Journal of Engineering Science and Technology
Special Issue on ICCSD2023, July (2023) 288 - 306

EXPERIMENTAL EVALUATION OF CLIMATE PARAMETERS IMPACT ON GRID-CONNECTED PV ELECTRICITY GENERATION: A PRACTICAL APPROACH

ALI O. ABD[1], TAMADHER M.A. AL-NASSER[2], NOORA S. EKAAB[3], WISSAM H. ALAWEE[4], HUSSEIN A. KAZEM[5], MIQDAM T. CHAICHAN[6,*]

[1]Department of Applied Sciences, University of Technology- Iraq
[2]Mechanical Engineering Department, University of Technology- Iraq
[3]Electromechanical Eng. Department, University of Technology- Iraq
[4]Control and Systems Engineering Department, University of Technology, Baghdad, Iraq
[5]Sohar University, Sohar, PCI 311, Oman
[6]Energy and Renewable Energies Technology Research Center, University of Technology- Iraq
*Corresponding author email: Miqdam.T.Chaichan@uotechnology.edu.iq

Abstract

Seasonal changes affect the performance of photovoltaic modules. An experimental study was conducted at the University of Technology, Baghdad, Iraq, in 2022 to evaluate a 3.3 kW grid-connected PV system. The environmental data such as ambient temperature, solar radiation intensity, wind speed, humidity, and dust were collected for the studied period. Also, several system parameters were evaluated during this period, including yield factor, capacity factor, and performance ratio (PR). The system's efficiency varied between 12.5% in December and 9.4% in June, with the highest productivity being 3.94 - 5.59 kWh/kWp daily. As for the inverter's efficiency, they ranged from 90% to 94%. Also, it found that the DC performance ratio (PR) was changed and reached its lowest point at 62% in January. PR percentages in June reached 73%. According to the study findings, the results were similar to those of arid region stations established in UAE, Kuwait, and Mauritania.

Keywords: Capacity factor, Climate parameters, Grid-connected PV system, Inventor efficiency Yield factor.

1.Introduction

In recent years, there has been a remarkable surge in the interest and adoption of photovoltaic (PV) modules worldwide. This growing trend can be attributed to several factors contributing to their increased global spread. First and foremost, there has been a heightened awareness of the urgent need to transition towards renewable energy sources to combat climate change and reduce greenhouse gas emissions. Photovoltaic technology, as a clean and sustainable energy solution, has garnered significant attention as it harnesses the power of sunlight to generate electricity without emitting harmful pollutants. Additionally, advancements in PV technology have significantly improved its efficiency and reduced production costs, making it a more financially viable option for individuals, businesses, and governments. Governments across the globe have also played a pivotal role in promoting the adoption of solar energy by offering incentives, subsidies, and favourable policies to encourage investments in PV installations.

Several environmental conditions affect photovoltaic modules, including solar radiation intensity, the most important factor influencing their productivity. It should be noted, however, that the high intensity of the sun's radiation in the solar belt countries and their neighbours (such as Iraq) increases their temperatures and reduces their productivity [1, 2]. The shade on PV panels can also reduce its performance [3]. The arrangement of the PV arrays can also affect wind patterns, influencing wind speed and direction, thus altering the cooling effects of wind on the system [4]. Lastly, dust accumulation on the surface of PV panels can reduce their efficiency, prompting concerns about potential effects on air quality and local health [5]. Addressing these questions and potential environmental impacts is crucial to ensure that the widespread adoption of PV technology remains a sustainable and responsible solution for the global transition to renewable energy. Proper planning, environmental impact assessments, and ongoing research will mitigate adverse effects and ensure a harmonious integration of photovoltaic units with the surrounding environment.

Certainly, the performance of solar cells deteriorates due to these weather conditions. For example, an increase in the temperature of the photovoltaic module by 10 °C higher than its 25 °C standard value will cause the electrical efficiency to deteriorate by about 5% [6, 7]. Dust accumulation also causes the generated energy deterioration, which is proportional to the amount of accumulated dust, the physical properties, and the quality of its chemical components [8, 9].

Several studies have explored the link between weather conditions and the productivity of grid-connected photovoltaic (PV) stations. Here are some examples of the results of such studies:

Solar Radiation and Efficiency: PV panel efficiency is significantly affected by solar radiation. According to research studies, photovoltaic systems produce electricity directly proportional to the intensity of sunlight [10, 11]. For instance, PV stations exhibit peak performance on sunny days with high solar irradiance, generating more electricity than overcast or cloudy days. However, high solar intensity increases the PV panels' temperatures, which causes a significant reduction in their productivity [12]. The scientists and researchers suggested using photovoltaic/thermal (PV/T) systems instead of PV ones. These techniques enabled maintaining the electricity generated at its highest values while producing heat that could be used in other applications [13].

Ambient Temperature and Efficiency: Temperature also plays a crucial role in PV panel efficiency. High temperatures can cause a reduction in PV module performance, as the efficiency of most solar cells decreases with rising temperatures [14, 15]. Similarly, low temperatures may cool down the PV modules' temperature and preserve the generated electricity near its maximum value most of the operating time. Researchers have studied the impact of temperature on PV productivity, and their findings emphasize the importance of proper thermal management and cooling systems to maintain optimal efficiency [16, 17].

Dust Accumulation and Degradation: Dust accumulation on the surface of PV panels can significantly affect their performance. Studies have demonstrated that even a thin layer of dust can considerably reduce power output. Regions with dry and dusty climates may experience more pronounced effects, emphasizing the importance of regular cleaning and maintenance to ensure maximum productivity [18-20].

Impact of Shading: Partial shading of PV modules can substantially negatively impact the overall productivity of a grid-connected system. When a section of a PV panel is shaded, it can significantly reduce the current produced, affecting the entire string or the entire array's output. Various studies have investigated the effects of shading, and techniques such as bypass diodes and improved system design have been proposed to mitigate the issue [21, 22].

Weather Variability and Energy Forecasting: Weather conditions' inherent variability challenges grid operators in managing power supply from PV stations. Studies have focused on weather forecasting models to predict solar irradiance and cloud cover accurately. Improving these forecasting methods enhances grid stability and enables better integration of solar energy into the power grid [23, 24].

