International Journal of Renewable Energy Resources 13 (2023) 25-31
https://doi.org/10.22452/ijrer.vol13no1.3

# PREDICTION AND EVALUATION OF THE PERFORMANCE OF A PV SOLAR MODULE IN AYN AL-TAMR ZONE/KARBALA

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**Abstract**
Renewables are one of the most important alternative energy sources to fossil fuels. Renewable energy projects, especially solar energy, are among the important and promising projects in the country of Iraq, as it is one of the countries rich in this type of source. The current research provides a new and innovative way to predict the performance of solar cells throughout Iraq and thus gives a clear idea to investors about the feasibility of solar energy investment projects in specific places. The current research provides a detailed analysis of the expected performance of solar panels in the Ain al-Tamr region of Iraq (latitude angle is 32.58°). The present study gives the expected values of the electrical power produced by specific solar panels (Sharp type NU-JC400B) during daylight hours and during the seasons of the year, depending on the specifications of these panels and based on the data provided by the weather stations located in this region. Among the most important data adopted are the values of incident solar radiation per unit area, temperature rates, and maximum temperature and wind speed rates. The main results indicated that the annual solar radiation incident in Ayn al-Tamr with the horizontal plane was 7541.67 kWh/m$^2$/year with an annual peak sun hour (solar fuel) of 7.54. The results show that the maximum monthly-daily average yield was 6.36 kWh/kWp in June, while it was at its minimum value in December at 1.33 kWh/kWp. The annual final yield was approximately 1718.33 kWh/kWp. The results also indicated a good similarity between the practical and predicted results of a particular solar panel model.

**Keywords:** Solar radiation, Meteorological Station, Solar cell efficiency, PV module.

## 1. INTRODUCTION

Over the past 10 years, many residents around the world have used electrical solar systems as a sub-source of energy in their homes. This is because solar energy is an unlimited energy resource, set to become increasingly important in the longer term, for providing electricity and heat energy to the user. Solar energy also has the potential to be a major energy supplier in the future. Solar Energy has been the power supply of choice for Industrial applications, where power is required at remote locations. Most systems in individual uses require a few kilowatts of power. Examples are powering repeater stations for microwave, TV and radio, telemetry, and radio telephones. Solar energy is also frequently used in transportation signalling e.g., lighthouses and increasingly in road traffic warning signals. Solar's great benefit here is that it is highly reliable and requires little maintenance so it's ideal in places that are hard to get to (Vinayak et al., 2018). While the output of solar cells depends on the intensity of sunlight and the angle of incidence, it means to get maximum efficiency; the solar panels must remain in front of the sun during the whole day. But due to the rotation of the earth, those panels can't maintain their position always in front of the sun. This problem results in a decrease in their efficiency. Thus, an automated system is required to constantly rotate the solar panel to get a constant output. The Solar Tracking System is made as a prototype to solve the problem, mentioned above. It is completely automatic and keeps the panel in front of the sun where we get maximum output (Vinayak et al., 2018).

Energy is a basic need for civilization and for the development of society. According to Miro Zeman 2014, the increasing demand for energy, the primary and traditional source of energy, the prediction of upcoming renewable energy demand, and the vast usefulness of the energy are explained clearly. In order to have a clear idea about the current situation of energy production we studied the report from (Li et al., 2020). The advantages of using renewable energy sources and disadvantages of using fossil fuels are stated in the work of Pranahita et al. (2014). Each Pranahita et al., 2014; Brano et al., 2014, and Ma et al., 2014 also discussed the huge scope of solar energy on Earth. Global electricity demand rises by 5900 terawatt-hours (TWh) in the Stated Policies Scenario (STEPS) and over 7 000 TWh in the Announced Pledges Scenario (APS) by 2030, equivalent to adding the current level of demand in the United States and the

