

An Analytical Study for the Installation of a Hybrid Photovoltaic System for a Power Substation at the University of Mosul campus

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ABSTRACT

Given the widespread interest in the use of renewable and sustainable energy sources to address the issue of electricity supply, as well as their limitations, high costs and high prices of fossil fuels, in addition to the availability of suitable solar radiation, this paper presented a case study for the design and feasibility assessment of a 382 kWh grid-connected solar power system to supply electricity to four buildings on the University of Mosul campus, where these buildings were combined and considered as one area for the design. The simulation was performed by PVSyst software using a 700W Huasun DS700 solar panel and a 33kW Deye inverter. The simulation results showed an annual energy production of 670,459 kWh/year with a system efficiency of 85.06%. The cost of energy produced is \$0.02/kWh, reducing emissions by 14,473.8 tons. Addressing the issues of fossil fuel depletion and greenhouse gas emissions, this strategy highlights the financial and environmental benefits of switching to renewable energy. This study can be applied to many government buildings and institutions that are transitioning to renewable energy, especially solar energy, in areas with suitable solar resources in terms of radiation, temperature and area to achieve clean and sustainable energy.

Keywords:

Solar energy, PVSyst software, grid-connected system, Economic Evaluation, carbon emissions, smart meter.

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1. INTRODUCTION

Because of the University of Mosul's shortage of electricity supply and its continuous interruptions, in addition to the high electricity bills, the continuous increase in environmental pollution, and the noise caused by diesel generators, the university was directed to use renewable energies, especially solar energy, due to Iraq's climate, which is characterised by sufficient solar radiation and moderate temperatures for most months of the year. Traditional energy sources like coal, fossil fuels, and nuclear are about to run out [1]. The US Energy Information Administration projects that between 2010 and 2040, the world's energy consumption will rise by 56%, mostly due to Asia's explosive economic expansion [2]. The best solution to the growing demand for energy is to utilise renewable energy sources [3]. With conventional fossil fuel supplies running out and emissions of greenhouse gases steadily rising, the

fast-shifting global energy environment has made the development of non-conventional power resources an effective means of safeguarding our planet. The adoption of renewable energy sources is constantly gaining steam to reduce carbon emissions and meet rising electricity consumption [4]. Since renewable energy can lower greenhouse gas emissions globally, it is a vital resource for sustainability. There is a 20-to-25-year long-term benefit to using solar power plants. To provide electrical energy to isolated locations or towns that are far from power supplies, solar panels can also be employed as a power generator [5]. The benefits of photovoltaic solar power generation include being fuel-free, clean and renewable, not geographically constrained, scalable, easy to maintain, and operating safely and reliably. However, its drawbacks include low energy density, significant investment, and high sensitivity to weather [6]. Mosul's city is

characterised by the availability of good sunlight throughout most days of the year, making it an ideal environment for applying solar energy technology.

Many previous studies have shown the importance of renewable energies, especially solar energy, and the important programs used in modelling and simulating this energy, such as the PVSYS, MATLAB, HOMER program and other important programs, because of their ability to provide accurate and practical results. Waqas Ali, Haroon Farooq, Ata Ur Rehman, Qasim Awais, Mohsin Jamil, and Ali Noman (2018) covered the design of a standalone solar photovoltaic (PV) system. The study includes the technical factors, site selection, stand-alone application method, and guidelines needed to construct a solar PV system [7]. To reduce environmental degradation caused by greenhouse gases emitted from burning fossil fuels like coal, etc., solar energy should be the major means of replacing power from coal, according to the United Nations Global Summit, which was held on September 23 in New York City. India views reaching this goal as crucial to producing at least 100 GW of solar energy in 2020 [8]. Kumar et al examined a 100 KWp grid-connected system that was deployed in India. They demonstrated how the PVsyst simulated system performed concerning the project's actual outcomes following construction [9]. The research conducted by Ahmed Haji and Mehdi F. Bonneya aims to evaluate the power quality in a 1.62 MW grid-connected photovoltaic solar power system using MATLAB modelling and the PVSyst program. The research analysed harmonic distortions and power quality at the grid connection point. The results showed that the system operates efficiently with a performance ratio (PR) of 0.857, with suggestions for improvements to reduce distortions using linear filters [10]. Beren Sardar Abdullah and Siddeeq Y. Ameen carried out this study, "Off-Grid Photovoltaic System for a Villa at AVRO City in Duhok", to address the problem of energy scarcity in Duhok, Iraq. The authors suggest replacing the noisy and costly diesel generators in villas with an off-grid photovoltaic system. The study looks into the system's size and design for a particular Avro City residence. It considers variables like target autonomous days, available solar radiation, and daily electricity usage. To assess the system and identify the ideal quantity and arrangement of solar panels, batteries, and inverters, the authors used PVsyst software [11].

This paper aims to design, model, and analyze a grid-connected solar power system for a substation within the campus of the University of Mosul, which supplies four buildings with

electrical power at a capacity of 382 KW. The available roof areas of the four buildings connected to the substation were collected and considered as a single area of approximately 1700 m², and the design was carried out as shown in "Table 1". The solar panels occupied an area of 1696 m². The system was designed and simulated using the PVsyst software, in addition to using a smart energy meter capable of selling excess photovoltaic energy to the grid when solar radiation is sufficient, as well as importing electrical energy from the grid in case of a solar energy deficit. The project aims to achieve financial returns that reduce electricity bills, ensure sustainability, and reduce carbon emissions resulting from the use of fossil fuels, which have become a major source of pollution.