Malik [25] explained that the electrical efficiency of the photovoltaic cells of grid-connected stations is permanently degraded at an annual rate of 0.5% to 1%. The practical study of several PV technologies has demonstrated that the life of these PV units depends on the type of PV cell manufacturing technology.

Al-Waeli [26] evaluated a photoelectric system connected to the grid with a capacity of 1006.74 kW made of silicon (C-Si). The photovoltaic system operated in a semi-continental climate. The evaluation results showed that the system's efficiency was deteriorating, from -0.30% to -0.17% starting from the third year of operation. The reference considered these limits acceptable according to the results of references [27, 28].

In summary, research on the relationship between weather conditions and grid-connected PV station productivity has demonstrated that solar radiation, ambient temperature, shading, dust, and weather forecasting play crucial roles in determining photovoltaic systems' overall efficiency and output. Understanding these factors is essential for optimizing PV system design, maintenance, and effectively into the global energy mix.

Usually, studies only last for a few weeks, but in this case, the grid-connected photovoltaic (GCPV) system will be evaluated in Baghdad's weather conditions for an entire year. A full year's monitoring and data analysis for a specific system under all weather conditions of the study area has never been done in Iraq before. Performance parameters were analysed in detail and compared with systems installed in other countries to determine their suitability to work in harsh Iraqi weather conditions. A 3.3-kW station was tested at the University of Technology, Baghdad-Iraq, Directorate of Laboratories and Training. The station was evaluated using data collected from January 1, 2022, to December 31, 2022.

2. Experimental Setup

2.1. Study location

Baghdad, the capital of Iraq, experiences a hot desert climate characterized by long, hot summers and relatively mild winters. The city is in the valley of the Tigris River, which contributes to its climate. During the summer months from June to September, temperatures rise to extreme levels, often exceeding 45 °C [29, 30]. The city receives very little rain during this period, resulting in arid conditions and dust storms for most of the year (up to 285 days). In contrast, the winter season is much milder from December to February, with temperatures ranging from around 10 to 15°C. Although the weather remains relatively dry during the winter, some rain may fall, bringing much-needed relief from the sweltering heat. In general, the climatic conditions in Baghdad are difficult, requiring adaptation measures to deal with extreme heat and water scarcity during the long summer months [4].

2.2. The experimental PV system

Since Iraq is located close to the solar belt and has high solar brightness hours with high radiation intensity, the use of solar energy to produce electricity is the alternative and the best option. Iraqi government reports indicated that within its vision to produce electricity in 2030, PV plants are expected to reserve a few gigawatts [31].

One of the practical experiences in this field is the experience of the Laboratories and Training Directorate – University of Technology, as a photoelectric electrical system connected to the grid was established. 140GH-2PU solar cells that can produce 3 kW and 12 V DC voltages (under standard test conditions) have been used. Figure 1 shows a photo of the system studied in this article. The photovoltaic cells are installed at a fixed tilt angle (34° to the south) and equal to the latitude value of Baghdad + 3 degrees, depending on the reference results [32].

Fig. 1. The studied GCPV system.

The PV modules are connected in series to achieve the voltage required to be connected to the grid-connected inverter. This system uses a Sunny Boy 1700 inventor. Table 1 lists the technical specifications for the PV cells and the reflector used in the system.

Table 1. The tested grid-connected photovoltaic system (GCPV) specifications.

Parameter	Value
Modules brand	Kyocera KD140GH-2PU
PV module rated power (16 modules)	3.3 kWp
Maximum voltage	17.65
Maximum current	7.88
Open circuit voltage	22.2
Short circuit current	8.38
PV module efficiency	13.7%
Inverter	4.5 kW
AC voltage	220-260
Inverter efficiency	94.1%

Figure 2 shows a flow chart for the experimental procedure used in the tests.

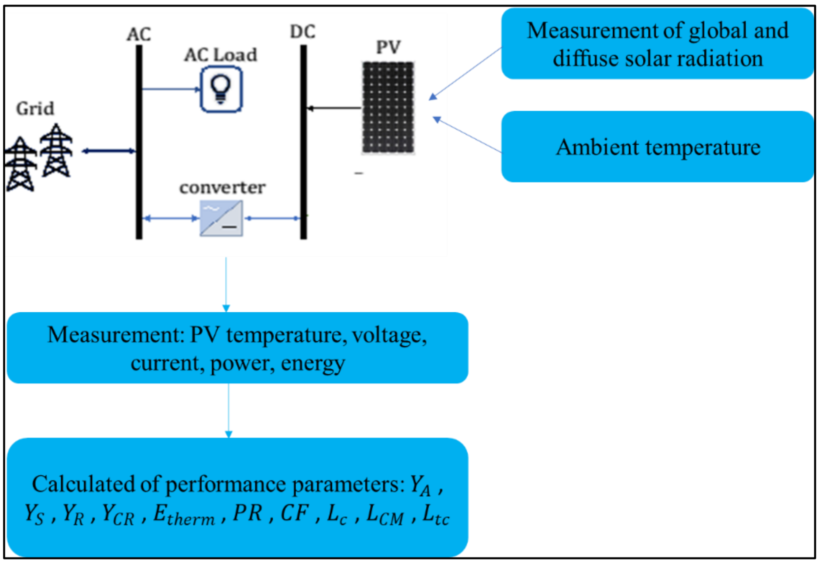

Fig. 2. Flow chart for the test procedure used in the study.

2.3. System performance evaluation

The main performance indicator for the evaluation and comparison of the PV system is the yield. There are four types of yields used in the current study, shown in Table 2, with the relevant equation of each one. In addition, thermal efficiency and losses are also counted in the evaluation of the system under this work. Table 2 lists the equations used to evaluate the performance parameters of the studied grid-connected PV systems and the source of each parameter.

Table 2. Evaluation equations for the studied system.