European Union. In advanced economies, transport is the largest contributor to increased electricity demand as the market share of electric cars rises from about 8% in 2021 to 32% in the STEPS and almost 50% in the APS by 2030. In emerging markets and developing economies, population growth and rising demand for cooling contribute to increasing electricity demand. In China, air conditioner ownership expands by around 40% from current levels in the STEPS and APS by 2030. Electricity provides a rising share of total final energy consumption in all economies. Global electricity demand in 2050 is over 75% higher in the STEPS than it is today, 120% higher in the APS, and 150% higher in the Net Zero Emissions by 2050 Scenario (IEA, 2022). Iraq plans to build a 750 MW solar power project in Muthanna Governorate. This project will support "several secondary plants" to help meet the growing demand for electricity. Because it absorbs sunlight and converts some of it into electricity, the PV system is an efficient method of generating electricity. There are no moving parts that will wear out over time, and no fluids or gases will escape. Fuel is not required to function (except in hybrid systems). It responds quickly, can reach full output quickly, and can operate at moderate temperatures (Hersch and Zweibel, 1982). Several studies have recently been conducted in this regard to assess and improve the performance of photovoltaic solar energy systems in Iraqi environments (Sumaryada et al., 2019). However, Iraq, like a number of other countries, suffers from a severe lack of access to electricity. Frequent outages caused by a supply-demand imbalance are becoming more common as Iraqi and global populations grow, industrial activities expand, and living standards rise. Thus, the results of this research came to serve solar energy investment projects that contribute to solving the problem of the acute shortage of electrical energy supply by providing a clear idea to the investor in the field of solar energy of the feasibility of building solar energy plants in specific places of the country of Iraq. The Ayn al-Tamr area in Karbala province was a model for this type of study. This work was implemented using MATLAB programs, and the results of total solar (global) radiation and maximum temperature were taken from Ayn al-Tamr meteorological station in Karbala, which is somewhat close to (Ismail, 2022).

## 2. THE MODULE CHARACTERISTICS AND A CASE STUDY

The maximum power $P_{max}$, short-circuit current $I_{sc}$, open circuit voltage $V_{oc}$, and fill factor $FF$ are the main parameters used to characterize the performance of solar cells. These parameters can be used to determine the output power P, efficiency η, and other elements, according to (Markvart, 2001), the short circuit current $I_{sc}$, is directly proportional to the incident solar radiation G. Therefore, $I_{sc}$ can be described by the following equation.

$$I_{sc}(G) = I_{sc}(STC) \text{ x } G \left(\text{in } 1 \frac{kW}{m^2}\right) \tag{1}$$

The maximum voltage produced by the photovoltaic cell is given by the parameter $V_{oc}$, in the absence of a connected load resistance or when the cell is not supplied with current (Pacheco, 2015).

$$V_{oc} = \frac{k_B T}{q} \ln\left(\frac{I_{ph}}{I_o} + 1\right) \tag{2}$$

where$k_B$, is the Boltzmann constant, $T$ is the operating cell temperature, $q$ is the charge of the electron $I_{ph}$ and, $I_o$ are already referred to as photo-generated and dark saturation currents respectively. Also, the open circuit voltage $V_{oc}$ is inversely proportional to the operating cell temperature $T$, and is given by the equation (Markvart, 2001).

$$V_{oc}(T) = V_{oc}(STC) - 0.0023 \text{ x } N_c \text{ x } (T-25) \tag{3}$$

where $N_c$ ,is the number of cells. The operating cell temperature T is calculated with wind speed $v_w$ by (Masud Rana Rashel 2018).

$$T = T_{am} + \left(\frac{0.32}{8.91+2v_w}\right) G \tag{4}$$

Where $T_{am}$ is the ambient temperature. The fill factor is the proportion of a solar cell's maximum power, $P_{max}$ to the product of $V_{oc}$, and $I_{sc}$ (Jäger et al., 2014).

$$FF = \frac{P_{max}}{I_{sc}V_{oc}} \tag{5}$$

Consider that the solar cell is an ideal diode, then the $FF$ is a function of the $V_{oc}$. The output power P of the PV solar module can be calculated by the following equation (Markvart, 2001).

$$P(G,T) = I_{sc}(G)V_{oc}(T) \tag{6}$$

The efficiency η (%) of the PV solar module is defined as the ratio of output power $P(G,T)$ to incident optical power (input power $P_{in}$) (Vokas, 2006)

$$\eta(\%) = \frac{P(G,T)}{P_{in}} \text{x}100\% \tag{7}$$

where $P_{in}$ is given by.

$$P_{in} = AG \tag{8}$$

where A is the area of the PV solar module. Therefore, the solar radiation falling on the PV solar module inclined at an angle, with the horizon is.

