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Study of the Performance of Five Parameter Model for Monocrystalline Silicon Photovoltaic Module Using a Reference Data

This paper presents the construction of a model for a photovoltaic module using the single-diode five-parameter model, based exclusively on data-sheet parameters. The model takes into account the series and parallel (shunt) resistance of the module. This easy and accurate method of modeling photovoltaic module, which is able to predict the module behavior in different temperatures and irradiance conditions under climate conditions of Baghdad city, is built and tested. This paper indicates how the parameters of the five-parameter model are determined, also estimates the output power generated and other electrical and internal parameters by photovoltaic module and compares predicted current–voltage curves and power-voltage curves with experimental data for monocrystalline and for four months. The theoretical results showed a slight increase in shunt resistance and photocurrent with solar radiation increasing. Also, the paper evaluates effects of weather factors on cell temperature using a simple formula. The results show that there is difference between theoretical (modeled) and experimental results. The maximum power validation result at radiation of 500, 750 and 1000W/m^2 was 5.5% in January, 18.4% in April and 20% in April respectively, the best validation of maximum power under standard testing conditions (STC) was 14.8% in January.The results obtained from modeling show agreement with experimental results of module temperature.

Keywords: Photovoltaic system, Solar module, Simulation, Five-Parameters.

1. INTRODUCTION

Because of the high deteriorating influence of the pollution and carbon emission from the power plants on the environment and the life on the earth, one of the better solutions in order to decrease the pollution is to employ renewable energy sources. The renewable energy can be generated without decay of source, some types of these energies are solar, wind, geothermal, ocean, biofuels, and tidalr but the wind, solar and biomass energy are considered to be the most popular renewable energy sources [1].

The solar cell is a p-n semiconductor junction exposed to sunlight, and generates electrical direct current. Photovoltaic (PV) cells have several advantages such as: no environmental pollution, high reliability, no noise and low maintenance cost. There are many factors affecting the efficiency and power output of photovoltaic panel such as radiation, ambient temperature, and wind speed [2] so that the efficiency of photovoltaic panel increases with increase of the wind speed,the decrease of the panel temperature and the

increase of the solar radiation striking the panel there. Photovoltaic devices illuminated on the surface of the earth give out an electrical response which depends primarily on the quality, the intensity of the radiation received and the temperature of the illuminated photovoltaic cells. This response consists of the set of electrical parameters and performances of the photovoltaic generator. Photovoltaic modules options will be used as design requirements for sizing the photovoltaic module.

To study the real system behavior we need an authenticated simulation model. Many photovoltaic MATLAB models are available in the literature. In the past few years many researchers are working to develop a sophisticated model to reduce the computational time and to get accurate information with less number of parameters. Detailed mathematical Simulink based single diode model was developed, and presented in this paper in section 3.

In the literature [3]showed that the five parameter model is accurate with experimental data under outdoor weather conditions in three days at different radiation and the error between the maximum power declared bymanufacturer and simulation standard test conditions under (STC) is 5.63%. The value of ideality factor obtained at maximum power 250.1W is equal 1.58. Soto et al. [4]calculated the panel internal parameters

photocurrent ,saturation current, series resistance, shunt resistance and ideality factor ($I_{ph,ref}$, $I_{o,ref}$, $R_{s,ref}$, $R_{sh,ref}$ and A_{ref}) respectively of five parameter model at reference condition (G=1000W/m² and T=25°C) to predict the (current –voltage) curve for four different cell(single crystalline, polycrystalline ,silicon thin film ,and triple-junction amorphous).The five parameter model agrees with both experimental measurements of the National Institute of Standards and Technology (NIST) and the king model for all four panel types at different working conditions. Dongue et al. [5] studied modeling of two different PV modules (mono-crystalline and multi-crystalline) for various working operation by using two models, a four parameter model which assumes shunt resistance of infinity value and a five parameter model which takes into account series and shunt resistance. They concluded that both four and five parameter models accurately fit experimental data of both PV panels and the five parameter model is more accurate than four parameter model in power and current.The double exponential model is the most accurate model,which contains seven unknown parameters. In general, this model is more accurate for polycrystalline silicon cells [6].

Bellia et al. [7] developed an empirical model to produce the current and voltage curve using five located points at the current-voltage curve. However, the method needs empirically determined parameters which are typically not available from the manufacturers' datasheet. The coefficients are provided by the Sandia National Laboratory. There are many researchers [8-11]thatstudied the effect of operating temperature upon the performance of free-standing PV panel and simple semi-empirical explicit correlation that was used included the environmental conditions. As a result, the power depends linearly on panel temperature.

This paper presents the study of experimental testing results for the performance of solar module (mono-crystalline silicon) under natural sun and outdoor exposure in Baghdad for four consecutive months. Also, the aim of the paper is to investigate validation of *I-V* and *P-V* output curves of the five parameter model of PV module (using Matlab/Simulink) and compare them with the corresponding experimental results. These comparisons were made at different solar irradiance values 500, 750, and 1000 W/m^2, and also and took into account environmental factors on module temperature.

2. PHOTOVOLTAIC MODULE OUTPUT PARAMETERS

The short - circuit current I_{sc}, is the current that flows through the external circuit when the electrodes of the solar cell are short circuited. The short -circuit current of a solar cell depends on the photon flux density incident on the solar cell that is determined by the spectrum of the incident light. The I_{sc} depends on the area of the solar cell.

