IMPACT OF SEVERE WEATHER CONDITIONS IN IRAQ ON THE PERFORMANCE OF GRID-CONNECTED PHOTOVOLTAIC SYSTEM

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The view of decision makers in Iraq has evolved towards the use of photovoltaic (PV) units to encourage the generation of green electricity. Previously, this technology was considered as a secondary option because its performance decreases in the summer due to high temperatures, in addition to the fact that Iraq is one of the countries with dusty weather conditions that reduce the productivity of these systems. The University of Technology - Iraq installed a PV system connected to the national grid in one of its buildings with a capacity of 3.3 kW as a field experiment. In this study, the performance of this system was evaluated over an entire year. Practical measurements were conducted under different weather conditions and focused on identifying the system losses and their various sources. The results indicated that the average daily reference yield ranged between 4.2 and 8.3 (hour/day). The study concluded that the worst months of the year for the grid-connected PV system production are the hot summer months, which cause a reduction in the system's productivity from 28% to 34% mainly due to the dusty weather and high ambient temperatures. In addition, the dust months (April, June and August) cause an increase in the deterioration of the network's productivity and require more maintenance than the rest of the months of the year. Practical measurements have proven the possibility of operating such systems in Iraq with a high focus on maintaining and cleaning the systems

Key words: Photovoltaic, climatic conditions, grid-connected, payback period, Iraq, production rate, yield.

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1. Introduction

Photovoltaic power plants serve as indispensable elements for building sustainable power systems around the world. PV systems utilize solar power to offer essential reductions of fossil fuel dependence and utilize environmentally friendly sources of energy. The primary function of PV systems transforms sunlight into electric power through solar panels that produce direct current electricity [1]. The power produced by PV cells needs to be converted into AC for utility grid incorporation, so inverters represent fundamental components that enable PV systems to be integrated [2]. PV systems rely on inverters to execute fundamental power conversion between DC solar panel electricity and the required AC electricity. The inverter serves both functions of power transformation while keeping electricity production safe and stable. Lower prices, better quality standards and optimal performance of inverters enable effective energy management which optimizes system efficiency and maintains grid standards [3].

Several research conducted to improve inverter technology to support larger PV system capacities. The advancement of solar energy systems requires this development because it enhances system performance while making solar power available during dim sunlight conditions [4]. Modern inverters with integrated Maximum Power Point Tracking (MPPT) capability function to extract maximum energy from solar panels and boost both reliability and efficiency of the complete energy conversion system [5].

Through power generation decentralization PV systems generate localized energy which gives individual communities and users independence from non-renewable energy resources [2]. Greater economic stability combined with growing efficiency levels has made solar power an increasingly desirable power generation method for world markets resulting in growth for renewable workforces [6].

PV system addition to current energy networks creates difficulties specifically regarding reliability and continuity within the system. Durable management systems need to be established to guarantee stable solar power delivery since this renewable energy source operates in sporadic patterns. Inverter technology research continues with the aim of developing hybrid power systems which will help stabilize solar power generation fluctuations. Research has resulted in new innovations which increase inverter capabilities alongside advanced system designs that enhance operation across different environmental circumstances [7].

Reference [8] provides a detailed review on the grid connected PV power plants using key thematic areas comprising of grid code, inverters and control circuitry in tries to achieve the optimum scenarios. Their research described the problem of the absence of unified communication interfaces of smart energy systems and their co-ordination with other global participants that is considered to be a major issue in integration of such systems into present power utilities. This forms the rationale of the study where the author highlights the need to fill these gaps for improved reliability and efficacy of PV systems due to higher penetration in energy markets. To support these multiple components of renewable energy sources such as solar power systems, the authors call for a unified of standardization that enhances their interaction with other elements in the grid for the provision of energy security [9, 10].

Other specimens of research conducted by Reference [11], where the study investigated more deeply the effectiveness centered at the grid-connected PV system under severe climate condition including high temperature and high humidity that is familiar in some areas. As per the research of these authors, dust affects the performance of PV systems gravely; this confirms that dust decreases the power produced by the systems by up to 27 % in cases where the system is exposed to dust in arid regions. Furthermore, Reference [12] worked on the feasibility study of a grid connected photovoltaic thermal (GCPVT) system with nanofluid cooling in Bangi, Malaysia. These operations take place with an average ambient temperature of 38.23 °C, according to their findings, the annual production factor varied within the scope of 128.34 to 183.00 with a power factor somewhere in the region of 17.82 % and 25.52 %. The study approved that the GCPVT system underwent reasonable efficiency and economic profitability rating but certain issues like dust depositions and high ambient temperatures hindered the rating and encouraged the researchers for further improvements in the similar climate conditions.

