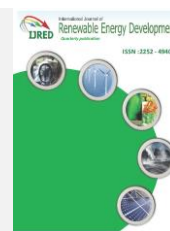




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Research Article

The Influence of Temperature and Irradiance on Performance of the Photovoltaic Panel in the Middle of Iraq

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Abstract. The photovoltaic (PV) panels are expected to be the most important systems to meet global energy demand by converting solar energy into electricity. The main obstacle to the widespread deployment of the PV systems is its limited efficiency, which is greatly affected by the solar radiation and the operating temperature. The full knowledge of the performance, efficiency and output power of photovoltaic modules and the extent of their change with the fluctuations of solar radiation and temperature is necessary to determine the optimal size of the system and avoid the financial risks of the project. This paper investigated numerically and experimentally the influence of operating temperature and solar radiation on the output power and efficiency of polycrystalline PV panels in Baghdad-Iraq. The PVsyst software was used to simulate a model implementing simulation results presented the impact of variations temperature and solar radiation in the curves of I-V, P-V and efficiency. In order to verify the reliability of the simulated results with experimental ones, several measuring devices have been used to conduct field experiments in the outdoor conditions. It was used to determine the characteristics and performance of a 120W polycrystalline PV panel for different ranges of solar radiation and operating temperature. The simulation results showed that the current, voltage, output power and efficiency increased with increasing solar radiation, while they decreased with increasing temperature except the current that was increased. The experimental and simulated results were identical in terms of the effect of temperature and solar radiation on the current, voltage, output power and efficiency of the PV panel. The experimental tests showed that when the temperature is increased by 1°C, the current was increased by about 0.068%, the voltage decreased by 0.34%, the output power decreased by 0.489% and the efficiency decreased about 0.586%. The experimental results displayed that the parameters of the PV panel under real operating conditions behave differently than in the standard test conditions (STC), as they are strongly affected by weather fluctuations in terms of temperature and solar radiation.

Keywords: Solar PV panel, Irradiance, PV temperature, Polycrystalline, Baghdad-Iraq.

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1. Introduction

The traditional energy sources, most notably fossil fuels, constitute the main source of energy for our planet, reaching 80% of the total resources at the present time (Al-Ghezi *et al.*, 2022). Non-renewable sources provide us with energy, but in return cause an increase in greenhouse gases and pollutants in the atmosphere (Bamehr and Sabetghadam, 2021). Electrical energy production obtained by burning fossil fuels leads to an increase in the emission of CO₂ and other gases such as methane, NO_x and unburnt hydrocarbons that lead to environmental pollution and the emergence of global warming (Fayad *et al.*, 2021). There is a bright spot calling for optimism, which is the limited of fossil fuels. These fuels are estimated to be depleted during the next few decades, or their stocks will drop significantly. This situation will lead to curbing dependence on it in the near future for energy production (Chaichan *et al.*, 2018; Moafaq, 2019). Global energy consumption is expected to reach 30 terawatts in 2050 compared to 10 terawatts at the present time. This

requires the production of 20 terawatts of new energy (Al-Ghezi *et al.*, 2022; Abdelhafidi *et al.*, 2021). Among the best plans put forward is to use large-scale PV systems, in addition to other renewable resources, contribute to the production of an additional 10 terawatts of electricity. Through the use of hydrogen in transportation, which can also be used to produce heat for industrial and domestic uses. In this way the required 10 terawatts can be saved. This scenario will make the use of photovoltaic energy a matter of urgency to make up the shortfall in global energy supply in the near future (Omar and Mahmoud, 2021; Islam and Hossain, 2022). Humans have used solar energy since ancient times in various fields. Solar energy applications passed through multiple stages using many technologies until it reached the invention of PV cells (Moafaq *et al.*, 2021). This technology today is the most promising technology in our time. PV technology uses the photoelectric effect property, which allows it to convert the incoming solar radiation directly into electricity (Moafaq *et al.*, 2022). The photovoltaic cells are characterized by being made of semi-conductive materials in which silicon

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element is used extensively. When the sun's rays fall on the surface of the photoelectric cell, an area called the depletion region will form at the p-n junction to transfer the energy carried by the incoming photon from the solar radiation to the electron in the photoelectric cell. If the electron gets enough energy, it will be released to the conduction level (Jatoi *et al.*, 2018). In this way an electric potential difference will be generated across the depletion region resulting in an electric field. This process is repeated between the photons and the electrons, leading ultimately to the production of electricity (Simon *et al.*, 2021). There are many parameters that affect the work of photovoltaic cells. The most important of which are climatic parameters. The solar radiation intensity variation, as well as increasing PV cell temperature reduce these devices ability to produce electricity at steady and stable rates (Al-Waeli *et al.*, 2016).

Any project that produces electricity using photovoltaic modules depends mainly on the energy generated by these panels. For this project to be economically feasible, it requires increasing the efficiency of these modules to obtain the highest possible output energy. There is an inherent obstacle to the use of photovoltaics, which is the limited efficiency and high manufacturing cost. Therefore, research efforts have been intensified to find methods to increase efficiency and reduce manufacturing cost (Chaichan and Kazem, 2018; Fayad and Dhahad, 2021). There are several factors that affect the solar panel efficiency can be studied, the most prominent of which are the solar radiation intensity and the PV panel temperature, which are closely related to each other and directly affect the efficiency and the output power of the solar panel (Sangeetha *et al.*, 2020). Usually, photovoltaic panels are manufactured under standard test conditions (STC), where it indicates that one degree increase of temperature causes a decrease in the PV panel efficiency by 0.004-0.005 (Natarajan *et al.*, 2011). In the actual operating conditions of PV modules, these panels are not likely to operate under standard conditions. Therefore, when initiating the construction and installation of PV systems, real external conditions and exposure to different environmental conditions must be taken into account (Al-Nasser *et al.*, 2020). When the solar radiation falls on the surface of the solar cell, 80% of the radiation energy is converted into thermal energy, which accumulates inside the solar cell (Zhang *et al.*, 2014; Roshen, 2017). Thermal energy accumulated in the PV panels causes two losses, the first loss is that this percentage of radiation is wasted in form of thermal energy inside the solar panel and cannot be utilized. The second negative disadvantage is accumulated heat, which raises the temperature of the photovoltaic cells, leading to a decrease in its efficiency (Kazem *et al.*, 2020).

