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Modeling of Monocrystalline PV Cell Considering Ambient Conditions in Baghdad City

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Abstract

The environmental conditions are important factors, because they affect both the efficiency of a photovoltaic module and the energy load. This research was carried out experimentally and modeling was done in MATLAB –Simulink by monitoring the variation in power output of the system with environmental conditions such as solar radiation, ambient temperature, wind speed, and humidity of Baghdad city. From the results, the ambient temperatures are inversely proportional to humidity and the output power performance of the system, while the wind speed is directly proportional with the output power performance of the system.

Keywords: *Ambient temperature, cell temperature, humidity, Photovoltaic, solar radiation, wind speed.*

1. Introduction

Solar energy has the greatest potential of all the sources of renewable energy. If only a small amount of this form of energy could be used, it will be one of the most important supplies of energy specially when other sources in the country have depleted energy comes to the earth from the sun. The use of solar energy for electrical power generation dates back to space age when solar photo voltaic cells were used to power satellites orbiting around the earth. With passing time it was realized that solar photo voltaic can be used as a power source not just for satellites but as also the cleanest and greenest power source on earth. Solar Energy thus started being used not just for conventional purposes such as heating but also power generation [1].

Modern PV cells are capable of converting up to 15% of the sun's energy into DC electric power. Sunlight provides roughly 100 Watts per square foot to the earth's surface, so on a clear day a 1-square foot PV panel can produce about 15 watts. Monocrystalline cell is also named single-crystal silicon cells and are the most common in the PV industry [1].

Single- crystal silicon has a uniform molecular structure compared to non-crystalline materials, its high uniformity results in higher energy conversion efficiency, more electricity is generated for a given area of exposure to the sunlight. The conversion efficiency for single-silicon commercial modules ranges between 20-30%. Certainly, the performance of these cells depends on ambient parameters including: ambient temperature, wind speed, direct radiation, etc. [4].

In this work, there will be a study of the impact of these parameters on the performance of photovoltaic cells.

2. Effects of Environmental Factors on Photovoltaic Cell

In order to predict the energy production of photovoltaic cell, it is necessary to predict the cell temperature as a function of ambient temperature, wind speed, humidity and total irradiance. The cell temperature equation was determined by using MINITAB program. Minitab has all the tools needed to effectively analyze the data. By guiding to the right analysis and giving clear results, Minitab helps to create equation showing relationship between the cell temperature and all other factors by entering the experimental data in MINITAB program as below:

$$T_{cell} = 1.4\ T_a - 0.566\ W + 13.97\ H + 0.01751\ G - 16.21 \quad \ldots (1)$$

where:
T_a: Ambient Temperature
W: Wind Speed
H: Humidity
G: Radiation

The success rate of the equation was 96.22% "depending on experimental results" as shown in fig. 1, which refers to the relation between success rate of equation and all values of residual cell temperatures predicted by the program. All factors in this equation are predicted depending on the P-Value in MINITAB program (Ranging of P-Value 0 to 0.05) and when the P-Value approach to zero that's mean the factor has a good effect in equation. The P-Value of ambient temperature, wind speed, humidity, radiation and constant was 0.000, 0.01, 0.005, 0.000 and 0.002 respectively.

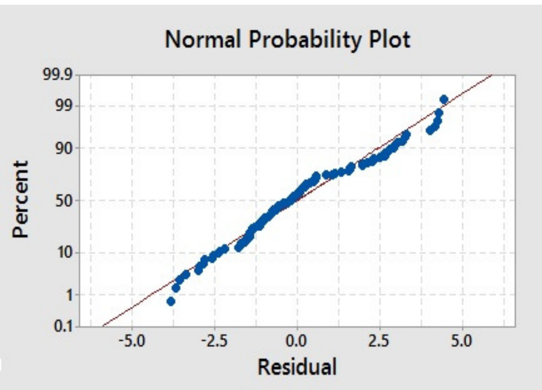


Fig. 1. Residual plot for T_{cell}.

