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# Design and Analysis of On-Grid 150 kW Bifacial Solar Photovoltaic System

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**A B S T R A C T**

The use of renewable energy, especially solar photovoltaic power, is essential for energy efficiency and reduces emissions that harm the environment and human health. In this study, a 150 kW on-grid photovoltaic system was designed and analysed by PV-sys software. The work's location near the river keeps the site cooler. The modules use a bifacial design, which offers high efficiency and a low annual degradation rate of about 1%. The optimum tilt angle, spacing between modules, and module height above the ground are 30°, 6m, and 1.5m, respectively. The rooftop and ceiling areas of the garage are sufficient for installing the system. The annual incident irradiance, output power, and PR are 2033.9 kWh/m$^2$, 268.169 MWh, and 85.89%, respectively. The total CO2 emission is 5697.1 t. The cost of the system is 150,000,000 $. At the local tariff of $0.0066-$0.023/kWh, the payback period is 6.6 years. The realized profits exceed 200% of the cost price in just twenty years. Installing the current system, providing heat insulation for the building's rooftop and garage ceiling. Also, free energy without gas emission, and new jobs. Compared to a hybrid system of the same capacity.

## 1. Introduction

To mitigate the negative impacts of fossil fuels and provide a sustainable energy source, global investment in renewable energy is rapidly growing [1]. In Iraq, where the electricity supply is down to 50%, the remainder is supplied by private generators for several reasons, most notably past wars and high population growth [2]. Environmental pollution from the use of these generators, which are found on every street, and from the impact of centralized government power plants, has caused significant

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environmental damage. One solution to reduce these impacts is to focus on renewable energy sources, including solar power. Many researchers have concentrated on studying solar cells and semiconductors [3]. Solar photovoltaic (PV) is one of the most important renewable energy sources, and the combined share of PV and wind energy is expected to rise to 25% of global energy production by 2028 [4]

There has also been increased interest in studying semiconductors used in solar cell applications, detectors, and others [5-7] A theoretical study was conducted to determine the optimal configuration of a 1 MW grid-connected solar photovoltaic system in Kerbala using the PVsyst program across three environments [8]. A theoretical study was conducted to install multi-capacity systems in educational institutions and various locations [9-11]. A Solar Photovoltaic (PV) system is considered an appropriate and secure solution for both energy and the environment, according to most researchers[12] . Some challenges and factors affecting the performance of solar systems include initial costs, production fluctuations, radiation reflection (angle of incidence), energy storage, heat, humidity, dust, and more. Researchers are working to improve performance to eliminate and mitigate the negative effects of these challenges [13-17]. The researchers used renewable energy simulation software and tools, especially solar energy such as PVSYST, PVGIS, and HOMER, to analyze the system and obtain outputs[18-20] . A standalone photovoltaic system was designed and its performance analyzed. Using PVsyst software, photovoltaic systems with various module types, including CIS, CdTe, poly, and mono were designed [21] . Conducted a study to determine the optimal design of a grid-connected hybrid PV/battery system, using MATLAB interface within HOMER software. The system achieved the lowest net current cost, generation, and grid purchases of (33,747 USD), (87 kWh/year), (6,188 kWh/year), respectively, and reduced CO2 emissions by (3,913 kg/year[22]. A study was conducted using PVsyst software to evaluate and predict the performance of a 10.81 kW photovoltaic (PV) system. The analysis indicated an annual energy generation of 16,981 kWh, with an annual performance ratio (PR) of approximately 67.2% [23].

Research conducted on bifacial photovoltaic cell technology over the past years, along with future trends and challenges, was reviewed. The study demonstrated the feasibility of installing bifacial cells in various orientations, including vertical and east-west orientations, which help balance energy loads and reduce bottlenecks. Bifacial solar cells were found to deliver higher current and power densities than single-phase cells. Under optimal conditions, bifacial modules can deliver up to 30% more power than conventional modules, especially on cloudy days with lower light intensity[24]. Conducted a significant benchmark study examining the site feasibility and optimal design of a 100 MWp solar power plant in Amman. The study demonstrated that bifacial systems outperformed single-phase systems, achieving a 5.5% increase in energy yield. The optimized plant design (comprising over 174,000 units) met up to 40% of the industrial city's annual energy needs, achieving an outstanding performance ratio (PR) of 84.9% [25]. The study and optimization of bifacial solar modules showed that increasing the albedo to 0.5 and raising the modules by 1 meter above the ground surface can increase power gain by up to 30%. It was also found that ground-mounted bifacial modules oriented vertically from east to west outperformed their perfectly tilted, north-south-oriented counterparts by up to 15% at latitudes below 30°, with a reflectance coefficient of 0.5 [26]. Rahimi et al [27] conducted a research paper focusing on the design of a 200-kW photovoltaic system using PVsyst software. Their results indicate that a 26° tilt angle and a 4-meter row spacing, which reduces the footprint by 43% compared to a 7-meter spacing, result in a slight decrease in energy production of only 4.4%, with a performance ratio of 0.817. The Removal of Barriers to Production Act and the Renewable Energy Agency (SATBA) authorize a 6.9 cents/kWh feed-in tariff, with a 4-year cost recovery period. Abdul-Hafiz and Abdul-Hamid [28], conducted a study focusing on the design and performance optimization of a grid-connected solar photovoltaic (PV) system. A PV system with a peak capacity of 33.3 kW was simulated using PVsyst software. By evaluating various trends, the system achieved a performance ratio of 84.3%, and financial analysis indicates a payback period of approximately 1.86 years, with projected cumulative savings exceeding 816,000 Jordanian dinars (1150931.28$) over 20 years at the current tariff rate – largely due to high electricity tariffs(0.32$/kWh). Mohammed and Hannun [29] conducted a study. A hybrid off-grid solar photovoltaic/wind turbine system was successfully implemented at four sites in Dhi-Qar Governorate, Iraq. Using the HOMER software, a static load of 40 kW was applied at each site. The average annual peak solar irradiance was 5.60 kW/m². The system consists of 148 kW of photovoltaic panels, 170 kW of wind turbines, a 50-kW inverter, and 530 battery units. Economically, the adjusted energy cost is \$0.3603/kWh, the net present value of the project is \$2,143,028, the operating cost is \$54,899.84, and the initial capital investment is \$1.21 million. This study is particularly important because it presents a theoretical model for reducing electrical loads through rooftop renewable energy generation in commercial environments. This eliminates the need for expensive land in prime commercial areas, thus helping to bridge the knowledge gap regarding the economic and technical feasibility of renewable energy projects by reducing costs.