Many previous studies have searched the effect of the solar radiation fluctuation and the volatility of the temperature on the performance of PV panels. Suwapaet and Boonla (2014) compared the behavior of different types of photovoltaics with increasing temperature. Their study proved that monocrystalline silicon panels are less efficient than amorphous PV panels provided it operate at similar conditions and high temperature. The study also investigated the effects of solar radiation on the PV performance. When solar radiation was 600 W/m², amorphous PV panels produced greater power than

monocrystalline silicon at the same temperature increase. Ike (2013) discussed the influence of weather parameters such as ambient temperature on the overall performance of the photovoltaic panels. The author claimed that there is an indirect correlation between the ambient temperature and the output energy of the system. Also, the study recommended the necessity to take care of the passage of an air stream through the panels when designing. Dash and Gupta (2015) investigated the relationship between temperature and the power produced by different types of photovoltaic panels. The authors used the temperature coefficient as a reference function for PV output power. It was concluded that the highest average output power loss was when using monocrystalline panels, as it reached 0.446% per degree Celsius. Swapnil *et al.* (2013) analyzed many studies and concluded that the temperature has a linear relationship with the photoelectric conversion procedures as well as the output power of the photoelectric modules. The researcher showed that numerical parameters depend on both matter and system at the same time.

Chander *et al.* (2015) simulated the effect of increasing the photovoltaic (PV) panel temperature on the overall performance independent of the effect of solar radiation intensity. The researchers used a constant-intensity light that was projected on a photovoltaic panel. The researchers concluded that increasing the temperature has an inverse effect with respect to fill factor (FF), open circuit voltage (V_{oc}), and maximum power (P_{max}). Whereas, the effect of temperature increase was direct with respect to the short circuit current (I_{sc}).

Khaled *et al.* (2015) studied the effect of shading on the maximum output power of the PV panels and the concomitant decrease in efficiency. The study concluded that increasing the PV temperature reduces its maximum output power. Tarak *et al.* (2012) analyzed the PV modules and how they performed under different weather conditions using basic semiconductor equations. Temaneh and Mukwekwe (2015) concluded that the increase in PV panel temperature is most important factor that causes the increase in its power losses. It was mentioned that the 37.8 kW photovoltaic systems operated daily in duration of 12 hours had recorded losses of 14.6 kWh due to the effect of temperature raise. The study proved that an increase of one kelvin in temperature caused a loss of power up to 0.31%. Zhe *et al.* (2021) investigated the effect of changing solar radiation intensity on the characteristics and performance of PV modules.

Many researchers have used mathematical models to linearly predict the effect of variables such as radiation intensity and temperature in several regions of the world. In such studies, the results are compared with the expected results of the artificial neural network, and the validity of the results is verified by comparing them with the results of practical experiments (Al-Waeli *et al.*, 2019). In Oman, Yousif *et al.* (2019) examined and analyzed weather data for the period from 1991 to 2015, in order to predict accurate future weather information and to encode the appropriate climatic dimensions for solar electricity generation. Therefore, the study focused on accurate prediction of temperature and relative humidity.

In current paper, the effects of the solar radiation fluctuation and the temperature increase on the overall performance of the solar panels have been analyzed. The

relationships among these variables and basic parameters of PV panels such as short circuit current, open circuit voltage, output power, efficiency and fill factor were studied. There may be many international studies similar to this study, but it is for the conditions of other countries, not for the weather conditions in Iraq rather than for the conditions of the city of Baghdad, the capital. Baghdad is characterized by continental weather, very hot in summer and very cold in winter. This city is also exposed to waves of relative humidity, but it is limited, and the wind speed is very moderate, not exceeding 3 m/s most days of the year. To the knowledge of the researchers, a similar study to this study has not been conducted locally or internationally before.

2. The Modeling of Photovoltaic Cell

The simplest mathematical model of the equivalent circuit of a photovoltaic cell can be described with an ideal current source connected in parallel with an ideal diode (Solmetric, 2016), as shown in figure 1. The current generated by the photons, represented by the ideal current source, it is usually stable at a certain temperature and light radiation (Gabriel and Odai, 2021). The relationship that relates current to both voltage and temperature is shown in Equation 1:

$$I = I_{ph} - I_o \left(e^{\frac{q(V+I R_s)}{m k T}} - 1 \right) - \frac{V + I R_s}{R_p} \tag{1}$$

Where I, I_{ph} , I_o , q, V, R_s , m, k, T and R_p are the current generated by the photons (ideal current), current generated by the light radiation (photocurrent), the diode saturation current, the electronic charge= 1.6×10^{-19} , the voltage of the PV unit, resistance of the cell series, quality factor of the diode, the Boltzmann's constant= 1.38×10^{-23} J/K, the ambient temperature in Kelvin, the cell (shunt) resistance respectively.

The PV cell's performance characteristics can be analyzed by five main parameters of the solar module, namely, the short circuit current, the open circuit voltage, maximum power, efficiency and fill factor. These characteristics can be determined by studying the I-V curve (Khan *et al.*, 2021). In an open circuit, $I=0$, $V=V_{oc}$ (Tiwari and Dubey, 2010), and in a short circuit, $I=I_{sc}$, $V=0$ (Rodrigues *et al.*, 2011), by substituting these values into the equation 1, the equation becomes as:

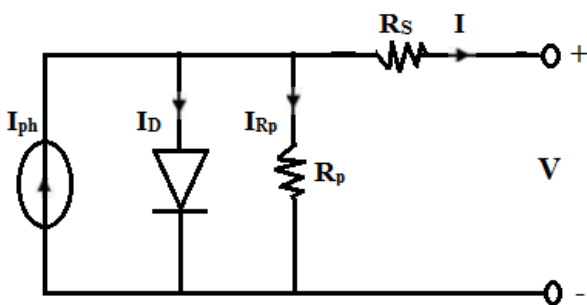


Fig. 1 The schematic diagram of the PV cell equivalent electric circuit.

