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Seasonal Analysis and Design of a Solar Power System to Meet Electricity Needs in Kirkuk Using PVsyst

This research aims to evaluate the operational efficiency of a 9 kW photovoltaic solar energy system in Kirkuk, Iraq, using version 7.4 of PVsyst Geographical location and local climate data were integrated to facilitate an accurate simulation of the system. This data helped determining the optimal tilt angle and the orientation of the solar panels. The results indicated that the optimal tilt angle is 32° with a southern orientation, which in turn increases the annual reception of solar radiation. The annual specific yield reached 1,764 kWh/kWp·yr, with a performance ratio (PR) of 0.84. The system was designed as ground-mounted, taking into consideration soiling and shading losses to ensure accuracy of results. However, performance decreases noticeably during the summer months due to high temperatures. This study demonstrates the feasibility of investing in solar energy in the city of Kirkuk and highlights the importance of analyzing environmental and technical variables to enhance the performance of solar energy systems in future installations.

Keyword: Photovoltaic devices; Solar energy; Optimal tilt angle, Performance ratio
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1. Introduction

Solar energy is considered one of the most important and rapidly expanding renewable energy sources around the world. This can be attributed to its constant availability and relatively low operating and maintenance costs compared to conventional energy sources. It represents a strategic option to meet electricity demands, because Iraq has high levels of solar irradiance, as climatic data indicate that most regions, including the Kirkuk Governorate, enjoy a high number of annual sunshine hours, making it a suitable environment to harness this natural resource for electricity generation [1,2]. PVsyst is considered one of the reliable tools for the design and analysis of photovoltaic systems that is used to perform the necessary simulations and provide accurate results on the annual and seasonal performance of the solar system [2,3]. PVsyst is an important tool used in the design and analysis of photovoltaic systems [4]. It simulates the performance of solar systems under varying climatic conditions [5]. In addition, it provides a suitable environment for accurately entering climatic data. While allowing users to specify of system characteristics such as panel type, inverter type, tilt angle, the potential losses, and analysis of results on a seasonal or annual basis [5,6]. Furthermore, the software allows users to evaluate performance parameters and system efficiency. PVsyst has been used in previous studies to assess effectiveness of solar systems and has been found to offer high precision in predicting system efficiency. It is considered a reliable planning tool for both small- and large-scale projects. In addition, it contributes to the improvement of production efficiency and the reduction of energy losses. In the context of solar applications among the studies that addressed solar chimney technology, Iraq was shown to have high solar irradiance and elevated temperatures, making it highly suitable for the application of various solar energy technologies. This study aims to design and analyze a solar power system to meet the electricity needs in the Kirkuk Governorate using PVsyst software and to address these gaps by performing a comprehensive seasonal analysis of the performance of the photovoltaic system in Kirkuk using PVsyst, with a focus on evaluating the economic feasibility and operational efficiency of solar batteries within the context of local climatic conditions. This is done by performing a seasonal analysis of the potential performance of the photovoltaic system based on local climatic conditions and selecting the optimal design for solar panels and inverters to meet the region's needs.

2. Literature Review

The study indicated that the efficiency of solar chimney systems increases temperatures. It also recommended the localization of component manufacturing to reduce costs and improve economic feasibility. The study focused on a system different from photovoltaic systems, it highlights the significant potential of solar energy in regions with arid climates [6,7]. The results from both experimental studies and simulations showed that the controlled cooling system effectively reduced the temperature of the units. This led to a significant improvement in energy production and improved the seasonal performance of solar panels in the hot environment of Kirkuk city [8]. Another study addressed the design aspects of the photovoltaic system, indicating that the size of the solar array mainly depends on the amount of available solar irradiance and the quantity energy needed to cover electrical loads and charge batteries. The study highlighted that selecting an appropriate tilt angle and orienting the array to the south in the northern hemisphere are key factors in improving the efficiency of the system. It is generally recommended that the tilt angle be equal to the geographic latitude of the site. In the case studied, a 10° tilt angle was adopted according to the design requirements to achieve optimal system performance [9]. The study showed that the effectiveness of solar panels varies with each season. In summer, solar panels perform excellently, with approximately 8.50 kilowatt-hours of electricity per day can be expected for each kilowatt of installed solar panels [9,10]. An experimental study revealed that the environmental and economic challenges associated with greenhouse gas emissions, along with the rising prices of fossil fuels, have led many countries to implement new energy policies focused on renewable energy sources. Among these sources, photovoltaic solar energy is one of the most significant of these technologies due to its abundance and sustainability [11]. The investigation showed that the advancement of photovoltaic systems depends on access to advanced software tools capable of accurately analyzing the performance of the system and estimating the energy output and its characteristics. This, in turn, facilitates the evaluation of production costs and the evaluation of the economic and technical feasibility of the project [12]. A scientific investigation emphasized the importance of standalone photovoltaic systems, which serve as a viable solution to provide electricity in off-grid areas. This type of system relies on the conversion of solar irradiance into energy, which is then stored using solar batteries, enabling energy usage during periods without sunlight. In this context, PVsyst represents a specialized simulation tool developed by the University of Geneva and is widely used in feasibility assessments, solar power system design, and operational efficiency evaluation [13]. The software enables the identification of geographic locations, the verification of power loads, and the selection of system components from an integrated database, followed by the calculation of optimal system dimensions [13,14]. The investigation confirmed that the accurate design of a photovoltaic system using simulation tools such as PVsyst constitutes a critical preliminary step prior to the implementation of the project, due to its essential role in ensuring optimal performance and efficient resource utilization [15].