Eq. No.	Parameter	Parameter definition	Equation	Unit	Ref.
1	Array yield (YA) E_{PV} P_{nom}	PV array productivity compared to nominal (electricity generated by PV arrays). In this equation, the output of the photovoltaic module is used to evaluate its performance. Array-generated electricity Nominal array productivity	$Y_A = \frac{E_{PV}}{P_{nom}}$	h/d	[33] [34]
2	System yield (Y_S)	Ys is the ratio of energy output from the inverter to the nominal energy of the PV array.	$Y_S = \frac{E_{AC}}{P_{nom}}$	%	[35]
3	Reference yield (Y_R)	In terms of solar radiation intensity, Y_R is the ratio between the intensity of solar radiation (H) and the intensity of solar radiation under STC conditions (G = 1000W/m^2)	$Y_R = \frac{H}{G_{STC}}$	%	[36]
4	Corrected reference yield (Y_{CR}) γ T_C T_0	YCR corrects a solar module's working yield due to the influence of temperature. The coefficient of temperature for maximum power Module temperature, Module temperature in STC conditions (25°C).	$Y_{CR} = Y_R(1 - \gamma(T_C - T_0))$	h/d	[37] [38]
5	Thermal energy losses (E_{therm})	In PV modules, the temperature effect led to performance losses. This parameter represents these losses.	$E_{therm} = E_{PV}(1 - \frac{1}{(1 - \gamma(T$	MWh	[37]
6	DC performance ratio (PR)	A PR formula is calculated by dividing the amount of useful electricity generated by the amount of energy generated if there were no waste. A grid-connected photovoltaic system in different locations can be compared with this equation.	$PR = \frac{Y_A}{Y_R} \times 100$	%	[37] [39]
7	Capacity factor (CF)	CF is defined as the actual AC generated vs. the supposed electricity generated by PV arrays under optimal conditions. Electricity provided by a generating system expressed as CR.	$CF = \frac{E_{AC}}{P_{nom}} \times 100$	%	[39]
8	Array capture losses (L_c)	Lc represents all losses that occur during the solar panel array's operation and indicates how long it will take for the system to provide losses when it is operating at nominal power.	$L_c = Y_R - Y_A$	h/d	[37]

9	Miscellaneous capture losses (L_{CM})	LCM measures all PV module losses except those caused by overheating, such as dust, contaminants, and dirt accumulating on the photovoltaic cells. Losses such as degradation, diode, wire, and shading losses can be also included.	$L_{CM} = Y_{CR} - Y_A$	h/d	[38]
10	Thermal capture losses (L_{tc})	LTC parameter describes the losses caused by PV modules operating above their nominal temperatures under standard conditions (T0).	$L_{tc} = Y_R - Y_{CR}$	h/d	[34]

2.4. Uncertainty analysis

It is important to measure uncertainties in experimental studies such as this one. A measurement error is the difference between the measured and true values. The partial derivative uncertainty of the result provided by the equation expressed using expressions found in the literature [40]:

$$\frac{U_R}{R} = \left(\frac{X_n \partial R}{R \partial X_n}\right)^2 \frac{U_{X_n}^2}{X_n^2} \tag{11}$$

During measurements, $R = R\,(X_1, X_2, \ldots, X_n)$ is the resultant of all uncertainties.

$$W_R = \sqrt{\left(\frac{\partial R}{\partial x_1} w_1\right)^2 + \left(\frac{\partial R}{\partial x_2} w_2\right)^2 + \cdots + \left(\frac{\partial R}{\partial x_n} w_n\right)^2} \tag{12}$$

For one variable ($\partial R / \partial x$) is the measurement sensitivity of the given functions of the independent variables. The calculated cumulative uncertainty of the experimental setup is less than 3% based on the characteristics of the used instrumentations or measurements. A maximum of 3% is acceptable, and the experimental evaluation is dependable for the system evaluation. Table 3 contains a list of all uncertainties.

Table 3. Instruments and their uncertainties.

Equipment	Measurement	Accuracy	Uncertainty (%)
Digital Multimeter	Current	±0.48+ 1 A	0.021
Digital Multimeter	Voltage	±0.33+ 1 V	0.38
Pyranometer	Solar irradiance	±8 W/m^2	0.53
Thermocouples (type K)	Surface temperature	±0.22 °C	0.12
Hg thermometer	Ambient temperature	±0.53 °C	0.50
AC voltmeter	Inventor voltage	±0.44 V	0.41
AC digital multimeter	Inventor current	±0.68	0.47

3. Results and Discussion

Iraq is located near the solar belt, so it receives high radiation intensity even during winter. Figure 3 shows practical measurements of global and diffuse solar radiation intensity over a year. The illustrated values were taken at the peak time from 12:00 AM to 01:00 PM. It is noted that the global radiation intensity reaches its peak during

July and August and exceeds 800 W/m^2. As for the lowest radiation intensity that the country receives, it is around 340 W/m^2 during December. Here, it should be clarified that these values are for clear days without a high concentration of dust or clouds. Also, the diffuse radiation is somewhat high compared to other countries, from 105 W/m^2 in January to 300 W/m^2 in August. From April to October, the values of dispersed radiation were high, but they decreased during June due to several sand and dust storms that reduced the field of vision to a minimum. The measurements achieved are consistent with what was obtained by references [39, 40].

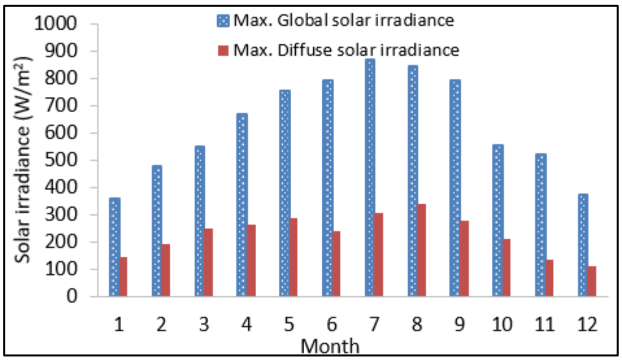

Fig. 3. Maximum global and diffuse solar irradiance for the test period

Figure 4 includes the arithmetic mean of the highest temperatures during the study months for both ambient air and PV modules. Air temperatures increase to reach close to 50 °C in the shade during July and August. Iraq is considered one of the few countries in which air temperatures are accustomed to reaching degrees that sometimes exceed the 50 °C barrier. Global climate change and the increase in agricultural areas bulldozed with the expansion of desertification have all led to an unprecedented rise in air temperatures. These high temperatures cast a shadow over the temperatures of the photovoltaic panels, as they increased to extremely high levels due to the absence or decline in the cooling rate during June, July, and August. It is noted that the effect of the northern cold masses that blow over the country during the autumn and winter seasons works to reduce the panel temperatures. These results show that the PV panels installed in Iraq need cooling to maintain high electrical efficiency, as was indicated by [42, 43].