$$0 = I_{ph} - I_o \left(e^{\frac{q V_{oc}}{m k T}} - 1 \right) - \frac{V_{oc}}{R_p} \tag{2}$$

$$I_{sc} = I_{ph} - I_o \left(e^{\frac{q I_{sc} R_s}{m k T}} - 1 \right) - \frac{I_{sc} R_s}{R_p} \tag{3}$$

From equations 2 and 3:

$$V_{oc} = \frac{m k T}{q} \ln \left(\frac{I_{sc}}{I_o} + 1 \right), I=0 \tag{4}$$

$$I_{sc} = I_{ph} - I_o \left(e^{\frac{q I_{sc} R_s}{m k T}} - 1 \right) - \frac{I_{sc} R_s}{R_p}, V=0 \tag{5}$$

The fill factor is defined as the ratio between the actual and ideal maximum output powers of the PV cell. It is one of the parameters that indicate the quality of the PV cell (Bhalchandra and Sadawarte, 2015), and can be obtained as:

$$FF = \frac{P_{max}}{V_{oc} I_{sc}} = \frac{I_{max} V_{max}}{I_{sc} V_{oc}} \tag{6}$$

The efficiency is defined as the ratio of the electrical output power of the PV cell to the energy of solar radiation falling on the surface of that cell (Soteris, 2014), and can be expressed as:

$$\eta = \frac{I_{sc} \times V_{oc} \times FF}{G \times A_c} \tag{7}$$

Where G is the solar radiation (W/m²) and A_c is the solar cell area (m²).

3. Material and Method

The present study was conducted under the conditions of Baghdad city. Baghdad is the capital of Iraq and located in the middle of Iraq at 33.34 N° latitude, 44.40 E° longitude, and 41 m above sea level. The study included two paths for obtaining and comparing results. The first path, was using PVsyst software to simulate the work of photovoltaic panels. This program provides the possibility of access to the basic parameters to evaluate the overall performance of PV panels. Some data were entered as inputs to PVsyst software. The most important input data were the longitude and latitude and the location of the study, in the current case it was Baghdad city. Also, the temperature, solar radiation value, model and the type of the PV panel and some other parameters were entered. This simulation was implemented at standard test conditions (STC), which are 25 °C ambient temperature, 1000 W/m² solar irradiance and air mass 1.5 (Zainal *et al.*, 2016). Since the standard test conditions are really unrealistic, various data were entered, which are closer to the real operating conditions. Through the simulation program, many data were obtained, the most important of which are: short circuit current, output power, open circuit voltage, and efficiency. Important relationships can be found to evaluate the overall performance of the PV panels, as the efficiency variation with solar radiation intensity and temperature, voltages with current, voltages with the output power, in addition to other less important relationships.

As for the other path of this study, it included analysis of the overall performance of the PV panel. The variance in electrical properties and output power were

analysed as a result of the influence of many parameters. These parameters were: contrasting solar radiation and increasing the operating temperature through exposure to real outdoor operating conditions and conducting the practical experiments.

4. Experimental Setup

The studied system was installed on the roof of the Energy and Renewable Energy Technology Center (ERETC) at the University of Technology which is located approximately in middle of Baghdad city. A 120 W polycrystalline silicon photovoltaic panel was installed with a tilt angle of 37° from the horizon facing south. The building of ERETc consists of four floors, with a height of 14 m. There are no elevated structures nearby, which ensures the absence of shade on the PV panel used and that it is exposed to direct sunlight throughout the test period. It is crucial that a PV panel with characteristics similar to those used in the PVsyst simulation software is used, in order to obtain a logical comparison of the performance behavior in both cases. The specifications of the PV panel are listed in Table 1.

Several measurement devices were used to obtain the parameters of the photovoltaic panel at the outdoor experimental site. The various parameters of the PV panel were measured from 8:00 am to 5:00 pm, where the readings were recorded every 15 minutes. An YK-80AM type anemometer was used to measure wind speed. Data logging solar power meter, type - ISO-TECH ISM 410 was used to measure the intensity of solar radiation. Multiple electrical parameters output of the PV panel were recorded using multimeter type-Proskit MT-1210. Three thermal sensors were installed on the back side, at the top, middle and bottom of PV panel in order to measure the average operating temperature. The used thermocouples were type k, which can measure a temperature range between -200 to 1260°C. The ambient temperature was measured by thermometer placed in the shade.

Table 1
The specifications of the PV panel

Typical power (Watts) at STC	120 W
Nominal rated voltage at STC	12V
Maximum power (Watts)	120.6 W
Tolerance (%)	+/- 3%
Voltage at max power	17.8V
Current at max power	6.73A
Open circuit voltage	22V
Short circuit current	7.52A
Dimensions	1205×675×42 (+/- 2 mm)

5. Results and Discussion

5.1. The output performance behavior of the photovoltaic panel in the simulation PVsyst program

Figure 2 represents the relationship between the current, voltage and output power at a constant temperature of 25 °C and a variable solar radiation between 200 and 1000 W/m². This is a hypothetical case that cannot be applied under the real operating conditions. The maximum values of the current and voltage were 7.52 A, 22 V, respectively at solar radiation intensity of 1000 W/m². While their minimum values were 1.51 A, 20.35 V, respectively at a solar radiation of 200 W/m². The output power of PV panel increased with the solar radiation increase, as it decreased to 23.4 W at solar radiation 200 W/m² while it was 120 W at 1000 W/m². Here it must be emphasized that the current, voltage and output power of the photovoltaic panel were increased with the increase of solar radiation with the temperature remaining constant. The best performance of the photovoltaic panel was under standard test conditions (STC). These results are consistent with the studies done by (Belkassmi *et al.*, 2017; Bouraiou *et al.*, 2015; Kachhiya *et al.*, 2011).