According to [13], Oman is currently seeking to encourage the use of grid-connected solar PV plants in some schools. The 150 kW system was monitored for a full year, during which system losses and seasonal variations in performance were observed depending on the weather. The reference daily yield ranged from 4.5 to 7.2 hours per day, 3.1 to 5.2 hours per day, and 11.74 to 20.54 hours per day for determining daily revenue. The researcher concluded that Oman's environment is conducive to hosting grid-connected solar PV systems. In a study related to the present work, [14] evaluated the effectiveness of GCPV systems in United Arab Emirates where the environmental conditions including high temperature and dust reduce the effectiveness of solar panels. The study suggested that dust accumulation threatens to cut down energy generation by up to seventy-five percent, while the general efficiency was influenced heavily by environmental issues such as heat and humidity, lowering efficiency by twenty seven percent. These studies show that the climatic conditions of the region in which GCPV systems are installed should be taken in account to give the best result, regarding their overall effectiveness.

Reference [15] more probing study also concerned itself with the feasibility regarding economic criteria for GCPV systems within the context of Turkey; their findings showed that electricity generation by such systems cost three to four times the amount of revenue from conventional diesel power stations. It is found that the high taxation on renewable energy projects reduce the competitiveness of solar energy in the market [16]. The analysis stresses the fact that the key factor that should be improved in order to stimulate the use of GCPV systems is the economic viability, for which policy changes should be introduced [17]. Moreover, the literature review reveals various needs and challenges of invoking GCPV systems for green energy production and implies that the integration of these systems into energy matrices depends upon the solutions to the technical and economic issues associated with local conditions [18].

In Oman, research work has been carried out on the viability of GCPV systems. Reference [19], has conducted the techno-economic analysis of these systems in 25 different places of Oman with the help of software known as the RETScreen. Consequently, this work established that the electricity produced cost ranged from 0.210 to 0.304 USD/kWh.

Another study by [20] achieved the feasibility analysis for renewable energy systems for electricity requirements of outlying areas in Oman using HOMER software. This paper also retrieved that the electricity cost for the studied systems ranged between 0.206 and 0.361 USD/kWh.

Besides, Reference [21] examined the effect of aging on results collected from a 4 kW GCPV system installed at Sohar, Oman, for seven years. As it can be observed, the results indicated a slight degradation on the efficiency of the system with a 6.3 % reduction of efficiency in module and systems. The study also revealed that the level of attachment to culture also has risen by 5 scale analysis of the obstacles; 88 % reduction in the rate of production. Thus, this situation provides around 91 % reduction in the capacity factor. This was because; there was increased intensity of radiation, high temperatures and the dust that collected on the panel during the summer months caused a higher rate of degradation.

These papers explain the potential and challenges of using GCPV systems in several regions of the world. Although electricity production from these systems is relatively expensive, the effects of degradation and such conditions as high temperature and dust must be taken into account when designing and operating these systems. Electricity consumption in Iraq increased from 13,800 MWh in 2007 to 45,000 MWh in 2024 and showed an annual growth rate of more than 28 %. The country's population growth has been accompanied by an explosive increase in housing construction. The bulk of the electrical energy is consumed by air conditioning units in homes, clinics, commercial buildings and factories. Iraq relies on fossil fuels (diesel, black oil and natural gas) for electricity production [22].

The adoption of GCPV systems integrated with three-phase grids reduces switching losses, especially when using passive anti-island protection strategies. Distributing power across three conductors allows for a more balanced load, reducing the risk of voltage fluctuations and improving system performance. Several research studies have shown that implementing passive anti-island protection techniques - such as voltage and frequency monitoring - can effectively prevent unintended grid outages during disturbances. As a result, this reduces switching losses associated with sudden changes in load or generation [23, 24]. The use of advanced inverter technologies that improve power flow and maintain grid stability can improve the efficiency of GCPV systems [25]. For example, one study highlighted that three-phase inverters can distribute solar power evenly across phases, mitigating the risk of single-phase overload and thus reducing switching losses during peak periods. Additionally, the ability to connect multiple single-phase PV systems to a three-phase grid allows for greater flexibility in power management, as they can accommodate varying power demands across different phases without compromising system performance. This adaptability is critical in commercial environments where power demands fluctuate significantly, making three-phase PV systems a viable solution for enhancing energy efficiency and reliability [26]. Combining three-phase grids with passive islanding protection can improve the performance of GCPV systems and provide a more flexible and efficient power infrastructure.

2. Experimental Setup

2.1. System description

In this study, the impact of weather and atmospheric conditions on a GCPV system located in Baghdad, Iraq, will be evaluated. This system produces power with an output of 3.3 kW and has an inverter that converts DC to AC. It's important to note that the power generated by this system is consumed by equipping it with a laboratory in the building above it. On holidays and when the laboratory is not in use, this generated power is injected directly into the system. The total area occupied by the PV modules is 39 square meters. The system uses polycrystalline silicon solar cells, and the detailed specifications of these PV modules are provided in Table 1. To optimize energy production, the system is installed facing south at an angle of 34 degrees to suit the sun movement conditions in the location.