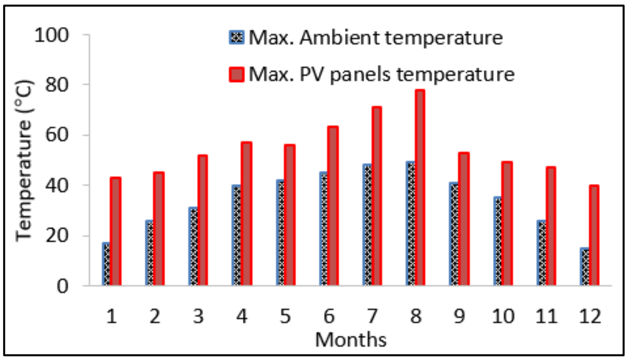

Fig. 4. Maximum ambient and PV panel temperature during the study period.

Figure 5 shows the differences between the maximum generated power and the average of this power. The figure intends to emphasize the effects of weather factors on the power produced by the system, which is continuously available during the month despite the convergence of weather conditions. It is noted that the lowest difference between the average and maximum productive power was obtained in June. In this month, two main factors came together to cause this result: high temperatures and rising dust most days of the month. Reference [44] has studied the dust storms during this month carefully and concluded that cleaning the photovoltaic modules during the storm is not feasible. Still, they must be cleaned immediately after the storm has passed by two days, during which most of the dust particles suspended in the air are deposited. In such a period, the losses in generated power are high. After this period, cleaning will be feasible, as the panels will regain their ability to produce energy efficiently. In July and August, the average productive power decreased due to the increase in panel temperatures, as shown in Fig. 3. In the rest of the months of the year, the values of the produced power (average and maximum) converge, which means that extreme effects of weather factors are limited or not available [45].

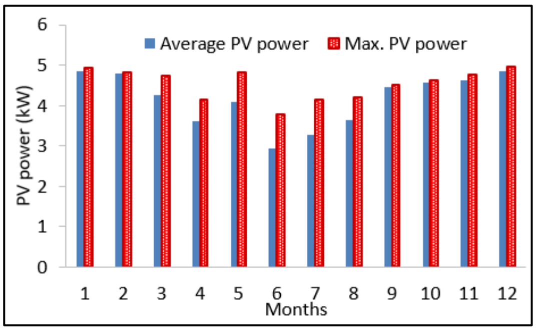

Fig. 5. The variation between the average and maximum monthly generated power

A full year's yield is shown in Fig. 6. As of June, the system yield ranged from 3.43 kWh/kWp to 5.95 kWh/kWp. According to the December, the output ranges from 3.16 to 4.75 kWh/kWp. A final output of 3.16 to 4.75 kWh/kWp is achieved. This yield is directly related to climatic parameters, usually solar radiation and dust, compared to Refs. [46-48] results show that the yield of the studied system is relatively high because of the high solar radiation intensity in Iraq.

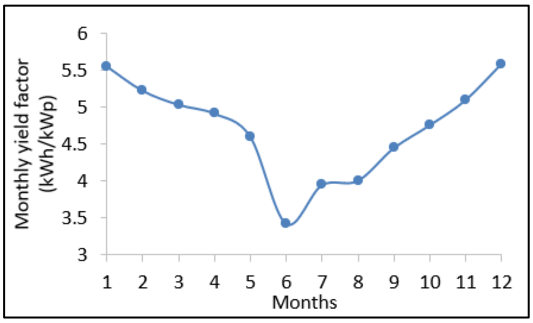

Fig. 6. Grid-connected PV system monthly yield factor variations.

An analysis of Fig. 7 shows a strong correlation between the change in average monthly capture losses and thermal capture losses. In December, the losses are as low as 1.47 hours/day, while in June, they are as high as 2.50 hours/day. Shade, wire losses, dust accumulation, diode losses, and display aging are among the causes of miscellaneous capture losses. It is possible to identify losses, but it is difficult to determine their exact nature. Losses are lowest in December (1.34 hours/day) and highest in June (2.0 hours/day). A change in unit temperature directly impacts heat capture losses. Therefore, during the warm months of the year, we find the highest heat capture losses. In December, heat capture losses are at their lowest (0.03 hours/day), while in June, they are at their highest (0.3 hours/day).

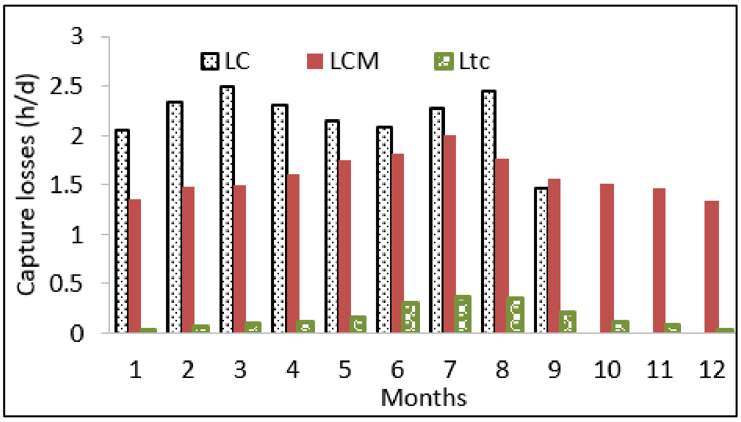

Fig. 7. Losses from array captures (L_C), miscellaneous captures (L_{CM}), and thermal captures (L_{tc}) at the studied station during the month.

Figure 8 shows the monthly productivity of PV modules. The highest productivity of these units is during December and January because the air temperatures are suitable and close to the standard temperature of 25°C. This productivity decreases during the rest of the year and is the lowest during the hot summer months of June, July, and August. It is noted from the figure that the lowest productivity of the units was during June because most of the days of this month were dusty, and three harsh sandstorms occurred during it.