The open-circuit voltage $V_{oc}$is the voltage at which no current flows through the external circuit. It is the maximum voltage that a solar cell can deliver. The V_{oc} corresponds to the forward bias voltage, at which the reverse saturation current compensates the photo-current.

The maximum power output $P=P_{m,}$ is a key parameter since solar cells are used to produce electrical energy. When a solar cell is in an open-circuit or short-circuits state, it produces no power. At a defined point known as the maximum power point (MPP), a solar cell reaches its maximum power (P_m), and this is clear in Figure1. The power of a solar cell produced at the MPP is always lower than the hypothetical value obtained by multiplying open-circuit voltage by short-circuit current. The ratio of P_m to the product of V_{oc} and I_{sc} is a key measurement value of a solar cell, along with efficiency. This ratio is known as the fill factor, FF written as follows,

$$FF = \frac{P_{m,practical}}{P_{m,theoretical}} = \frac{V_m I_m}{V_{oc} I_{sc}} \qquad (1)$$
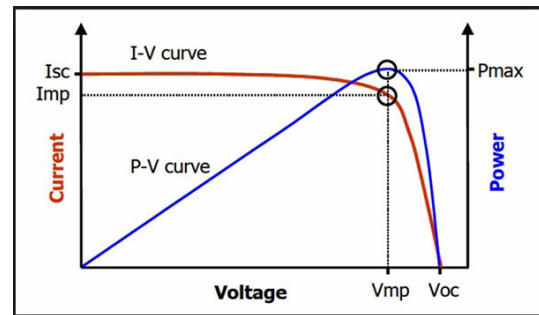

Figure 1. Current-voltage and power-voltage characteristic curves of a mc-Si (microcrystalline-silicon) cell. (P_{max} refer to P_m)

3. THE FIVE PARAMETER MODEL

The most important component that affects the accuracy of a simulation of the PV cell is modeling which primarily involves the estimation of the non-linear *I-V* and *P-V* characteristics curves .The simplest model is the single diode model (five parameters model). In Figure 2 is shown the simple equivalent electrical circuit of a solar cell, a single diode connected in parallel with a photocurrent source and the shunt resistance (R_{sh})expressing a leakage current and series resistance (R_s)describes an internal resistance to the current flow. Applying Kirchoff laws, the cell terminal current is expressed by,

$$I = I_{ph} - I_D - I_{sh} \qquad (2)$$

In which I is the output current and I_{Ph} refers to the photo-generated current, I_D represents the diode current, and I_{sh} represent shunt current. The diode current is given by Shockley equation:

$$I_D = I_S \left[\exp\left(\frac{q(V + IR_S)}{AkT} \right) - 1 \right] \qquad (3)$$

where $V_{sh} = V_D$ and $V_D = V + IR_S$.

V_D or V_{sh} refers to the diode or shunt voltage, I_S the saturation current in diode, V is the output voltage, q is the electron charge, and T is the solar cell temperature.

$$I = I_{ph} - I_S \left[\exp\left(V \frac{V + IR_S}{V_T} \right) - 1 \right] - \frac{V + IR_S}{R_{sh}} \qquad (4)$$

Equation 4 is the fundamental basic equation, for the modeling in this study. V_T is the thermal voltage of the diode.

Measurements of *I-V* curve at reference conditions are commonly available by the manufacturer at three points: open-circuit, short-circuit, and maximum power. In this study, two methods for five parameter model were applied for the modeling of the PV module using Matlab:
(a) Five parameter model (Iterative method) at standard test condition.
(b) Five parameter model (Simulink method) at another condition.
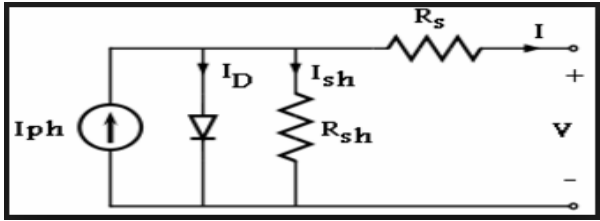

Figure 2. Equivalent electrical circuit of five parameter model

3.1 Mathematical model for Iterative method

To evaluate five parameters with less approximation, an iteration process needs to be done. An iteration method was presented by Villalva et al. [12] and others in similar manner. The method proposes changing R_s and R_{sh} according to the fact that there is only one pair of (R_s, R_{sh}) that achieves the maximum power. The model changes the value of the mentioned resistances until the maximum power determined by (4) equals the experimental maximum power provided in the manufacturer datasheet ($P_{m,d} = P_{m,exp}$). The 5par-model calculates the five parameters according to the following points:

The photo generated current I_{ph} calculate by the advantage of the iteration process for R_s and R_{sh}. Each iteration change R_s and R_{sh} towards the best converging solution of I_{ph} which is given in the following equations:

$$I_{ph} = \frac{R_{sh} + R_S}{R_{sh}} I_{SC} \qquad (5)$$

where I_{sc} is the short circuit current at STC from data sheet.

