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Identification the internal parameters for mono-crystalline solar module using Matlab-simulation and experimental ascertainment

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ABSTRACT

The research studies the effects of some weather parameters for Baghdad city on the output of the solar module of the type monocrystalline. The experimental part measures the electrical parameters of the photo-voltaic (PV) module for three levels of radiation rate 500, 750, and 1000 W/m^2. The theoretical part includes the modeled and simulation of the PV panel, via the proposed mathematical single–diode model (SDM, 5 parameters), and Matlab-simulation. The Newton Raphson method was applied to find the output current of the solar panel and the plotting P-V, I-V curves. The work involves preparing a simple mathematical model to estimate the optimal ambient conditions to give the highest output of the solar module. The validation of the model was verified by the practical testing of the cell for 6 months. The best results were obtained at standard testing conditions (25℃, 1000 W/m^2). The output power calculated by the mathematical model was 30.1 W while from experimental work was 30.45 W. The relative error is 1.15%. The converge between experimental and modeling results for the same conditions is about 98.9% that proves the validity of the proposed model and the possibility of using it for all types of photovoltaic.

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1. INTRODUCTION

The world's energy requirements are rising and the traditional sources of energy are finite. It is regarded as a promising source of green energy, which is solar energy. It cannot consume and does not cause environmental pollution when used. The converting of solar radiation (SR) into electricity using solar cells system for producing this alternate energy occurs when the sunlight drops on the surface of the solar cell [1-6]. Creating simulation or modeling and analysis programs for the solar unit is a necessary and urgent procedure before installing the solar system because it helps to understand the unit's behavior in the actual climatic conditions of the worksite [7]. The main models usually used in studying any photovoltaic cell are; the SDM, the double-diode model (DDM), and the empirical model [8-15]. An enormous number of enhancements have been introduced in these models to simplify the model and reduce the number of its parameters. Some researchers have premeditated the types of ray of light related to receive power from sun light and the result compared with [16-20]. The empirical photovoltaic cells model is vastly used in modeling because of its simplicity and its utilization of a limited number of parameters. However, it is not considered the most accurate model. The two-diode model is not frequently used even though its high accuracy, this is due to its complexity. It is preferable in studies that required detailed cell's information. The one-diode model takes into account all the necessary parameters in the identification of the impacts of photo-voltaic (PV) systems on the electric network. This accurate modeling of the PV attracted most of the researchers to use the one-diode model [21-26]. R. Chenni and et al. used single–diode model (SDM) to model the output features of three popular types of photovoltaic panels in an expression of irradiance and temperature environment variations. The data needed for their suggested model were from either by-products' datasheet or experimental testing results [27]. M. R. Al Rashidi and his team presented a new technique based on pattern search optimization to estimate the solar cell parameters. They used DDM to minimize the error associated with the estimation process [28]. X. Nguyen and M. Nguyen suggested an empirical model to study a hybrid power generation system. Their model contained tag tools, icons, and dialogs in Matlab/Simulink block libraries. They studied the output curves of the solar module which was connected to other renewable energy sources [29]. The solar module is expensive and has nonlinear characteristics under varying operating conditions. In addition, getting operating curves takes long time. It represents a fast tool for the performance description of several types of solar cells based on the Matlab program. Also, the method determines the environmental conditions which affect the operation of the proposed system. The proposed method extracts the characteristic of PV panels and studies the effect of different values of SR at different temperature values for the optimum output power of PV cells. Solar radiation and the cell temperature (CT) are considered in simulating the output' current and the power properties of the photovoltaic model. The details of the modeling procedure for the circuit model are given in the next sections.

2. EXPERIMENTAL SETUP

The experimental system adopted for this work consists of; a PV panel monocrystalline fixed frame used with tilt angle 33◦ (local latitude of Baghdad city) towards the south, a solar module analyzer is a connect of PV panel electrodes with computer for data transfer, solar meter used to measure solar radiation, weather station for measuring the (ambient temperature, wind speed, humidity), and temperature sensor to measure the CT as shown in Figures 1 and 2. The experiment was conducted on the system for six months. At the time from 8 a.m. to 2 p.m. The PV module specifications of the manufacturer are given under standard conditions in Table 1.

Figure 1. Experimental setup

Figure 2. The measuring system components, (from left to right): solar module analyzer, solar power meter, digital thermometer, and weather station vantage prova

Table 1. The data sheet of solar module (monocrystalline module)

Modul specifications of 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℃
Module weight	3.5 Kg
Area	0.282^2

2.1. The mathematical model of a PV cell

For the aims of simplifying the analysis process of PV cells in electrical circuits, an electrical prototypical of a PV cell is introduced. Figure 3 displays the comparable circuit of an ideal PV cell for the SDM (5 parameters). Where: I_{ph} is photocurrent in (A), R_{sh} and R_s are the parallel and the series resistance (Ω) respectively, I is the output current of a PV module in (A), and V is the output cell's voltage.