Tab. 1 The studied stations' PV module specifications

PV Module	Monocrystalline
Modules' type	Kyocera KD140GH-2PU
Number of modules	16 modules
Module dimensions	1679×800×25 mm
Rated power	3.3 kWp
Voltage (max.)	17.6 V
Current (max.)	7.88 A
Open circuit voltage	20.8 V
Short Circuit current	8.5 A
Panel efficiency	13.6 %

Fig. 1 Investigated PV system.

In addition to the PV panels, the system includes various accessories to monitor efficiency. This system does not need to store electricity in batteries as it is directly connected to the grid. A power meter is used to record the generated electricity, along with a weather station that measures key weather parameters such as solar radiation, wind speed, humidity, and temperature.

DC current is converted to AC current using an inverter, which plays an important role in safely transmitting electricity to and from the grid. The inverter can sense fluctuations in the actual grid current and respond quickly to such fluctuations by regulating the power distribution between the grid and the PV system. The electrical wiring used in the system is designed to withstand the critical conditions associated with the flow of electric current, intense solar radiation, and prevailing ambient temperature. This ensures the reliable operation and safety of the GCPV system.

2.2. The Tested System Performance

When evaluating the efficiency of a GCPV plant, basic performance parameters must be calculated. These parameters give a clear indication of the actual losses incurred by the plant during its operation. They also indicate the potential of this plant on the other hand. These parameters are: Array yield (Y_A), System yield (Y_S), Reference yield (Y_R) and Corrected reference yield (Y_{CR}).

Array Yield (YA):

- Array yield is the ratio of the total DC energy generated by the PV array (EA) to the nominal rated power of the PV plant (Pnom).

- It represents how many hours the array would need to operate at its rated power to generate the observed energy.

- Unit: kWh/kWp (or hours/day)

$$Y_A = \frac{E_{PV}}{P_{nom}} \quad (h/d) \tag{1}$$

System Yield (YS or YF):

- System yield (sometimes called final yield, YF) is the ratio of the total useful AC energy delivered by the PV system (EAC) to the grid, divided by the nominal rated power of the PV system.

- It reflects the effective energy output after all system losses (including inverter losses).

- Unit: kWh/kWp (or hours/day)

$$Y_S = \frac{E_{AC}}{P_{nom}} \quad (h/d) \qquad (2)$$

Reference Yield (YR):

- Reference yield is the ratio of the total in-plane solar irradiation (H, in kWh/m²) received by the PV array to the reference irradiance (G, usually 1 kW/m²).
- It represents the ideal energy yield if the system operated at its nominal power for every hour of peak sun received.
- Unit: kWh/kWp (or hours/day)

$$Y_R = \frac{H}{G_{STC}} \quad (h/d) \qquad (3)$$

Corrected Reference Yield (Y_{CR}):

- The corrected reference yield (Y_{CR}) is the reference yield adjusted for certain real-world losses (such as soiling, shading, or other site-specific factors).
- It provides a more realistic baseline for system performance comparison, accounting for predictable losses not related to the PV module or inverter efficiency.

$$Y_{CR} = Y_R(1 - \gamma(T_C - T_0)) \quad (h/d) \qquad (4)$$

2.3. Uncertainty Analysis

The uncertainty analysis process before starting measurements is an important process, and it involves ensuring that the measuring instruments used are appropriate. After calibration, the measurement instrument accuracy is analyzed individually and then the total uncertainty of the experiment is determined. Several effects attention should be paid to in this process. As an example of such effects ease of data collection and cost. It is the responsibility of the researcher to identify and correct any experimental errors. Determining the acceptable level of uncertainty in scientific investigations can help determine the errors' potential values. Reference [27] presented an equation to calculate the total uncertainty value based on several independent variables, while emphasizing that the final result satisfies all possible probabilities.

$$w_R = \left[\left(\frac{\partial R}{\partial x_1} w_1\right)^2 + \left(\frac{\partial R}{\partial x_2} w_2\right)^2 + \cdots + \left(\frac{\partial R}{\partial x_n} w_n\right)^2\right]^{1/2} \qquad (5)$$

From the listed values in Table 2, the overall uncertainty in this study were less than 1.5 %. This result shows that the conducted measurements have high accuracy level.

3. Results and Discussions

3.1. PV performance parameters evaluation

Figure 2 shows the monthly system production. In Baghdad, summer starts in mid-May and lasts until the end of October. The temperatures during this season are very high. The need for electricity increases during this season to meet the demand for air conditioning.