The shunt resistance R_{sh} considered to be a function of the series resistance and experimental maximum power and the other parameters. During the iteration, R_s gradually incremented starting from $R_s = 0$ and for each value of R_s there will be a value of R_{sh} that ensures that the modeled *I-V* curve pass through the experimental maximum power point.

$$P_{m,exp} = P_{m,mod} = (V_m I_m)_{mod} =$$
$$= V_m \left(I_{ph} - I_S \left(\exp\left((V_m + I_m R_S)/V_t \right) - 1 \right) \right) \quad (6)$$
$$(V_m + I_m R_s)/V_t$$

I_m and V_m are the maximum current and maximum voltage at STC from data sheet value.

$$R_{sh} = \frac{V_m (V_m + I_m R_s)}{\left(V_m I_{ph} - V_m I_S \left(\exp\left(\frac{V_m + I_m R_s}{V_t} \right) - 1 \right) \right) - P_{m,exp}} \qquad (7)$$

The reverse saturation current I_S is calculated from the open circuit condition for (4),

$$i_S = \left(I_{ph} - \frac{V_{OC}}{R_{sh}} \right) \Big/ \left(\exp\left(\frac{V_{OC}}{V_T} \right) - 1 \right) \qquad (8)$$

V_{oc} is Open circuit voltage (v) at STC from data sheet value.

The diode ideality factor (A) equation is shown below:

$$A = \left(K_{V_{OC}} - \frac{V_{OC}}{T} \right) \Big/ \left(\frac{N_S k T}{q} \left(\frac{K_{I_{SC}}}{I_{ph}} - \frac{3}{T} - \frac{E_g}{A k T^2} \right) \right) \qquad (9)$$

$K_{V_{OC}}$ is open circuit temperature coefficient equal -0.07207 V/K [12].
- N_S is the number of cells in series, equal 36
- $K_{I_{SC}}$ is short circuit temperature coefficient equal 0.009284 A/K [12].
- E_g is band gap energy for the silicon semiconductor which is equal to 1.124 eV [12].

Initial guesses for R_s and R_{sh} are necessary to start the iterative process. R_s tends to be small, therefore many authors take ($R_{s,min} = 0$) as an initial guess. $R_{sh,min}$ was estimated from the slope of the straight line bet–ween the short circuit current point and the maximum power point [13].

$$R_{sh,min} = \frac{V_m - 0}{I_{SC} - I_m} \qquad (10)$$

An iterative method is used for simulation resolution of (5)–(11) yielding the five reference parameters at STC. Now, there are certain equations for the five parameters except R_s which will be changed until achieving the condition. To execute the iteration process, a numerical approach based on the Newton Raphson's method will be implemented and progra–mmed in Matlab. The Newton-Raphson method, or Newton's method.

$$X_{n+1} = X_n \frac{f(X_n)}{f'(X_n)} \qquad (11)$$

Where Xn = In. Consider $f = f(I,V)$ then $(I_n) = 0$.

$$f(I_n) = I_{ph} - I_O \left[\exp\left(\frac{V + I_n R_S}{V_T} \right) - 1 \right] - \frac{V + I_n R_S}{R_p} - I_n \quad (12)$$

$$f'(I_n) = \frac{\partial f(I_n)}{\partial I} = -\frac{I_S R_S}{V_T} \left[\exp\left(\frac{V + I_n R_S}{V_T} \right) \right] - \frac{R_S}{R_{sh}} - 1 \quad (13)$$

where I_o is diode current, and R_P parallel resistance and equal to shunt resistance R_{sh}. Table 1 summerises the parameters of mc-Si module extracted by five parameter model at STC based on module datasheet.

Table 1. Solar module parameters of 5par–m at STC based on the module datasheet.

Parameters	Calculated values
I_{ph}(A)	3.1
I_o(A)	$2.06*10^{-10}$
R_{sh} (Ω)	209.21
R_s (Ω)	0.6034
A	1.02

3.2 Dependence of the parameters on operating conditions

The unknown electrical parameters (I_{Ph}, I_o, A, R_s and R_{sh}), was measured under standard test condition (1000 W/m^2 and 25˚C), in order to use these parameters for any other operating conditions, it is necessary to obtain expressions for their temperature and irradiance dependence.
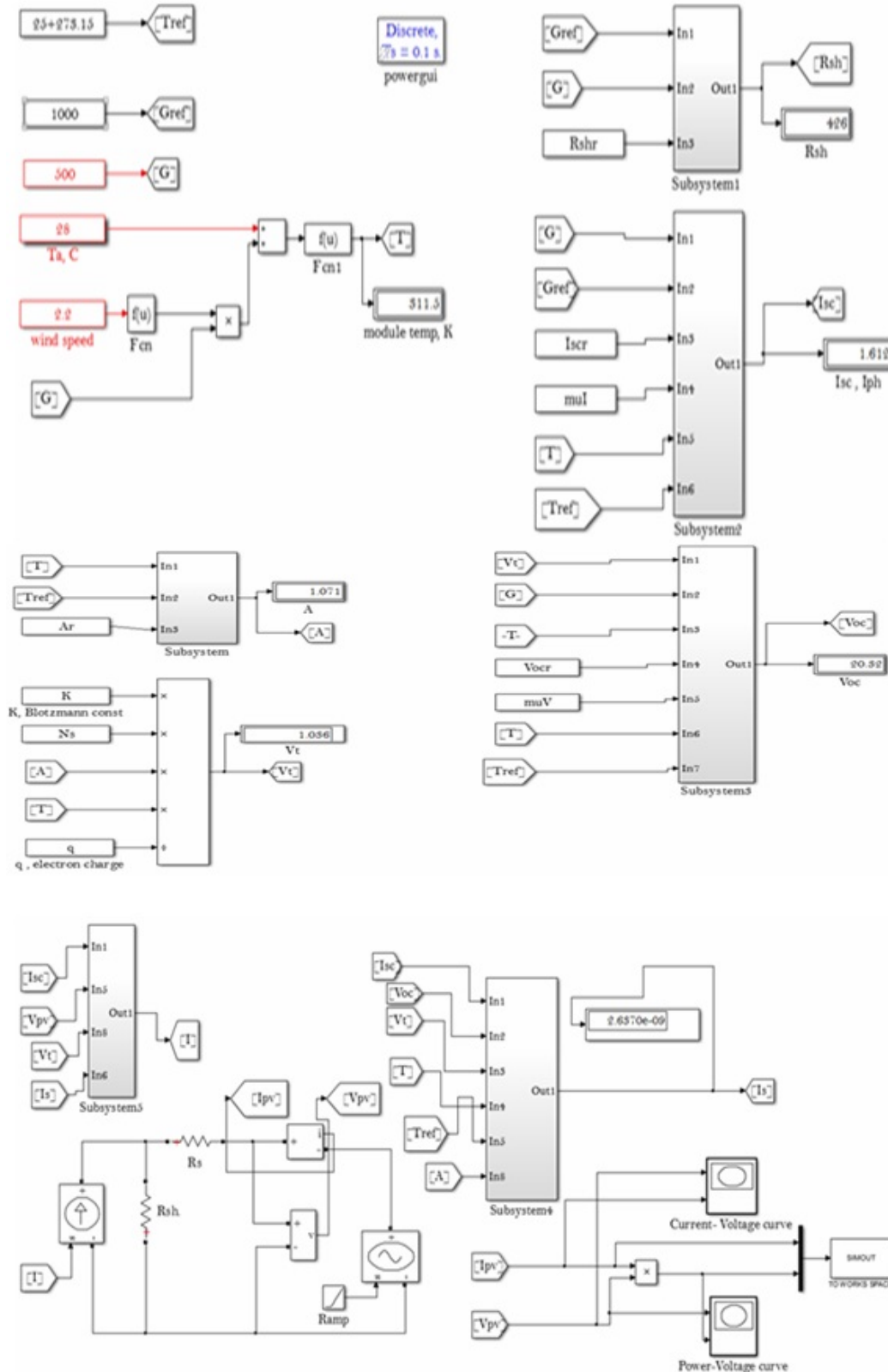

