خلال تحديد قيم معايير الوحدة الشمسية الخمسة. هذا النموذج يبين دقة عالية في نمذجة وحدة الطاقة الشمسية الكهروضوئية تحت ظروف الطقس المختلفة. يتم محاكاة النمذجة باستخدام برنامج الماتلاب-السميولنك. تم اختبار أداء الوحدة الكهروضوئية الشمسية تجريبيًا في مدى محدد من قيم الإشعاع الشمسي ودرجة الحرارة المحيطة والتي يتم جمعها من أكتوبر 2017 إلى أبريل 2018 في مدينة بغداد. تم تدوين البيانات التي جمعها للأشهر المختارة خلال الفترة الزمنية المحددة بين 8:00 صباحًا الى 1:00 مساءً. يوضح هذا العمل أن التغيير في درجة حرارة وحدة الطاقة الشمسية يتناسب طرديًا مع قيمة تيار وحدة الطاقة الكهروضوئية ، بينما يتناسب عكسياً مع قيمة وحدة الجهد الكهربائي. بالإضافة إلى ذلك ، تزداد الطاقة المنتجة من الوحدة الكهروضوئية مع انخفاض درجة حرارة الوحدة الشمسية. علاوة على ذلك، يتم استخدام مخطط التصميم للسميولنك لتقييم تأثير العوامل الجوية على درجة حرارة الوحدة الكهروضوئية عن طريق الربط ببرنامج الماتلاب. افضل نتيجة تم الحصول عليها من النتائج المذكورة في الدراسة في شهر اذار حيث الاشعاع الشمسي 1000 واط/م2هي :

Isc,exp= 3.015, Isc,mod=3.25 , RE=7.79
&Voc,exp=19.67 , Voc,mod= 19.9 , RE=1.1

الكلمات الرئيسية: الكهروضوئية الشمسية ، الإشعاع الشمسي ، وحدة الطاقة الشمسية السليكونية أحادية البلورية ، ماتلاب-سميولنك.

1. INTRODUCTION

The rapid growth in electricity demand around the world, especially in advanced countries, due to perturbed increases in population, urbanization, and industrialization. Most of the world's produced electrical power is generated by burning fossil fuels or using other conventional energy sources. Tremendous emissions of greenhouse gas and depleting in fossil fuel resources represent the challenging issues which induce the entire world to find more clean and sustainable energy sources. Consequently, solar energy offers a successful alternative solution for the existing problems which are accompanied by the traditional power plants operation because it is considered as a renewable and clean source. Solar photovoltaic energy is one of the most significant technologies which can convert solar irradiance directly to electricity with pollution free, fuel-free, and less maintenance. Thus, there is a necessity to study the performance of a solar photovoltaic system through modeling a solar module, which is consisted of the combination of solar cells. This modeling is important to trade-off among the operation conditions (e.g., solar irradiance intensity, temperature, wind flow rate, etc.) to maximize the efficiency of a PV module along with reducing its cost**, Mrabti, et al., 2009, Tsai, 2010, Dubey, et al., 2013, Schwingshackl, et al., 2013,** and **Bouraiou, et al., 2015.** A solar cell is fabricated as a thin layer from semiconductor material (with p-n junction). A photon current is generated. When the solar cell is exposed to sunlight, a photon current is generated due to the increase in photon energy than the band gap energy**, Walker, 2001**. To simplify the concept of the modeling of the photovoltaic module, the performance comparison between the solar cell with series resistance model and the ideal solar cell model has been carried out under the effect of solar radiation change, temperature, series resistance, and diode ideality factor. The series resistance model for the solar cell showed a more actual performance for the photovoltaic system**, Bikaneria, et al., 2013**. The insolation-oriented PV model has been developed. This model was performed using MATLAB/Simulink software to analyze and optimize the PV power system through solar irradiance and ambient temperature. The influence of solar irradiation on cell temperature was studied to find the output current and output power characteristics. The experimental measurements were used to verify the proposed model, **Tsai, et al., 2008, Tsai, 2010, Ding, et al., 2012, Sharma, et al., 2015**. The various MATLAB models for a photovoltaic system were proposed depending on the one-diode model, the two-diode model and the circuit-based simulation model for a PV cell to understand the I-V and P-V characteristics of a solar PV module **,Ishaque, and Salam, 2011 ,Pukhrem, 2013, Azzouzi, et al., 2014, Bouraiou, et al., 2015, Mahmood, and Selman, 2016**. A solar PV panel is considered a nonlinear power source that requires precise identification for the optimal operating point. Therefore, modification of the solar cell SIMULINK model was shown that it is better for the solar PV system operates at its maximum power output for economic purposes, **Husain et al., 2012**. The nonlinear current-voltage and power-voltage characteristics curves for a photovoltaic module have been obtained by using embedded MATLAB function with various values of solar cell temperature and solar irradiation. The effect of the series resistance was included, while the influence of the parallel resistance was neglected**, Vimalarani, and Kamaraj, 2015** while the single diode model with both series and parallel resistors has been selected for better accuracy**, Zerhouni, et al., 2010, Bellia, et al., 2014**. The main models which are used for a photovoltaic cell/module ar one-diode model, two-diode model, and empirical model. The empirical model is the most used due to its simplicity and limited parameters. Though the accuracy of the two-diode model, it is not used due to its complexity. The one-diode model is more proper because it considers all the necessary parameters for an accurate model of a PV system. There are four major parameters: shunt resistance, series resistance, ideality factor and reversed saturated current, which has different values based on the preceding models**, Aly, and El-Aal, 2005, González-Longatt, 2005, Altas, and Sharaf, 2007,Sera, et al., 2007, Houssamo, et al., 2010, El Tayyan, 2011, Wang, et al., 2011, Ramos-Hernanz, et al., 2012**. Experimental simulations were carried out to assess the solar PV performance characteristics in Iraq along with determining the gained energy from solar PV collector**, Al-Najjar, 2013, Al-Najjar, 2015.** In this work, the effect of two factors such as solar irradiance and ambient temperature on the performance of the monocrystalline silicon photovoltaic module is studied theoretically (mathematical modeling in MATLAB –SIMULINK) and experimentally (measured data). Additionally, the single diode model with a series resistor is selected to find the characterization of current-voltage and power-voltage curves by determining the values of five parameters ($I_{Ph}, I_S, I_{rs}, R_{Sh}, A$) for more accuracy.