The present work aims to design and evaluate the performance of a 150 kW off-grid PV system by using PV-sys. Also, calculating the amount of energy produced, the performance ratio, the amount of gas it will save, and the payback period as a balance sheet. Also, compared with a solar stand-alone system, the current system demonstrates its suitability.

## 2. System Description and Design

### 2. 1. Location of the system

The location of the mall site under construction in Baghdad. Baghdad city, the capital of Iraq, is located at 33°17'42.3"N 44°30'35.1"E, with an altitude of 43 m, as shown in Figure 1. The solar energy system can be installed on roofs and other available spaces of Garage rooftops within the project to meet part of the project's operational requirements.

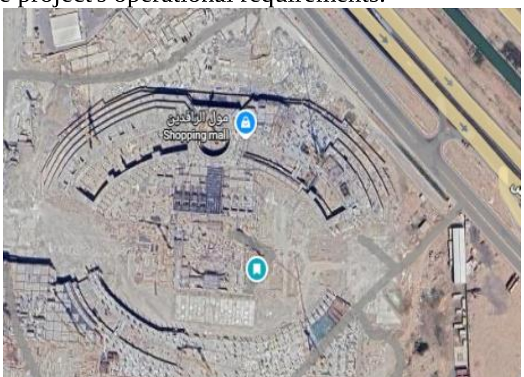



Figure 1. The Mall site, under construction, in Baghdad city. (Google map**)**

The location near the Diyala River, where the area is suitable for installing the system due to its wet climate. The system is intended to supply a portion of the building's total demand.

### 2. 2. System description

### 2. 2. 1 System factors

1-Array yield ($Y_A$): It is the actual amount of electrical energy ($E_a$) produced by the solar panel array and reaching the inverter input, during a specific period of time, to the nominal power($Po$) [30, 31] .

$$Y_A = \frac{E_a}{P_o} \tag{1}$$

2- Reference System Yield ($Y_r$ ):

This is the total horizontal irradiance on the matrix ($H_T$), divided by the total irradiance ($G_o$) under standard test conditions (W/m²)

$$Y_r = \frac{H_T}{G_o} \tag{2}$$

3-. Final yield ($Y_f$ ):

The rate of $E_{AC\text{-}out}$ is the electrical energy produced by the solar plant to $P_{max,\ STC}$ is the total installed power of the modules [32].

$$Y_f = \frac{H_{ACount}}{P_{\max\ STD}} \tag{3}$$

4-System efficiency ($\eta_{PV}$):

It is the ratio of power output to the solar power incident on the panels [33].

$$\eta_{PV} = 100 * \frac{E_{AC}}{E_{DC}} \% \tag{4}$$

The system has a peak capacity of 150 kW and consists of 250 half-cut bifacial solar panels and six 25 kW Growatt On-Grid inverters. Half-cut solar panels are a modern technology that increases panel efficiency, reduces losses by approximately 75%, and reduces current flowing through the cells by 50%. This, in turn, reduces current-resistance losses to a quarter, according to the following relationship [34]:

$$I_{loss} = I^2 R \tag{5}$$

5- Performance Ratio (PR) is the ratio between the yield factor of the PV system and the reference yield (system yield).

$$PR = \frac{Y_f}{Y_R} \tag{6}$$

6-Collection Loss (Lc): is the loss in the PV arrays, and is calculated as follows [34]:

$$L_C = Y_r - Y_a \tag{7}$$

Bi-faced solar panel technology replaces the rear polymer layer with a glass layer, allowing reflected radiation to reach the solar cells on the back of the panel. This technology produces significantly more power than single-faced panels of the exact specifications. A bifacial module characterized by its bifacial coefficient, which is the ratio of the nominal efficiency of the back side to the nominal efficiency of the front side. It's worth noting that nominal efficiency is simply the nominal power (under standard test conditions) divided by the area of the photovoltaic module (m²). The output performance of the back side is similar to that of the front side; that is, they follow the same single-sided diode model. The PV-sys 7.4.5 software provides the size and types of inverters and solar panels to meet the highest annual requirements. The components of the 150kW grid-tied photovoltaic solar power system are listed in Table 1.

Table 1. PV array components

| Parameters | Value |
|---|---|
| No. of Cells | 2(parall)×78(series) |
| Weight | 35.1 (kg) |
| Dimensions | 2256x1133x30(m3) |
| ISc | 14.03(A) |
| VOC | 54.05(V) |
| Imp | 13.1 (A) |
| Vmp | 45.53 (V) |
| Bifaciality factor | 0.75 |
| Vmpp(60oC) | 39.4 (V) |
| PMAX | 600 (W) |
| Temperature coefficient VOC | -155(mV /oC) |
| Temperature coefficient ISc | 7 (mA / oC) |
| Temperature coefficient Pmax | -0.34 %/oC |
| Module efficiency | 23.25% |
| Technology | Mono |
| Cell erea | 182*91(mm) |
| Module area | 2.795(m2) |
| Vmmp(-10oC) | 59.3(V) |

Table 2. The technical specifications of Longi solar LR5-78HBD-600WBifacial, PAN solar modules

| Parameters | Description |
|---|---|
| No. of modules | 252 |
| No. of modules in strings | 14 |
| No. of strings | 18 |
| P.Nominal (STC) | 150 kWp |
| Modules Area | 704 m2 |
| No. of Inverters | 25 kWac) |
| Nominal PV power | 650-1350kWp |

(Half-Cut Bifacial Monocrystalline**)**

The specification for the mono (600wp) module model LR5-72 HIBD is listed in Table 2.