Figure 3. Simulink model for modelling module by five parameters model.

The parameters: photocurrent, saturation current, ideality factor, series resistance and shunt resistance are corrected for new environmental weather using (12) to (18) respectively. Equation (4) is solved in the Matlab /Simulink by using the five parameters at reference condition extracted from first model in the equations below as shown in Figure 3.

$$I_{ph} = \left[I_{SC} + K_{I_{SC}} \left(T - T_{ref} \right) \right] G / G_{ref} \qquad (14)$$

where G is the solar irradiance at operation conditions (watt), G_{ref} is the solar irradiance equal 1000W/m² and T_{ref} is reference temperature equal 25ºC.

$$I_{r,S} = I_{SC} \Bigg/ \left(\exp\left(\frac{qV_{OC}}{N_S T_{ref} kA} - 1 \right) \right) \qquad (15)$$

where $I_{r,s}$ is the reverse saturation current (A).

$$I_S = I_{r,S} \left(\frac{T}{T_{ref}} \right)^3 \exp\left[\frac{E_g}{Ak} \left(\frac{1}{T_{ref}} - \frac{1}{T} \right) \right] \qquad (16)$$

$$R_{sh} = R_{sh,ref} \frac{G_{ref}}{G} \qquad (17)$$

where $R_{sh,ref}$ is the shunt resistance at reference con–dition is takes from Iterative method.

$$A = A_{ref} \frac{T}{T_{ref}} \qquad (18)$$

Where A_{ref} the ideality factor at reference condition is takes from iterative method.

$$R_S = R_{S,ref} \qquad (19)$$

Where $R_{s,ref}$ is the series resistance at reference condition is takes from iterative method.

$$V_{OC} = V_{OC,ref} + V_T T_{OP} \ln\left(\frac{G}{G_{ref}} \right) + K_{V_{OC}} \left(T_{OP} \cdot T_{ref} \right) \qquad (20)$$

The unknown parameters are denoted at STC as $I_{ph,ref}$, $I_{s,ref}$, A_{ref}, $R_{sh,ref}$ and R_s; where the "ref" subscript refers to the reference operating conditions.

Table 2. The parameters of mc-Si module extracted by five parameter model at constant radiation 500 W/m² from Matlab Simulink.

Month 2017	$T_{cell,model}$ (°C)	I_{ph} (A)	I_s (A)	R_s (Ω)	R_{sh} (Ω)	A
Jan.	17.5	1.549	2.62×10^{-10}	0.6034	418.4	0.99
Feb.	19.0	1.550	4.49×10^{-10}	0.6034	418.4	1.01
Mar.	35.1	1.551	1.53×10^{-9}	0.6034	418.4	1.05
Apr.	33.8	1.551	1.35×10^{-9}	0.6034	418.4	1.04

As a result, Tables 2, 3 and 4 show the five parameters change with solar irradiance and cell temperature at operating conditions 500,750 and 1000 W/m² for four months. The value of reverse saturation current and ideality factor change with cell temperature, and the value of shunt resistance and photocurrent

change with solar irradiance. The series resistance (R_s) assumes to be constant at all operation conditions and equal to reference series resistance ($R_{s,ref}$) according to (19). While, shunt resistance (R_{sh}) will be function of solar irradance (G= 500,750, and 1000 W/m²) according to (17) and so it is have a variable value for each solar irradance and constant value for the corresponding months.

Table 3. The parameters of mc-Si module extracted by five parameter model at constant radiation 750 W/m² from Matlab Simulink.