Despite numerous studies exploring the implementation of photovoltaic systems in regions with high solar irradiance, such as Iraq, a significant portion of these inquiries focus primarily on general applications without delving into the complexities of seasonal design and scrutinizing the implications of seasonal climatic variations on solar system effectiveness. Furthermore, many studies have not adequately examined the use of PVsyst to assess systems within specific geographic contexts, such as the city of Kirkuk, which has distinctive climatic conditions that can profoundly affect system performance. In contrast, some studies exhibit shortcomings in providing an accurate assessment of the costs associated with solar energy production based on seasonal performance simulations, which could enhance the economic feasibility of solar energy initiatives in regions facing fluctuating climatic conditions. Moreover, there is a lack of research on the integration of solar system design and the evaluation of solar battery performance within an independent framework, specifically tailored to local conditions [15,16].

3. Methodology

The climatic data for Kirkuk were obtained through the integrated database within the PVsyst software, which is based on reliable global data sources, including NASA-SSE, PVGIS, and Meteonorm. This information serves as a fundamental component for accurate simulation and engineering of the photovoltaic system, offering a realistic representation of the climatic variables that directly influence the effectiveness and operational performance of the solar energy system. The data set employed included monthly measurements of global horizontal irradiance (GHI), which is a key determinant of the amount of generated energy, as well as daily temperature readings, considered essential due to their significant impact on the operational efficiency of solar panels, since high temperatures are often associated with reduced efficiency. Wind speed and relative humidity were also included, as they can influence the operational stability of the system, its installation processes, and the functionality of its components in certain scenarios. These data were incorporated into the simulation parameters within PVsyst, facilitating the seasonal performance analysis and enabling the evaluation of energy production under realistic conditions. Furthermore, the software provides the ability to compare expected performance across different months of the year [17], thus allowing the identification of the most productive periods for solar energy generation.

The simulation was based on typical meteorological data for the location of Kirkuk city, Iraq, with geographical coordinates of 35.47° North and 44.39° East. Weather data was obtained from the Meteonorm 8.1 database, which provides a typical meteorological year (TMY) based on annual data. The system was designed with a fixed ground installation (Fixed plane), with an optimal tilt angle of 32° and an orientation of 0°. To ensure simulation accuracy, the ground albedo value was taken into consideration at a rate of 0.20.

This data set includes comprehensive details on global horizontal irradiance, tilted plane irradiance, monthly average temperatures, wind speeds, and various other environmental parameters that influence

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the efficiency of photovoltaic systems. For the designated study area, Kirkuk City, the climatic data were imported through the integrated Meteororm database within PVsyst, as it offers longitudinal data and meets the essential requirements for accurate simulation. These values were utilized in the design and simulation methodologies to ensure the performance of the photovoltaic system under authentic meteorological conditions. The monthly climatic data relevant to the research location (Kirkuk city) were meticulously examined using the Meteonorm database integrated within the PVsyst software. The analysis revealed noticeable fluctuations in both Global Tilted Irradiation (GTI) and the average temperatures across different months of the year. Peak levels of solar irradiation were observed in June and July, with measurements exceedingly approximately 230 kWh/m²/month, whereas the lowest values were recorded in December and January, constrained to around 75 kWh/m²/month. The temperature spectrum ranged from approximately 6°C during the winter months to nearly 40°C in the summer, illustrating the warm continental climate that characterizes Kirkuk. In addition, supplementary data was incorporated, including: monthly relative humidity, wind speed, and duration of the daily sunshine. These parameters served as essential inputs in simulation processes designed to evaluate the effectiveness of the photovoltaic system under specific meteorological conditions that authentically reflect the contextual environment of the study site.