3. Modeling of Photovoltaic Solar Cell Using Matlab/ Simulink Program

Mathematical model implemented in this work in order to study the effect of weather factors on power of PV module. Also, it's used for comparison between theoretical and experimental results. The main system of photovoltaic cell created as shown in fig.2. The blocks of photovoltaic cell are designed for simulation system according to the inputs and outputs of photovoltaic cell. The main system can change very quickly and easily. The main system of photovoltaic cell with obtained mathematical model of photovoltaic cell is established. the current of a PV module can be expressed, as function of voltage [2].

$$I_P = I_{SC}\ .\ [\ 1 - C_1\ .\ (\ e^{(V_P / C_2 \cdot V_{OC})} - 1)\ ] \quad \ldots (2)$$

Where

$$C_1 = (\ 1 - I_{MPP} / I_{SC}\ )\ .\ e^{(-V_{MPP} / C_2 \cdot V_{OC})} \quad \ldots (3)$$

$$C_2 = [\ (V_{MPP} / V_{OC}) - 1]\ /\ \ln [\ 1 - (\ I_{MPP} / I_{SC}\ )\ ] \quad \ldots (4)$$

I_{SC} = short circuit current;
V_{OC}= open circuit voltage;
V_{MPP}= maximum power point voltage;
I_{MPP}= maximum power point current;
V_P = voltage of PV module.
Such parameters can be expressed as follow:

$$I_{SC}(G, T) = I_{SCS}\ .\ (G / G_s)\ .\ [1+\alpha\ (\ T - T_S\ )] \quad \ldots (5)$$

$$V_{OC}(T) = V_{OCS} + \beta\ (\ T - T_S\ ) \quad \ldots (6)$$

$$I_{MPP}(G, T) = I_{MPPS}\ .\ (G / G_s)\ .\ [1+\alpha\ (\ T - T_S\ )] \quad \ldots (7)$$

$$V_{MPP}(T) = V_{MPPS} + \beta\ (\ T - T_S\ ) \quad \ldots (8)$$

where parameters I_{SCS}, V_{OCS}, I_{MPPS} and V_{MPPS} are defined at standard conditions, STC (G_s=1000W/m^2 and T_s=25°C) and α and β are respectively the current and the voltage temperature coefficient; all the above parameters are provided by manufacturers on module datasheet. It is possible to note that the parameters referred to currents depends on module solar irradiance G and temperature T, while the voltage ones depends only on temperature [2].

To improve the accuracy of the model it is convenient to modify expressions (6) and (8) by inserting a correction term, $\Delta V(G)$, taking into account voltage variation as function of solar irradiance:

$$V_{OC}(G,T) = V_{OCS} + \beta\,(T - T_S) - \Delta V(G) \quad \ldots (9)$$

$$V_{MPP}(G,T) = V_{MPPS} + \beta\,(T - T_S) - \Delta V(G) \quad \ldots (10)$$

Correction term $\Delta V(G)$ is obtained by the following relationship:

$$\Delta V(G) = V_{OCS} - V_{OCm} \quad \ldots (11)$$

where voltage V_{OCm} represents the open circuit voltage of the IV curve translated from STC to the considered irradiance G and it defined as:

$$V_{OCm} = C_2 \,.\, V_{OCS} \,.\, \ln\,[\,1 + [(\,1 - I_t / I_{SCS}) / C_1\,]] \quad \ldots (12)$$

I_t is the short circuit current at irradiance G and can be written as:

$$I_t(G) = I_{SCS}\,.(G/G_S) \quad \ldots (13)$$

In order to determine the value of series Rs, as function of panel parameters, it is convenient to express the module voltage as function of current by inverting eq. (2):

$$V_P = C_2 \,.\, V_{OC} \,.\, \ln\,[\,1 + [(1 - I_P / I_{SC}) / C_1]] \quad \ldots (14)$$

The value of series resistance R_S can be calculated by deriving eq. (14) with the current calculated for I_P=0: [2]

$$-R_S = -\,[d\,V_P / d\,I_P]_{I_P = 0} = (\,C_2 \,.\, (V_{OC} / I_{SC})\,) \,.\, (1/(1+C_1)) \quad \ldots (15)$$

Finally, we used the empirical equation that's create by using MINITAB program as above mention (1) in order to find other parameters as shown in flow chart Fig. 3.