2. EXPERIMENTAL WORK and PRACTICAL MEASURED DATA of PHOTOVOLTAIC MODULE

The monocrystalline silicon photovoltaic module is selected for this study. The general characteristics of the solar module are shown in **Table 1**. The process of calibration in(energy laboratory, Department of Energy Engineering, College of Engineering) in October month for the module is carried out based on standard instructions of the manufacturer and standard testing conditions (STC). These conditions are solar irradiance (1000 W/m^2) and cell temperature (25^{o}C). The solar module analyzer (which is Prova 200 type with resolution 0.001v and 0.1mA) can be used for several tasks such as accurate tests, maintenance, as well as manufacture and research activities of a solar PV system. Therefore, the analyzer is utilized to obtain the current and voltage values, I-V and P-V curves, and maximum power for the solar module. The solar module system is installed by connecting all the required items for this work, as shown in **Fig. 1**. The experimental measurements of electrical parameters for a PV solar module have been collected for several selected values of the solar radiation intensity (200, 400, 600, 800 and 1000 W/m^2) and various cell temperatures. These measurements have been summarized from October 2017 to April 2018 in **Tables 2, 3** and **4** To obtain the maximum outputs, the PV module is fixed to face south direction with inclined angle of 33.3^o approximately by using engineering protractor, which represents the optimum tilt angle in Baghdad city to maximize the solar module gain, at the horizontal line. The collected data at the outdoor-monitoring system are the module surface temperature by the temperature sensor (which is

TPM-10 type), the module voltage by the voltage divider circuit, and the module current by the current sensor using a relay. All measurements are recorded with the support of the solar module analyzer. More details for Prova 200 are available in the appendix.

Table 1. The general characteristics of the solar module.

Area m^2	V_{OC} V	I_{SC} A	Peak power W	Peak voltage V	Peak current A	No. of cells	Production data
0.46	21.8	3.25	50	17.2	2.9	36	2016

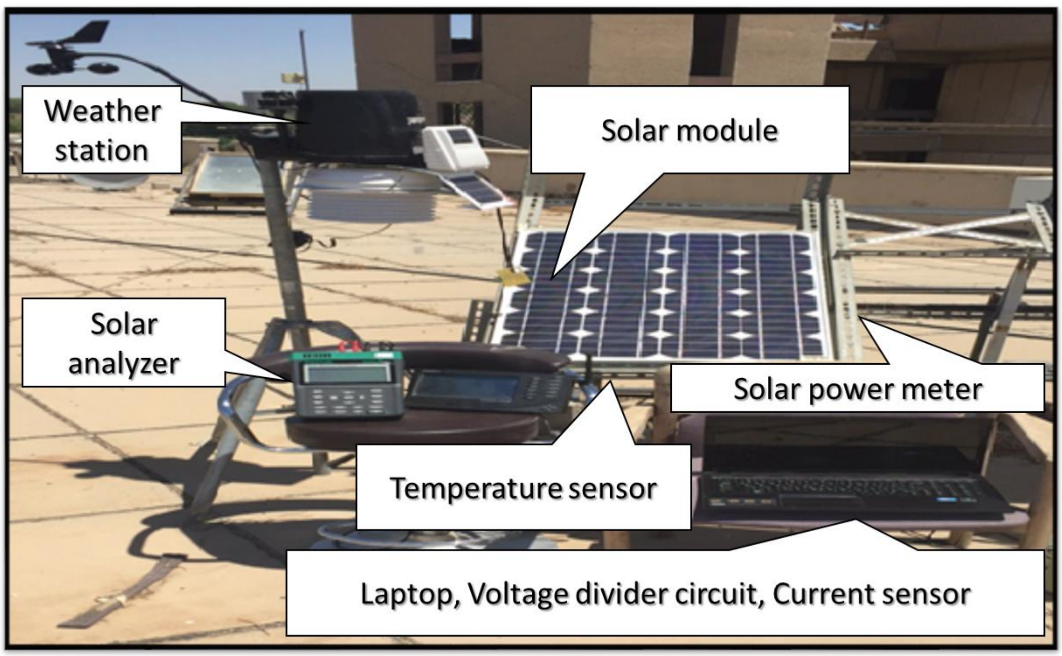

Figure 1.a. The solar module system.

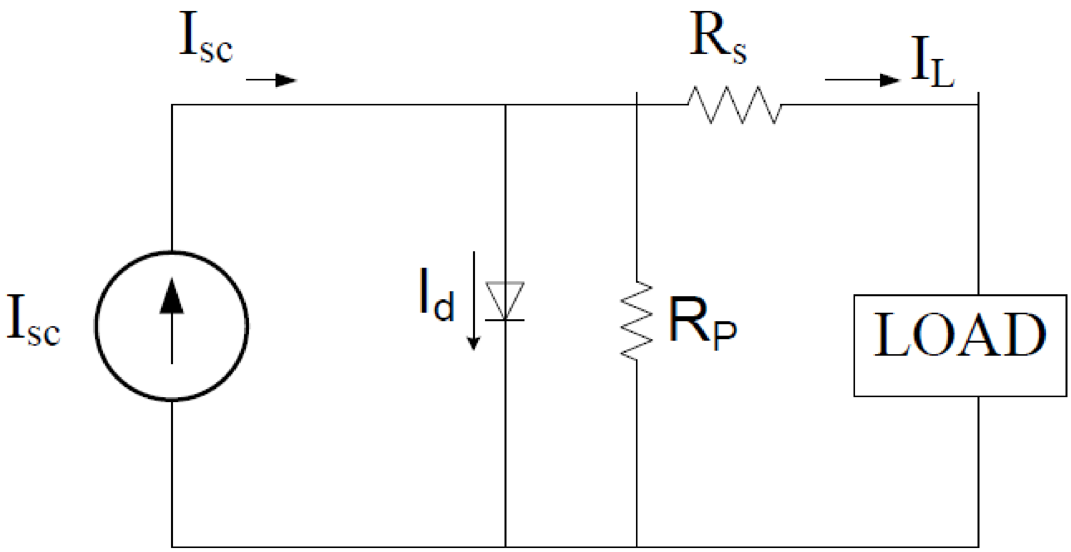

Figure 1.b. Electrical equivalent circuit of a PV cell (**Roger et al., 2003).**

Table 2. Module temperature and electrical solar module Parameters at constant solar radiation 200 W/m²