Tab. 2 The PVT system measurements' uncertainties

Equipment	Parameter	Experimental uncertainty
Multi-meter	Voltage	±0.35 %
Multi-meter	Current	±0.023 %
Thermocouples	Temperature (PV module, PVT collector, inlet, outlet, and ambient)	±0.67 °C
Solar radiation intensity meter	Irradiance	±0.85

While winter (mid-December to mid-February) is characterized by a significant drop in temperatures and the need in this season is for air heating, which causes an increase in electricity consumption during this season. In the fall (mid-October to mid-December) and spring (mid-February to mid-April), the demand decreases because there is no need to cool or heat spaces. The electricity generated by the GCPV station ranged from 3.15 kWh in December to 2.40 kWh in August. In December and January, solar radiation intensity in Baghdad ranges between 140 and 280 W/m², while ambient air temperatures do not exceed 10 °C under the worst conditions. These weather conditions do not cause significant temperature increases in the units. Instead, they act to cool the units, resulting in minimal reduction in productivity. In August, the solar radiation intensity reaches its peak of 960 W/m² with an air temperature of 46 °C, which causes the modules to overheat and their productivity to deteriorate. April and June are characterized by high levels of dust in the air, which reduces the electricity produced. The lowest productivity of the station was in August and the highest in January. According to the results of Figure 2, the station can produce a surplus amount of energy during July and August (which represent the students' summer vacation at the university). This surplus can be pumped into the grid and thus benefit from reducing the national electricity costs and compensating for part of them.

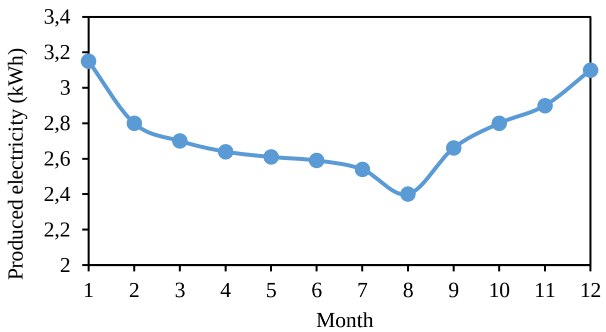

Fig. 2 The net energy produced per month.

Figure 3 shows the monthly electricity supply to the grid and imports from it. Electricity consumption peaks during September and October while the minimum electricity demand is during January and February.

During the summer vacation period in July and August, the demand for energy is at its lowest. During May and June, the demand for electricity for cooling purposes increases, which causes the amount of electricity exported to the grid to decrease. During the spring and autumn months, there is a decrease in electricity demand because there is no need to cool or heat spaces. The figure shows that electricity exports decrease during hot days and increase during moderate days and summer vacation.

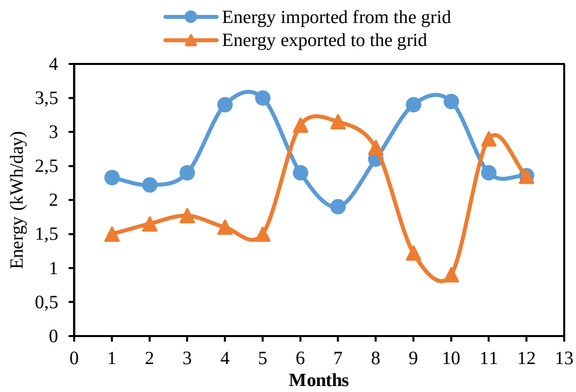

Fig. 3 The monthly imported and exported electricity.

Figure 4 shows the fluctuation of the station efficiency, which was measured employing the equation: (generated power – power imported from the grid) / total power generated. The system efficiency was high in the cold and moderate months while for the hot months, it reduced the station's productivity. GCPV systems can contribute to reducing the load on the national grid during the holiday period when there is a surplus of electricity. Therefore, working to install such systems in government institutions, hospitals, universities and schools will actually contribute to reducing the load on the national grid.