Monocrystalline solar panels with a capacity of 375W were used in the system design. The technical specifications of these panels are shown in table (2).

Table (2) Technical specifications of the PS-M72-375 PV module

Feature	Value
Maximum Power at STC (P_{max})	375 Wp
Open Circuit Voltage (V_{oc})	46.8 V
Short Circuit Current (I_{sc})	10.19 A
Temperature Coefficient of Power (Temp. Coeff. of P_{max})	-0.38 %/°C
Nominal Operating Cell Temperature (NOCT)	44±2 °C
Cell Technology	Monocrystalline PERC

The panel field was connected to a GW8000-DT inverter with a capacity of 8.00 kWac. The system was designed with a DC/AC ratio of 1.125 to ensure maximum productivity under different radiation conditions. Table (3) shows the technical specifications of the inverter.

4. Results and Discussion

The 7.4 version of PVsyst represents an advanced and comprehensive tool for designing and simulating photovoltaic solar power systems. Its application is widespread in assessing the performance of both grid-connected and standalone systems. When simulating a solar power system for the Kirkuk area in Iraq, the software facilitates the integration of precise geographic location data, including solar radiation and local climatic conditions, which is essential to estimate the actual productivity of the system under real environmental and operational conditions. Additionally, it has the capability to evaluate various losses, including shading, temperature fluctuations, and cable losses, thereby providing a detailed insight into the system's performance before actual implementation [18]. The use of PVsyst 7.4 significantly reduces the time and effort required to assess and design the system, concurrently lowering the costs associated with field experiments, making it an ideal tool for engineers and designers working in the solar energy sector [19].

Table (3) Technical specifications of the GW8000-DT inverter

Feature	Value
Nominal AC Power	8.00 kWac
Number of MPPT Inputs	2
MPPT Voltage Range	200 - 850 V
Maximum Efficiency	98.4%
Euro Efficiency	97.4%
Recommended DC/AC Ratio	1.125

Figure (1) illustrates the solar path for the city of Kirkuk, Iraq, annually, showing the elevation of the Sun before the azimuth angle. Lines numbered (1-7) indicate the position of the sun at noon for key days of the year, from the summer solstice on June 22 to the winter solstice on December 22. The solar path and elevation change according to the seasons, helping to determine the best tilt angle for solar panels to achieve maximum energy production.

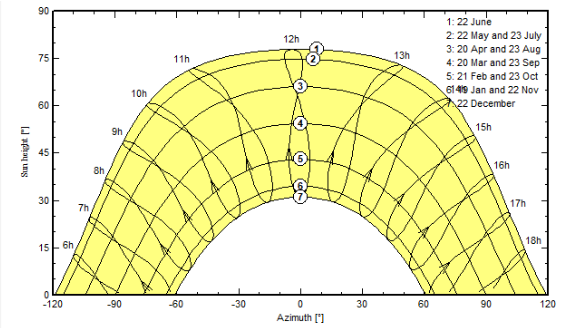

Fig. (1) Graph of the daily and annual sun path (Sun Path Diagram)

Figure (2a) illustrates the effect of the tilt angle of the solar panels on the annual solar transmission coefficient associated with the photovoltaic energy system located in the city of Kirkuk. It should be noted that the maximum value of the solar energy transfer coefficient (1.15) is achieved at a tilt angle of approximately 32 degrees, as shown by the purple point on the curve. At this specific angle, the losses compared to the optimal position are non-existent (0.0%),