Month 2017	$T_{cell,model}$ (°C)	I_{ph} (A)	I_s (A)	R_s (Ω)	R_{sh} (Ω)	A
Jan.	25.7	2.328	6.09×10^{-10}	0.6034	278.9	1.02
Feb.	33.3	2.327	1.21×10^{-9}	0.6034	278.9	1.04
Mar.	43.9	2.325	3.41×10^{-9}	0.6034	278.9	1.08
Apr.	38.4	2.329	2.06×10^{-9}	0.6034	278.9	1.06

Table 4. The parameters of mc-Si module extracted by five parameter model at constant radiation 1000W/m² from Matlab Simulink.

Month 2017	$T_{cell,model}$ (°C)	I_{ph} (A)	I_s (A)	R_s (Ω)	R_{sh} (Ω)	A
Jan.	33.8	3.106	1.35×10^{-9}	0.6034	209.2	1.04
Feb.	41.0	3.105	3.02×10^{-9}	0.6034	209.2	1.07
Mar.	47.6	3.105	5.23×10^{-9}	0.6034	209.2	1.09
Apr.	45.5	3.107	3.91×10^{-9}	0.6034	209.2	1.08

4. MODELING THE OPERATION TEMPERATURE OF PHOTOVOLTAIC MODULE

In order to predict the performance ofPV modules, it is necessary to know the PV module temperature. The modeling of PV module temperature is obtained as a function of solar irradiance G, ambient temperature T_a and wind speed v. Equation (21) is used to calculate the PV-cell temperature [8].

$$T = T_a + \left[\frac{0.32}{8.91 + 2\dfrac{v}{0.67}} \right] G \qquad (21)$$

T_a: The ambient temperature in ºC
v: The local wind speed in m/s
G: The solar radiation in W/m²
W: mounting effect which equals to 1 [8]
T: Operation temperature of the module in kelvin

5. EXPERIMENTAL SETUP

Performance of PV solar module is tested for four months from 1ˢᵗ January to 1ˢᵗ May 2017 under solar radiation of 500, 750 and 1000W/m². The tests were done under the outdoor exposure in Baghdad city, at the energy laboratory / department of energy engineering / Baghdad University. Measurements of a PV module electrical output traditionally are done at standard test conditions (STC): incident solar radiation of 1000 W/m², module temperature of 25ºC, and a 1.5 air mass (AM) .The module was placed on a steel holding stand which fixed to the ground as shown in Figure4. Solar

module analyzer Prova 200 is used to test the characteristics (I_{sc}, V_{oc}, V_m, I_m and P_m), efficiency and fill factor of solar panel, also provides the "*I-V* and *P-V*" curves. Solar radiation was kept constant as possible (The solar module system is on the outside door and the solar module is installed at the angle of inclination , which should be around 33.3º, which is the ideal angle to obtain the highest solar energy gain in Iraq and wait for the access of radiation intensity to 1000 W/m² in a net atmosphere-panel heat flux and then run the module analyzer(Prova 200) to make the scan within ten seconds); Solar Power Meter TES1333R is used to measure the total incident solar radiation. The temperature of the module was measured using digital thermometer (TPM-10) attached firmly to the back of the module. Weather Station Vantage Pro2 was used to measure weather factors such as ambient temperature and wind speed. Table 5 demenstrates module specifications at STC as presented by the manufacturer.

Table 5. Module specifications at STC as presented by the manufacturer.

Rated power	50W
Voltage at maximum Power (V_{max})	17.5V
Current at maximum Power (I_{max})	2.86A
Open circuit voltage (V_{oc})	21.6V
Short circuit current (I_{sc})	3.1A
Module type	(50)17M800 541
Module weight	5.6Kg
Area	0.43m²
Ns	36

Figure 4. Setup of the experimental work.

Table 6 provides some of the technical specifications of the apparatus (solar module analyzer Prova 200A) used in this study.

Table 6. Measurement apparatus range, resolution and accuracy.

	Measuring range	Resolution	Accuracy
Solar module analyzer Prova 200A			
DC voltage measurements	0-60 V	0.001-0.01	±1%±(1% of Voc±0.09V)
DC current measurements	0-6 A	0.1-1 A	±1%±(1% of Isc±0.9mA)
Solar power meter TES1333R			
Solar Radiation measurements	0-2000W/m²	0.1W/m²	±10W/m² or 5%, higher temperature Induced error of 0.38W/m²/ °C From 25°C
Digital thermometer TPM-10			
Temperature measurement	-50 70°C	p.1°C	±1°C

6. VALIDATION OF THE FIVE-PARAMETER MODEL

In the Matlab code, there is a command added specially to export the model results also as an Excel sheet where the experimental and model results are combined together in individual curves at three radiation level.In order to find out the compatibility between the practical and the theoretical by extracting the error ratios because there is differences between the experimental results and theoretical because of the inaccuracy of equipment and environment interactions.The percentage of error between the practical (Laboratory measurements) and theoretical (Matlab Simulink) by (22) was calculated.

$$\% Error = \frac{Matlab\,simulink - Laboratory\,measurements}{Laboratory\,measurements}100 \quad (22)$$

Table 7 shows the validation between experimental result and five parameter model result at solar radiation of 500, 750 and 1000W/m² and STC operating condition for four months.

In solar radiation of 750 W/m² the best theoretical and practical maximum power value is 39.93W and 33.73W respectively in the month of April. The theoretical values of the 1000W/m² solar radiation are almost constant in the four months, with the highest power value of 50.05W in April; the experimental results vary with each month, with the highest power value of 42.39W at January and a decrease of 40.52W in March due to increased cell temperature as shown in Table 7. While the theoretical maximum power value considered constant at fourth month equal 50.09 W was extracted from the iterative program as shown in Table 7, the best value of experimental P_{max} was 44.61W in January.