In this study, the system's full output was achieved using a 6 (25) kW AC inverter. To ensure compatibility with the Iraqi electricity grid, the inverter's output was set to 1001V (50Hz). The inverter specifications are listed in Table 4.

Table.3. 25 kW AC inverters Specifications

| Parameters | Description |
|---|---|
| Efficiency | 98% |
| Manufacturer | Canadian |
| Power thresheld | 125V |
| Max Vmpp (STC) | 1000 V |
| Min Vmpp (STC) | 200V |
| Isc (STC) | 26.4A |
| Array nominal power | 1000Wp |

**2. 3. The proposed system**

Figure 2 illustrates the schematic design of the current proposed photovoltaic solar system.

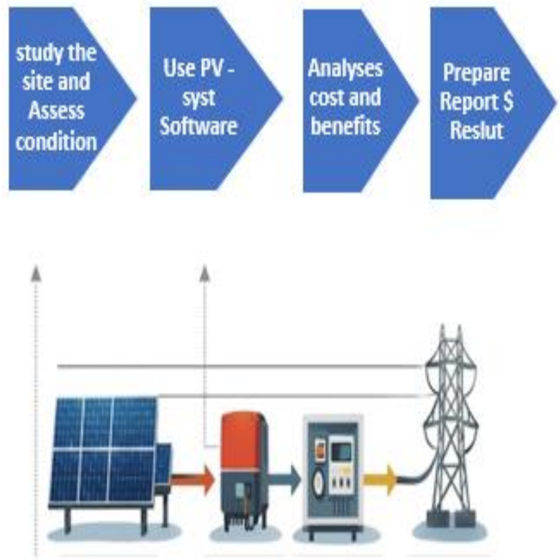



Figure 2. Design of the current proposed system

Figure 2 is divided into two main parts:

First: The work methodology flowchart (top arrows). This flowchart consists of: Site study and condition assessment, use of the PV-sys simulator software, inputting data from the site study into the PV-sys software, accurately calculating the expected annual energy production along with loss ratios and other factors, cost-benefit analysis, and drafting a comprehensive engineering and financial report presenting the final results and technical recommendations.

Second: The system components diagram (bottom drawing). This includes, the photovoltaic array (PV array), the inverter, the distribution panel, and bidirectional meters for monitoring the amount of energy consumed locally or exported to the grid, and the public electricity grid.

**3. Result and Discussion**

Figure 3.a illustrates the effect of temperature on photovoltaic cells (essentially p-n diodes), where the voltage drops from 59.3 V at -10 °C to 39.4 V at 60 °C. This decrease is attributed to an increase in the reverse saturation phenomenon within the cell, which intensifies with rising temperature. Figure 3 A, showing the relation between the efficiency and temperature. The best efficiency ratio at low temperature degrees.

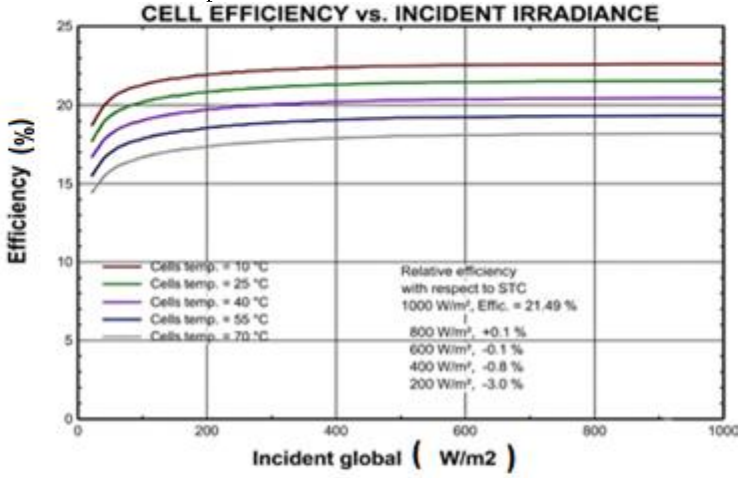



Figure 3a. The effect of temperature (°C) on the efficiency (%)

Figure 3b shows the relationship between irradiation and power, as a function of V-I, obtained from the PVsyst program. The best efficiency ratio at low temperature degrees.