Figures 3 and 4 show the performance test of PV panel at a constant solar radiation while the temperature was changed. The behavior of the current-voltage (I-V) and power-voltage (P-V) curves were studied at different temperatures. It is clear that the relationship between current and temperature was a direct relationship, although the increase in current was slight when the temperature was increased. The curves analysis shows the inverse relationship of the voltage with temperature, as the voltage values gradually decreased with increasing temperature at constant solar radiation of 1000 W/m². The voltage value at the temperature of 25 °C was 22 V while it was decreased to 18.8 V when the temperature was increased to 70 °C. When the temperature of the PV panel reached 35 °C, it was noticed that the value of the output power decreased to 115.7 W while it was 120.6W at 25 °C. In other words, an increase in the temperature of 10 °C caused a decrease in the output power by approximately 4.08%. Through the overall analysis of the P-V curve, it was found that when the temperature rise to 70 °C, the output power decreased to 98.3W while it was 120.6W at 25°C. This result indicates that the output power decreased by 0.41% for each one degree temperature rise. These results agree with the works done by (Tobnaghi and Naderi, 2015; Arjyadhara *et al.*, 2013).

There is a strong relationship between the ambient temperature and the solar radiation intensity. As it is known, the temperature increases with the increase in the value of solar radiation. Although the increase in ambient temperature leads to an increase in the operating temperature of the PV panel, which leads to a decline in the output power. However, this increase in temperature is accompanied by a significant increase in the solar radiation intensity, which enhances the production of the solar panel. Usually, the increase in the output power of the PV panel as a result of the increase in solar radiation is greater than the deterioration in the output power due to the increase of temperature associated with the increase in solar radiation. Before conducting the simulation, the average ambient temperature was measured during the time of practical experiments using a thermometer, it was

set at 34 °C. An anemometer device was used to measure the average wind speed in the outdoors on the roof of the work building and its value was approximately 3 m/sec. Average ambient temperature and wind speed rate measured were used as inputs to the simulation PVsyst software. Figure 5 highlights the P-V curves characteristics of the PV panel at constant ambient temperature and variable values of solar radiation, as well as a constant value of the heat transfer coefficient. The heat transfer coefficient (U) was calculated using a simplified equation including the effect of wind speed ($U=5.7+3.8V$), and its value was 17 W/m²K.

STC has an irradiance value of 1000 W/m² and a temperature of 25°C, which is almost impossible to achieve under real operating conditions. As it can be seen in Figure 5, the maximum radiation value of 1000 W/m² is accompanied by the highest value of the temperature about 82 °C while the lowest value of the temperature is 43 °C at the minimum radiation of 200 W/m². Temperature increased by 46.56% due to the impact of increased solar radiation between minimum and maximum values. One of the most important factors that determine the quality of the performance of PV panel is the output power. It was

found that the output power increases with the increase in the value of the solar radiation. This increase is not ideal due to the energy loss resulted from the increase in temperature, as can be seen from the curves in Fig. 5. These results agree with study done by (Ugwuoke and Okeke, 2012).

Figure 6 examines the effect of temperature contrast on the efficiency of the PV panel for a certain solar radiation range. The highest efficiency of the photovoltaic panel can be obtained at the maximum solar radiation provided that the temperature is in minimum value, as is the case in the standard test conditions. By looking at Figure 6, it can be said that the highest value of the PV panel efficiency was 12.18% at solar radiation of 1000 W/m² and PV temperature of 25°C, which is similar to the standard test conditions. The lowest efficiency value of 9.95% was found at 70°C and solar radiation of 200W/m². As the temperature increased, the efficiency of the photovoltaic panel deteriorated, and its values were 10.7%, 11.3% and 11.7% at temperature 55°C, 45°C, and 35°C, respectively. This behavior of efficiency with temperature agreed with the study conducted by (Tobnaghi *et al.*, 2013).

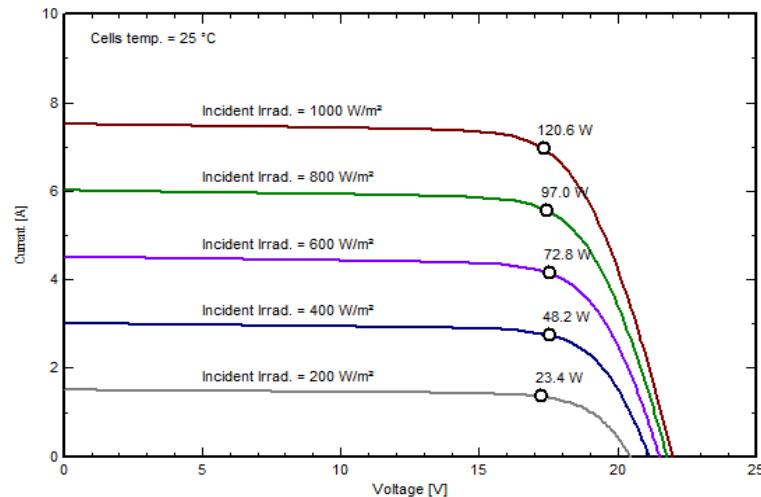


Fig. 2 The output performance of the PV panel at constant temperature of the PV panel, 25 °C and different solar irradiance.

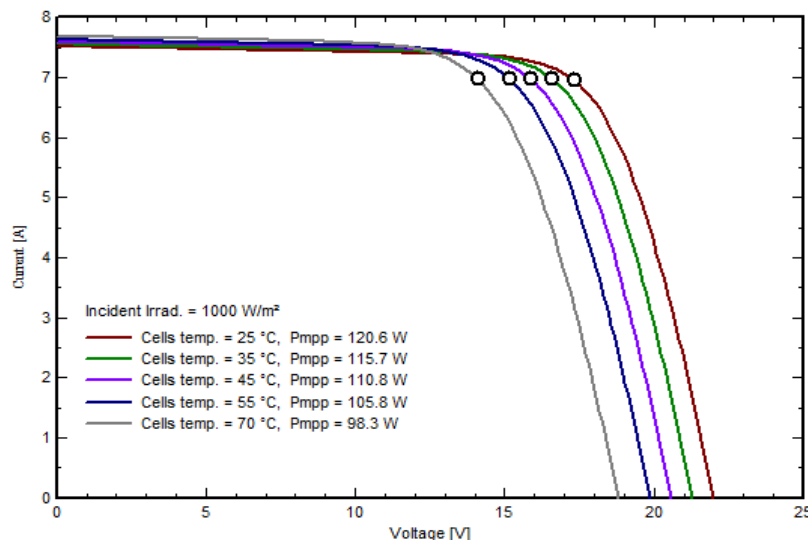


Fig. 3 The I-V curve of the PV panel at constant solar irradiance, 1000W/m² and different temperature of the PV panel.