It can be seen that the *I-V* and *P-V* curves extracted with the method of this paper is not agreement with experimental dataset, there is a difference between experimental and calculated values of maximum power for radiation of 500, 750, 1000W/m² and STC operating condition equal 10.9%, 19.3%, 21.4% and 17.3% respectively.

Table 8 show the result from monocrystalline PV module at four operation conditions with the corresponding solar cell temperatureson four months.

Table 8 also summerised comparisons between; $P_{m,mod.}$ and $P_{m,exp.}$, $I_{m,mod.}$ and $I_{m,exp.}$, $V_{m,mod.}$ and $V_{m,exp.}$, $\eta_{m,mod.}$ and $\eta_{m,exp.}$ with the corssponding percentage errors. Figures 5 and 6 represented *I-V* and *P-V* curves respec–tively for January for different levels of irradiance of 500, 750, 1000 W/m^2 and STC operating condition, despite the modeling curves do not match experimental data in all points, the percentage error between the experimental (measured) maximum power and five parameter model (predicted) maximum power at STC was 14.8%. It is considered the best match of the reference condition on four months, except for the low irradiance of about 500 W/m² where the five-parameter modeled curve is closer to the experimental data at other radiation. The percentage error at solar radiation of 500W/m^2 at January month equal 5% showing good agreement at this month. The validation of percentage error at solar radiation of 750 and 1000 W/m^2 for all months is approximately same equals 19% for 750 W/m^2 and 20% for 1000W/m^2.

Table 7. The maximum power modelling and experimental at four operating conditions for four months.

$P_{m,model}$				
G W/m^2	January	February	March	April
500	23.22	24 .67	24.10	25.00
750	38.46	38.08	36.04	39.93
1000	50.03	50.04	50.01	50.05
STC	50.09	50.09	50.09	50.09
$P_{m,experimental}$				
500	22.00	22.23	22.03	23.40
750	32.09	31.92	29.17	33.73
1000	42.39	41.20	40.52	41.70
STC	44.61	42.70	43.13	42.34

7. CONCLUSIONS

The presented work is a modeling and simulation of the monocrystillane silicon solar module performance. It is implemented under MATLAB/Simulink environment; the most used software by researchers. A five parameter PV module modeling has been selected for simulation scenario under environment of solar irradiance from 500-1000 W/m^2. This model can be used to obtain the $I(V)$ and $P(V)$ characteristics.

This model can be considered as a tool which can be used to study all types of PV modules available in markets, especially their behavior under different weather data of standard test conditions (STC). It is important to assume that R_S, is constant to simplify the MATLAB/Simulink modeling. The average percentage error of the validation between the experimental measured maximum power and five parameter model (predicted) maximum power at radiation of 500W/m² was analyzed with the best value of validation was 5.5% at cell temperature 17°C.

The maximum measured power percentage error at radiation 500, 750 and 1000W/m^2 was 5.5% in January, 18.4% in April and 20% in April respectively with the corresponding calculated (simulated) ones.The best validation of maximum power under standard testing conditions (STC) was 14.8% in January. We can conclude that single diode Simulink model perfectly describes the *I-V* and *P-V* characteristics of asolar module system. The Newton-Rapshon method is an appropriate method to extract the parallel resistance used for simulation for fixed series resistance (assumed constant).
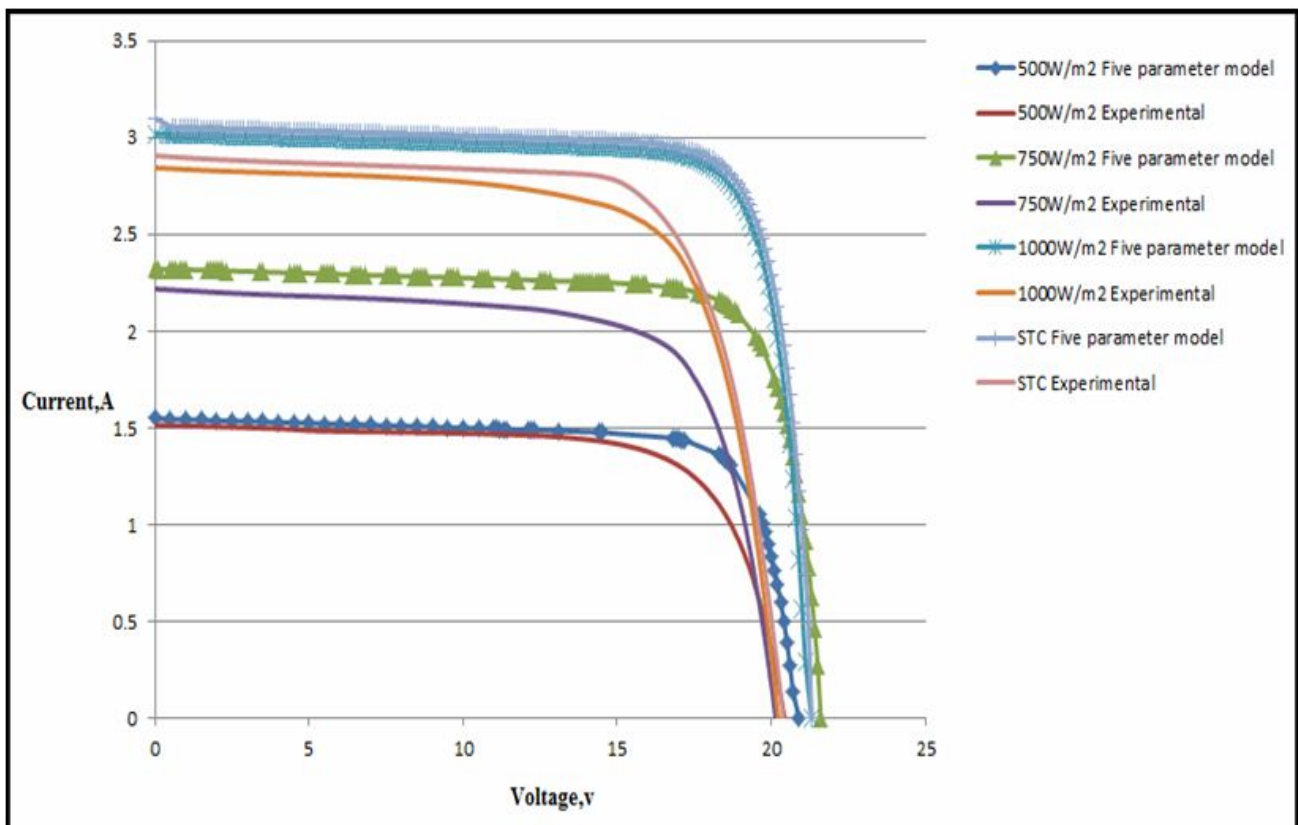