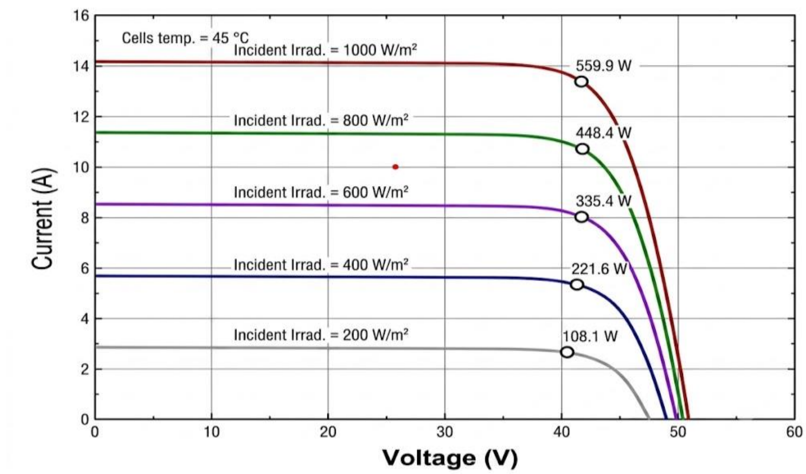


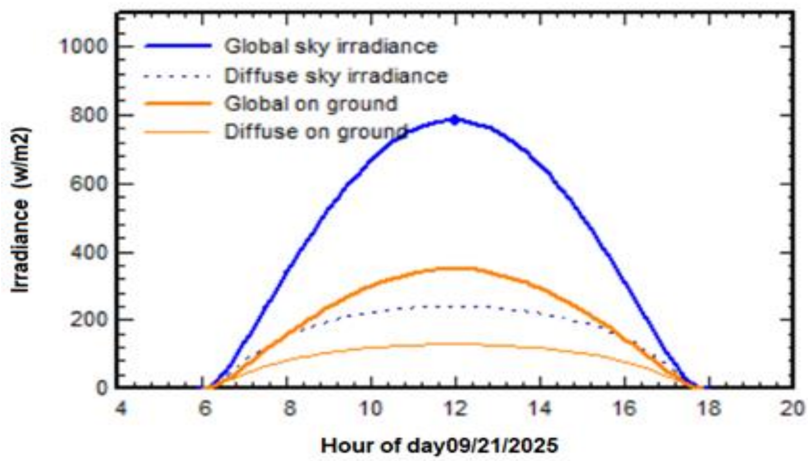

Figure 3b. The effect of solar irradiation on the I-V value

After testing performance using the PV-syst program with many tilt angles (10-60°) for Winter, Summer, Spring, and Autumn. The transposition Factor is the ratio of the solar radiation incident on an inclined surface (or any surface oriented at a given angle) to the total horizontal solar irradiance (GHI). The optimum tilt angle, Transposon Factor, and the Global on module plan for Seasons for bifacial modules are listed in Table 4.

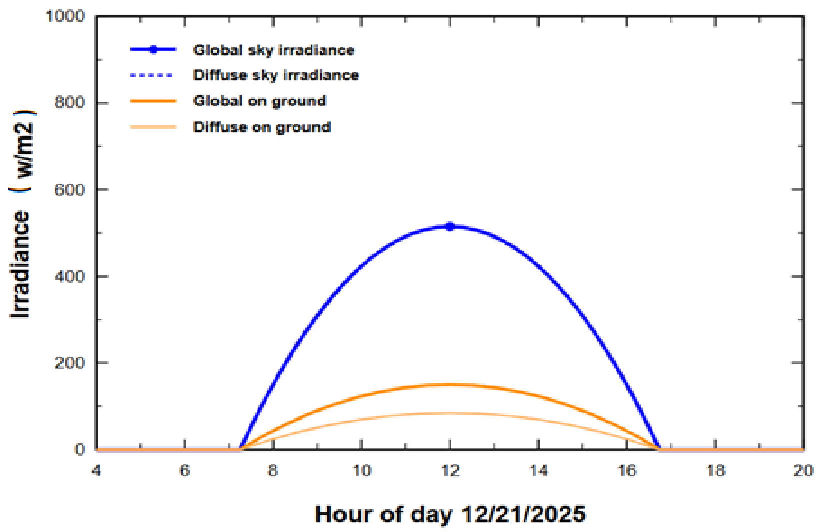
Table 4. The optimum tilt angle of bifacial

| | Tilt angle degree | Transposon Factor | Global on module plan |
|---|---|---|---|
| Summer | 15 | 1.02 | 1196 kWh/m2 |
| Winter | 45 | 1.21 | 787`kWh/m2 |
| Yearly | 30 | 1.12 | 2040 kWh/m2 |

Table 4 highlights the importance of adjusting the tilt angle of solar panels to optimize solar radiation capture throughout the year. A low tilt angle is chosen in summer when the sun is high, and a steep tilt angle in winter when the sun is low. For stationary panels, a medium tilt angle is optimal year-round and often achieves the best total annual irradiance if seasonal tilt adjustment is not possible. The transfer factor is the ratio of solar radiation incident on the inclined surface (where the panels are located) to solar radiation incident on a horizontal surface. A value greater than 1 means that the inclined surface receives more solar radiation than the horizontal surface. Global on-board irradiance is the total amount of solar radiation (direct, diffuse, and reflected) that actually falls on the inclined panels. The bifocal coefficient in this work is 0.75.




a

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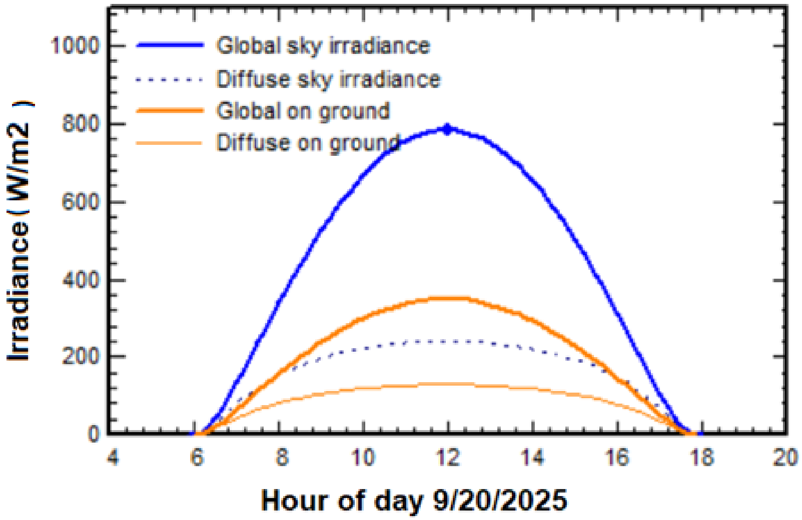
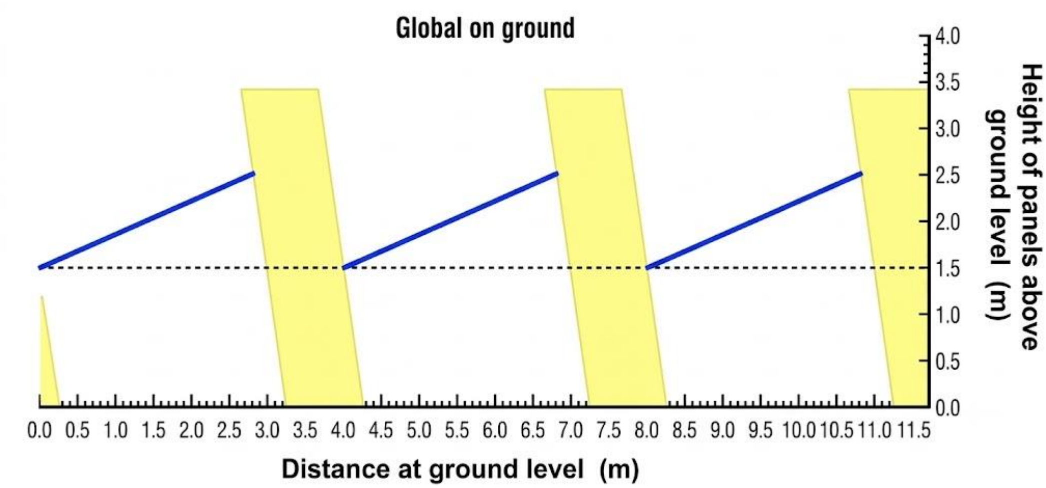