T_c (ºC)	P, (W)	V (V)	I (A)	V_{oc} (V)	I_{sc} (A)	P_{max} (W)	V_{max} (V)	I_{max} (A)	Eff%	F.F	Date
36.0	6.533	14.22	459.4	18.23	492.3	6.635	14.97	443	1.442	0.739	**5/12/2017**
27.9	16.01	16.47	972.4	19.85	1.072	16.09	16.79	958.1	3.498	0.755	**14/12/2017**
30.1	16.71	16.60	1.007	19.57	1.119	16.71	16.60	1.007	3.634	0.763	**19/12/2017**
24.6	8.941	16.15	553.5	19.48	633.8	8.952	16.42	545.0	1.946	0.724	**27/12/2017**
22.2	6.732	16.30	413.0	19.69	568.4	6.737	16.46	409.2	1.464	0.601	**9/1/2018**
20.1	6.240	16.02	389.4	19.56	460	6.250	16.43	380.2	1.358	0.694	**29/1/2018**
21.0	6.174	15.43	400.0	19.20	468.8	6.196	15.73	393.7	1.346	0.688	**14/2/2018**

Table 3. Module temperature and electrical solar module parameters at constant solar radiation 400 W/m²

T_c (ºC)	P (W)	V (V)	I (A)	V_{oc} (V)	I_{sc} (A)	P_{max} (W)	V_{max} (V)	I_{max} (A)	Eff. %	F.F	Date
38.1	27.15	16.28	1.668	19.60	1.912	27.15	16.28	1.670	14.76	0.724	**19/10/2017**
36.6	11.7	10.61	1.102	19.08	1.102	16.69	16.11	1.035	3.628	0.793	**5/12/2017**
28.9	23.52	16.88	1.393	20.08	1,514	23.58	17.17	1.373	5.126	0.775	**14/12/2017**
35.4	23.43	16.64	1.407	19.65	1.563	23.48	16.93	1.386	5.104	0.763	**19/12/2017**
22.3	15.82	17.39	0.909	20.37	1.033	15.82	17.53	0.902	3.44	0.751	**9/1/2018**
26.1	18.10	17.36	1.042	20.37	1.176	18.10	17.36	1.042	3.936	0.755	**7/2/2018**

Table 4. Module temperature and electrical solar module parameters at constant solar radiation 600 W/m.²

Tc (ºC)	**P (W)**	**V (V)**	**I (A)**	**V_{oc} (V)**	**I_{sc} (A)**	**P_{max}, (W)**	**V_{max} (V)**	**I_{max} (A)**	**Eff %**	**F.F**	**Date**
43.8	31.26	15.94	1.960	19.36	2.242	31.27	15.96	1.958	11.32	0.720	**19/10/2017**
35.4	24.58	15.99	1.537	19.63	1.623	24.95	16.70	1.493	5.424	0.782	**5/12/2017**
23.2	26.05	17.57	1.482	20.73	1.236	26.13	17.88	1.460	5.680	0.776	**27/12/2017**
19.8	24.17	17.97	1.344	20.91	1.505	24.18	18.11	1.334	5.257	0.767	**29/1/2018**
23.9	25.79	17.47	1.476	20.42	1.640	25.82	17.62	1.465	5.614	0.770	**14/2/2018**
35.8	26.10	16.54	1.577	19.57	1.715	26.67	16.67	1.566	5.676	0.777	**5/3/2018**

Table 5. Module temperature and electrical solar module parameters at constant solar radiation 800 W/m².

T_c (ºC)	**P (W)**	**V (V)**	**I (A)**	**V_{oc} (V)**	**I_{sc} (A)**	**P_{max} (W)**	**V_{max} (V)**	**I_{max}, (A)**	**Eff. %**	**F.F**	**Date**
44.3	31.85	16.31	1.952	19.44	2.234	31.85	16.32	1.951	8.508	0.733	**19/10/2017**
28.5	38.22	17.66	2.164	20.69	2.352	38.27	17.81	2.148	8.321	0.786	**14/12/2017**
21.5	36.93	18.12	2.037	21.06	2.230	36.99	18.28	2.022	8.041	0.787	**29/1/2018**
24.6	33.22	17.37	1.912	20.25	2.109	33.22	17.37	1.912	7.223	0.777	**14/2/2018**
32.9	32.96	17.12	1.924	20.07	2.077	32.98	17.25	1.911	7.169	0.790	**12/3/2018**
33.8	36.42	17.12	2.10	20.20	2.277	36.46	17.28	2.110	7.927	0.792	**26/3/2018**

Table 6.Module temperature and electrical solar module parameters at constant solar irradiance 1000 W/m^2.

Tc (ºC)	**P (W)**	**V (V)**	**I (A)**	**V_{oc} (V)**	**I_{sc} (A)**	**P_{max} (W)**	**V_{max} (V)**	**I_{max} (A)**	**Eff. %**	**F. F**	**Date**
48.5	37.04	15.70	2.359	19.16	2.677	37.05	15.72	2.356	8.055	0.721	**19/10/2017**
36.9	37	20.35	1.820	20.37	2.739	43.91	17.68	2.483	9.546	0.786	**5/12/2017**
26.4	43.62	17.94	2.427	20.77	2.677	43.63	17.97	2.427	9.485	0.784	**27/12/201**
26.0	46.7	18.25	2.558	20.94	2.781	46.71	18.39	2.540	10.15	0.802	**9/1/2018**
25.4	41.68	16.87	2.470	19.97	2.665	41.81	17.17	2.434	9.090	0.785	**14/2/2018**
33.5	40.12	17.16	2.337	20.24	2.522	40.20	17.32	2.320	8.739	0.787	**12/3/2018**

3. MODELING and SIMULATION of PHOTOVOLTAIC MODULE USING MATLAB-SIMULINK

Mathematical modeling and simulation of photovoltaic module based on the single diode model with series resistors are presented. The modeling is simulated by using a special code through MATLAB/Simulink software package (Iterative method) that includes the equations of five parameters ($I_{Ph}, I_S, I_{rs}, R_{Sh}, A$). The MATLAB code is used to study the effect of various values of solar irradiation and ambient temperature on the performance of a PV module, to evaluate the value of resistance. Furthermore, the Simulink block diagram, which provides an easy solution of complex systems, is used to assess the influence of weather factors on the module temperature by connecting to the MATLAB code.