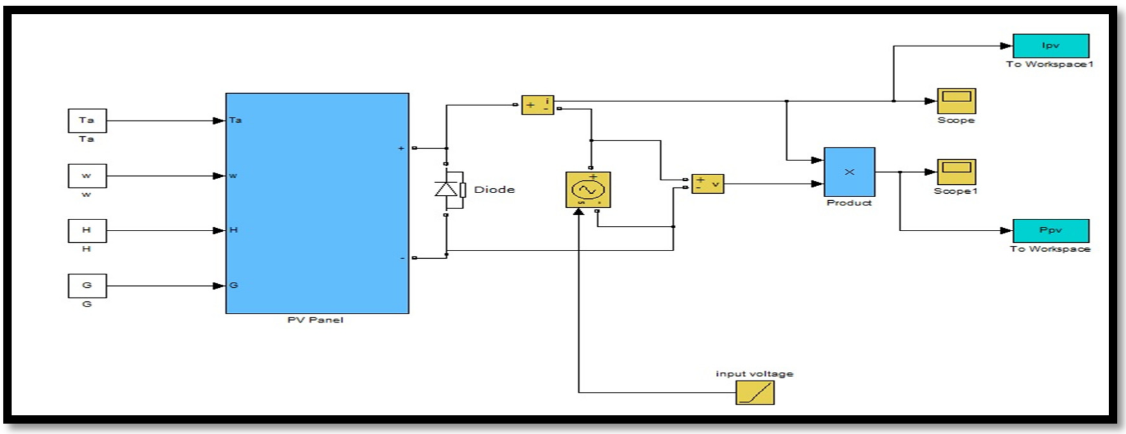


Fig. 2. Simulink model of weather factors effect on performance of PV solar cell.

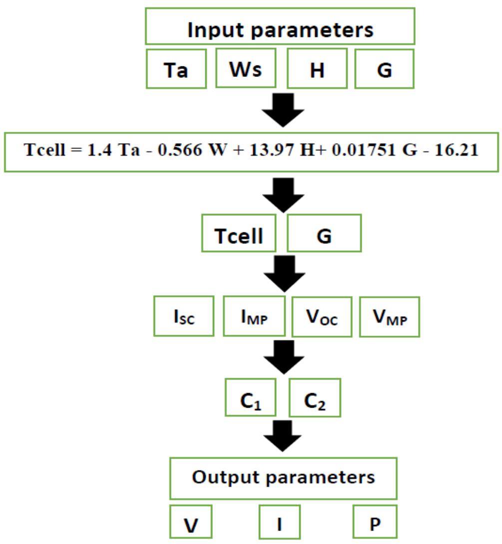


Fig. 3. Flow chart of mathematical model for PV solar cell.

4. Experimental Works

The experimental work focused on the study the effect of weather factors on the performance of PV solar cell and modeling these results in MATLAB- SIMULINK. These tests were conducted at the environment of Baghdad city starting from Nov. 2015 up to Apr. 2016.The laboratory devices used through the experimental work was:

- Monocrystalline solar module with maximum power: 30W, cell area: 0.282m^2, open circuit voltage: 22V, short circuit current: 1.9Amp, voltage at maximum power: 17V, current at maximum power: 1.76Amp. A standard calibration procedure has been made to the monocrystalline PV solar cells according to standard procedure supplied by the manufacture

- Prova 200 solar module analyzer used to measure output power, efficiency, fill factor (F.F), Vmax, and Imax of the solar module.
- Solar power meter "Data Logging Solar Power Meter TES-1333R" simply measuring the radiation intensity in W/m².
- Temperature sensor used to measure the temperature of the PV solar cell.
- Weather station vantage pro2 used to measure the weather factors.