$$G(\text{inclined}) = G(\text{horizontal})/\cos(\text{latitude angle}) \tag{9}$$

The performance elements of the PV systems are given by the International Energy Agency (IEA) to analyze the energy-related performance of a grid-tied solar PV system including array yield $Y_A$, final yield $Y_F$, reference yield $Y_R$, performance ratio $P_R$, capacity factor $C_F$, system efficiency $\eta_{sys}$, and specific energy losses (Sharma and Chandel, 2013; Ayompe et al., 2011; Sharma and Goel, 2017; Arora et al., 2022). Final yield $Y_F$, is the ratio of actual AC energy output $E_{avail}$ by the PV system on a daily, monthly, or yearly basis to its nominal power $P_{PV,nom}$ at STC, and is denoted by (Sharma and Goel, 2017; Arora et al., 2022).

$$Y_F = \frac{E_{avail}\langle kWh\rangle}{P_{PV,nom}\langle kW_P\rangle} \tag{10}$$

Reference yield $Y_R$, is the ratio of total daily incident global irradiation in the collector plane to the solar irradiance at STC ($G_{STC}$), and is denoted by (Sharma and Goel, 2017; Arora et al., 2022).

$$Y_R = \frac{G_{global}(kWh/m^2)}{G_{STC}(1kW_p/m^2)} \quad (11)$$

Performance ratio $P_R$, is the ratio of the final yield to the reference yield and is denoted by (Arora et al., 2022).

$$P_R(\%) = \frac{Y_F}{Y_R} \quad (12)$$

Capacity factor $C_F$, is the ratio of the actual annual AC energy output of the PV system $E_{avail}$ to its full nominal energy generated as it operates 8760 hours yearly and is denoted by (Ayompe et al., 2011).

$$C_F = \frac{E_{avail}(kWh)}{P_{PV,nom}(kW_P)x8760} \quad (13)$$

On the other hand, the data of the Agricultural Meteorology Center in the Ministry of Agriculture for the year 2021 eleven meteorological stations were selected for the present work. The measured data of global solar radiation and maximum temperature by these stations were used to predict the performance of solar PV modules in the zone of this station.

A monocrystalline solar module, SHARB (NU-JC400B), was used as a unit of the solar module. Some characteristics of this solar module (under standard conditions, air mass 1.5, irradiance 1000 W/m$^2$, and cell temperature 25 $^o$C) are listed in Table 1.

Table 1: Some electrical data (STC) of the solar module (NU-JC400B-SHARP).

| Parameter | Value |
|---|---|
| Maximum power $P_{mp}$ (W) | 400.0 |
| Open-Circuit Voltage $V_{oc}$ (V) | 37.29 |
| Short-Circuit Current $I_{sc}$ (A) | 13.66 |
| Voltage at point of maximum power $V_{mpp}$ (V) | 30.92 |
| Current at point of maximum power $I_{mpp}$ (A) | 12.94 |
| Module efficiency | 20.5% |
| Fill Factor | 78.53% |
| Cells (Half-cut cell mono, 182 mm x 91 mm, MBB, 2 strings of 54 cells in series) | |
| Weight (Kg) | 21.8 |

## 3. RESULTS AND DISCUSSION

Ayn al-Tamr meteorological station is located in the Ayn al-Tamr district a district of Karbala Governorate, which is located in central Iraq, located about 67 km west of Karbala near Razzaza Lake, at an elevation of 50 m above sea level, and its longitude is equal 43.46° E, while its latitude is equal 32.58° N. The total solar radiation (global) incident on the horizontal surface in Wh/m$^2$/day for all days of the year is plotted in Fig. 1. It can be noted from the Fig., that global solar radiation increased rapidly in the summer season and decrease towards the winter seasons due to the climate. The maximum value of the global solar radiation rate is equal to (7541.67 Wh/m$^2$/day) in June. It is well known from Fig. 2 that the peak sun hours per day which equates to daily solar insolation (Wh/m$^2$) divided by solar irradiance in standard conditions (1000W/m$^2$), this fact represents the solar fuel and equal to 7.54 hours in summer spatially in June month.