The mathematical equations of PV module in MATLAB-SIMULINK as follows.

3.1 The PV module photocurrent model

This model can be used to evaluate the photocurrent, which is given as follows: **(Bellia, et al., 2014)**

$$I_{ph} = \left[I_{SC} + K_{ISC}\left(T - T_{ref}\right)\frac{G}{G_{ref}}\right] \quad (1)$$

where short circuit current (I_{SC}) at reference temperature (3.1 A), and current temperature coefficient (K_{ISC}) (0.0003 (A/K).

The following block diagram of MATLAB-Simulink represents the solar radiation and temperature at reference condition for the PV module ($T_{ref} = 25℃$, $G_{ref} = 1000\,W/m^2$), as shown in **Fig. 2**.

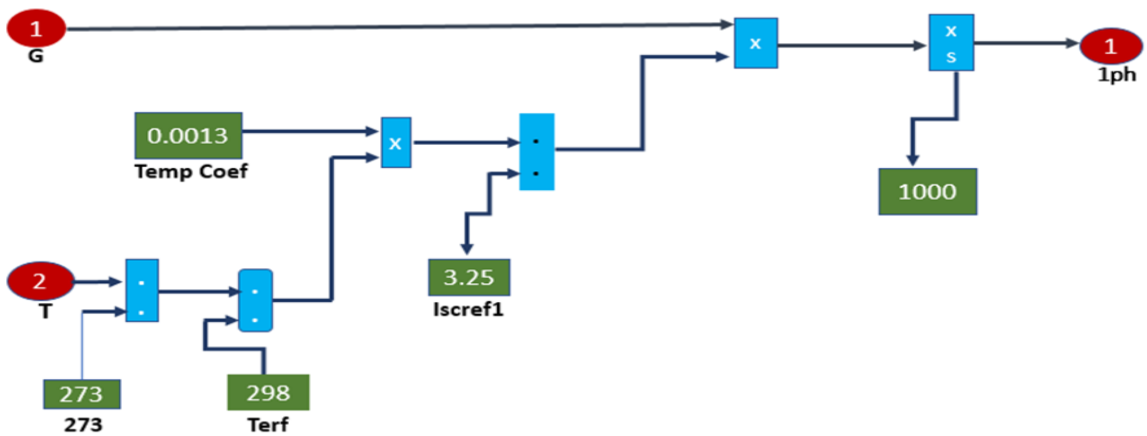

Figure 2. Block diagram of photovoltaic current.

3.2 The PV module saturation current model

The following block diagram is utilized to calculate the saturation current I_S and the reversed saturation current $I_{s,r}$ by using the following equations 2 & 3 **(Bellia, et al., 2014)** and **Fig. 3** and **Fig 4**.

$$I_{s,r} = I_{SC}/exp\left(\frac{q\,V_{OC}}{N_S\,T_{ref}\,K\,A} - 1\right) \quad (2)$$

where K is Boltzmann constant, A is diode ideality factor for Mono-crystalline silicon solar module, q is electron charge, T is module operating temperature, N_s is 36 cells (series connected).

$$I_S = I_{s,r}\left(\frac{T}{T_{ref}}\right)^3 exp\left[\frac{qE_g}{A\,K}\left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right] \quad (3)$$

where E_g is band gap energy (1.12 eV)

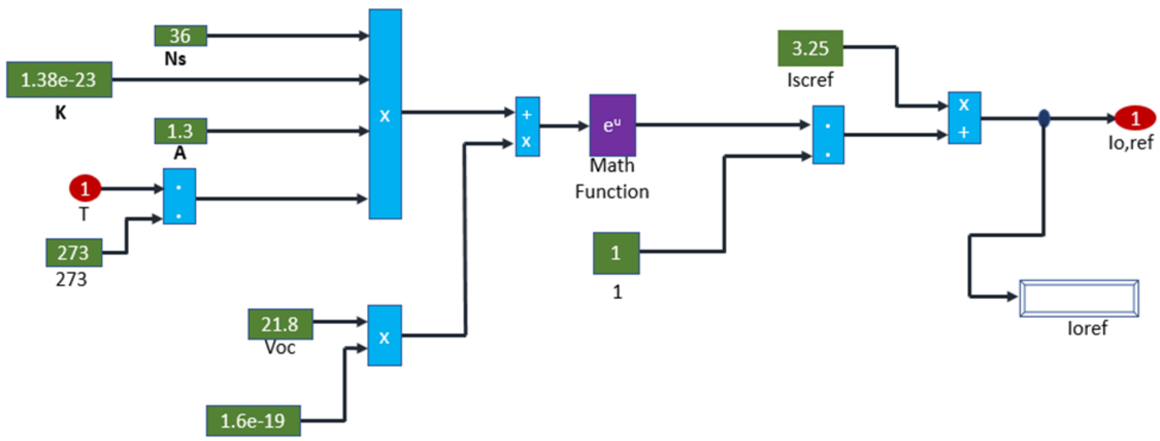

Figure 3. Saturation current block system.