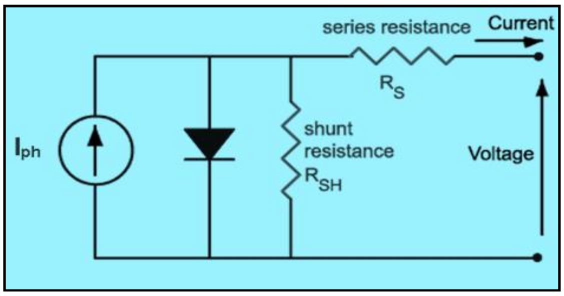

Figure 3. The equivalent circuit of practical PV device for SDM

2.2. Equations for determine cell parameters

For calculation the cell temperature, in (1) is utilized. Thus, the weather conditions like ambient temperature, solar radiation, and wind velocity should be identified [30].

$$T = T_a + W\left[\frac{0.32}{8.91+2\frac{v_W}{0.67}}\right]G \tag{1}$$

The change of these parameters according to the SR and/or cell temperature is given below [31];

$$I_{ph} = G_{pu}.[I°_{sc} + \alpha_{Isc}.(T_c - 25)] \tag{2}$$

$$I_{mmp} = G_{pu}.[I°_{mmp} + \alpha_{Isc}\ .(T_c - 25)] \tag{3}$$

$$V_{oc} = V°_{oc} - \alpha_{Voc}.\Delta T \tag{4}$$

$$V_{mmp} = V°_{mmp} - \alpha_{Voc}.\Delta T \tag{5}$$

$$I_{sc} = \rho.[G_{pu}.(I°_{sc} + \alpha_{Isc}.\Delta T] \tag{6}$$

$$R_{sh} = \frac{V°_{mmp} - \alpha_{Voc}.\Delta T}{G_{pu}.(\frac{I°_{sc} - I°_{mmp}}{2})} \tag{7}$$

$$R_s = \frac{(\frac{V°_{oc} - V°_{mmp}}{4})}{G_{pu}.(I°_{mmp} + \alpha_{Isc}.\Delta T)} \tag{8}$$

$$\rho = \frac{R_{sh}}{R_{sh} + R_s} \tag{9}$$

Thermal voltage depended on cell temperature is given by [32].

$$Vt = \frac{K\,T N_s}{q} \tag{10}$$

where: K (1.3806x10^{-23} J/K) is Boltzmann constant, N_s is the number of the series in the connected cells (equal 36) in a PV module, and q is the electron charge (1.602x10^{-19} C), so it is depending on T. The production power (p) of the PV panel is specified in the simplest form as in [33, 34]:

$$P = IV = \{I_{ph} - I_o\left(exp\left(\frac{V+R_sI}{a\,Vt}\right) - 1\right) - \frac{V+R_sI}{R_{sh}}]V \tag{11}$$

All these equations are calculated in the flowchart in Figure 4.

The single-diode five parameters model was solved by simulation in the Matlab program. In this model, two variables were entered; solar radiation and temperature of the cell (module). These inputs were measured in normal conditions of those measurements for six months. For each of these input values, there were output powers. The output power of one diode five parameter model and the measured via experimental work for various levels of SR (500, 750, and 1000 W/m^2) and inconstant temperature are given in the Tables 2-4. Figures 5-7 disply the comparison between the P-V curve obtained from the experimental work for solar radiations (500, 750 and 1000 W/m^2) respectively for six months. Figure 5 P-V feature of monocrystalline PV solar module at a constant radiation 500 W/m².