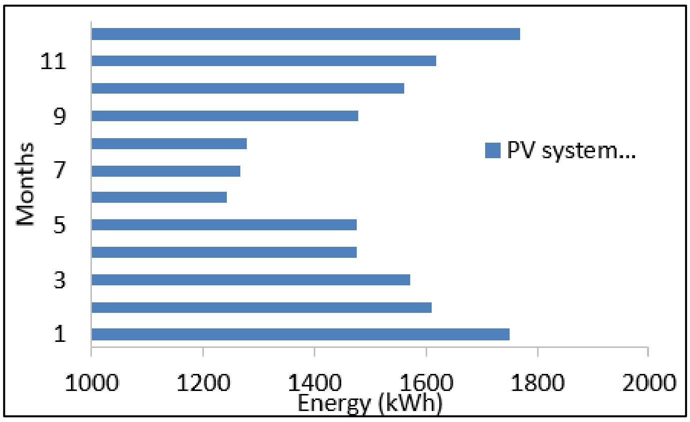

Fig. 8. GCPV system monthly productivity.

Each month of the studied period is depicted in Fig. 9 on the change in PV array and inventor efficiencies. Performance ratios range from 0.489 in June to 0.74 in January, with an annual average of 0.67. During summer, PV modules lose voltage due to a high temperature, so performance ratios are relatively low. During winter, PV voltages are high because PV modules work near the standard temperature of 25 °C. The electrical efficiency fluctuation was about 9.1% to 10.8% in the GCPV system in Baghdad, with maximum efficiency recorded in December and minimum efficiency recorded in June.

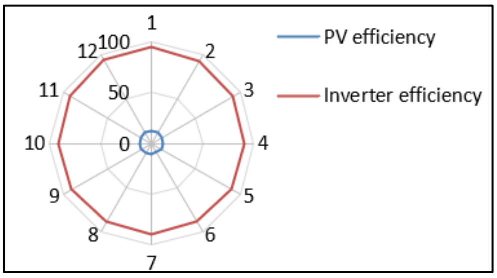

Fig. 9. Efficiency of PV and inverters every month.

There is a higher intensity of solar radiation during June than in December. Also, in June 2022, Baghdad suffered from high suspended dust density in the atmosphere and high photovoltaic cell temperatures, so the GCPV station's yields were lower than in December. This invention has a year-round efficiency of 91% to 94%. As the air temperature increases, the inverter's efficiency decreases. It is more efficient at lower temperatures as could be realized in the results of [49] for PV systems in India and Denmark.

It should be noted that the inverter maintained its high efficiency throughout the year. These PV efficiency results differ totally from Ref. [50, 51], while in Refs. [52, 53], the maximum efficiency was in June, and the minimum was in January. The climate conditions between the recent study (Baghdad-Iraq) and the former references (Sohar-Oman) differ, and the results were different and spaced out.

As part of the constructed plant evaluation, the ratio of useful electricity generated divided by the power that would have been generated in an ideal condition without wasting any energy can be used to compare the productivity of different grid-connected PV systems at different locations. PR changes are shown in Fig. 10. PR changes as seasons change and reaches its lowest point at 62% in January. PR percentages in June reached 73%, the maximum of the current system.

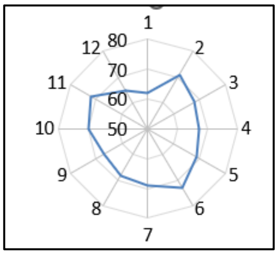

Fig. 10. Performance ratio (PR) variation by month for the studied GCPV system

According to the definition, CF is the amount of electricity generated by the PV arrays operating under standard conditions, compared with the alternating current generated by the generation system. Based on the change in CF throughout the year, Figure 11 shows the change in CF. June had the lowest average daily energy rate of 11.4%, and January had the highest at 22.2%. CF values remain small due to high losses during the hot and dusty months (June, July, August). There is an increase in CF values during the remaining months, especially cold ones.

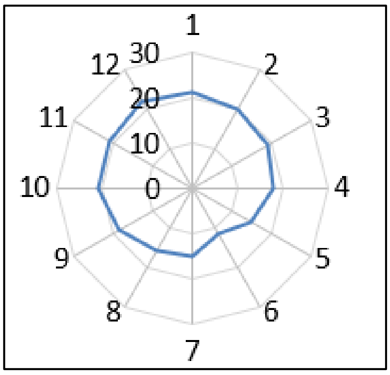

Fig. 11. Capacity factor (CF) variation by month for the studied GCPV system.

In Table 4, some similar studies in the literature are listed and compared with the results of the current study for grid-connected PV plants in different countries. This comparison may be partially unfair because of the differences between the power generated at each station, the technologies available, such as photovoltaic units, inverters, and control devices, and their relationship with the surrounding environment [48]. The current system was analysed based on the climate in Baghdad-Iraq, which has very hot summers and low rainfall winters. This region also experiences wind speeds between 0 and 3 m/s [31].

The manufacturing technology of PV modules influences system performance, the method of connecting the modules to the system, and the matrix arrangement. Performance ratio, array return, and system return are the most important parameters influencing solar cell performance [41]. Table 5 compares these parameters for different regions based on these parameters. According to the current study, the closest results are from a station study in Greece [5], despite the great differences in climate between the two sites. There was a large difference between the stations in Trieste (Italy) and Dublin (Ireland), which were cold weather stations [55, 57]. Note that the yields of the two stations mentioned in the previous paragraph are lower than those of the current study.

In contrast, UAE, Kuwait, and Mauritania [60, 61, 64], which were established in arid environments, produced higher yields than the current study, according to the table. Baghdad has a longer period of sunshine and high solar radiation intensity, which causes the photovoltaic unit to lose power due to high temperatures. In Baghdad, dust storms occur continuously 285 days a year [53]. Dust accumulation causes the photovoltaic units' productivity to deteriorate due to losses resulting from dust accumulation.

Table 4. Comparison of performance parameters of PV grid-connected systems installed in various countries and the recent study.