1. Firstly, use a frame with angle 33.3°, installing of monocrystalline PV solar cell, solar analyzer and thermometer towards the south.
2. Using weather station vantage pro2 to measure weather factors such as ambient temperature, wind speed, humidity.
3. Solar power meters placed at the surface of the PV solar cells vertically to measure the radiation flux 500, 750 and 1000W/m^2.
4. Connect solar analyzer prova 200 with the PV solar module electrodes to measure power and other electrical parameters such as V_{oc}, I_{sh}, V_{max}, I_{max}, fill factor(F.F), and efficiency will be automatically calculated and then transferred the information to be store in work sheet of Excel program.
5. Measure the temperature of PV solar cells by temperature sensor.
6. Measure the weather parameters such as ambient temperature, wind speed, cell temperature, radiation, and humidity in order to study their effects on voltage, current, power and efficiency of PV solar cell and modeling this results in MATLAB-SIMULINK.

5. Results and Discussion

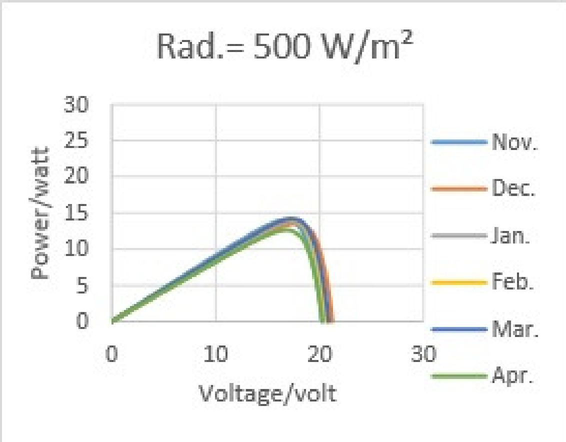
5.1 I-V and P-V Characteristic for Monocrystalline Solar Cell

The influence of cell temperature on the I-V and P-V characteristic curve of monocrystalline solar cell has been evaluated under three different radiations intensity 500,750 and 1000 W/m².Figures 4, 5 and 6 showing that the cell temperature has a strong influence on I-V and P-V characteristic of monocrystalline PV solar cell at constant radiation because its effect on open circuit voltage (V_{OC}). Decreasing cell temperature, PV current decreases slightly while PV voltage increases clearly. Output power of photovoltaic module increases with decreasing cell temperature up to 15°C.

The maximum value of voltage (V_{MAX}) and open circuit voltage (V_{OC}) at radiation intensity, 500W/m² was 17.95 Volt and 21.31 Volt respectively on December at 19.1°C while they were equal to 16.5 Volt and 20.06 Volt on November at 38.2°C. Also, the fill factor (F.F) changes directly proportional with the values of the V_{MAX}, I_{MAX}. The best value of F.F achieved is 0.75, and the best value of efficiency was 12.3% in December.

The maximum value of voltage (V_{MAX}) and open circuit voltage (V_{OC}) at radiation intensity, 750W/m² was 17.89 Volt and 21.27 Volt respectively on December at 23.1°C while they were equal to16.1 Volt and 19.81 Volt on November at 44.1°C. Also, the F.F changes directly proportional with values of the V_{MAX}, I_{MAX}. Whereas the best value of F.F achieved is 0.75, and the best value of efficiency was 10.76% on March. Also, noted these values of V_{MAX} and V_{OC}, and efficiency at radiation 750W/m² less than the values at radiation 500W/m² because the cell temperature was higher at radiation 750W/m².

The maximum value of voltage (V_{MAX}) and open circuit voltage (V_{OC}) at radiation intensity 1000W/m², was 17.22 Volt and 20.85 Volt respectively on December at 30.3°C while they were equal to 15.58 Volt and 19.63 Volt on November at 48.1°C. Also, the F.F changes directly proportional with values of the V_{MAX}, I_{MAX}. Whereas the best value of F.F achieved is 0.74, and the best value of efficiency was 10.25% on March. Also, noted that values of V_{MAX} and $V_{OC,}$ and efficiency at radiation 1000W/m² less than the values at radiations 500, 750W/m² because the cell temperature was higher than cell temperature at radiations 500, 750W/m². The short circuit current (I_{SC}) and maximum current (I_{MAX}), increases with increasing radiation. These results matched with previously published data such as [4].