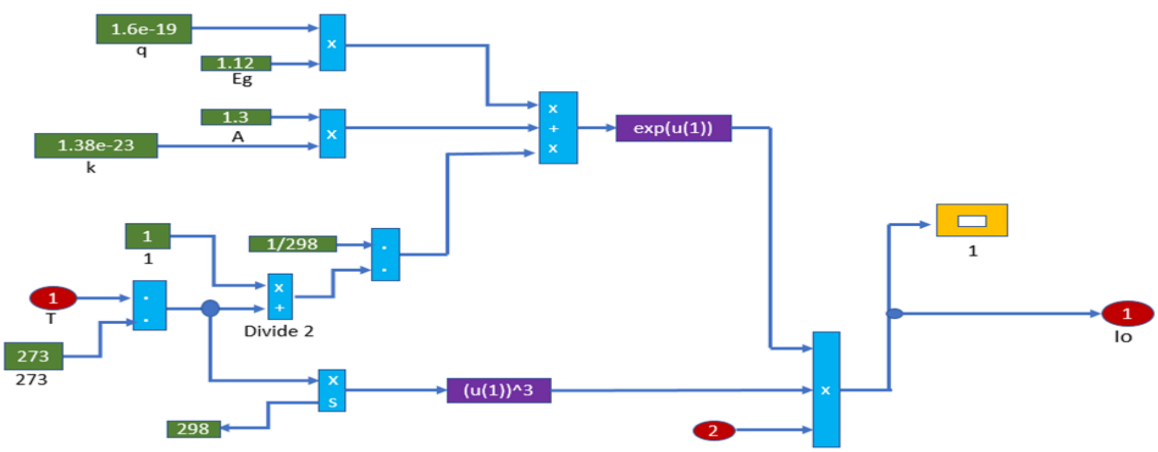

Figure 4. Reverse saturation current block system (Io ref.).

3.3 The PV module photovoltaic current model

The current photovoltaic model is used to calculate the photovoltaic current by **Eq. 4 (Bellia, et al., 2014)** and **Fig. 5** and **Fig. 6** (subsystem 5).

$$I = I_{Ph} - I_s\left[exp\left(\frac{q(V_{PV} + IR_S)}{AKTN_S}\right) - 1\right] - \frac{V_{PV} + IR_S}{R_{sh}} \qquad (4)$$

where R_s is series resistance, Rsh_{sh} is shunt resistance at reference condition (G_{ref} is 1000 W/m^2)

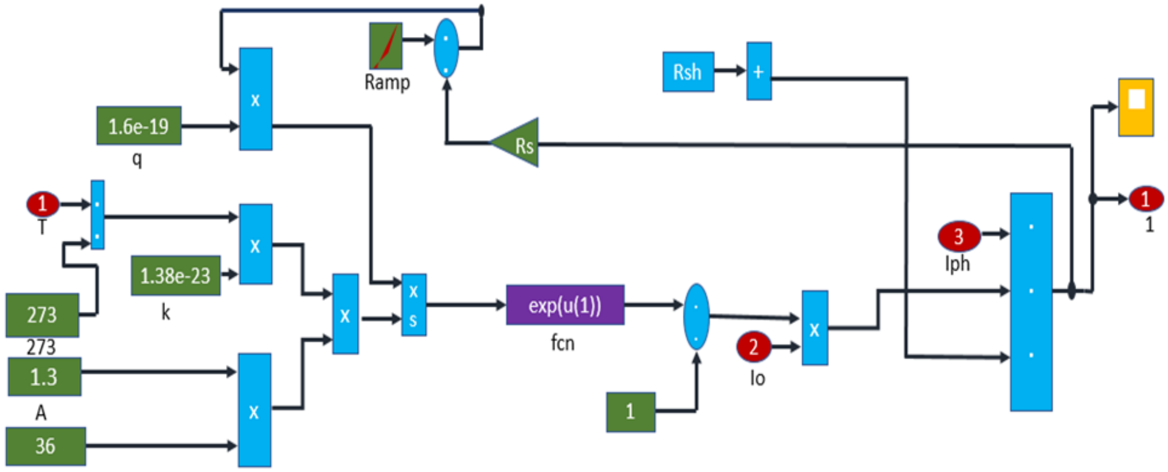

Figure 5. The circuit of the photovoltaic current block system (Iph).

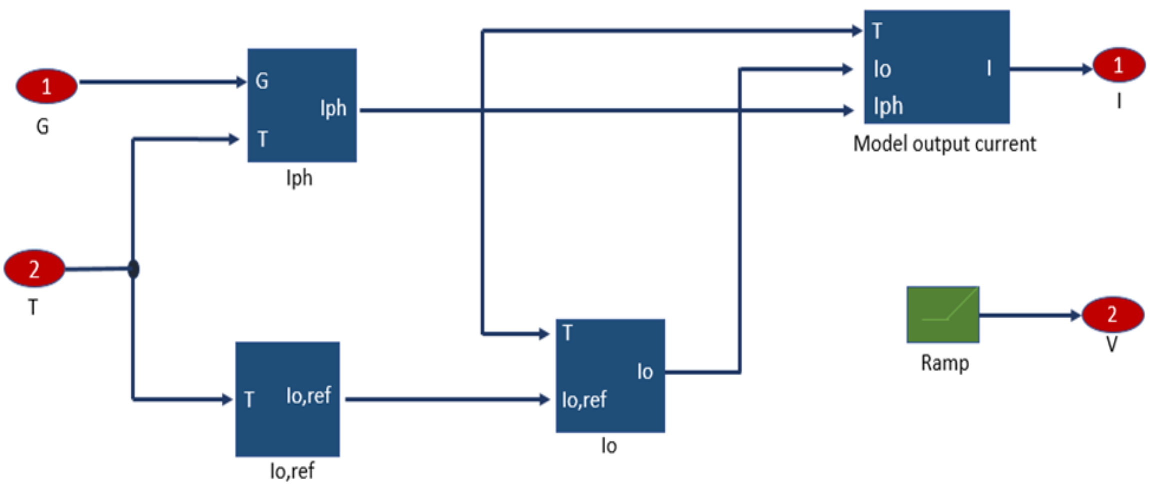

Figure 6. The circuit under subsystem 5.