	Ref. [52]	Ref. [53]	Ref. [54]	Ref. [55]	Ref. [56]	Ref. [57]	Recent study
Location	Trieste-Italy	Abu-Dhabi-UAE	Kuwait	Ireland	Greece	Mauritania	Baghdad-Iraq
Climate conditions	Humid subtropical	Arid	Humid subtropical	Oceanic	Temperate Mediterranean	Arid	Arid
PV technology	HIT	Polycrystalline Si	CIGS	Monocrystalline Si	Polycrystalline Si	a-Si nla-S	Monocrystalline Si
Station Capacity (kWp)	17.94	36	85.05	1.72	171.4	954.7	3.0
PR (%) Min. Mean Max.	82 89.8 95	-	70 - 85	79.3 81.5 84.4	57 67 73	63.6 68 74	63 68 73
Y_S (h/d) Min. Mean Max.	-	4.5 - 5.6	- 4.5 -	1.31 - 3.42	1.95 - 5.7	2.95 4.57 4.94	2.8 4.17 4.9
Y_A (h/d) Min Mean Max	1.4 3.84 5.5	-	-	1.44 - 3.42	-	3.05 4.39 5.07	2.9 4.2 5

4. Conclusions

A grid-connected photovoltaic system installed on the roof of one of the University of Technology, Baghdad-Iraq, was evaluated in this practical study. The power generated by the GCPV system is 3.3 kW. Monitoring and recording of measurements took place from 01/01/2022 through 12/31/2022.

- High solar radiation intensities and air temperatures during the hot summer months, which last from May to September, severely affected the temperatures of the photovoltaic modules. Due to this, the power generated by the GCPV system was deteriorated.
- There are high losses in the system during this period. A direct consequence of the blowing and escalation of dust most days of the year is a reduction in the system's productivity.
- The maximum final productivity is 3.94 - 5.59 kWh / kWp per day, while the system's efficiency ranges between 12.5% in December and 9.4% in June. As for the inverter's efficiency, it ranges from 90% to 94 %.
- Even though Baghdad experiences harsh weather conditions throughout the year, GCPV systems have a relatively high degree of reliability for variable applications. The Iraqi government is advised to deploy these systems to mitigate the power interruption problem in Iraq.

Nomenclatures

A_c	The collector area (m^2)
c_1, c_2, c_3	The PV module coefficients
CA_i	The capacity of the i^{th} component of SAPV, SAPVT nanofluid, and nano-PCM
$C_{capital}$	The capital cost of a project
$C_{O\&M}$	The yearly operation and maintenance costs
$C_{replacement}$	The cost of all equipment replacement and repair
E_{AC}	Alternating current energy
E_{DC}	Direct current energy
G	The incident solar irradiance (W/m^2)
$G_{standard}$	solar radiation (1000 W/m^2) at standard test conditions
ICI	Total constant cost, including the cost of installation and civil works (USD)
IC_k	The initial cost of the k^{th} component (USD)
IC_r	The initial cost of the r^{th} component (USD)
I_{SC}	Short Circuit Current
K	Value of 1 and 2, which are equivalent to the inverter and pump, respectively.
k_r	A constant refers to the maintenance cost as a percentage of the initial cost of the r^{th} component.
MC	The system's total maintenance cost
MC_r	The maintenance cost (USD)
N	Number of years
N_r	The number of components replaced over the lifetime of the system
$P_{in}(t)$	The instantaneous input power
P_{Inv}	The inverter power
$P_{loss}(t)$	The instantaneous power losses
P_{peak}	The PV peak power
P_{PV}	The PV module power
P_R	Rated power
RC_k	The replacement cost of the k^{th} component (USD)
RH	Relative Humidity
R_{PV}	Performance factor
T	Temperature
t_1	The hour, day, month
$-t_2$	The minute, hour, day
T_c	The cell temperature
$T_{standard}$	The temperature of (25°C) at standard test conditions (STC)
V_{OC}	Open Circuit Voltage
WS	Wind Speed
YF	The yield factor
YF_d	The daily/monthly yield
YF_F	Final yield
YR	Reference yield

Abbreviations

CF	Capacity Factor
COE	Cost of Energy
GCPV	Grid Connected PV
LCCA	Life Cycle Cost Analysis
MLP	Multilayer Perceptron
PBP	Payback period

PV	Photovoltaic
STC	Standard test conditions
SY	Specific yield

References

1. Reda, M.N.; Spinnler, M.; Al-Kayiem, H.H.; and Sattelmayer, T. (2019). Experimental investigation of temperature and condensation control of photovoltaic panels. In *2019 6th International Conference on Electrical and Electronics Engineering (ICEEE)* (312-316). IEEE.
2. Reda, M.N.; Spinnler, M.; Al-Kayiem, H.H.; and Sattelmayer, T. (2020). Analysis of ground thermal control systems for solar photovoltaic performance enhancement. *WIT Transactions on Ecology and the Environment*, 246, 41-50.
3. Mamun, M.A.A.; Hasanuzzaman, M.; and Selvaraj, J. (2017). Experimental investigation of the effect of partial shading on photovoltaic performance. *IET Renewable Power Generation*, 11(7), 912-921.
4. Estephan, J.; Chowdhury, A.G.; and Irwin, P. (2022). A new experimental-numerical approach to estimate peak wind loads on roof-mounted photovoltaic systems by incorporating inflow turbulence and dynamic effects. *Engineering Structures*, 252, 113739.
5. Gholami, A. et al. (2020). Photovoltaic potential assessment and dust impacts on photovoltaic systems in Iran. *IEEE Journal of Photovoltaics*, 10(3), 824-837.
6. Al-Kayiem, H.H.; and Reda, M.N. (2021). Analysis of solar photovoltaic panel integrated with ground heat exchanger for thermal management. *International Journal of Energy Production and Management*, 6(1), 17-31.
7. Ajel, M.G.; Gedik, E.; Abdul Wahhab, H.A.; and Shallal, B.A. (2023). Performance Analysis of an Open-Flow Photovoltaic/Thermal (PV/T) Solar Collector with Using a Different Fins Shapes. *Sustainability*, 15(5), 3877.
8. Khalid, H.M.; Rafique, Z.; Muyeen, S.M.; Raqeeb, A.; Said, Z.; Saidur, R.; and Sopian, K. (2023). Dust accumulation and aggregation on PV panels: An integrated survey on impacts, mathematical models, cleaning mechanisms, and possible sustainable solution. *Solar Energy*, 251, 261-285.
9. Dehshiri, S.S.H.; and Firoozabadi, B. (2023). Dust cycle, soiling effect and optimum cleaning schedule for PV modules in Iran: A long-term multi-criteria analysis. *Energy Conversion and Management*, 286, 117084.
10. Reda, M.N.; Spinnler, M.; Al-Kayiem, H.H.; and Sattelmayer, T. (2021). Assessment of condensation and thermal control in a photovoltaic panel by PV/T and ground heat exchanger. *Solar Energy*, 221, 502-511.
11. Nwokolo, S.C.; Obiwulu, A.U.; Amadi, S.O.; and Ogbulezie, J.C. (2023). Assessing the impact of soiling, tilt angle, and solar radiation on the performance of solar PV systems. *Trends in Renewable Energy*, 9(2), 120-136.
12. Mustafa, R.J.; Gomaa, M.R.; Al-Dhaifallah, M.; and Rezk, H. (2020). Environmental impacts on the performance of solar photovoltaic systems. *Sustainability*, 12(2), 608.
13. Allouhi, A.; Rehman, S.; Buker, M.S.; and Said, Z. (2023). Recent technical approaches for improving energy efficiency and sustainability of PV and PV-