c

Figure 4. Global and diffuse sky irradiance(w/m$^2$) for, a. Summer, and b-Winter seasons, and c. for Autumn seasons

Figures 4A and 4B illustrate incident and diffuse radiation at 30° in space and on Earth for summer, winter, and year-round. It is at its highest in summer, lowest in winter, and moderate in spring and autumn. The annual amount of irradiance is 2033.9 kWh/m2.

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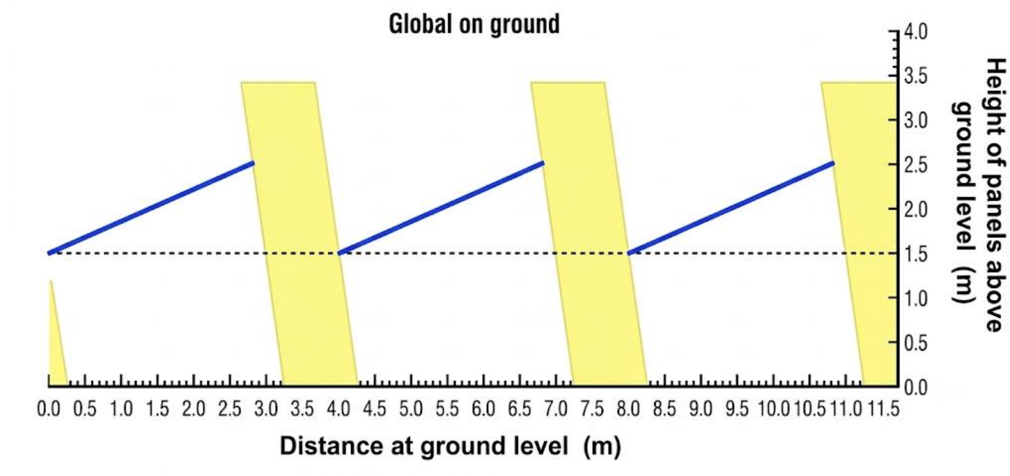


b

Figure 5. a-The effect of the distance between solar units and between solar units and b- the Earth on the value of solar radiation

The effect of the distance between modules on the amount of irradiation reflected from the rear face of the modules. are shown in Fig. 5a. The best performance over a vast distance, due to an increase in the amount of solar irradiance reflected to the rear face of the modules. The effect of the distance between modules on the amount of irradiation reflected on the rear and the front face of the modules.

The best performance occurs at a height distance above the ground, due to an increase in the amount of solar irradiance reflected to the rear face of the modules. The beam was received and reflected to the rear of the unit; the other units are shown in Figure 6. The shape of the reflected beam depends on the Ground's color, nature, and absorption coefficient of the ground surface between the modules.

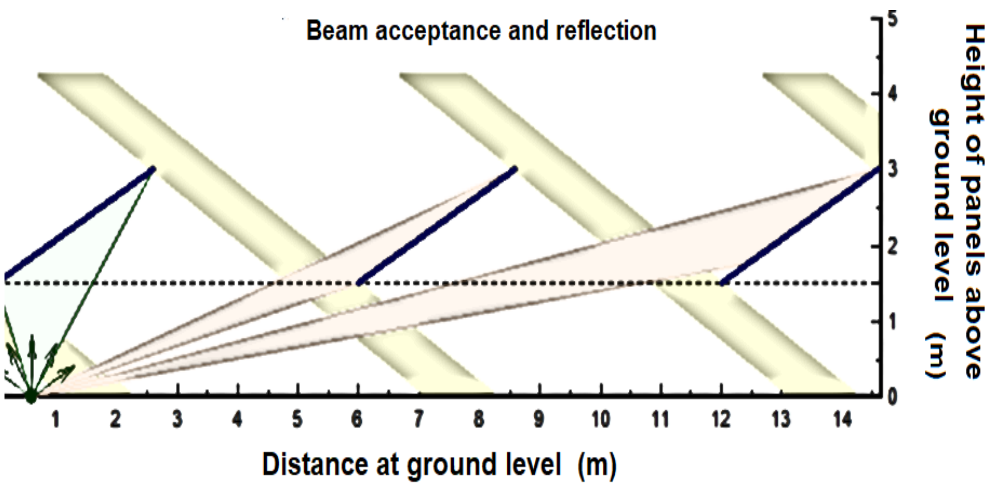


Figure 6. Beam acceptance and reflected

This area illustrates how light reflected from the front rows can reach the back of the panel, thus increasing panel performance. The light green area (small triangle on the far left) represents diffuse light (albedo, light reflected from the ground) captured by the back of the first panel. The small green arrows pointing upwards and outwards from the green dot at the bottom indicate the sources of diffuse or albedo light that the back of the panel can receive.