Figure 5. Comparisons of current-voltage curves of monocrystalline module predicted by the five-parameters model and experimental measured values of radiation flux 500,750, and 1000 W/m² and STC operating condition on February month.
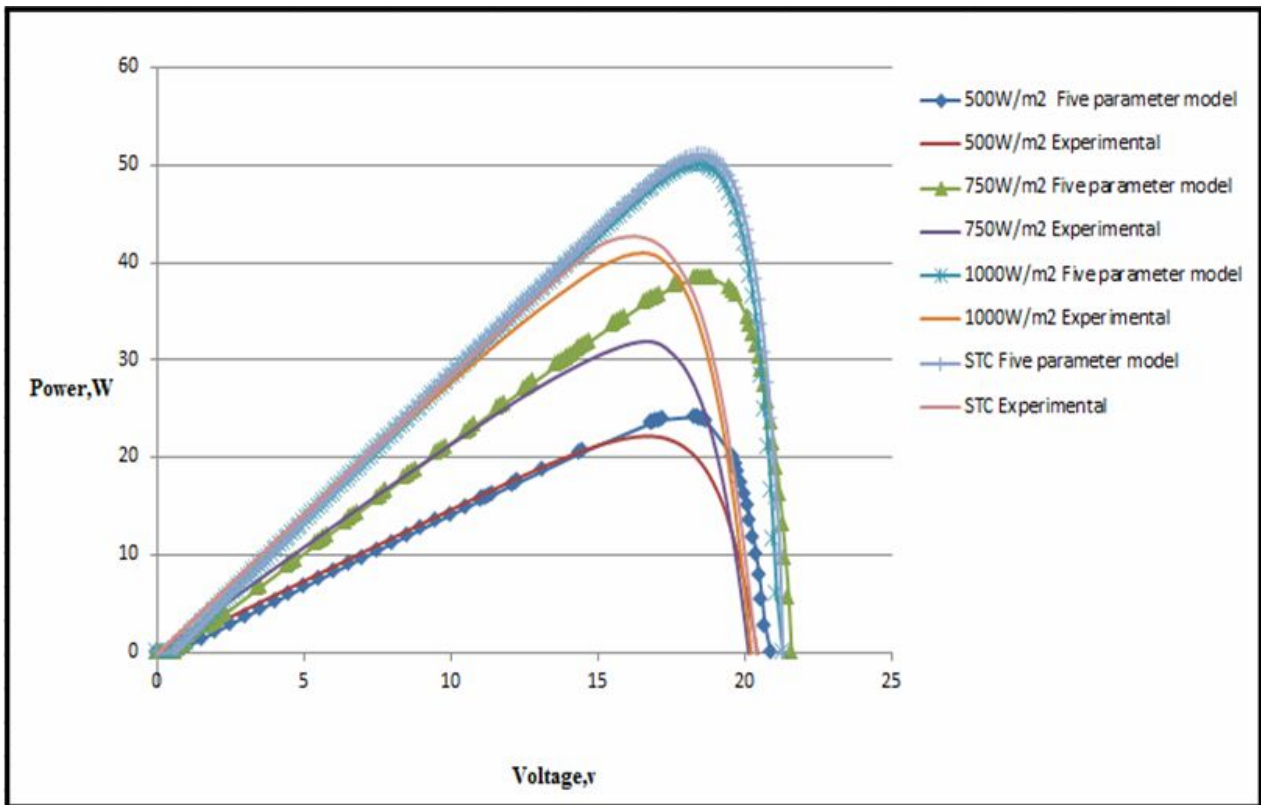
Figure 6. Comparisons of power-voltage curves of monocrystalline module predicted by the five-parameters model and experimental measured values of radiation flux 500,750, and 1000W/m² and STC operating conditions onFebruarymonth.

Table 8 . The validation between experimental result and five parameter model result at solar radiation 500, 750, and 1000W/m² and STC operating condition for four months.