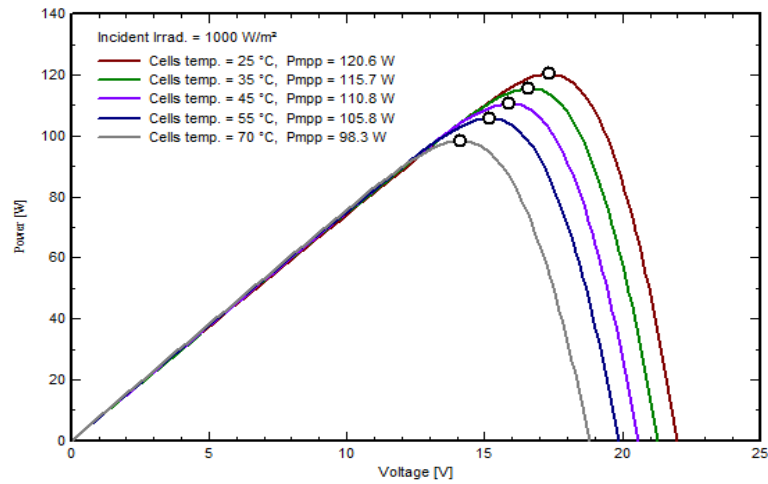


Fig. 4 The P-V curve of the PV panel at constant solar irradiance, 1000W/m² and different temperature of the PV panel.

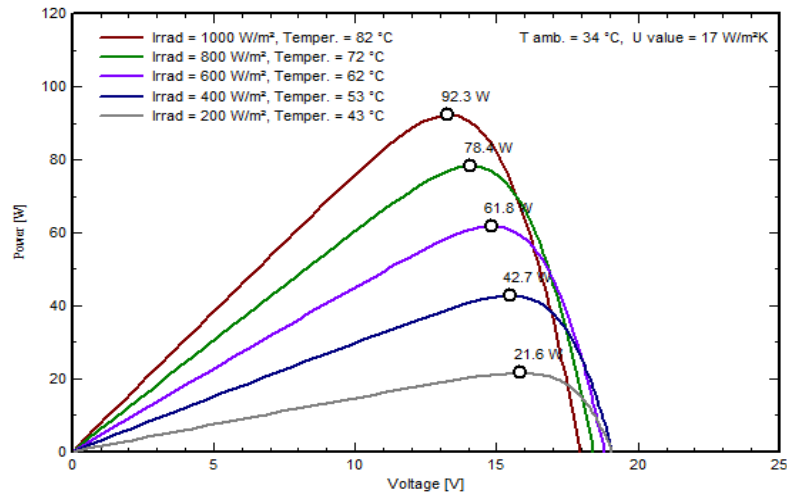


Fig. 5 The P-V curve characteristics of the PV panel at the constant ambient temperature and heat transfer coefficient, and various solar irradiance and PV panel temperature.

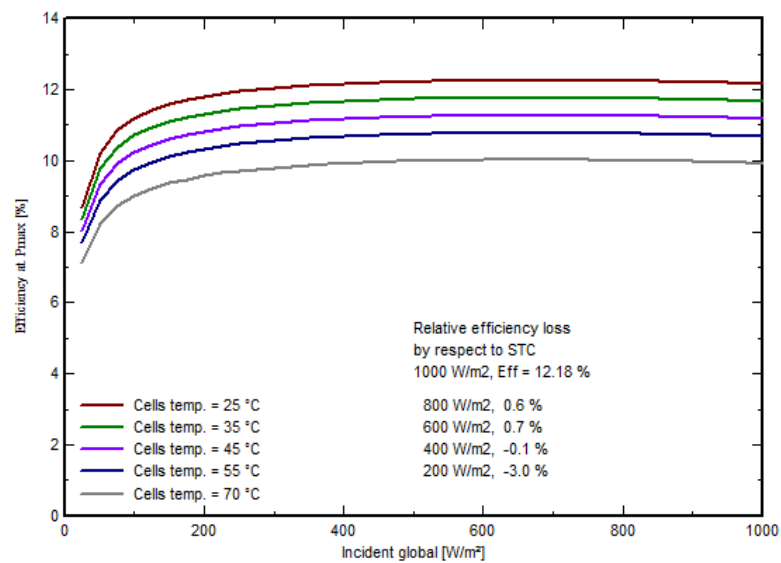


Fig. 6 The Efficiency curve characteristics of the PV panel at various PV panel temperatures and solar radiation.

5.2. The output performance behavior of the PV panel in outdoor conditions: Experimental results

The solar radiation intensity is one of the most important factors affecting the output power of the PV panel. It is expected that the output performance of PV panel will be improved with the increase in the solar radiation intensity. To study the behavior of PV panel in the real operating environment, it was necessary to measure the solar radiation intensity. This issue was achieved using data logging solar power meter. Solar radiation was measured from 8:00 am to 5:00 pm, with one reading every 15 minutes at the experimental site. Figure 7 illustrates the variation of solar radiation during daytime hours. It is easy to note that the solar radiation is very high throughout the day, reaching more than 800

W/m² from 9:15 am until 2:45 pm. The maximum value of the measured radiation was at 2:45 pm, reaching 1195.235 W/m², while the lowest value was 158.755 W/m² at 5 pm. It is clear that the solar radiation curve during the day was regular and does not contain any anomalies. During the period of outdoors experiments, the sky was clear, free of clouds, and the solar radiation intensity was high. The lack of high buildings in the vicinity also prevented shading on the photovoltaic panels. It can be emphasized that the study site and the city of Baghdad in general possess great and promising potentials for the establishment of projects based on solar energy, the most important of which are photovoltaic systems. These results agree with study done by (Al-Ghezi *et al.*, 2022).