In the current project, assess environmental parameters, such as temperature and wind, over 1 year. The environmental parameters are shown in Figure 7.

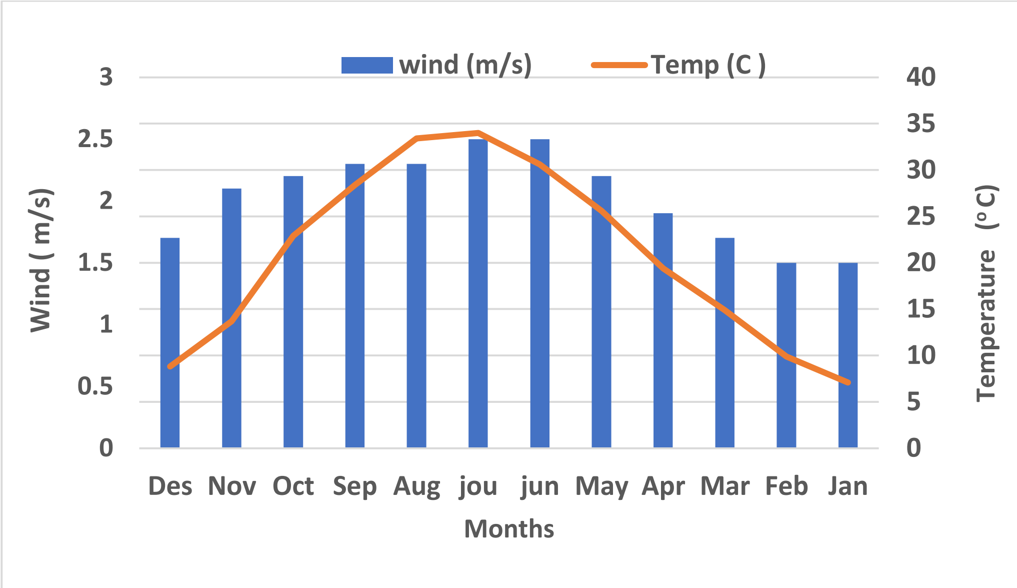


Figure 7. The amount of wind and temperature at the site

Wind speed is a positive factor that reduces panel heat and also removes some of the dirt from the panel. Heat is a challenge associated with increased radiation and leads to increased heat losses. The module's performance can be improved using cooling technologies, tracking, cleaning, and other methods. The annual global solar irradiation incident on the modules and the E-grid produced is 1996.4 kWh/m2 and 268169 kWh, respectively, for a total module area of 704 m2. The amount of solar irradiation and the E-grid produced are shown in Fig. 8.

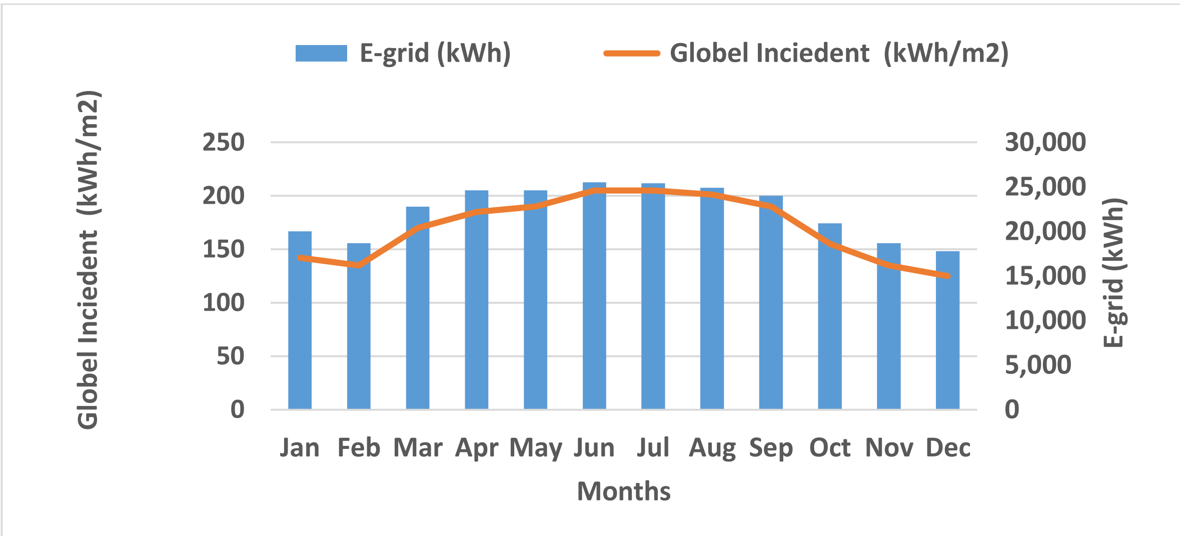


Figure. 8. Solar Irradiation incident on the system, ambient temperature and E-Grid

During the summer months (June, July, and August), incident solar radiation increases, leading to a greater energy supply. However, as ambient temperatures rise, energy production falls below average solar radiation levels during cooler seasons.

The average performance ratio (PR%) of a solar system is 85.9%. This performance ratio is highest during the cold winter months (January, February, November, and December) and lowest during the rest of the summer months, as high temperatures reduce energy production, as illustrated in Figure 9.