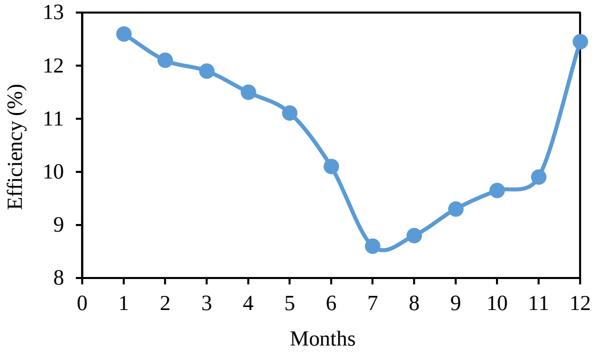

Fig. 4 The station's efficiency variation per month

When analyzing the performance of any PV array, the focus should be on the array's productivity, which reflects the power generated and the energy conversion efficiency. Understanding the array's productivity helps determine how effectively solar panels convert solar radiation into electricity. This conversion efficiency is affected by several factors such as temperature, irradiance, shading, and dust. By assessing this yield, system design can be optimized, operational strategies improved, and overall energy production enhanced. Array productivity analysis also allows for the identification of performance degradation over time, enabling proactive maintenance and upgrades. Ultimately, a comprehensive understanding of array productivity is essential to maximizing the efficiency and sustainability of solar energy systems, and contributing to broader goals of renewable energy adoption and climate change mitigation. In Figure 5, the monthly variations in daily array productivity, which are clearly related to the average daily sunlight hours, range from 4.2 h/d in January to 8.6 h/d in August. Array productivity is subject to large fluctuations throughout the year. The lowest daily yield was recorded in August (3.5 h/d) and the highest in February (4.6 h/d).

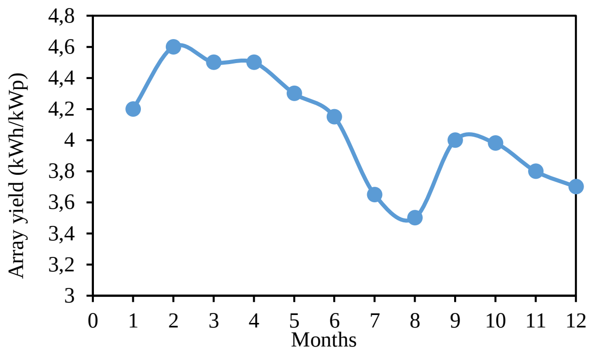

Fig. 5 Changes in the daily array yield per month.

The reference yield is used to evaluate the performance of GCPV systems, as it expresses the amount of solar energy incident on the PV array per unit area, which is usually measured in kilowatt-hours (kWh)/m^2. Under standard test conditions (STC), where the solar irradiance (G) is 1000 W/m^2, the ratio of solar energy incident on the PV array (H) to solar irradiance (G) is equal to the time period (t) in hours. This ratio, H/G, provides a measure of the intensity of solar radiation and is essential for determining the potential power generation of a PV system. Figure 6 studies the reference yield, the available solar resources can be evaluated, the tilt angle and orientation of the PV array can be optimized, and the expected power output of the system can be estimated. Furthermore, analyzing the reference yield over time can help identify any changes in solar resources due to factors such as weather, shading, or soiling, enabling proactive maintenance that improves performance. Since this yield depends on solar radiation, which peaks in August in Iraq, we find as Figure 6 manifests that during this month this reference yield was at its peak.

To evaluate the overall performance and effectiveness of GCPV systems, it is essential to examine the system productivity. In this context, productivity refers to the ratio of the inverter output to the rated capacity of the GCPV array.

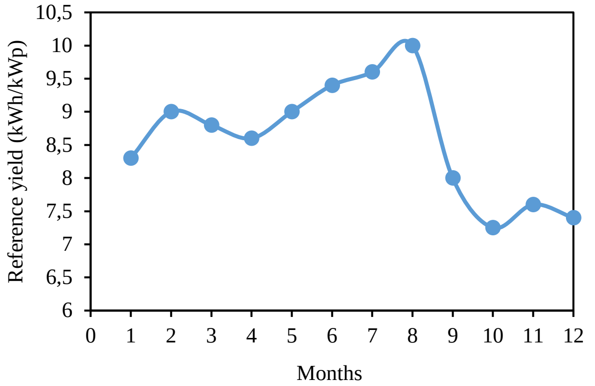

Fig. 6 The monthly changes in the station's reference yield.

This metric provides insights into how efficiently a PV system converts sunlight into usable electrical energy, taking into account variables such as shading, temperature fluctuations, and system inefficiencies.

By analyzing system productivity (Figure 7), scientists and practitioners can identify operational challenges, optimize system design, and deploy maintenance strategies to optimize power generation. Furthermore, understanding system productivity helps in comparing different PV technologies and configurations, thus facilitating informed decisions for future installations. Ultimately, a comprehensive assessment of system productivity is essential to maximize the efficiency and reliability of solar power systems, thereby contributing to the overarching goals of adopting renewable energy sources and promoting sustainability. Figure 7 shows that the worst productivity of the system occurs during the summer months due to dust storms and high unit temperatures resulting from high solar radiation intensity and air temperatures.