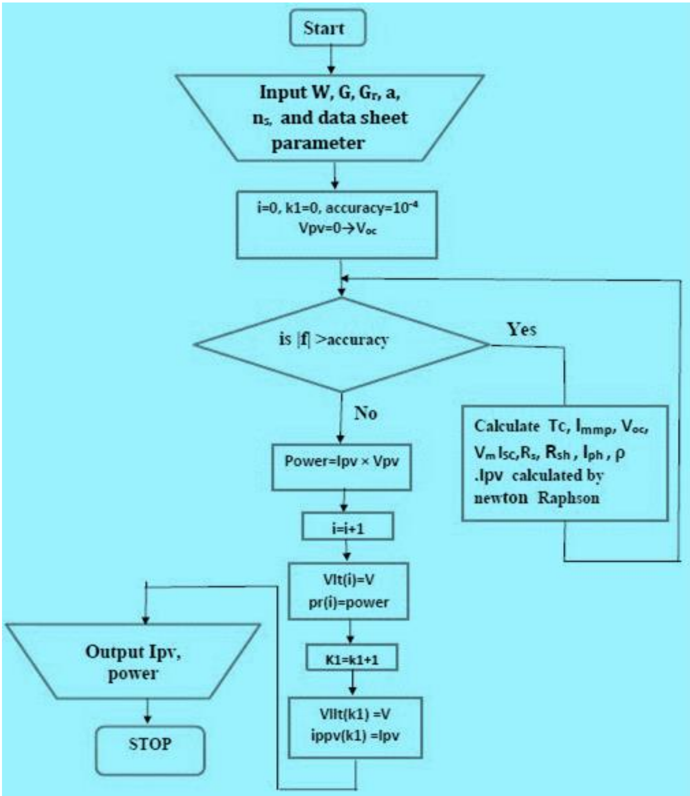

Figure 4. Flowchart of Matlab program

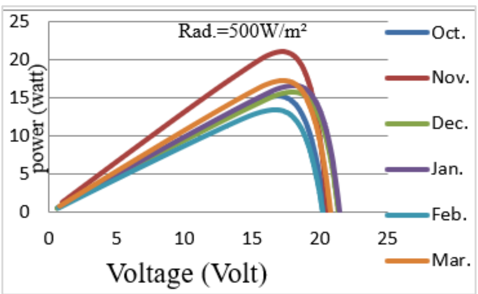

Figure 5. P-V feature of monocrystalline PV solar module

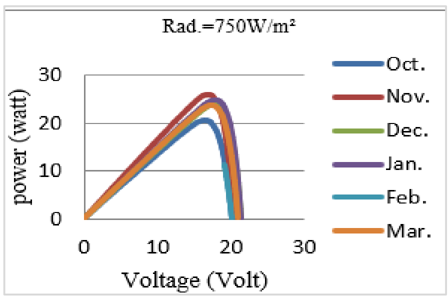

Figure 6. P-V feature of monocrystalline PV solar

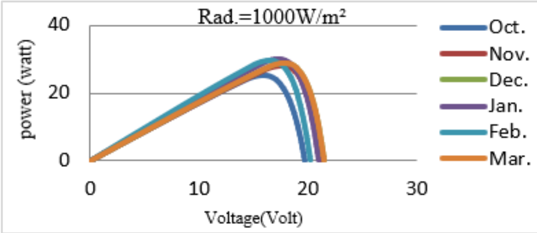

Figure 7. P-V feature of monocrystalline PV solar module at a constant radiation 100 W/m²

Table 2 displays a comparison of the theoretical results with that of the experimental results for SR 500 W/m^2. It was found that the lowest value of power 13.82 W in radiation 500 W/m^2 at the low-temperature module and the maximum power 22.12 W was at 28 ℃. When increasing the temperature above 30 and below 25, the output power decreased. This indicates that the lower and higher temperatures of the module (about 25 and 30 ℃) reduce the values of the power. Also, the short circuit current slightly increased with the variation of the temperature while the open-circuit voltage decreases with the increasing of the temperature. Tables 3 and 4 offer a comparison of the results obtained from theoretical and experimental studies for SR 750 and 1000 W/m^2 respectively. It was found that the value of power didn't evidently affected by the changing of the temperature because of the high intensity of the radiation proves the non-linear nature of the PV module. From Tables 2-4, the simulation results showed that the radiation more influence on output power than temperature. The heat transfers between the PV module and the ambient increased when wind speed increased so that the cell temperature decreased.

As illustrated in Table 5, at the steady radiation and raising temperature of the solar cell (module) in Matlab-simulation, the Rs, Rsh, Voc, and Power decreased with the temperature increases. While Isc increased with the temperature increment. Table 6 shows that increasing the radiation with constant temperature exhibited a significant increment in the output power reach to 30.1 (W) with 1000 W/m^2 solar radiation.

Table 2. The authentication between the five parameters model results and the experimental results at constant radiation 500 W/m²

Mon.	T_{cell}/℃	T_a/℃	W/m/s	$P_{max(exp)}$/watt	$P_{max(m)}$/watt	$V_{oc(exp)}$/Volt.	$V_{oc(m)}$/Volt.	$I_{sc(exp)}$/Amp.	$I_{sc(m)}$/Amp
October	33.8	27	1.4	15.32	14.27	20.39	21.09	1.018	0.998
November	28	20	5.5	22.13	15	20.66	21.7	1.379	0.948
December	25	17	4.5	17.08	15	21.49	21.68	1.004	0.947
January	21	12	2.4	16.6	15.22	21.64	22	1.025	0.947
February	24	16.8	1	13.82	14.9	21.32	21.8	0.907	0.947
March	30	24.4	5	17.21	14.45	20.76	21.28	1.1	0.948

Table 3. The authentication between the five parameters model results and the experimental results at constant radiation 750 W/m²