T systems: A comprehensive review. *Sustainable Energy Technologies and Assessments*, 56, 103026.

14. Alktranee, M.; Shehab, M.A.; Németh, Z.; Bencs, P.; and Hernadi, K. (2023). Effect of zirconium oxide nanofluid on the behaviour of photovoltaic–thermal system: An experimental study. *Energy Reports*, 9, 1265-1277.
15. Mazaheri, N.; and Bahiraei, M. (2023). Performance enhancement of a photovoltaic thermal system through two-phase nanofluid simulation in a channel equipped with novel artificial roughness. *Applied Thermal Engineering*, 230, 120709.
16. Sato, D.; and Yamada, N. (2019). Review of photovoltaic module cooling methods and performance evaluation of the radiative cooling method. *Renewable and Sustainable Energy Reviews*, 104, 151-166.
17. Alami, A.H.; Rabaia, M.K.H.; Sayed, E.T.; Ramadan, M.; Abdelkareem, M.A.; Alasad, S.; and Olabi, A.G. (2022). Management of potential challenges of PV technology proliferation. *Sustainable Energy Technologies and Assessments*, 51, 101942.
18. Younis, A.; and Alhorr, Y. (2021). Modelling of dust soiling effects on solar photovoltaic performance: A review. *Solar Energy*, 220, 1074-1088.
19. Eisa, K.; Shenouda, R.; Abd-Elhady, M.S.; Kandil, H.A.; and Khalil, T. (2023). Mitigation of dust on PV panels that operate light posts using a wind shield, mechanical vibrations and AN antistatic coating. *Ain Shams Engineering Journal*, 14(5), 101993.
20. Hachicha, A.A.; Al-Sawafta, I.; and Said, Z. (2019). Impact of dust on the performance of solar photovoltaic (PV) systems under United Arab Emirates weather conditions. *Renewable energy*, 141, 287-297.
21. Li, SY; and Han, J.Y. (2022). The impact of shadow covering on the rooftop solar photovoltaic system for evaluating self-sufficiency rate in the concept of nearly zero energy building. *Sustainable Cities and Society*, 80, 103821.
22. Kazem, HA; Chaichan, M.T.; Alwaeli, A.H.; and Mani, K. (2017). Effect of shadows on the performance of solar photovoltaic. In *Mediterranean Green Buildings & Renewable Energy: Selected Papers from the World Renewable Energy Network's Med Green Forum* (379-385). Springer International Publishing.
23. Meenal, R. et al. (2022). Weather forecasting for renewable energy system: A review. *Archives of Computational Methods in Engineering* 29(5), 2875-2891.
24. Neal, R. et al. (2020). Deriving optimal weather pattern definitions for the representation of precipitation variability over India. *International Journal of Climatology*, 40(1), 342-360.
25. Malik, A.S. (2007). Impact on power planning due to DSM in commercial and government sectors with rebound effect: a case study of central grid of Oman. *Energy*, 32(11), 2157-2166.
26. Al-Waeli, A.H.A. et al. (2019). Artificial neural network modelling and analysis of photovoltaic/thermal systems based on the experimental study. *Energy Conversion and Management*, 186, 368–379.
27. Dahmoun, M.E.H., Bekkouche, B., Sudhakar, K., Guezgouz, M., Chenafi, A. and Chaouch, A. (2021). Performance evaluation and analysis of grid-tied

large scale PV plant in Algeria. *Energy for Sustainable Development*, 61, 181-195.