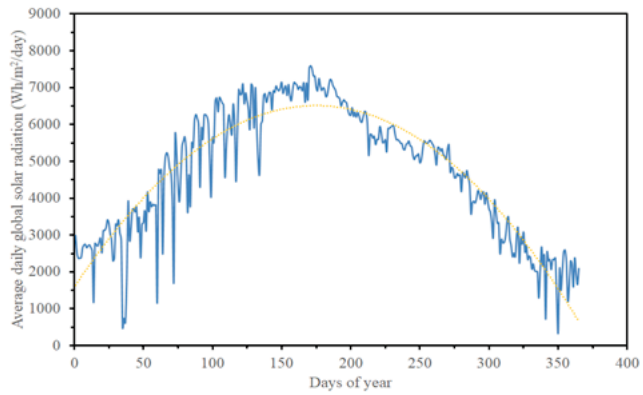


Fig. 1 Variation of incident global solar radiation rates in the horizontal surface along the year.

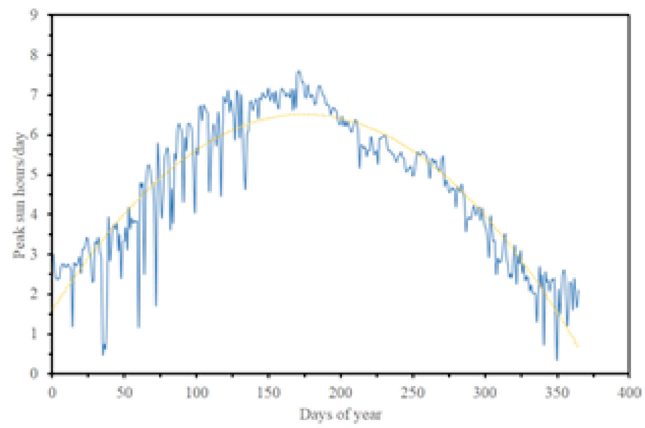


Fig. 2 Variation of peak sun hours throughout the year.

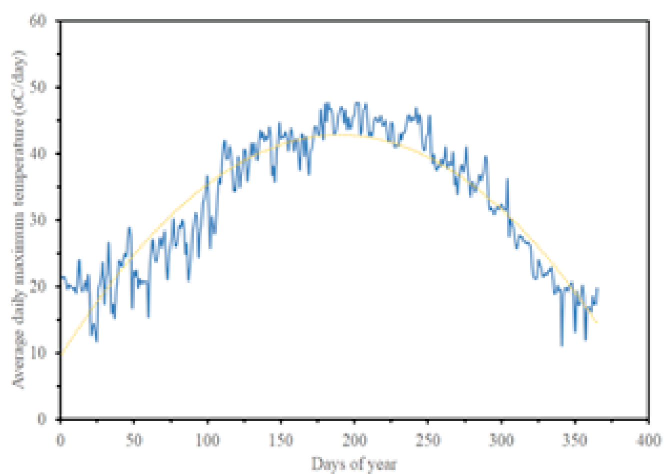


Fig. 3 The average daily maximum temperature throughout the year.

Fig. 3 represents the average daily maximum temperatures recorded by the Ayn al-Tamr meteorological station during the year 2021, as it is clear from the Figure that the maximum average temperature was 47.66 °C on July 1, 2021. The global radiation values were calculated in W/m$^2$ at each hour of the last days of the year with a tilt angle of 32.58° which represents the best annual angle at which the solar module can be tilted.

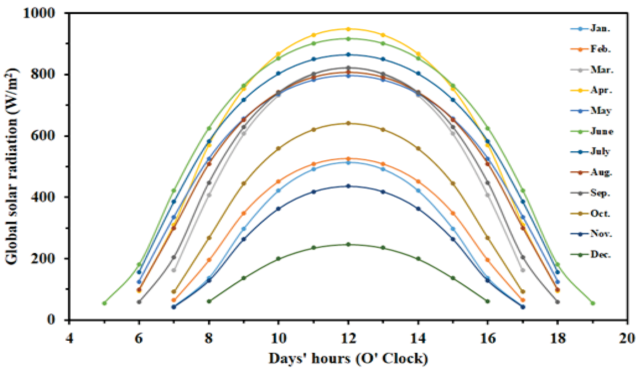


Fig. 4 Variation of daily global solar radiation received with the tilt angle of 32.58° along the year.