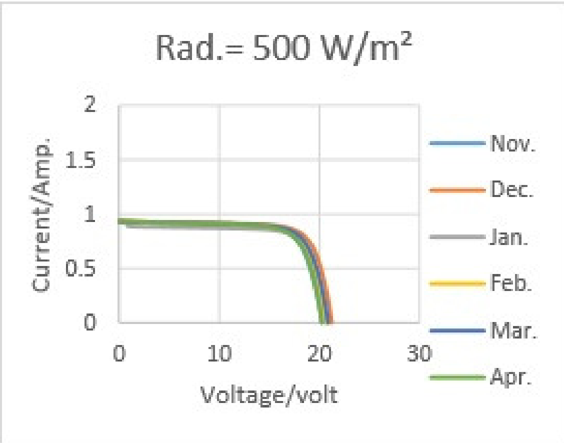
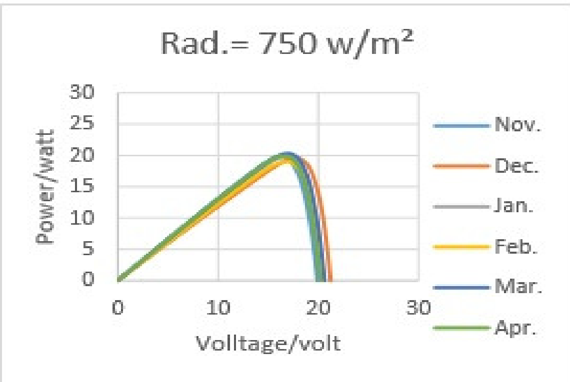


Fig. 4. P-V and I-V characteristic of monocrystalline PV solar cell at constant radiation 500W/m².



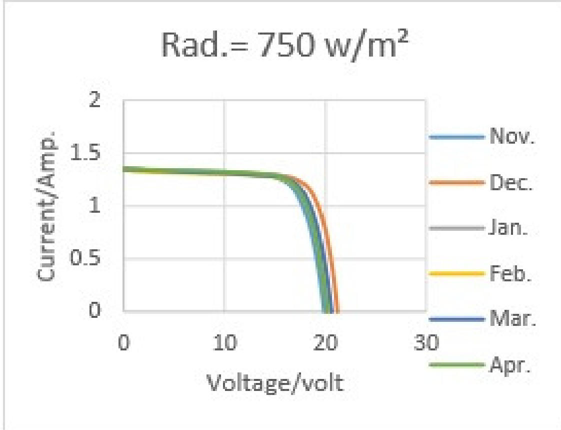
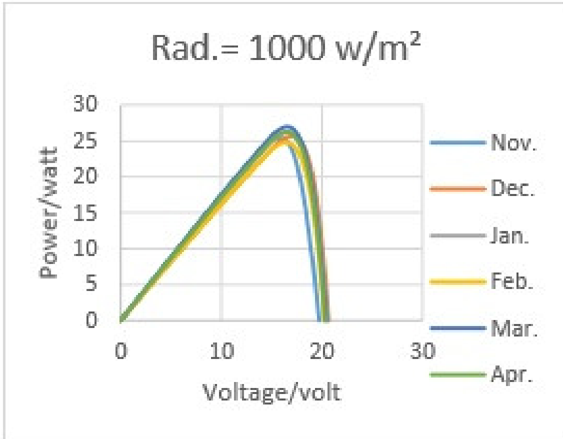


Fig. 5. P-V and I-V characteristic of monocrystalline PV solar cell at constant radiation 750W/m².



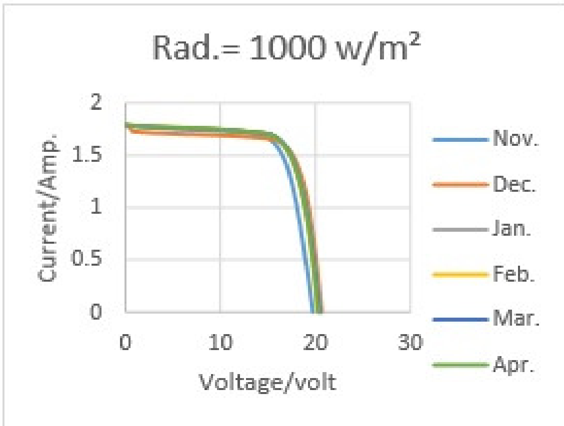


Fig. 6. P-V and I-V characteristic of monocrystalline PV solar cell at constant radiation 1000W/m².