3.4 The final Simulink model

The final Simulink model shows measured data (I_{PV},V_{PV}, P_{PV}) and it is used to plot a graph. The simulation model of the PV system can determine the value of the five parameters (I_{Ph}, I_S, I_{rs}, R_{Sh}, A) as well as the operating temperature after entering the value of solar irradiation, and ambient temperature into the system collected in the experimental part of this work, as shown in **Fig. 7.**

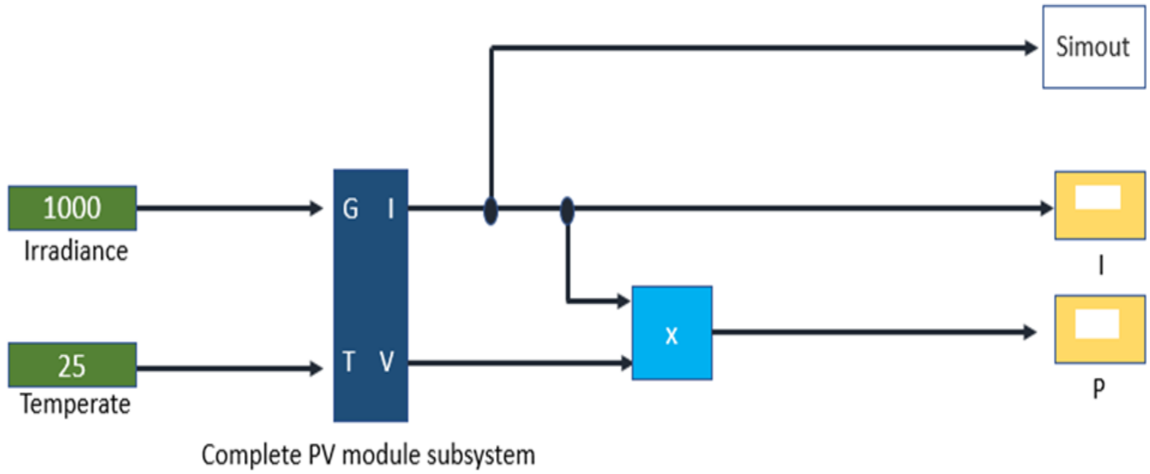

Figure 7. Block system of the final Simulink model.

4. RESULTS and DISCUSSION

The effect of module temperature on the characteristic of the I-V and P-V curves of the monocrystalline solar module has been evaluated for five different solar radiations intensity 200, 400, 600, 800, and 1000 W/m². The months of January and March were taken asa paradigm, as shown in **Figs. 8-12**. This work demonstrates that the change in a cell temperature is directly proportional to the PV module current, while it is inversely proportional with the PV module voltage. Additionally, the output power of a PV module increases with decreasing the cell temperature up to 15°C. Consequently, the cell temperature shows the significant influence on the characterization of I-V and P-V curves for the monocrystalline PV module at constant values of the solar irradiation intensity.

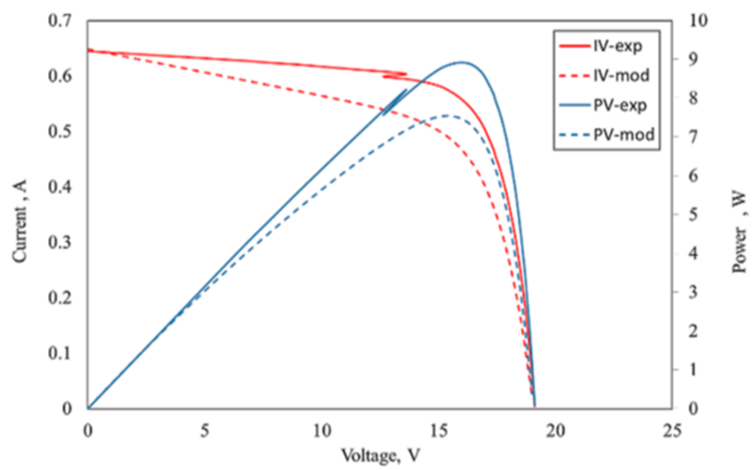

Figure 8. I-V and P-V of the monocrystalline PV module at solar irradiance 200W/m² for January.

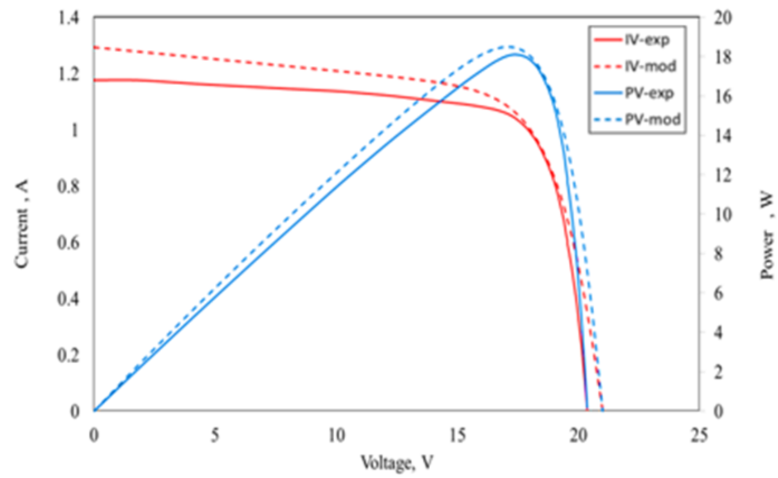

Figure 9. I-V and P-V of the monocrystalline PV module at solar irradiance 400W/m² for January.

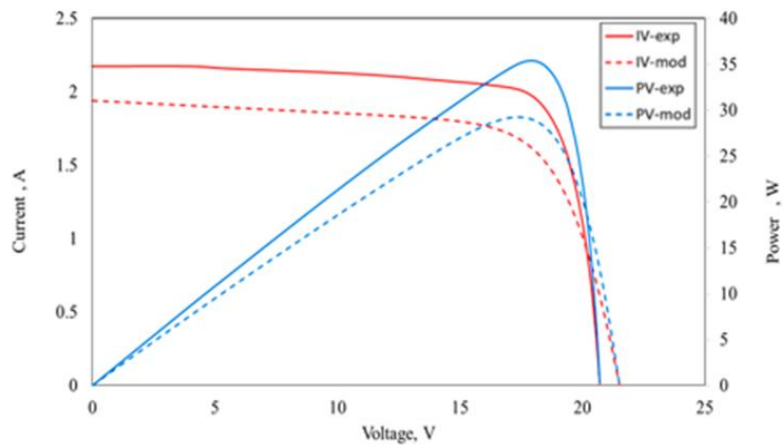

Figure 10. I-V and P-V of the monocrystalline PV module at solar irradiance 600W/m² for January.