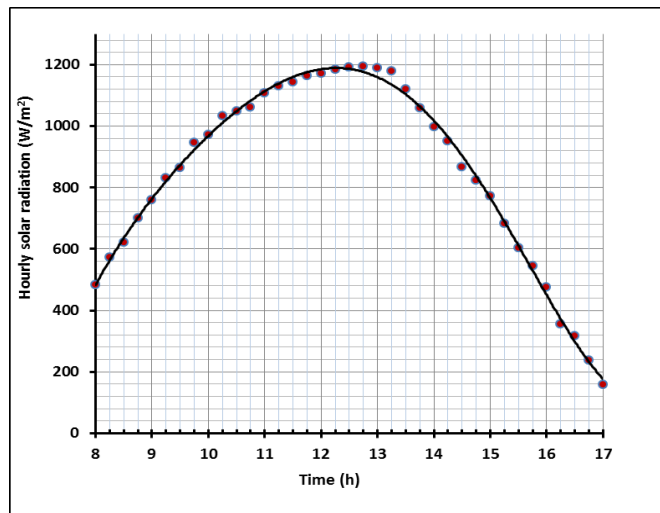


Fig. 7 Variation of solar radiation during the experimental day

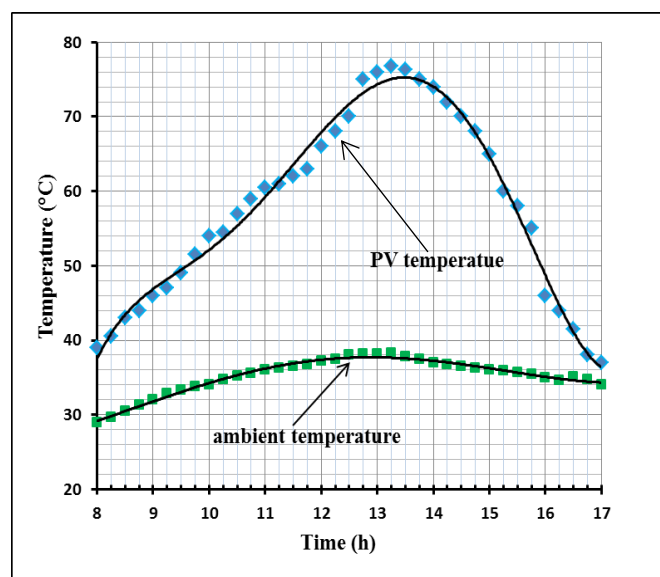


Fig. 8 Variation of ambient temperature and the PV panel temperature during the experimental day.

There is a close relationship between the solar radiation intensity and the ambient temperature, and thus the temperature of the PV panel. This is evident from the observation of Figure 8. Obviously, when the solar radiation was increased, both the ambient and PV temperatures were increased. It was noted that the temperature was somewhat low at the start of the experiment and increased with the passage of time and reached its peak during rush hour and then decreased again to reach its lowest values at the afternoon. The lowest solar radiation intensity at the morning period was at 8:00 am with a value of 484.064 W/m², accompanied by an ambient temperature of 29°C. Ambient temperature continued to increase until it reached a peak of 38.23°C with 1178 W/m² at 1:15 pm. The lowest value of the ambient temperature was 34°C at the afternoon with 158.755 W/m² solar intensity at 5:00 pm. The average ambient temperature during the day through the experiments period was 34.216 °C. The temperature of the photovoltaic panel behaved similarly to the ambient temperature, as both of them increased with increasing

solar radiation. However, there was a large difference between them in terms of values. This difference was increased during the peak hours of the day. The difference between the ambient temperature and the PV panel temperature is very important because the bulk of the energy produced by the PV panel occurs when the difference between the two temperatures is large. By contemplating at figure 8, the highest value of the PV panel temperature was 76.8°C with 1178 W/m² at 1:15 pm and the lowest value was 37°C with minimum solar radiation of 158.755 W/m² at 5:00 pm. The average PV temperature during the day for the experiment period was 57.89°C. The relatively large difference between the temperature of the PV panel and the ambient is attributed to several reasons, the most important of which is that the wind speed in the city of Baghdad is low throughout the year and the sun's brightness is high. As well as the low heat transfer coefficient between air and PV body, which reduces heat transfer from the surface of the hot PV panel to the ambient air.

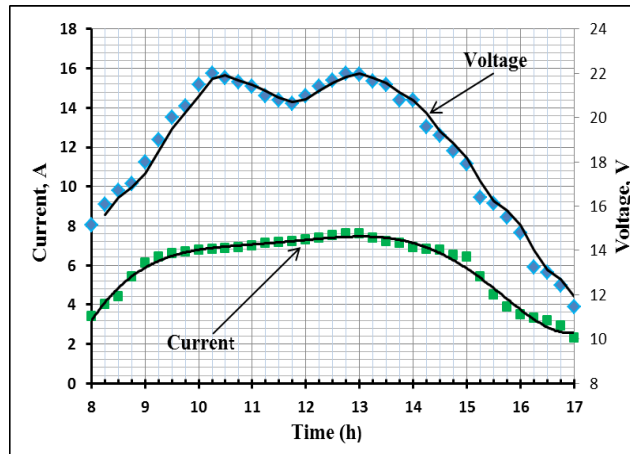


Fig.9 The effect of the PV panel temperature on the characteristics of current and voltage.

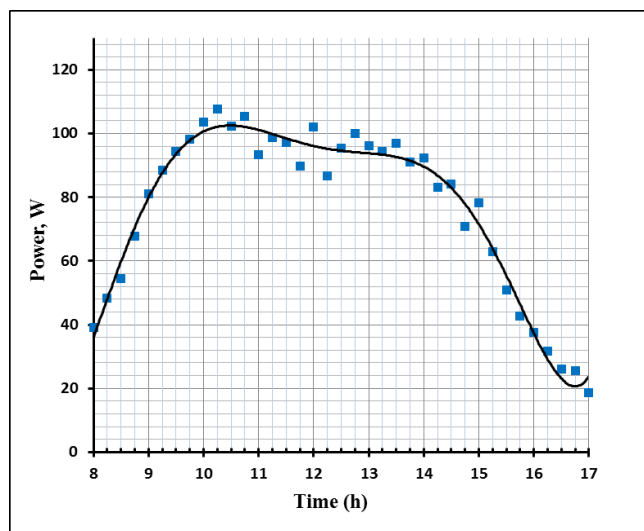


Fig.10 The effect of the PV panel temperature on the characteristics of the out power curve.