Mon.	T_{cell}/℃	T_a/℃	W/m/s	$P_{max(exp)}$/Watt	$P_{max(m)}$/watt	$V_{oc(exp)}$/Volt.	$V_{oc(m)}$/Volt.	$I_{sc(exp)}$/Amp.	$I_{sc(m)}$/Amp
October	40	27.5	4.6	20.34	20.83	20.17	20.67	1.371	1.42
November	30	19.5	2	25.96	21.7	20.25	21.2	1.673	1.422
December	25.5	17.7	3.7	24.29	21.8	21.35	21.39	1.481	1.422
January	23	13.5	5	24.79	22.3	21.40	21.7	1.470	1.421
February	26	14.7	2.2	20.52	22	20.67	21.6	1.307	1.42
March	33.5	23	3.5	23.6	21.28	20.89	21	1.479	1.43

Table 4. The authentication between the five parameters model results and the experimental results at constant radiation 1000 W/m²

Mon.	T_c/℃	T_a/℃	W/m/s	$P_{max(exp)}$/watt	$P_{max(m)}$/watt	V_{oc}/Volt.	$V_{oc(m)}$/Volt	$I_{sc(exp)}$/Amp	$I_{sc(m)}$/Amp
October	51	31.5	3	25.38	26.5	19.68	20	1.796	1.9
November	42	23	2	28.10	27.68	21.24	20.62	1.744	1.899
December	38.5	18.5	0.9	29.02	28.3	21.48	20.95	1.777	1.898
January	30	14.5	2.8	29.9	28.84	20.9	21.2	1.936	1.897
February	35	16.3	1.8	29.7	28.6	21.2	21.21	1.866	1.89
March	41	26.4	4.8	29	27.22	20.26	20.37	1.974	1.9

Table 5. The results calculated at constant G =1000 W/m² and a variable cell temperature

T_c /(℃)	R_s /(Ω)	R_{sh} /(Ω)	V_{oc} / (V)	I_{sc} /(A)	Power/(w)
25	0.71	242.14	21.95	1.895	30.1
35	0.708	231.66	21.21	1.897	28.8
45	0.707	221.17	20.45	1.9	27.4
55	0.706	210.69	19.74	1.93	26

Table 6. The results calculated at a constant Tc=25 ℃ and a variable solar radiation

G (W/m²)	R_s /(Ω)	R_{sh} /(Ω)	V_{oc} /(V)	I_{sc} /(A)	Power /(W)
100	7.1	2427	21.95	0.189	3
200	3.55	1213	21.959	0.378	6
300	2.36	808.8	21.96	0.565	9
400	1.77	606.4	21.965	0.761	12
500	1.42	485	21.967	0.943	15
600	1.18	404.1	21.97	1.136	18
700	1.01	346.2	21.97	1.326	21
750	0.95	323.8	21.98	1.421	22.7
800	0.88	302.8	21.98	1.515	24
900	0.79	269.1	21.99	1.705	27
1000	0.71	242.14	21.995	1.895	30.1

3. CONCLUSION

Parameters extraction accurately is an essential step to obtain PV outputs. In all the datasheets of solar module, the manufacturers usually only supplied four parameters. These selected parameters are not enough to deduce the required parameters of SDM thus, we proposed mathematical 5 parameters SDM and Matlab-Simulation to find the output current of the solar panel and the plotting P-V, I-V curves. When comparing the solar module selection, the output power is a significant factor to consider. The simulation results in Tables 5 and 6 explained that the influence on the output power due to SR is more than that of the temperature. The parameters of the solar cell specification have also presented in the current study by employing a factors extraction method. The arrangements of solar cell model parameters gotten from this technique are capable to breed the behavior of the PV array (in the real conditions) with high output power around 29.9 W. The variance of solar irradiance in Iraq is sufficient to apply the photovoltaic cells to generate electricity with good performance, therefore, choosing solar energy as an alternative of oil is an ideal option. One can conclude that at minimum SR (500 W/m^2), the change in temperature has more effect that leads to minimum output power. While in high SR(1000 W/m^2) the effect of the change is slight. With increasing solar radiation, we notice the rising in power, short circuit current, and open circuit voltages, except for the internal resistance (series and parallel resistance). While with the increase in temperature and constant radiation, we notice that the power, (series and parallel resistance), and open-circuit voltages will be increasing, except the current is affected slightly in this case because it depends on the solar radiation. The compatibility between theoretical and experimental results indicates that the suggested model can be used for all types of photovoltaic and also for high output power. Also, using the proposed model to estimate the optimal ambient conditions to give the highest output of the solar module reduces the effort, time of work, and cost before installing PV systems.

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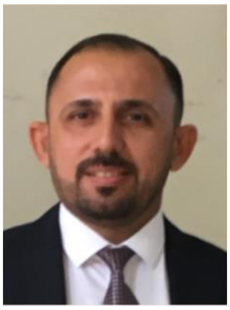

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