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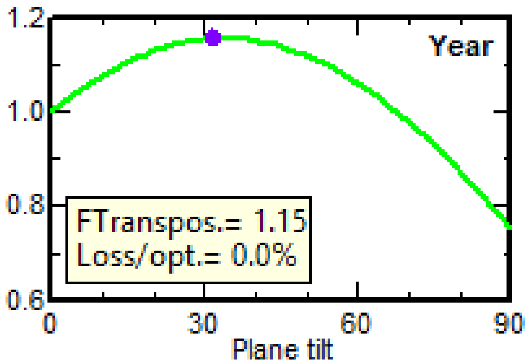
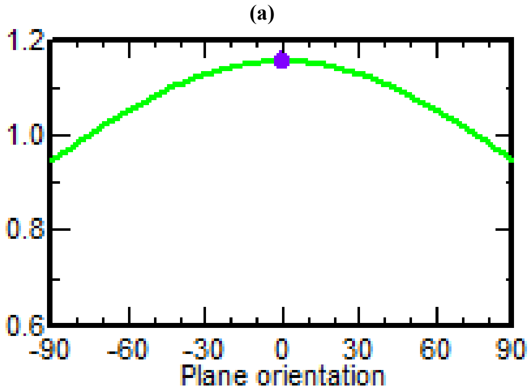
indicating that this angle is optimally configured to maximize the reception of annual solar radiation on the surface of the panels.

Figure (2b) The point of peak (purple) at zero indicates that orienting the panels directly south (Azimuth = 0°) is optimal in Kirkuk to achieve the highest solar energy productivity, as the orientation angle moves away from the south (either east or west), the solar conversion efficiency gradually decreases. This decline is evident in the graph, where performance drops from approximately 1.2 to below 0.8 at a deviation of ±90°, a slight deviation (±10° or ±20°) from the south results in a minor decrease in performance, but larger deviations significantly impact system productivity.



(a)



(b)

Fig. (2) Annual solar transmission coefficient curve and optimal tilt angle for solar energy system

PVsyst allows for the simulation of photovoltaic energy systems, including a variety of graphs and detailed reports, enabling the user to accurately analyze the system's performance. In addition, the software provides the ability to export results to other programs for further analysis, and data and reports can be saved within the program for future use.

Figure (3) illustrates the direct relationship between daily solar radiation and the energy contributed to the grid. It is known that the amount of generated energy increases in conjunction with rising levels of solar radiation. The data points show an almost linear distribution, indicating the effectiveness and reliability of the system in converting solar radiation into electrical energy that can be fed into the grid. At the minimum radiation values (less than 2 kWh/m²/day), energy production remains low; conversely, at higher values (6-7 kWh/m²/day), the energy delivered peaks (approximately 50-55 kWh/day). The figure also indicates that there are no anomalies or sudden drops in performance or significant unaccounted losses throughout the simulation period.

Table (4) PVsyst Simulation Parameters for a Grid-Connected System in Kirkuk

Parameter	Value
System type	Grid-Connected
PV modules	PS-M72-375
Nominal power	9.00 kWp
MPP voltage	39.6 V
MPP current	9.5 A
Inverter	GW8000-DT
Inv. Unit power	8.0 kW
Number of MPPT inputs	2

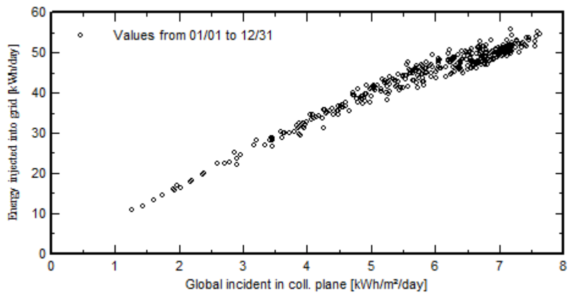


Fig. (3) Relationship between Daily Solar Irradiance and delivered Energy into the Grid for the PV System

Figure (4) indicates that the annual performance factor is 0.84, a commendable figure that reflects the high efficiency of the system. The monthly performance factor ranges from approximately 0.80 to 0.90, showing a marginal decline during the summer months (June, July, and August), primarily attributed to the high temperatures that negatively affect the efficiency of the solar panels. In contrast, the performance factor is noted to be superior during the winter, spring, and fall months, where temperatures are moderate, leading to more favorable operating conditions.

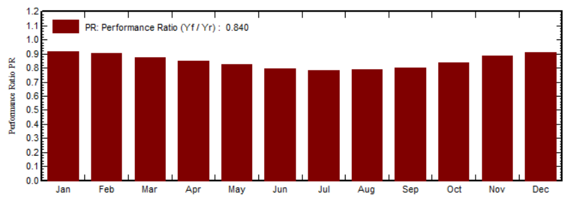


Fig. (4) Monthly Performance Ratio (PR) of the PV System

Figure (5) shows that most of the energy delivered into the grid accumulates in the range between 5 and 7 kW, with the frequency peaking at around 6 kW. This indicates that the system operates most of the time near its nominal capacity, achieving high productivity levels during peak solar hours. It is also noted that there is a lower distribution at lower capacities (below 3 kW), reflecting early morning or evening periods or days with low solar radiation.