5.2 Effect of Ambient Temperature on Power of Monocrystalline PV Solar Cell

The influence of ambient temperature on the power of monocrystalline solar cell has been evaluated under three different radiations 500,750 and 1000 W/m². Figure 7 showing that the ambient temperature has a strong influence on power of PV solar cell, when the ambient temperature increases, the output power of the cell decrease due to increase cell temperature, therefore decreasing in voltage will occur, causing drop in the power of PV solar cell. This results matched with previously published data such as [5].

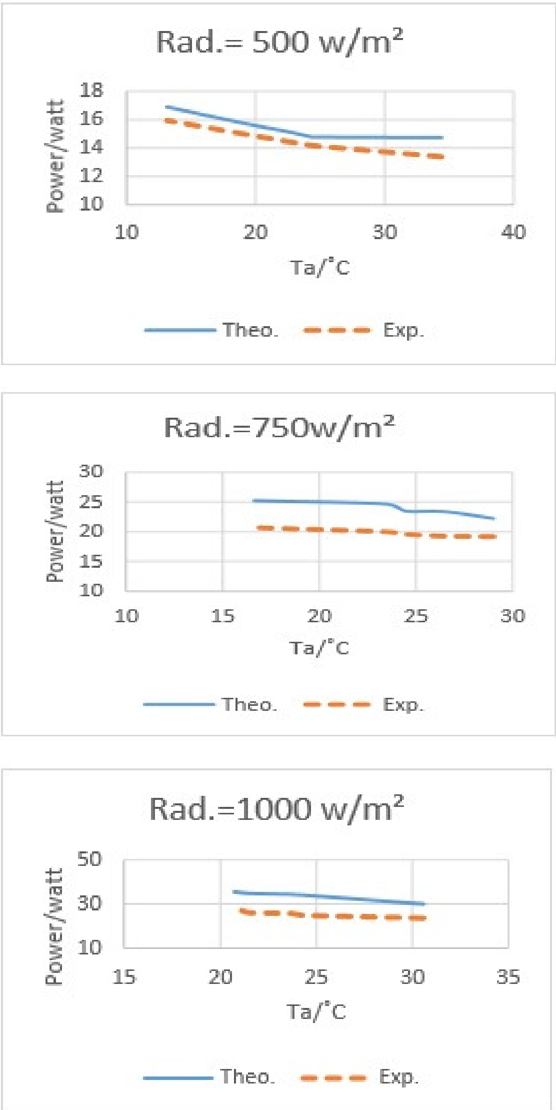


Fig. 7. Effect of ambient temperatures on power of monocrystalline PV solar cell at different radiation intensities.

At radiation intensity 500W/m², the best value of power was 15.95, 16.9 Watt experimentally and theoretically respectively when ambient temperature was 13.15°C in December. At radiation intensity 750W/m², the best value of power was 21.81, 26.76 watt experimentally and theoretically respectively where ambient temperature was 15.49°C in December. At radiation intensity 1000W/m², the best value of power was 28.82, 35.57 watt experimentally and theoretically respectively where ambient temperature was 20.73°C in January.

5.3 Effect of Wind Speed on Power of Monocrystalline PV Solar Cell

The influence of wind speed on the power of monocrystalline solar cell has been evaluated under three different radiations 500,750 and 1000 W/m². Figure 8 showing that when the wind speed increase, the power of PV solar cell increase because of decreases the cell temperature due to increase wind speed. These results matched with previously published data such as [6].

At radiation intensity 500W/m², the best value of power was 15.95, 17 watt experimentally and theoretically respectively when the average wind speed was 0.73m/s in December. At radiation intensity 750W/m², the best value of power was 21.81, 24.74 watt experimentally and theoretically respectively when the average wind speed was 2.09 in December. At radiation intensity 1000W/m², the best value of power was 28.82, 32.67 watt experimentally and theoretically respectively when the average wind speed was 2.64m/s in January.