Figure 9 shows the current-voltage (I-V) curve, where it was necessary to measure the current and voltage to calculate the PV panel output power. I-V curve is one of the most important characteristics of the photovoltaic panel. Figure 9 includes the distribution of current and voltage measured throughout the day during the experiments period, i.e. from 8:00 am to 5:00 pm. It is clear that the current was increased with the increase in solar radiation that was accompanied by an increase in the PV panel temperature. The increase in current is more pronounced for the period from 9:00 am to 3:15 pm. The maximum measured value of the current was 7.2 A at 11:45 am with PV temperature of 63 °C and solar radiation of 1164 W/m². The minimum value of the current was recorded at 2.3 A at 5:00 pm with PV temperature of 37 °C and solar radiation of 158.755 W/m². To understand more about the effect of increasing the PV panel temperature on the current produced, it is necessary to compare two cases in which the values of solar radiation are equal or at least close at different PV panel temperatures. For example, at 9:30 am, the solar radiation value was 864 W/m², and the PV panel temperature was 49 °C. It was found that the current was 6.6 A. At 2:30 pm, the value of solar radiation was 868 W/m² and the temperature of the PV panel was 70 °C. The generated current was about 6.75 A. This difference between the two measured current values is due to the effect of increasing the PV panel temperature, which is directly proportional to the value of current. In other words, the high PV panel temperature means that the panel has absorbed a greater amount of solar radiation falling on the panel surface. This condition leads to greater amounts of current generation and vice versa. Also, if the PV panel is exposed to the same amount of radiation at varying PV temperatures, it produces more amperes at the higher temperature. Figure 9 includes the behavior of the output voltage of the PV panel throughout the day during the experiment period too. As it shows the effect of PV panel temperature combined with solar radiation on the output voltage of the panel. It is clear from the curve that the output voltage was increased with the increase in solar radiation from 8:00-10:15 am despite the increase in PV panel temperature. This behavior is attributed to the fact that the increase in the voltage is much affected by the large increase in solar radiation. In the same time, the decadence of the output voltage as a result of the increase in the PV panel temperature is less than the increase by the solar radiation effect. Also, the increase in temperature was not large to be sufficient for the deterioration of the voltage to large levels. The output voltage was 15.16 V at 8:00 am when the solar radiation was 484.064 W/m² and the PV panel temperature was 39°C. The output voltage reached 22 V at 10:15 am when the solar radiation was 1034 W/m² and the panel temperature was 54.5°C. The effect of the PV panel temperature on the output voltage is evident from 10:30 am until 12 pm. The output voltage started to decrease despite the increase in solar radiation. The output voltage was about 21.8 V at 10:30 am when solar radiation was 1048 W/m² and the PV panel temperature was 57 °C. However, the output voltage reached 21V with solar radiation of 1171.32 W/m² and panel's temperature of 66 °C at 12:00 pm. The decrease in the output voltage was due to the fact that the PV panel had witnessed a significant increase in its temperature accompanied by a small change in solar radiation during

this period. The output voltage was increased from 12:15 – 1:00 pm due to a large increase in solar radiation accompanied by a small increase in temperature. The voltage difference returns to decrease again from 1:15 to 5:00 pm due to the decrease in solar radiation while the temperature remaining somewhat high. For further clarification on the effect of the temperature of the PV panel on the output voltage, the output voltage was compared under equal or close values for solar radiation and different PV temperatures. The output voltage was at a value of 21.6 V when the solar radiation was 1061W/m² and the panel temperature was 59 °C at 10:45 am. At 1:45 pm the voltage was 20.8 V with solar radiation 1060 W/m² and the temperature was 75 °C. These results agree with study done by (Fesharaki *et al.*, 2011).

Figure 10 shows the behavior of the output power curve of the PV panel throughout the day during the experiment. There is a close relationship between current and voltage on the one hand, and the output energy of the PV panel on the other. Since both current and voltage are affected by the increase in the temperature of the PV panel, the output power is also affected as a result of the temperature variation. It was found that the maximum PV output power produced was 106 W at 10:15 am and 54.5 °C, whereas the minimum value of the output power was recorded about 18.57 W at 5:00 pm with temperature of 37°C. It is not possible to reach the maximum power output of the PV panel used (120 W) during the experiments due to the influence of several factors. The most important of which is the increase in temperature. In addition to the panel specifications estimated under standard test conditions as explained previously. In general, from the output power curve, it was found that the value of the output power was increased from 8:00 am to 10:15 am due to the large increase in solar radiation accompanied by a slight rise in the PV temperature. When the solar radiation was 864 W/m² and temperature 49 °C at 9:30 am, the output power was 94.50W. At 2:30 pm, the radiation was 868 W/m² and the temperature was 70 °C, the output power was 84.03W. Although the solar radiation is almost the same, the output power has decreased due to the negative temperature effect. This behavior of the output power with temperature agrees with the results of (Zia *et al.*, 2015).

Figure 11 describes an important parameter of the solar panel, which is the efficiency. It is noted that the efficiency was increased from 8:00 am to 10:30 am and then started to decline until 1:15 pm. After 2:00 pm, it was increased again until the end of the experiment time, i.e. at 5:00 pm. It is not necessary that the maximum efficiency be associated with the highest value of solar radiation, but rather the opposite. At the peak period from 12:00 to 3:00 pm, the minimum values of efficiency were recorded, when the solar radiation is at its maximum values. This result can be referred to the effect of increasing the temperature on efficiency, as during this period the temperature reached its maximum values. The maximum efficiencies were recorded in the morning period from 9:00 to 10:00 am. Also, another maximum efficiencies were recorded for the period from 4:30-5:00 pm, where the PV temperatures are moderated at these times. For example, at 9:30 am, the solar radiation 864 W/m² and the temperature 49 °C, the efficiency was 11%. At 2:30 pm, the radiation was 868 W/m² and the temperature was 70 °C, the efficiency was 7.6%. This behavior shows the negative effect of the PV

panel temperature increase on the efficiency, despite the convergence of the solar radiation values. This behavior of the efficiency with temperature agrees with (Kabbani and Mohamed, 2021) results.