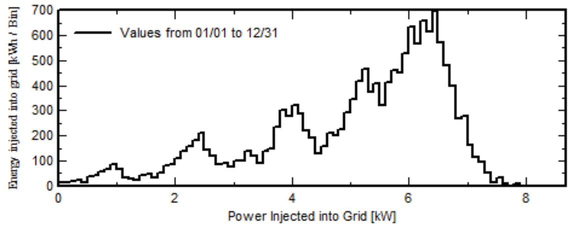


Fig. (5) Distribution of Power delivered into the Grid by the PV System throughout the Year

It is clear from the above that this distribution is a positive indicator of the system's efficiency and stability, as the designed system is capable of supply large amounts of energy into the grid for most days of the year, with limited periods of low production. Figure (6) illustrates the pathway starting from the total horizontal solar radiation of 1827 kWh/m² annually. The main losses within the system are categorized into two dominant groups: the first is thermal losses, which reach 10.16% and are attributed to high temperatures, and the second is losses due to panel mismatch, identified at 2.00%. Additionally, there are diminishing losses associated with panel quality (0.75%), transmission losses (1.13%), and inverter deficiencies totaling 2.02%. In the end, the effective energy integrated into the grid is recorded at 15878 kWh annually.

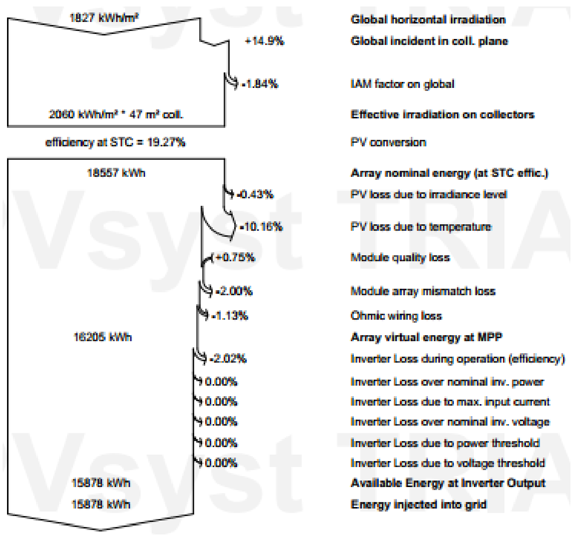


Fig. (6) Energy Loss Diagram for the PV System

5. Conclusion

The simulation of the solar energy system in Kirkuk using the PVsyst program showed that the southern orientation combined with an angle of 32° represents the most suitable configuration for maximizing energy production. The unified annual productivity reached 1,764 kWh/kWp·yr. The system demonstrated a good annual performance factor of approximately 0.84, although there was a slight decrease during the summer months due to high temperatures. The energy loss analysis indicated that initial losses were primarily due to thermal effects and panel mismatch. However, the system operates efficiently close to its nominal capacity during peak demand periods. The results confirm the feasibility of harnessing solar energy in Kirkuk, also considering environmental and technical criteria to enhance performance in future investigations.

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Table (1) Climatic and solar irradiation data in Kirkuk City

Month	Global Horizontal Irradiation (kWh/m²/month)	Horizontal Diffuse Irradiation (kWh/m²/month)	Temperature (°C)	Wind Velocity (m/s)	Linked Turbidity [-]	Relative Humidity (%)
January	86.1	30.8	6.9	1.89	4.199	71.5
February	95.6	44.5	9.4	2.30	4.785	65.6
March	139.8	65.8	14.3	2.59	5.789	50.4
April	173.3	83.2	19.3	2.70	7.846	43.9
May	193.7	94.0	25.5	2.69	7.960	33.8
June	229.5	83.6	30.7	3.19	6.881	26.2
July	223.7	86.9	34.2	3.40	7.514	26.0
August	203.9	80.4	33.2	2.70	6.306	30.7
September	175.1	53.0	28.0	2.30	5.490	35.8
October	130.7	49.4	22.2	1.79	5.684	44.7
November	94.7	34.4	13.3	1.60	4.386	56.1
December	80.8	29.9	8.2	1.69	4.220	68.9
Year	**Total: 1826.8**	**Total: 736.0**	**Average: 20.4**	**Average: 2.4**	**Average: 5.922**	**Average: 46.1**