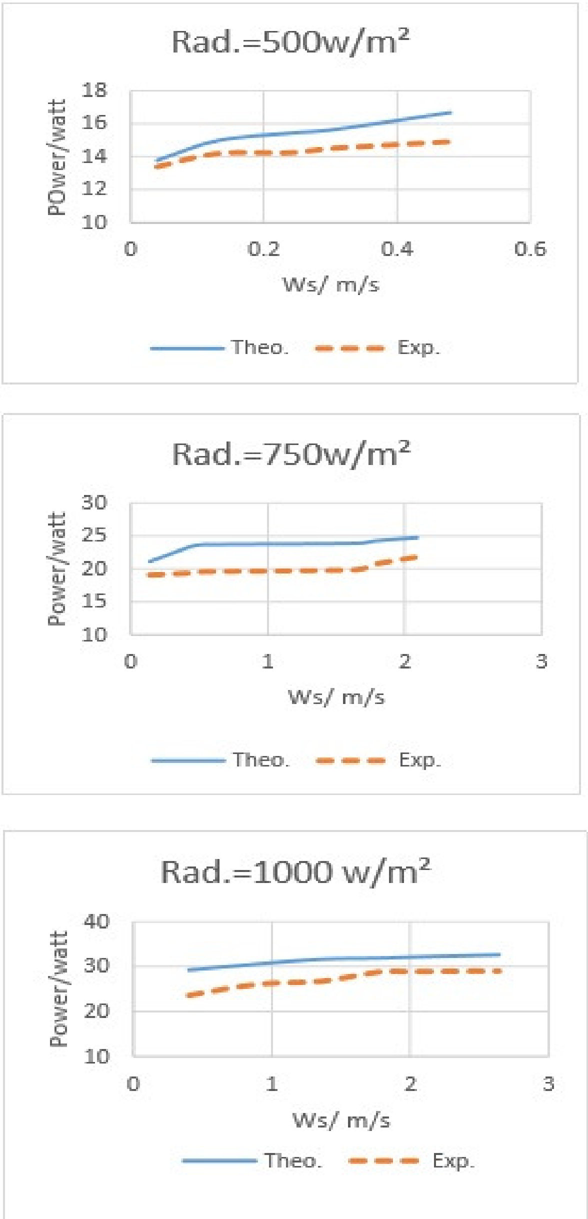


Fig. 8. Effect of wind speed on power of monocrystalline PV solar cell at different radiation intensities.

5.4 Effect of Humidity on Power of Monocrystalline PV Solar Cell

The influence of humidity on the power of monocrystalline solar cell has been evaluated under three different radiations 500,750 and 1000 W/m². Figure 9 showing that when relative humidity decreased the output power of PV solar cell increases when the humidity decreases. This results matched with previously published data such as [7].

At radiation intensity 500W/m², the best value of power was 15.95, 16.79 watt experimentally and theoretically respectively where the average humidity was 21 in December. At radiation intensity 750W/m², the best value of power was 21.81, 24.97 watt experimentally and theoretically respectively where the average humidity was 27 in December.