G w/m²	°C	pp$P_{m, mod}$ ww(W)		Error (%)	$I_{sc,mod.}$ (A)	$I_{sc,exp.}$ (A)	Error, (%)	$V_{oc,mod.}$ (v)	$V_{oc,exp.}$ (v)	Error (%)	$\eta_{mod.}$ (%)	$\eta_{exp.}$ (%)	Error (%)
Jan. 2017													
500	17	23.22	22.00	5.5	1.54	1.49	3.3	20.57	20.50	0.3	10.8	10.2	5.8
750	28	38.46	32.09	19.8	2.31	2.29	0.9	21.70	20.15	7.7	11.9	9.9	20.2
1000	33	50.03	42.39	18.0	3.11	2.84	9.5	21.72	20.76	4.6	11.6	9.8	18.4
STC	25	50.09	44.61	12.3	3.10	2.97	4.5	21.60	20.71	4.8	11.7	10.4	12.5
Feb.2017													
500	18.0	24.67	22.23	10.9	1.55	1.52	1.9	21.54	20.44	5.4	11.5	10.3	11.6
750	33.3	38.08	31.92	19.3	2.35	2.28	3.1	21.69	20.00	8.4	11.8	9.8	20.4
1000	41.0	50.04	41.20	21.4	2.99	2.83	9.5	21.37	20.54	4.0	11.6	9.6	21.4
STC	25.0	50.09	42.70	17.3	3.10	2.91	6.6	21.60	20.41	5.8	11.7	9.9	18.2
Mar. 2017													
500	33	24.10	22.03	9.4	1.50	1.47	2.0	20.67	20.60	0.3	11.2	10.2	10.8
750	42	36.04	29.17	23.6	2.33	2.22	4.9	21.50	19.46	10.5	11.2	9.0	24.4
1000	47	50.01	40.52	23.4	3.01	2.80	7.5	21.16	20.24	4.5	11.6	9.4	24.7
STC	25	50.09	43.13	16.1	3.10	3.00	3.3	21.60	19.15	10.2	11.6	10.1	14.8
Apr. 2017													
500	33	25.00	23.40	6.8	1.59	1.45	0.2	20.94	20.85	0.4	11.6	10.8	7.4
750	37	39.93	33.73	18.4	2.41	2.32	3.9	21.86	20.16	8.4	12.4	10.5	18.1
1000	44	50.05	41.70	20.0	3.12	2.81	11.0	21.70	20.80	4.3	11.6	9.7	19.6
STC	25	50.09	42.34	18.3	3.1	2.93	5.8	21.60	19.90	8.5	11.6	9.8	18.4

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NOMENCLATURE

A	diode ideality factor
A_{ref}	ideality factor parameter at STC
E_g	band gap of semiconductor. eV
G	solar radiation, W/m^2
I_m	current at maximum power point, A
I_o	diode current, A
I_{ph}	photo-generated current, A
$I_{ph,ref}$	light current at STC, A
I_s	reverse saturation current, A
I_{sc}	short circuit current, A
$I_{s,ref}$	diode reverse sapration current at STC, A
k	Boltzmannconstant, k $=1.38\times10^{-23}$J.K^{-1}
N_s	number of cells
P_m	maximum power output from experimental, W
$P_{m,exp}$	maximum Power output, W
$P_{m,mod}$	maximum power output from modelling, W
q	electric charge of electron, C
V_{oc}	open circuit Voltage, V
R_p	parallel resistance, Ω-
$R_{sh,ref}$	shunt resistance at STC, Ω
$R_{s,ref}$	series resistance at STC, Ω
R_s	series resistance, Ω
R_{sh}	shunt resistance, Ω
V_m	voltage at maximum power point, V
T	operating temperature of the module, K
T_a	the ambient temperature, ^{o}C
W	mounting affect which equal to 1

Greek symbols

υ	local wind velocity, m/s
η_m	modelled solar module efficiency, %
η_{exp}	measured solar module efficiency, %

ПЕРФОРМАНСЕ ПЕТО-ПАРАМЕТАРСКОГ МОДЕЛА ФОТОНАПОНСКОГ МОДУЛА ОД МОНОКРИСТАЛНОГ СИЛИЦИЈУМА ПРИМЕНОМ РЕФЕРЕНТНИХ ПОДАТАКА

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Приказана је израда модела фотонапонског модула коришћењем једно-диодног пето-параметарског модела базираног искључиво на техничким подацима. Модел користи само серијску и паралелну везу отпорника (шант). Израђен је и тестиран овај лак и прецизан метод моделирања фотонапонског модула који је у стању да предвиди понашање модула на различитим температурама и сунчевом зрачењуу климатским условима Багдада. Показано је како фотонапонски модул одређује параметре пето-параметарског модела, процењује добијену излазну снагу и остале електричне и унутрашње параметре. Рад врши упоређивање предвиђених крива напона и снаге и експериме-нталних података код монокристалног силицијума за период од четири месеца.
Резултати теоријских разматрања указују на незнатан пораст отпорности шантова и фотоелектричног тока са порастом интензитета сунчевог зрачења. Извршена је евалуација утицаја временских фактора на температуру ћелија коришћењем једноставне формуле. Резултати показују да постоји разлика између теоријских и експерименталних резултата. Максимална снага добијена код радијације од 500, 750 и 1000 W/m^2 била је у јануару 5,5%, у априлу 18,4% и 20%, при чему је добијена максимална снага за јануар месец

била 14,8% тестирањем услова стандардном методом. Резултати добијени моделирањем се слажу са експерименталним резултатима добијеним за температуру модула.