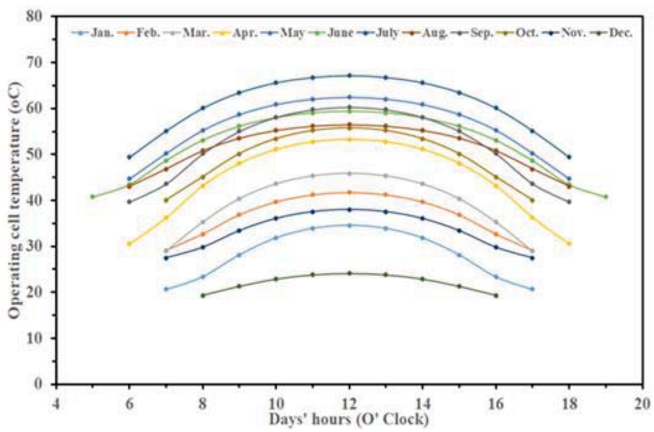


Fig. 5 Solar cell temperature rates in Ayn al-Tamr meteorological station during the year 2021.

These values are required in the prediction of the performance of the solar modules in the solar plant that will be installed in Ayn al-Tamr to generate electrical energy. The incident global solar radiation annually was 1718.33 kWh/m$^2$/year in the horizontal plane, which corresponds to 2038.35 kWh/m$^2$/year at a tilt angle of 32.58° from the horizon. As is customary, the rates of falling radiation are at their highest in the summer months and recede to their smallest values on winter days as a natural result. The number of hours of the day is greater in summer than in winter, and the sun is closer to the vertical path in the sky on summer days than in winter, while the degree of its slope increases as we approach winter. All these facts are embodied in Fig. 4. It is interesting to note from this Figure that the incident solar power per unit area reaches its peak at about midday during the days of the year. High radiation rates act to increase the temperature of solar cells (see Fig. 5). This Fig., represents the rates of solar cell temperature as a function of incident solar radiation. The high levels of cell temperature contribute to a decrease in its performance efficiency. Although the rise in cell temperature rates ends up in a decrease in the maximum output voltage Fig. 6, the output power will increase as we tend to move toward the summer as a result of the fact that it depends a lot more on the amount of incident radiation than the cell temperature.

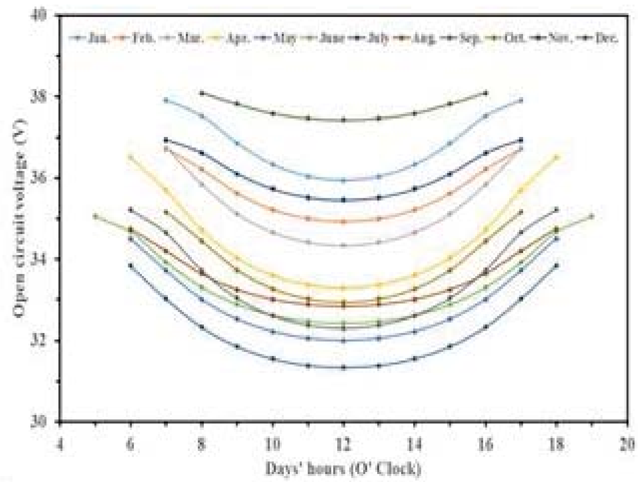


Fig. 6 Daily rates of open circuit voltage in Ayn al-Tamr meteorological station.

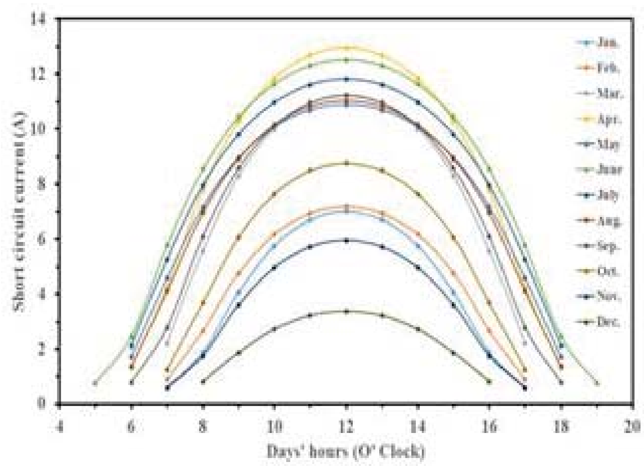


Fig. 7 Daily rates of short circuit current in Ayn al-Tamr meteorological station.