Figure 12 describes the variation of the fill factor of the PV panel throughout the day during the experiment period. The fill factor is an important parameter to determine the quality of the PV panels. Usually, the PV panels fill factor ranges from 0.5-0.82. The PV panels are considered to be of good quality when the fill factor is 0.7 or above. It was found that the PV fill factor is more than 0.7 throughout the experiment periods, except for the period between 11:45 am - 2:15 pm when the sun is at its peak. This is due to the increase temperature of the

photovoltaic panel during this period. This means that the fill factor is inversely proportional to the PV panel temperature increase. The maximum value of the fill factor was recorded at 8:00 am when the temperature of the photovoltaic panel was 39°C with a value of 0.81 while the minimum value was found at 12:30 pm with a value of 0.635 at a temperature of 70°C. This behavior of the fill factor with temperature agrees with the works of (Bhalchandra and Sadawarte, 2015; Kabbani and Mohamed, 2021).

For the purpose of validating the experimental results, they were compared with the outputs of the simulation software; the comparison of the results is listed in Table 2.

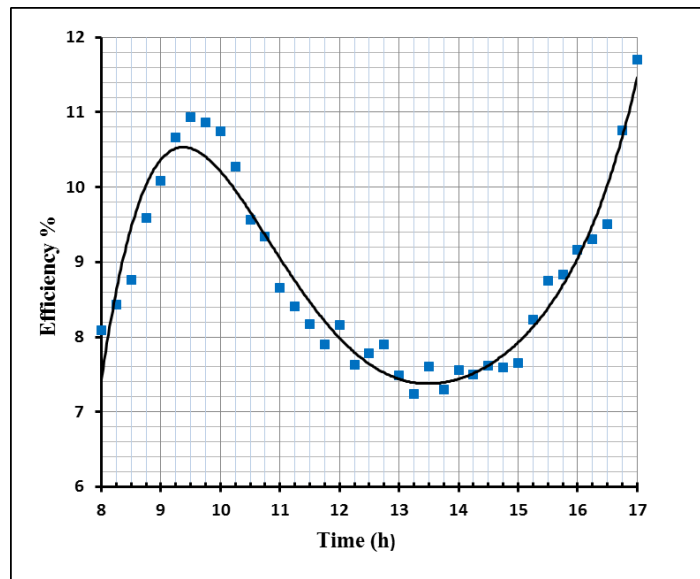


Fig.11 The effect of the PV panel temperature on the characteristics of efficiency curve.

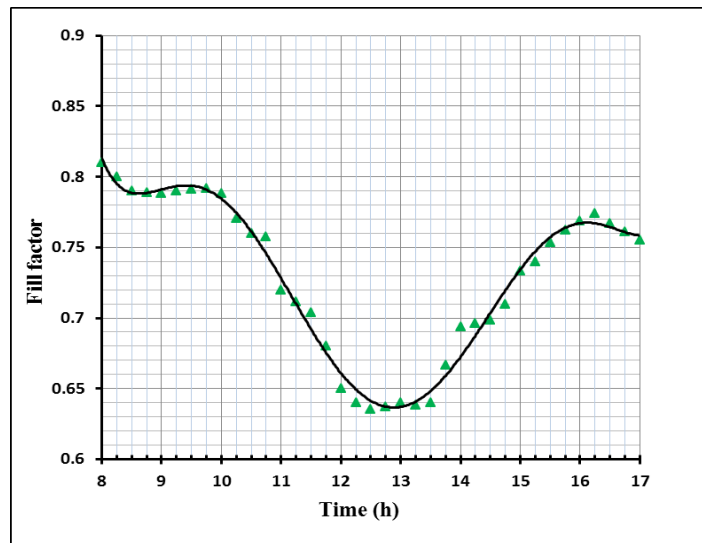


Fig.12 The effect of the PV panel temperature on the fill factor.

Table 2

Comparison between the experimental results and the outputs of the simulation software.

Parameter	Simulation software results	Experimental results
For constant temperature and the solar radiation was increased by 50%		
Current	increased by 43.17%	increased by 42.56%
Voltage	increased by 4.650%	increased by 4.390%
Output power	increased by 49.76%	increased by 48.88%
For constant solar radiation and the temperature was increased by 1°C		
Current	increased by 0.073%	increased by 0.068%
Voltage	decreased by 0.320%	decreased by 0.340%
Output power	decreased by 0.439%	decreased by 0.489%
Efficiency	decreased by 0.408%	decreased by 0.586%

6. Conclusion

In the current study, the effect of solar radiation and operating temperatures on the parameters of photovoltaic panels is explained. Two paths were taken to obtain the results, namely, the use of PVsyst simulation software and practical outdoor experiments. Efficiency values were recorded during the peak of the sun when the maximum values of solar radiation existed. The experimental study and the simulation program agreed that increasing the operating temperature had a negative impact on the performance of the photovoltaic panel in general. Increasing the temperature of the solar panel by 1°C causes the current to rise by about 0.068%, and the voltage drop by about 0.34% which reduces the output power by 0.489% causing the electrical efficiency to deteriorate by about 0.586%. Increasing the temperature also causes the filling factor to decrease. A method has been adopted to evaluate the effect of solar radiation and operating temperature on the parameters of the PV panel. In this method, two equal or close values of solar radiation and different operating temperatures at two different times during the day were taken and the behavior of each parameter of the PV panel was studied separately. It is important to know that the specifications of photovoltaic panels provided by manufacturers under Standard Test Conditions (STC) differ from what was achieved under external conditions. So, when constructing a project, it is necessary to rely on data provided by field studies to determine efficiency, output power and size of panels PV. It is very important to develop this study in the near future by including the influence of other weather factors such as wind speed, relative humidity and dust.

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