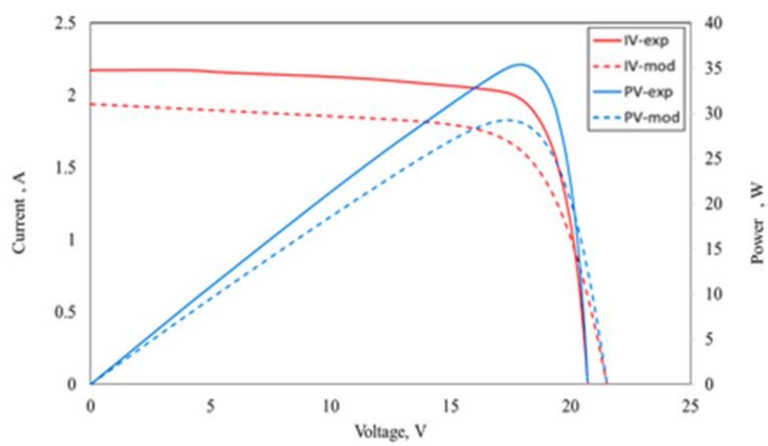

Figure 11. I-V and P-V of thmono crystalline PV module at solar irradiance 800W/m² for January.

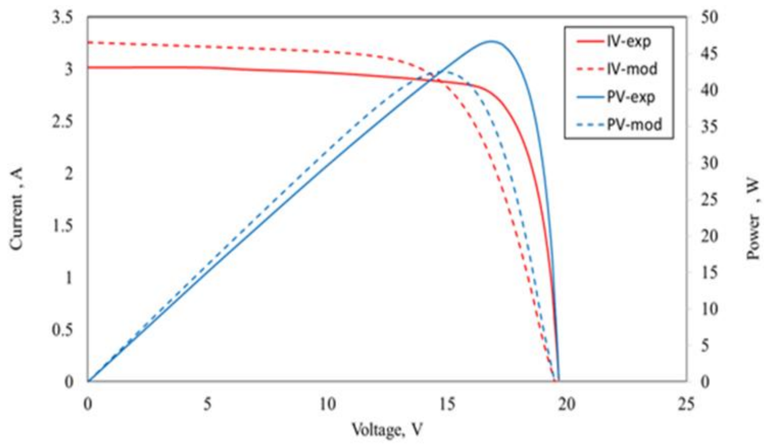

Figure 12. I-V and P-V of the monocrystalline PV module at solar irradiance 1000W/m² for March.

The effect of the shunt resistance (R_s) has been evaluated on a behavior of cuthe rrent-voltage (I-V) curve. The two values of R_s (0, 0.55Ω) were selected to plot I-V curves, as shown in **Fig. 13**. The values of I_{sc} and V_{oc} are not change with value of R_s. Although the I-V curve may be approached to the rectangular shape, the value of a maximum power moves to the right. Therefore, P_{mp} is inversely proportional to the series resistance based on the fill factor correlation, as shown in the following correlation, **Kalogirou, 2013**:

$$FF = \frac{P_{mp}}{V_{oc} \, . I_{sc}} \qquad (5)$$

If I_{sc} and V_{oc} are constant, the fill factor FF changes based on P_{mp} only. From **Fig. 14**, it can be shown that the manufacturer did not take into consideration the parallel resistance because of the peak power of R_s which is used in the model of this work coincides with the given peak power of the data sheet for (R_s =0.55 Ω. From the Matlab code)

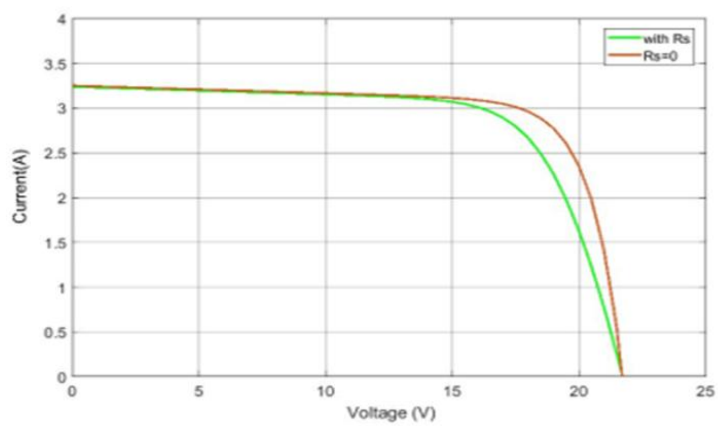

Figure 13. I-V curve of the monocrystalline PV solar module with shunt resistance and without shunt resistance.

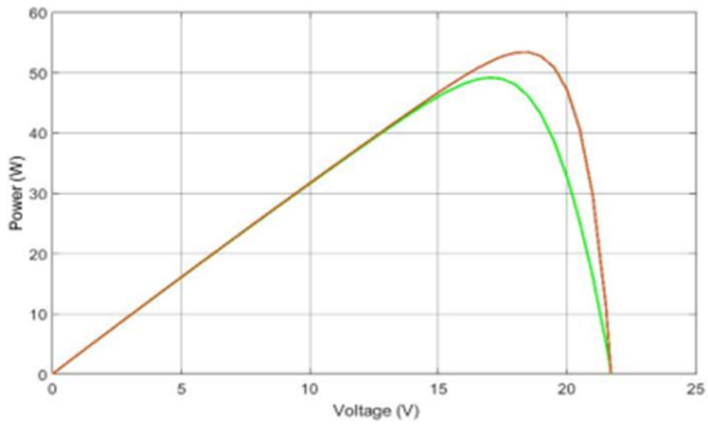

Figure 14. P-V curve of the monocrystalline PV solar module with shunt resistance and without shunt resistance.

4.1. Effect of surrounding temperature on the output power production of the monocrystalline photovoltaic solar module

The effect of surrounding temperature on the output power production from the monocrystalline PV solar module has been estimated for five values of the solar radiation intensity 200, 400, 600, 800 and 1000 W/m². The measured data of the surrounding temperature and the maximum output power was summarized in **Tables 2, 3**, and **4**. Furthermore, the previous tables include the comparison between experimentally measured maximum power and calculated maximum power by using MATLAB SIMULINK as well as the percentage errors. The increase in the ambient temperature causes decreasing in the output power production of the PV module due to the rise in the cell temperature and the lessening in the PV module voltage**.**

Table 7. Comparisons between maximum measured power and calculated maximum power with corresponding ambient temperature at solar irradiance 200W/m².