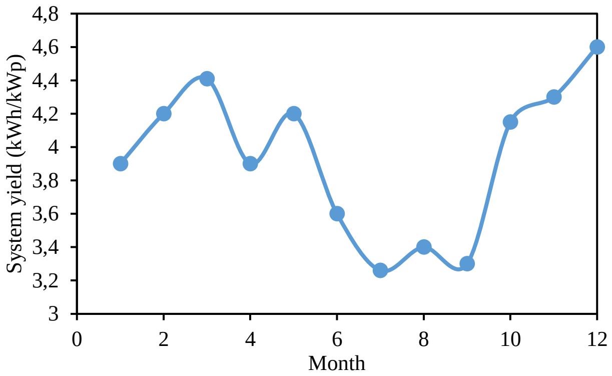

Fig. 7 Changes in the system yield per month

3.2. Comparison with literature

A comparison has been made between the current study results and the results of some updated studies in this field. Such a comparison cannot be fair to some studies due to the differences in terms of the study location and the resulting differences in weather conditions, the type of panels used, and the size of the system. The measurements were carried out in different weather conditions. Also, the PV panels used in GCPV systems differ from one system to another. Also, the methods of connecting the modules (parallel or series) differ between the stations listed in the table. Also, the GCPV stations used were of different sizes. However, the comparison provides an initial indication of whether the PV system's performance aligns with findings from published studies in the literature. When taking all these variables into consideration, the studied system's efficiency in the Iraqi weather conditions was similar to the systems used for comparison. It can also be emphasized that the studied GCPV system provided better efficiency than the other systems for references [30], [31], [33], and [35].

Tab. 2 Current study results compared to some recent articles in literature

Ref. No.	Site	Year	System Performance (kWp)	Max. Final Yield	Min. Final Yield	Annual Average Efficiency (%)
[28]	India	2022	81.9	4.5	2.4	13.3
[29]	Morocco	2022	1.8	4.89	2.68	20.79
[30]	South Korea	2022	9521	7.15	4.44	11.2
[31]	Iran	2023	9	5.725	-	12.3
[32]	Ghana	2023	8.58	36.224	-	15.1
[33]	India	2023	90.3	90.5	90.1	9.87
[34]	India	2024	200	8.45	4.48	20
[35]	Iran	2024	3	8.21	3.96	3
[36]	Italy	2024	10	131.5	104	28.2
Current study (Iraq)		2023	15.0	10.54	8.0	12.6

4. Conclusions

There is growing interest in Iraq toward PV systems, with a particular focus on installing grid-connected PV systems and evaluating their anticipated benefits. The University of Technology has conducted a pioneering experiment in this field by installing a 3.3-kilowatt system on top of one of its buildings and connecting it to the grid for the purpose of producing clean and green electricity and possibly selling the surplus to the national grid. The potential of this station was examined in this study by monitoring the system outputs for a full year. The station was operated, its outputs were measured, documented and linked to the factors affecting it such as weather conditions such as temperature, solar radiation, humidity, wind movement and dust. The results showed that the station's outputs are directly affected by weather conditions and the extent of its exposure to sunlight. The average daily energy production was at its peak in winter, followed by spring and fall. In the summer, production deteriorated due to the high temperatures of the PV units. It was also noted that the dust suspended in the atmosphere has a significant effect, causing partial shading on the station, and its accumulation on the units causes a decrease in their productivity. Dust increases during the period from April to August and reaches its peak with the occurrence of dust storms, especially in June. This observation calls for attention to the periodic cleaning of the panels and the cleaning period should be reduced during the mentioned period. The average daily reference yield ranged between 4.2 and 8.3 (h/d). The study proves, especially after comparing its results with many studies from the literature, that Iraq can be a good environment for the use of GCPV systems, especially in government departments, hospitals, universities and schools, which reduces the demand for electricity and provides additional environmentally friendly electricity.