High temperatures affect the voltage values of the cell; those decreased by increasing the temperature, whereas the value of the short circuit current (Fig. 7) will increase by increasing the number of incident rays and is clearly, not tormented by the rise in cell temperature. Fig. 8 shows that the output power reaches its maximum value at noon on all days of the year (from 338.59 W in April to 99.01 W in December).

Furthermore, it is clear that the most output was generated on summer days.

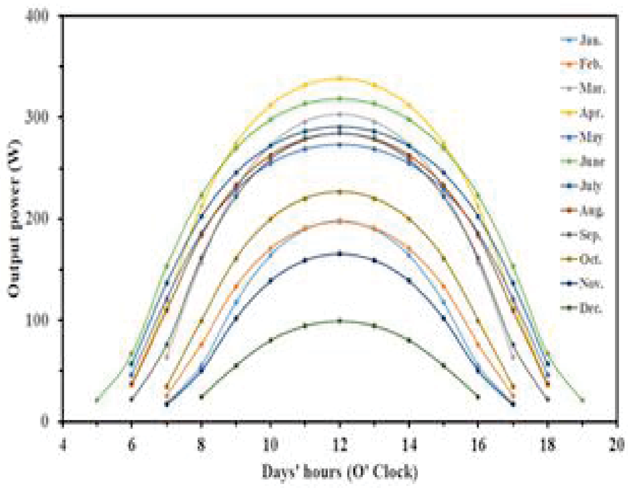


Fig. 8 Daily rates of output power in Ayn al-Tamr meteorological station.

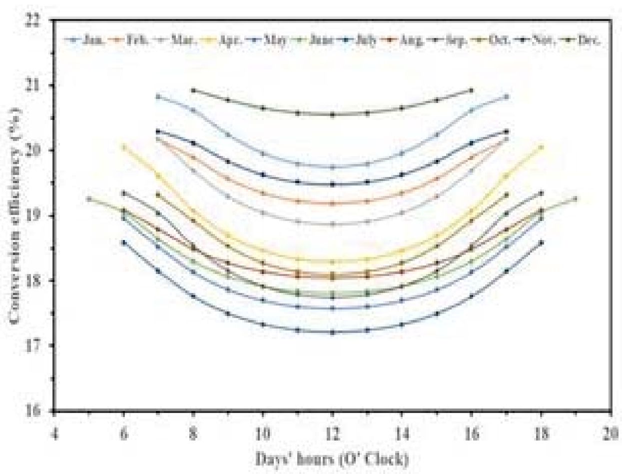


Fig. 9 Variation of daily electrical conversion efficiency in Ayn al-Tamr meteorological station throughout the year.

Depending on the ambient temperature, and thus cell temperature, the electric conversion efficiency takes its minimum value on the hot days of the year at 17.21% at solar noon in July and increases, and exceeds its standard condition value of 20.5%, and reaches 20.93% in the morning of winter days when the cell temperature rates down to lower than 19.32 $^{o}$C as demonstrated in Fig. 9. The final yield and performance ratio are two of three performance parameters used to define overall PV solar system performance in terms of energy produced, effective PV solar system losses, and solar resources. The PV solar module yield is the net output energy of the PV system divided by the rated power (Standard Test Condition: 1kW/m$^2$, 25$^o$C) of the installed PV module. It is the number of hours in which the PV solar array would need to work at its rated power to supply the same energy. Monthly averages of daily reference yield, are summarized in Fig.10. The Fig., shows that the reference yield range between a maximum value equal to (62%) in April and a minimum value equal to (17%) in December, the difference in reference yield values caused by temperature changes. The difference in the reference yield of the PV system is due to the different temperatures in the summer and winter seasons in the Ayn al-Tamr zone.