Month	**Ta °C**	**Tc °C**	**P_{exp} W**	**$P_{mod.}$ W**	**Error %**
27/12/2017	11.6	24.6	8.3	7.2	**-13.-**
3/1/2018	13.6	25.5	8.2	7.1	**-6.0**
30/1/2018	12.2	21.9	6.5	6.4	**-1.5**
5/3/2018	21.2	27.5	8.4	7.1	**-15**
12/3/2018	22	34	7.6	6.1	**-19**
26/3/2018	25.1	29.8	10	7.1	**-29**

Table 8. Comparisons between maximum measured power and calculated maximum power with corresponding ambient temperature at solar irradiance 400W/m².

Month	**Ta °C**	**Tc °C**	**P_{exp} W**	**$P_{mod.}$ W**	**Error %**
5/12/2017	20.6	36.6	13.4	14.2	**5.9**
19/12/2017	19.7	35.4	13	14.9	**14.6**
3/1/2018	13.6	25.3	15.6	15.2	**-2.5**
30/1/2018	12.2	21.4	15	16	**6.6**
12/3/2018	23.2	32.5	12.9	14.1	**9.3**
27/12/2017	12.4	23.7	8.9	7.5	**-15.7**
26/3/2018	25.2	30.5	15	16	**6.6**

Table 9. Comparisons between maximum measured power and calculated maximum power with corresponding ambient temperature at solar irradiance 600W/m².

Month	**Ta, °C**	**Tc, °C**	**P_{exp} W**	**$P_{mod.}$ W**	**Error %**
16/10/2017	34	42.2	26	24	**-7.6**
19/10/2017	31.2	43.7	26	24	**-7.6**
5/12/2017	20.6	35.4	22.5	25	**11**
14/12/2017	13.9	28.3	25	24	**-4**
19/12/2017	19.9	36.3	27	23	**-14.8**
27/12/2017	12.7	23.2	32	27	**-15.6**
3/1/2018	13.8	26.8	32	27	**-15.6**
7/2/2018	20.4	26.2	27.5	22.5	**-18**
30/1/2018	12.5	22.3	33	27	**-18**
5/3/2018	23.9	35.8	34	29	**-14.7**

Table 10. Comparisons between maximum measured power and calculated maximum power with corresponding ambient temperature at solar irradiance 800W/m².

Month	**Ta, °C**	**Tc, °C**	**P_{exp}, w**	**$P_{mod.}$, w**	**Error %**
16/10/2017	35	43.9	30	32	**6.6**
19/10/2017	30.7	44.3	32.5	31	**-4.6**
5/12/2017	20.6	37.1	43	39	**-9**
14/12/2017	14	28.5	43	39	**-9**
19/12/2017	19.9	37	35	34	**-2.8**
3/1/2018	13.8	28.3	41	37	**-9.7**
27/12/2017	12.9	24.4	42	38	**-9.5**
30/1/2018	12.6	24	42.5	37	**-12.9**
7/2/2018	20.4	30.2	37	33	**-10.8**
12/3/2018	23.2	32.9	35	32.5	**-7**
9/1/2018	12.7	25.1	44	37	**-15.9**

Table 11. Comparisons between maximum measured power and calculated maximum power with corresponding ambient temperature at solar irradiance 1000W/m² .

Month	Ta, °C	Tc, °C	P_{exp} W	$P_{mod.}$ W	Error %
5/3/2018	24.2	41.2	40.5	36	**11**

Table 12. Maximum power, Voltage open circuit & current short circuit comparison with some previous work.

1000w/m²	$P_{max,exp}$	$P_{max,mod}$	T_C	T_a	$V_{OC,exp}$	$V_{OC,mod}$	$I_{sc, exp.}$	$I_{sc, mod.}$
Proposed work	46.64	44.10	41.2	24.2	19.67	19.9	3.015	3.25
Zainab et al., 2017	41.20	50.04	45	25	21	21.5	3	3.02
Tsai et al., 2016	-	87	-	25	-	24	-	4.45
Bouraiou et al ., 2015	54.23	73	37	25	19.357	20.3	4.015	5.252
Huan- ling Tsai., 2010	-	60	-	25	-	21.1	-	3.8

5. CONCLUSIONS

1. The performance of monocrystalline silicon photovoltaic module has been evaluated theoretically and experimentally in this work.

2. The single diode model with series resistors is selected to find the characterization of current-voltage (I-V) and power-voltage (P-V) curves through five parameters ($I_{Ph}, I_S, I_{rs}, R_{Sh}, A$).

3. The model is simulated by using MATLAB/Simulink software, and it shows high accuracy in modeling the solar PV module under various conditions such as solar irradiation and ambient temperature.

4. The performance of the solar PV module is tested experimentally for different weather data that is gathered from October 2017 to April 2018 in Baghdad city between 8:00 AM and 1:00 PM. Consequently, the cell temperature shows a significant influence on the characterization of I-V and P-V curves for the monocrystalline PV module.

5. The fill factor is proportional with the values of the maximum output, short circuit current, open circuit voltage, Series resistance for the solar PV module.

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NOMENCLATURE

A	diode ideality factor
I_m	current at the maximum power point, A
I_o	reverse saturation current, A
I_{ph}	photo-generated current, A
$I_{sc,exp}$	measured short circuit current, A
$I_{sc,mod}$	modeled short circuit current, A
I_{sc}	short circuit current, A
G_{ref}	reference radiation, (W/m^2)
G	solar radiation, W/m^2
N_s	number of cells
$P_{max,exp}$	experimental maximum power output, W
P_m, P_{mp}	maximum power output, W
q	charge of the electron, C
R_p	parallel resistance, Ω
R_s	series resistance, Ω
T_a	ambient temperature, ºC
T_{ref}	reference module temperature, ºC

T	module operating temperature, K
V_T	the thermal voltage at reference condition, V
V_m	the voltage at the maximum power point, V
$V_{oc,exp}$	experimental open circuit voltage, V
V_{oc}	open circuit voltage, V

GREECK SYMBOLS

k_B	Boltzmann constant
μ_{oc}	temperature coefficient of open circuit voltage, V/K
μ_{sc}	temperature coefficient of short circuit current, A/K
v_w	local wind speed, m/s