References

1. Li, N. Experience and enlightenment of energy transition in Germany. *In IOP Conference Series: Earth and Environmental Science. IOP Publishing*, **2021**, *621*(1), 012172. https://doi.org/10.1088/1755-1315/621/1/012172
2. Shakeel, M.R.; Mokheimer, E.M. A techno-economic evaluation of utility scale solar power generation. *Energy*, **2022**, *261*, 125170.
3. Kabeyi, M.J.B.; Olanrewaju, O.A. Sustainable energy transition for renewable and low carbon grid electricity generation and supply. *Frontiers in Energy research*, **2022**, *9*, 743114.
4. Sharma, B.; Manna, S.; Saxena, V.; Raghuvanshi, P.K.; Alsharif, M.H.; Kim, M.K. A comprehensive review of multi-level inverters, modulation, and control for grid-interfaced solar PV systems. *Scientific reports*, **2025**, *15*(1), 661. https://doi.org/10.1038/s41598-024-84296-1
5. Obaideen, K.; AlMallahi, M.N.; Alami, A.H.; Ramadan, M.; Abdelkareem, M.A.; Shehata, N.; Olabi, A.G. On the contribution of solar energy to sustainable developments goals: Case study on Mohammed bin Rashid Al Maktoum Solar Park. *International Journal of Thermofluids*, **2021**, *12*, 100123.
6. Hassan, Q.; Viktor, P.; Al-Musawi, T.J.; Ali, B.M.; Algburi, S.; Alzoubi, H.M.; Al-Jiboory, A.K.; Sameen, A.Z.; Salman, H.M.; Jaszczur, M. The renewable energy role in the global energy Transformations. *Renewable Energy Focus*, **2024**, *48*, 100545. https://doi.org/10.1016/j.ref.2024.100545
7. Gidiagbaa, J.O.; Ninduwezuor-Ehiobub, N.; Ojunjobic, O.A.; Ofonagorod, K.A.; Daraojimbae, C. Ensuring the Future of Renewable Energy: A critical review of reliability engineering applications in renewable energy systems. *Materials & Corrosion*, **2023**, *4*(2), 60-69.
8. Boscaino, V.; Ditta, V.; Marsala, G.; Panzavecchia, N.; Tinè, G.; Cosentino, V.; Cataliotti, A.; Di Cara, D. Grid-connected photovoltaic inverters: Grid codes, topologies and control techniques. *Renewable and Sustainable Energy Reviews*, **2024**, *189*, 113903. https://doi.org/10.1016/j.rser.2023.113903
9. Kazem, H.A.; Chaichan, M.T.; Al-Waeli, A.H.; Sopian, K. A novel model and experimental validation of dust impact on grid-connected photovoltaic system performance in Northern Oman. *Solar Energy*, **2020**, 206, 564-578. https://doi.org/10.1016/j.solener.2020.06.043
10. Yim, J.; You, S.; Blaabjerg, F.; Lee, Y.; Gui, Y.; Kim, W. Energy management systems for forecasted demand error compensation using hybrid energy storage system in nano-grid. *Renewable Energy*, **2024,** *221*, 119744. https://doi.org/10.1016/j.renene.2023.119744
11. Sidrach-de-Cardona, M.; Lopez, L.M. Evaluation of a grid-connected photovoltaic system in southern Spain. *Renewable Energy*, **1998**, *15*(1-4), 527-530. https://doi.org/10.1016/S0960-1481(98)00218-3
12. Al-Sabounchi, A.M.; Yalyali, S.A.; Al-Thani, H.A. Design and performance evaluation of a photovoltaic grid-connected system in hot weather conditions. *Renewable Energy*, **2013**, *53*, 71-78. https://doi.org/10.1016/j.renene.2012.10.039
13. Kazem, H.A.; Chaichan, M.T.; Al-Waeli, A.H.; Sopian, K. Evaluation of Omani experience in using grid-connected photovoltaic stations. *In Sustainable Energy Development and Innovation: Selected Papers from the World Renewable Energy Congress (WREC) 2020. Cham: Springer International Publishing.* Springer, Cham, **2022**, 53-59. https://doi.org/10.1007/978-3-030-76221-6_8
14. Celik, A.N. Present status of photovoltaic energy in Turkey and life cycle techno-economic analysis of a grid-connected photovoltaic-house. *Renewable and Sustainable Energy Reviews*, **2006**, *10*(4), 370-387. https://doi.org/10.1016/j.rser.2004.09.007
15. Al-Badi, A.H.; Albadi, M.H.; Al-Lawati, A.M.; Malik, A.S. Economic perspective of PV electricity in Oman. *Energy*, **2011**, 36(1): 226-232. https://doi.org/10.1016/j.energy.2010.10.047
16. Zidane, T.E.K.; Aziz, A.S.; Zahraoui, Y.; Kotb, H.; Aboras, K.M.; Jember, Y.B. Grid-connected Solar PV power plants optimization: A review. IEEE Access, **2023**.
17. Abdullah, G.; Nishimura, H. Techno-economic performance analysis of a 40.1 kWp grid-connected photovoltaic (GCPV) system after eight years of energy generation: A case study for Tochigi, Japan. *Sustainability*, **2021**, *13*(14), 7680.
18. Raturi, A.; Singh, A.; Prasad, R.D. Grid-connected PV systems in the Pacific Island Countries. *Renewable and Sustainable Energy Reviews*, **2016**, *58*, 419-428.
19. Kazem, H.A.; Albadi, M.H.; Al-Waeli, A.H.A.; Al-Busaidi, A.H.; Chaichan, M.T. Techno-economic feasibility analysis of 1 MW photovoltaic grid connected system in Oman. Case Study of Thermal

Engineering, **2017**, *10*, 131-141. https://doi.org/10.1016/j.csite.2017.05.008