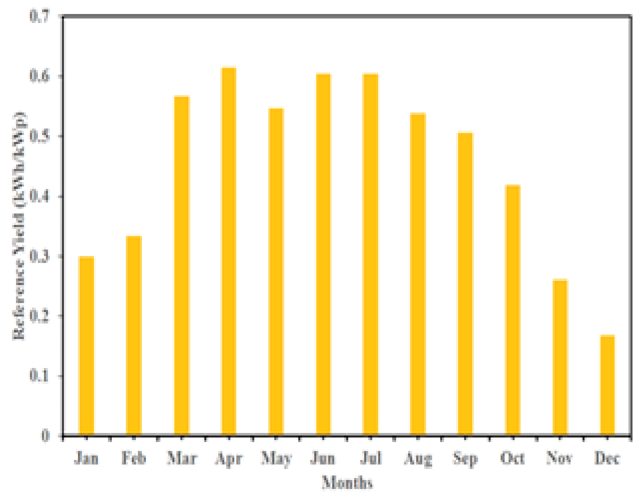


Fig. 10 Reference yield of the PV module during the year.

Fig. 11 shows that the maximum monthly-daily average yield was, 6.36 kWh/kW$_p$ in June, while it was at its minimum value in December at 1.33 kWh/kW$_p$.The annual final yield was approximately 1718.33 kWh/kW$_p$.

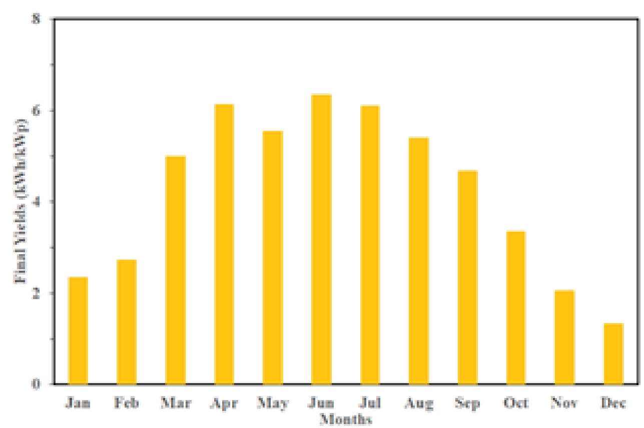


Fig. 11 Monthly-daily average final yield as a function of time in Ayn al-Tamr meteorological station during the year.

The performance of the solar PV system decreases as the temperature increases because the increase in ambient temperature rates causes an increased loss in produced power rates. Therefore, the performance ratios of this system reach their lowest levels in the summer, especially in September (0.84). This fact was embodied by performance ratio values. The behaviour of the performance ratio is demonstrated in Fig. 12.

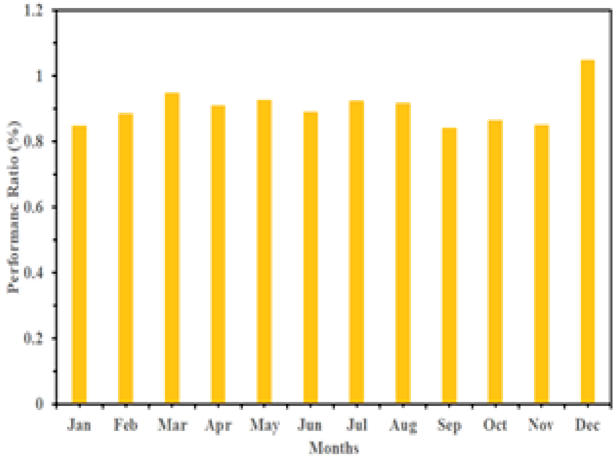


Fig.12 Performance ratio of the PV module during the year.

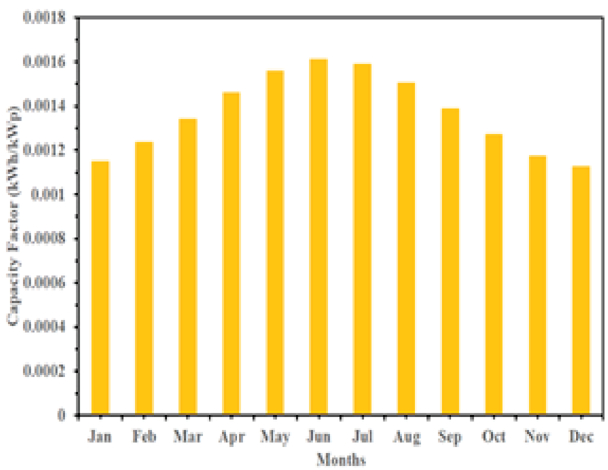


Fig. 13 Measured capacity factor of PV module since the year 2021 in Ayn al-Tamr.