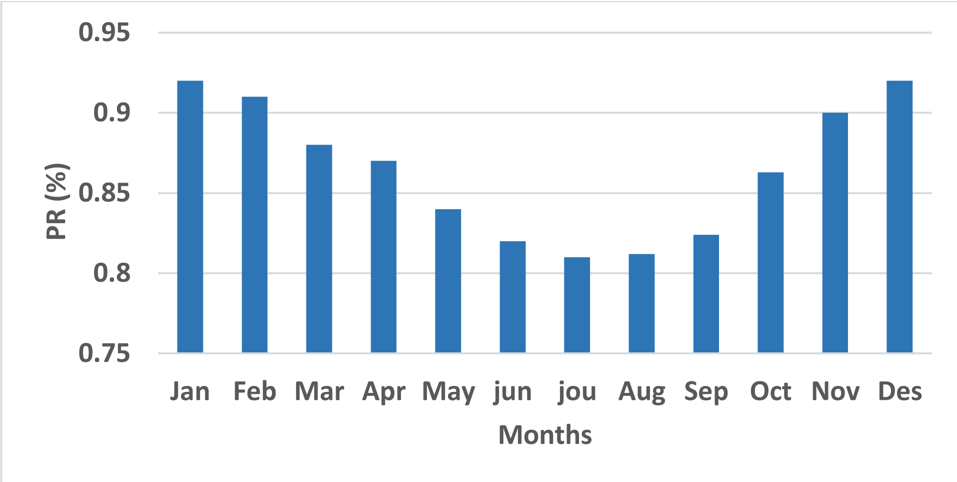


Figure 9. Monthly PR of the system

Daily energy production in kilowatt-hours (kWh) throughout the year, as shown in Figure 10, ranges from 220 to 900 kWh, indicating fluctuations in electricity production. It also shows the impact of factors such as winter humidity and cloud cover, increased solar radiation, rising temperatures, and increased dust levels, which can lead to humidity dropping to zero. Energy production peaks during the summer months (June, July, and August), reaching approximately 900 kWh per day. It then declines significantly (December, January, and February), sometimes falling below 220 kWh per day. Carbon dioxide emissions are a major contributor to global warming and environmental pollution. The savings resulting from reducing these emissions are estimated at approximately 5,697.1 tons.

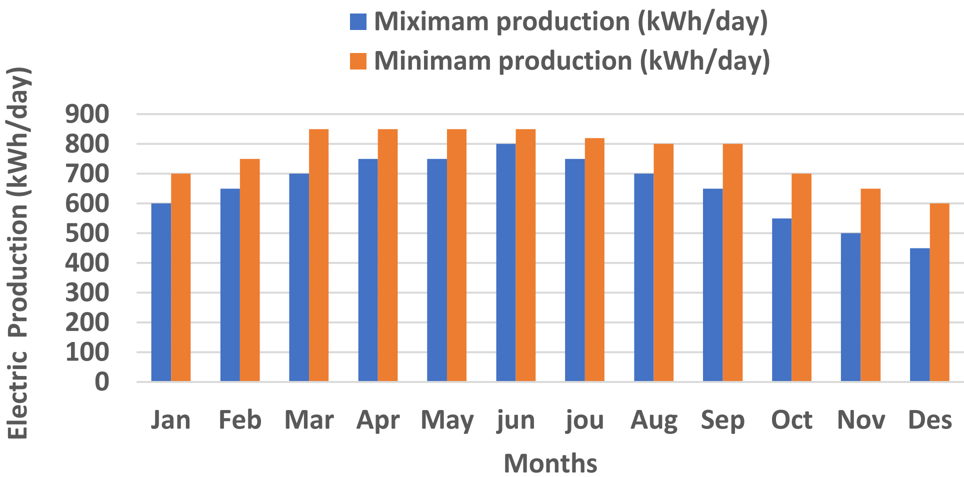


Figure 10. Daily System energy output

The cost of a solar power system in the local market is approximately US$150,000. The average price per kilowatt-hour (kWh) under the commercial electricity tariff is approximately 120 Iraqi dinars (IQD), equivalent to 0.0857 $ at an exchange rate of 1400 IQD per 100 $. The cost of energy produced by a current solar power system, under the commercial tariff class, over one year is 22,631 $. The payback period is 6.6 years, assuming maintenance and management costs are excluded. Assuming a system lifespan of approximately 20 years, the net profit (over 16 years) is approximately 316,834 $.

The current grid connection system consists of the national electricity grid, a diesel generator, and a photovoltaic solar power system. The generator covers power outages from the national grid, while the photovoltaic solar power system feeds power back into the national grid, thus reducing electricity bills. Figure 11 illustrates the electrical performance of the PV system.

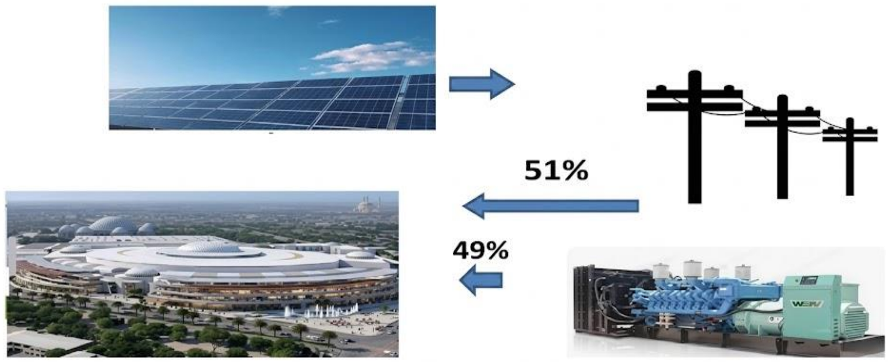


Figure 11. Components of the proposed on-grid power system with electrical power supply ratios [35]

The large size of the building and its significant electricity needs, which require a photovoltaic solar power system to cover the deficit or meet total energy demand, pose a challenge due to the limited space available in the existing building. However, a photovoltaic solar system to cover a portion of the demand is a suitable solution, as demonstrated in the current project.

**3. 1. Hybrid system**

The hybrid grid power system components and their electrical power supply ratios are shown in Figure 12.