28. Al-Waeli, A.H.; Kazem, HA; Chaichan, M.T.; and Sopian, K. (2021). A review of photovoltaic thermal systems: Achievements and applications. *International Journal of Energy Research*, 45(2), 1269-1308.
29. Saeed, I.M.; Tarkhany, A.; Hama, Y.; and Al-Shatri, S. (2022). Environmental considerations, sustainability opportunities and Iraqi government's energy policies: a comparative study. *Environment, Development and Sustainability*, 25(7), 6879-6895.
30. Al-Rubaye, L.A.H.; Zaidan, L.Y.; and Al-Samari, A. (2023). Study the Investment Opportunity of Hybrid Energy Resources (Biomass and Solar) System, Iraq as a Case Study. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 105(1), 107-121.
31. Ali, O.M.; and Alomar, O.R. (2023). Technical and economic feasibility analysis of a PV grid-connected system installed on a university campus in Iraq. *Environmental Science and Pollution Research*, 30(6), 15145-15157.
32. Abed, A.N.; Kasim, N.K.; and Hussain, H.H. (2023). On-grid Mono-Si PV solar system performance evaluation in Baghdad. In *IOP Conference Series: Earth and Environmental Science*, 1223(1), 012025.
33. Ketjoy, N.; Sirisamphanwong, C.; and Khaosaad, N. (2013). Performance evaluation of 10 kWp photovoltaic power generator under hot climatic condition. *Energy Proc*, 34, 291–297.
34. Ferrada, P.; Araya, F.; Marzo, A.; and Fuentealba, E. (2015). Performance analysis of photovoltaic systems of two different technologies in a coastal desert climate zone of Chile. Solar Energy, 114, 356–363.
35. Trillo-Montero, D.; Santiago, I.; Luna-Rodriguez, J.; and Real-Calvo, R. (2014). Development of a software application to evaluate the performance and energy losses of grid connected photovoltaic systems. *Energy Convers Manage*, 81, 144–159.
36. Congedo, P.M.; Malvoni, M.; Mele, M.; and De Giorgi, M.G. (2013). Performance measurements of monocrystalline silicon PV modules in South-Eastern Italy. *Energy Convers Manage*, 68, 1–10.
37. Ayompe, L.; Duffy, A.; McCormack, S.; and Conlon, M. (2011). Measured performance of a 1.72 KW rooftop grid connected photovoltaic system in Ireland. *Energy Convers Manage*, 52(2), 816–825.
38. Kazem, HA; Yousif, J.H.; Chaichan, M.T.; and Al-Waeli, A.H.A. (2019). Experimental and deep learning artificial neural network approach for evaluating grid-connected photovoltaic systems, *International Journal of Energy Research*, 43(14), 8572-8591.
39. Hammoodi, K.A. et al. (2023). Improving the performance of a pyramid solar still using different wick materials and reflectors in Iraq. *Desalination and Water Treatment*, 285, 1-10.
40. Fu, C.; Sinou, J.J.; Zhu, W.; Lu, K.; and Yang, Y. (2023). A state-of-the-art review on uncertainty analysis of rotor systems. *Mechanical Systems and Signal Processing*, 183, 109619.

41. Al-Yozbaky, O.S.A.D.; and Khalel, S.I. (2022). The future of renewable energy in Iraq: Potential and challenges. *Indonesian Journal of Electrical Engineering and Informatics (IJEEI)*, 10(2), 273-291.
42. Ghazy, M.; Ibrahim, E.M.M.; Mohamed, A.S.A.; and Askalany, A.A. (2022). Experimental investigation of hybrid photovoltaic solar thermal collector (PV/T)-adsorption desalination system in hot weather conditions. *Energy*, 254, 124370.
43. Hasan, H.A.; Hatem, A.A.; Abd, L.A.; Abed, A.M.; and Sopian, K. (2022). Numerical investigation of nanofluids comprising different metal oxide nanoparticles for cooling concentration photovoltaic thermal CPVT. *Cleaner Engineering and Technology*, 10, 100543.
44. Chaichan, M.T. et al. (2023). Sand and Dust Storms' Impact on the Efficiency of the Photovoltaic Modules Installed in Baghdad: A Review Study with an Empirical Investigation. *Energies*, 16(9), 3938.
45. Gonçalves, B.; Fernandes, J.F.; Torres, J.P.N.; and Lameirinhas, R.A.M. (2023). Experimental investigation and modelling of sediments effect on the performance of cadmium telluride photovoltaic panels. *Energies*, 16(12), 4777.
46. He, Y.; Mendis, G.J.; and Wei, J. (2017). Real-time detection of false data injection attacks in smart grid: A deep learning-based intelligent mechanism. *IEEE Transactions on Smart Grid*, 8(5), 2505-2516.
47. Shadid, R.; Khawaja, Y.; Bani-Abdullah, A.; Akho-Zahieh, M.; and Allahham, A. (2023). Investigation of weather conditions on the output power of various photovoltaic systems. *Renewable energy*, 119202.
48. Obaid, N.M.; Sultan, H.S.; Abed, A.M.; Jweeg, M.J.; and Abdullah, O. (2023). A new correlation for solar radiation incidence angle and dust accumulation of photovoltaic PV systems. *Environmental Research, Engineering and Management*, 79(1), 56-68.
49. Kshatri, S.S.; Dhillon, J.; and Mishra, S. (2021). Impact of Solar Irradiance and Ambient Temperature on PV Inverter Reliability Considering Geographical Locations. *International Journal of Heat and Technology*, 39(1), 292-298
50. Kazem, H.A; Chaichan, M.T.; Al-Waeli, A.H.; and Sopian, K. (2020). Evaluation of aging and performance of grid-connected photovoltaic system northern Oman: Seven years' experimental study. *Solar Energy*, 207, 1247-1258.
51. Shafee, A. et al. (2023). Techno-economic feasibility analysis of hybrid system in Bangladesh-A case study for higher learning institution. In *2023 3rd International Conference on Robotics, Electrical and Signal Processing Techniques (ICREST)* (275-279). IEEE.
52. Micheli, D.; Alessandrini, S.; Radu, R.; and Casula, I. (2014). Analysis of the outdoor performance and efficiency of two grid connected photovoltaic systems in northern Italy. *Energy conversion and management*, 80, 436-445.
53. Al-Sabounchi, A.M.; Yalyali, S.A.; and Al-Thani, HA (2013). Design and performance evaluation of a photovoltaic grid-connected system in hot weather conditions. *Renewable energy*, 53, 71-78.

54. Al-Otaibi, A.; Al-Qattan, A.; Fairouz, F.; and Al-Mulla, A. (2015). Performance evaluation of photovoltaic systems on Kuwaiti schools' rooftop. *Energy Conversion and Management*, 95, 110-119.
55. Ayompe, L.M.; Duffy, A.; McCormack, S.J.; and Conlon, M. (2011). Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland. *Energy conversion and management*, 52(2), 816-825.
56. Kymakis, E.; Kalykakis, S.; and Papazoglou, T.M. (2009). Performance analysis of a grid connected photovoltaic park on the island of Crete. *Energy conversion and management*, 50(3), 433-438.
57. Sidi, C.B. et al. (2016). Performance analysis of the first large-scale (15 MWp) grid-connected photovoltaic plant in Mauritania. *Energy conversion and management*, 119, 411-421.