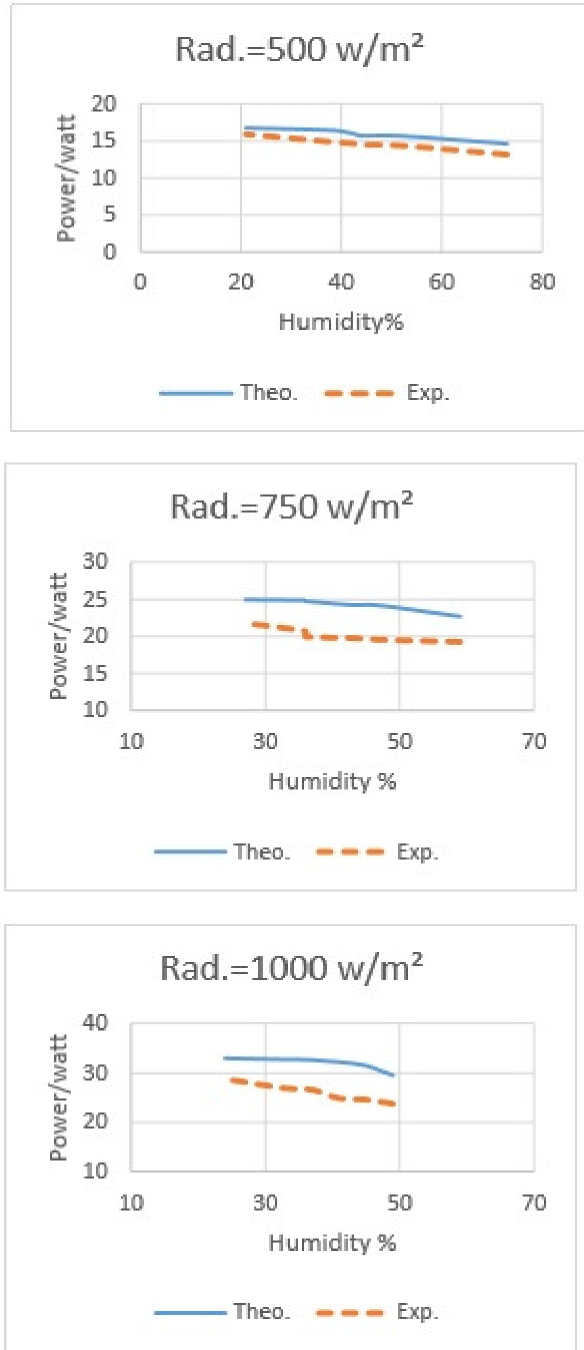


Fig. 9. Effect of humidity on power of monocrystalline PV solar cell at different radiation intensity.

6. Conclusions

From the results obtained we can conclude the followings:

- The cell temperature has a strong influence on performance of PV solar cells because its effect on open circuit voltage (V_{OC}). Decreasing cell temperature, PV current decreases slightly while PV voltage increase clearly. Output power of photovoltaic module increases with decreasing cell temperature.
- The ambient temperature has a strong influence on performance of PV solar cells when the ambient increase, the cell temperature increase, therefore decreasing in voltage will occur, causing drop in the power of PV solar cell.
- The wind speed has influence on performance of PV solar cells because its decreases the cell temperature, therefore increasing in voltage will occur causing increases in the power of PV solar cell.
- Low relative humidity increase in output current from solar panels. Voltage output also increased with decrease in relative humidity. Therefore the power of PV solar cell increases when humidity keeps at low values.
- The decreasing of solar radiation has impact to the ISC and VOC.
- Were these differences between the experimental results and theoretical results are because of the inaccuracy of equipment and environment interactions, therefore noted that the theoretical power of PV solar cells more than actual and practical power. After calculated error ratio according to relation between experimental and theoretical results as show in below:
- Error (%) = (theoretical results – experimental results / experimental results) * 100

Error ratio was equal 6.88, 5.91 and 4.53 when the radiation intensity equal 500, 750 and 1000 W/m² respectively.

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▯مذ▯ة الخلية الفوتوفولتائية احاديه الكريستالين أخذين بنظرالأعتبارالظروف الجوية في مدينة بغداد

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الخلاصة

الظروف البيئية هي عوامل مهمة، لأنها تؤثر بشكل كبيرعلى كل من كفاءة اللوح الشمسي والطاقة الناتجه. حيث أجري هذا البحث تجريبيا وتمت نمذجة النتائج في برنامج الماتلاب من خلال رصد التغير في انتاج الطاقة من النظام مع الظروف البيئية مثل الإشعاع الشمسي ودرجة حرارة المحيط، وسرعة الرياح، والرطوبة في مدينة بغداد. ومن خلال النتائج وجدنا ان هناك تناسباً عكسياً بين درجة حرارة المحيط وأداء انتاج الطاقة للنظام والرطوبة وأداء انتاج الطاقة للنظام، في حين أن سرعة الرياح تتناسب تناسبا طرديا مع أداء انتاج الطاقة من النظام.