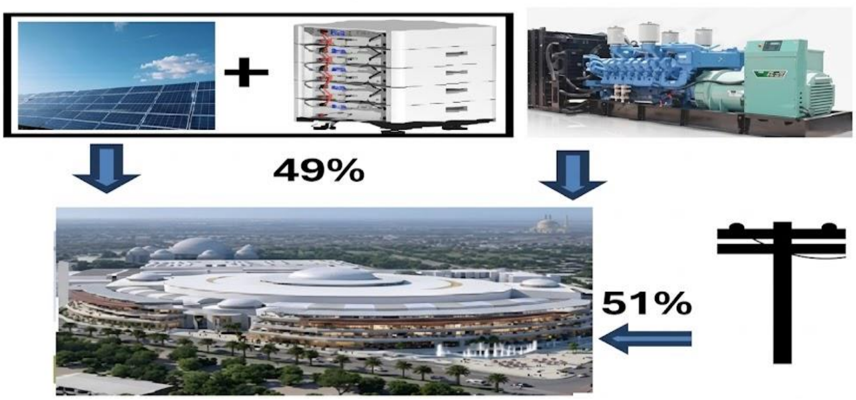


Figure 12. The hybrid -grid power system components

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The components of a hybrid system differ from those of a grid-tied system only in that it includes batteries and shares the same components. Using software for photovoltaic solar power systems, a standalone system was designed and found to require 25 batteries with a capacity of 5 kW and a 48 V voltage. The cost of the batteries accounts for more than half the system's total cost. Comparing the two systems, we find:

1- The off-grid-tied system reduces the energy produced by the diesel generator during power outages.

2- In contrast, the off-grid photovoltaic solar system reduces the value of energy supplied by the national grid during power outages.

3- The energy production in the hybrid system is almost equal to the energy production in the grid-tied system. Therefore, the grid-tied system is more financially advantageous than the hybrid system because batteries are more expensive. However, the two systems are technically identical and reduce pollution. Using on-grid and hybrid solar systems leads to sustainable energy, which is a very important aspect of human life.

Table 5 aims to verify and compare the results with the relevant published results, as follows.

Table 5. comparing current results with previous results

| | Capacity kW | PR% | Payback period | Tariff $/kWh |
|---|---|---|---|---|
| Current work | 150 | 86.89 | 6.6 year | 0.0066-0.023 |
| [26] | 100000 | 84 | | 0.4-0.8 |
| [28] | 200 | 81 | 4 years | 0.06 |
| [29] | 33.3 | 84 | 1.86 year | 0.32 |
| [30] | 170 | 74 | 5-10 year | 0.0066-0.023 |

Analysis of Table 4 indicates the following:

1. The coefficient of performance (COP) is the most important indicator for evaluating the quality of system design and its suitability to the surrounding conditions. In the current system (86.89%), it clearly outperforms the other studies. This percentage indicates that the geographical location is suitable for installing a solar system and that there is a significant reduction in losses, whether thermal or due to the quality of modern components.

Study [30] reported the lowest COP (74%), which often indicates problems with orientation, shading, or operating in a very high-temperature environment without adequate cooling.

2. Tariff and Payback Period Analysis: Here, we examine the purely economic aspect, and there is a clear inverse relationship between the energy purchase price and the capital payback period: Study [29]. It is the "fastest" in cost recovery (1.86 years) despite its small capacity (33.3 kW). This is due to the very high tariff ($0.32/kWh). Current System ($0.0066- $0.023/kWh): The tariff is extremely low. However, the payback period (6.6 years) is excellent considering the price.

Technical Advantage: The current system (150 kW) is technically superior in terms of incident radiation utilization (highest PR).

Financial Advantage: Reference [29] is the most attractive to investors due to its very short payback period, despite the system's small size.

For the current system, a payback period of 6.6 years is considered "ideal" for commercial projects, especially with a very low tariff, thus ensuring the project's long-term sustainability (20-25 years).

## 4. Conclusion

Environmental pollution and resource depletion are increasing in the energy sector, negatively impacting communities. This work, based on economic, environmental, and technical feasibility studies, clearly demonstrates the superiority of bifacial solar panels used in the system. Furthermore, optimal performance was achieved by selecting the ideal angle, panel spacing, and ground height using PV-syst software. The annual solar irradiance reached 1996.4 kWh/m², resulting in an energy output of 268,169 kWh and a payback period of 6.6 years. The savings from reduced $CO_2$ emissions amounted to 5697.1 tons. The realized profits exceed 200% of the cost price in just twenty years. This study covers several research contributions, starting with the design of a grid-connected photovoltaic system to meet the electricity needs of a specific building. The study also included calculating the overall economic feasibility and demonstrating the advantages of grid connection compared to off-grid connection

The use of solar systems in commercial applications is an economically, environmentally, and socially sound process that promotes energy sustainability. Compared to a hybrid system of the same capacity, the grid-tied system is less expensive due to the battery cost, while both have the same technical performance and pollution reduction.

The current research relied on computer simulation, and the focus was on solar panel efficiency without delving into a deep economic analysis of costs.

Possible future applications of the current study include:

1- Integrating an electrical and thermal energy storage system and wind turbines with the proposed system.
2- Studying the impact of long-term environmental factors such as corrosion or dust on system efficiency.

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| ***Nomenclature*** | | ***Abbreviations*** | |
|---|---|---|---|
| $I_m$ | Maximum power output point current (Amp) | $Y_A$ | Array yield |
| $I_{sc}$ | Short-circuit current (Amp) | $E_a$ | Actual amount of electrical energy |
| *Tamb* | Ambient temperature (°C or K) | Po | Nominal power |
| *Tcell* | PV cell temperature (°C or K) | $Y_r$ | Reference System Yield |
| *Tsun* | Sun temperature (°C o K) | $H_T$ | total horizontal irradiance on the matrix |
| *PR* | Performance Ratio | $G_o$ | total irradiance output under STC. |
| Vm | Maximum power output voltage (V) | $Y_f$ | Final yield. |
| Voc | Open-circuit voltage (V) | EAC-out | Electrical energy produced by solar plant |
| Lc | Collection Loss. | Pmax, | Total installed power of the modules. |
| ***Greek Symbol*** | | $E_{AC}$ | power output of the modules |
| $\eta$ | Energy efficiency (%) | $E_{DC}$ | solar power incident |
| | | *STC* | Standard test condition |

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