20. Al-Badi, A.H.; Al-Toobi, M.; Al-Harthy, S.; Al-Hosni, Z.; Al-Harthy, A. Hybrid systems for decentralized power generation in Oman. *International Journal of Sustainable Energy*, 2012, *31*(6), 411-421. https://doi.org/10.1080/14786451.2011.590898
21. Kazem, H.A.; Chaichan, M.T.; Al-Waeli, A.H.; Sopian, K. Evaluation of aging and performance of grid-connected photovoltaic system northern Oman: Seven years' experimental study. *Solar Energy*, **2020**, *207*, 1247-1258. https://doi.org/10.1016/j.solener.2020.07.061
22. Hassan, Q.; Khadom, A.A.; Algburi, S.; Al-Jiboory, A.K.; Sameen, A.Z.; Alkhafaji, M.A.; Mahmoud, H.A.; Awwad, E.M.; Mahood, H.B.; Kazem, H.A.; Salman, H.M. 2024. Implications of a smart grid-integrated renewable distributed generation capacity expansion strategy: The case of Iraq. *Renewable Energy*, **2024**, *221*, p.119753.
23. Raza, S.A.; Jiang, J. Dynamic phase balancing of three single-phase sections having phase-wise generation and storage in a residential network. *Electric Power Systems Research*, **2024**, *232*, 110349.
24. Glas, A.C.; Cocquyt, M.J.; Ratcliff, C. Implementation of a 3-phase grid-coupled solar electricity and back-up system at Mulanje Mission Hospital, Malawi. Tropical Doctor, p.00494755241241565.
25. Singh, Y.; Singh, B.; Mishra, S. Control strategy for multiple residential solar PV system in distribution network with improved power quality. *IEEE Transactions on Industry Applications*, **2023**, *59*(3), pp.3686-3699.
26. Popescu, M.; Bitoleanu, A.; Suru, C.V.; Linca, M.; Alboteanu, L. Shunt active power filters in three-phase, three-wire systems: A topical review. *Energies*, **2024**, 17(12), 2867.
27. Holman, J.P. (2012) Experimental Methods for Engineers, McGraw-Hill, New York.
28. Khan, M.A.; Islam, N.; Khan, M.A.M.; Irshad, K.; Hanzala, M.; Pasha, A.A.; Mursaleen, M. Experimental and simulation analysis of grid-connected rooftop photovoltaic system for a large-scale facility. *Sustainable Energy Technologies and Assessments*, **2002**, *53*, 102773. https://doi.org/10.1016/j.seta.2022.102773
29. Boulmrharj, S.; Bakhouya, M.; Khaidar, M. Performance evaluation of grid-connected silicon-based PV systems integrated into institutional buildings: An experimental and simulation comparative study. *Sustainable Energy Technologies and Assessments*, **2022**, *53*, 102632. https://doi.org/10.1016/j.seta.2022.102632
30. Owolabi, A.B.; Yakub, A.O.; Li, H.X.; Suh, D. Performance evaluation of two grid-connected solar photovoltaic systems under temperate climatic conditions in South Korea. *Energy Reports*, **2022**, *8*, 12227-12236. https://doi.org/10.1016/j.egyr.2022.09.053
31. Razmjoo, A.; Ghazanfari, A.; Østergaard, P.A.; Abedi, S. Design and analysis of grid-connected solar photovoltaic systems for sustainable development of remote areas. *Energies*, **2023**, *16*(7), 3181. https://doi.org/10.3390/en16073181
32. Akpahou, R.; Odoi-Yorke, F.; Osei, L.K. Techno-economic analysis of a utility-scale grid-tied solar photovoltaic system in Benin republic. *Cleaner Engineering and Technology*, **2023**, *13*, 100633. https://doi.org/10.1016/j.clet.2023.100633
33. Bhavani, M.; Reddy, K.V.; Mahesh, K.; Saravanan, S. Impact of variation of solar irradiance and temperature on the inverter output for grid connected photo voltaic (PV) system at different climate conditions. *Materials Today: Proceedings*, **2023**, *80*, 2101-2108. https://doi.org/10.1016/j.matpr.2021.06.120
34. Boruah, D.; Chandel, S.S. Techno-economic feasibility analysis of a commercial grid-connected photovoltaic plant with battery energy storage-achieving a net zero energy system. *Journal of Energy Storage*, **2024**, *77*, 109984. https://doi.org/10.1016/j.est.2023.109984
35. Pishkar, I.; Beigi, S.M. A comprehensive evaluation of renewable energy systems with a backup to provide a part of electrical needs of a hospital: A case study in grid-connected mode. *Iranica Journal of Energy & Environment*, **2024**, *15*(1), 1-9. https://doi.org/10.5829/ijee.2024.15.01.01
36. Migliari, L.; Petrollese, M.; Cau, G.; Cocco, D. Techno-economic assessment and grid impact of thermally-integrated pumped thermal energy storage (TI-PTES) systems coupled with photovoltaic plants for small-scale applications. *Journal of Energy Storage*, **2024** *77*, 109898. https://doi.org/10.1016/j.est.2023.109898