It is important to note in Fig. 13 the annual average capacity factor there is a relatively large difference between winter minimum and summer maximum capacity factors for Ayn al-Tamr station. The capacity factors of the largest solar photovoltaic PV energy facilities of Ayn al-Tamr are computing through the year 2021. The annual capacity factor of about 1.64 %, and the average annual capacity factor is less than 0.14%.

## 4. VALIDITY OF THE PROPOSED METHOD

To verify the effectiveness of the present method that was used to predict the performance of solar PV panel in the Iraqi environment, the performance of solar modules (NT-R0E3E-SHARP/Prated=170 W) was evaluated practically at the Energy Training and Research Center/Ministry of Electricity. The performance of the photovoltaic solar panel was re-evaluated in the new method and the results were compared as shown in Table 2. The results show that there is a clear convergence between the results.

Table 2: Experimental data of measured parameters related to the mono-crystalline solar module (NT-R0E3E-SHARP/Prated=170 W), and the predicted output power.

| Time (hr) | $T_{am}$ (°C) | T (°C) | $G_0$ (W/m$^2$) | $G_{30}$ (W/m$^2$) | $V_w$ (m/s) | $I_{sc}$ (A) | $V_{oc}$ (V) | $P_{practical}$ (W) | $P_{predict}$ (W) |
|---|---|---|---|---|---|---|---|---|---|
| 09.00 | 13 | 22 | 070.7 | 294.1 | 0.30 | 2.15 | 42.2 | 065.87 | 069.24 |
| 09.30 | 15 | 26 | 275.1 | 446.5 | 0.37 | 2.78 | 41.9 | 084.57 | 089.52 |
| 10.00 | 17 | 33 | 315.6 | 0543 | 0.30 | 3.25 | 41.6 | 098.16 | 103.64 |
| 10.30 | 19 | 37 | 414.8 | 634.4 | 0.35 | 3.61 | 39.3 | 102.99 | 107.61 |
| 11.00 | 20 | 38 | 430.5 | 720.0 | 0.30 | 3.98 | 39.1 | 112.98 | 118.08 |
| 11.30 | 21 | 39 | 438.8 | 757.3 | 0.30 | 4.14 | 40.9 | 122.93 | 129.46 |
| 12.00 | 22 | 40 | 457.3 | 787.0 | 0.35 | 4.24 | 40.8 | 125.59 | 132.13 |
| 12.30 | 23 | 41 | 537.2 | 793.2 | 0.78 | 4.17 | 40.6 | 122.91 | 129.01 |
| 13.00 | 22 | 40 | 503.3 | 0780 | 0.35 | 4.11 | 40.5 | 120.85 | 126.88 |
| 13.30 | 21 | 38 | 475.6 | 744.3 | 0.52 | 3.85 | 40.9 | 114.32 | 120.31 |
| 14.00 | 20 | 36 | 425.4 | 644.0 | 0.42 | 3.40 | 40.9 | 100.96 | 106.12 |

## 5. CONCLUSION

The current study showed that the Ayn al-Tamr area in Karbala province is one of the areas rich in solar activity, where the annual incident solar radiation with the horizontal plane was 7541.67 kWh/m$^2$/year with an annual peak sun hour of 7.54 and with a maximum monthly-daily average yield of 6.36 kWh/kWp in June and minimum value in December at 1.33 kWh/kWp. The annual final yield was approximately 1718.33 kWh/kWp. The present work introduced a new technique for predicting the performance of a PV solar module in different climate zones, and the results confirmed the effectiveness of this technique. Thus, it can be concluded that with the help of this technique, it is possible to provide a feasibility study for the investor in the field of solar energy on the construction of solar panel matrices plants in any region of Iraq and at all times.

## 6. ACKNOWLEDGEMENTS

The authors would like to thank the Ministry of Agriculture's Agricultural Meteorology Center for providing us with the data from Ayn al-Tamr meteorological station in Iraq, as well as Mustansiriyah University for its assistance in this work.

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