Table 1: Area of the proposed system

The building	Area(m ²)
Mosul University Stadium	400
Nursery	500
Deanship of the Faculty of Physical Education and Sports Sciences	400
Faculty of Archaeology	400
Total Area	1700

2. Overview of the proposed photovoltaic system

The proposed hybrid electrical power system within the University of Mosul campus consists of two main parts. The first part includes the substation power connected to the university power plant, which converts the incoming voltage from 11 kV to 0.4 kV at a frequency of 50 Hz to supply the loads and the four connected buildings. The second part is the solar panel array, which consists of 546 HUASUN DS700 solar panels distributed on the rooftops of the four buildings mentioned in Table 1. The areas of these rooftops have been combined into a single area of 1700 m², and this area has been input into the program for simulation with a total nominal capacity of 382 KWP. Ten Deye 33KW inverters convert the energy from DC to AC, supplying and powering the loads and buildings. A smart meter is used, a bidirectional meter that imports electricity from the grid when the photovoltaic system's production is insufficient due to clouds, maintenance, or at night. It also supplies excess energy to the grid when production exceeds demand. At the end of the month, the difference between the energy sold to the grid and the energy purchased from the grid is calculated. If the bill amount is negative, it indicates that the energy sold to the grid is more than the energy purchased from the grid, and the difference is paid to the consumer at a specified selling price between the electric grid suppliers and the consumer. The power supply unit, control unit, measurement unit, timing unit, communication

unit, signaling unit, encoding unit, and timing unit are all components of smart meters. The smart meter is capable of detecting real-time energy consumption rates by capturing voltage, phase angle, and frequency [12]. The term "in-home display", which describes the gadget or screen that links to the smart meter and gives users information about their energy expenses and usage, may be present in the smart meter (House of Commons Science and Technology Committee, 2016). The smart meter facilitates easy switching between suppliers, more accurate billing, and avoiding debt accumulation by providing access to precise information in near real-time. It eliminates the need for field visits to complete meter readings, reduces enquiries about estimated bills, improves theft detection, and enables remote disconnection. The smart meter enhances electricity generation and grid management, connects networks, fosters technological innovation, develops new business models, welcomes new providers, and contributes to the achievement of binding climate change goals by reducing low-carbon generation [13]. Figure 1 shows the proposed photovoltaic system.

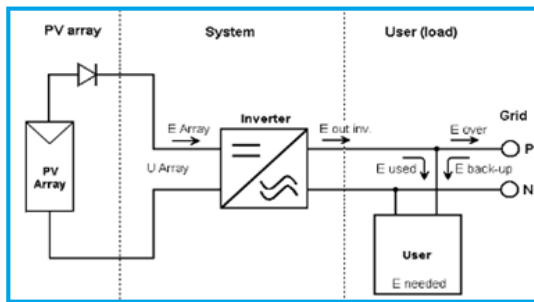


Figure 1: The proposed photovoltaic system[14]

3. Method and tools

To achieve the optimal design for the hybrid photovoltaic system and create an effective, reliable system that closely resembles reality. The presented study used the PVSyst program to model and simulate the proposed system, which is a reliable and efficient program known for its accurate results and is used by researchers and designers [9, 15-17]. The PVSyst program requires several inputs, including the determination of the available area, the maximum load, latitude and longitude coordinates for importing meteorological data, and specifications for the panels and inverters. This way, the outputs, which include tables, charts, and values representing the program's results, are obtained. Figure 2 shows the methodology used by the program in simulating the photovoltaic system, as its results depend on equations stored within, such as LCOE & NPV, and ROI ratio as in "equations (1), (2), (3) and (4)".

$$NPV = \sum_{t=1}^n \frac{R_t}{(1+i)^t} \quad \dots 1$$

$$LCOE = \frac{\sum_{t=1}^n \frac{I_t + M_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}} \quad \dots 2$$

$$ROI = \frac{\text{Net benefit at the end of life time}}{\text{Total investment}} \quad \dots 3$$

$$PR = \frac{YF}{YR} \quad \dots 4$$

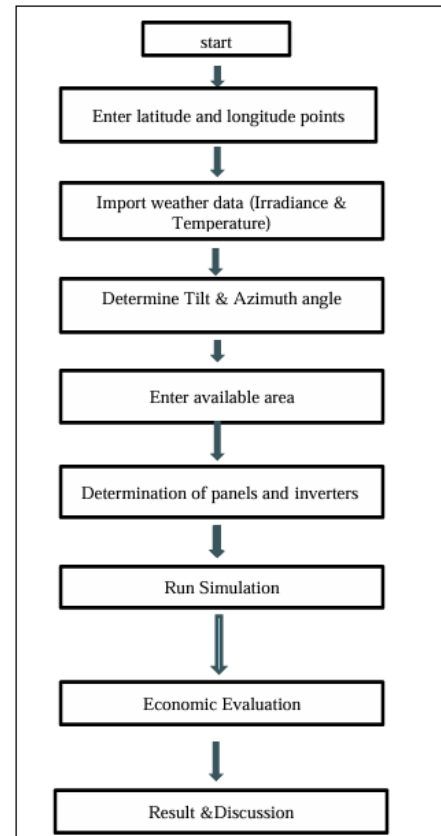


Figure 2: PVSyst software simulation flowchart

The design begins by determining the geographical location of the substation and its associated buildings, which are situated within the campus of the University of Mosul at longitude 43.14° E and latitude 36.39° N, with an elevation of 231m above sea level. When these points are entered into the PVSYST program, the program will import the meteorological data represented by solar radiation, temperature, and wind speed from the program's database (2003–2010 Meteo 7.2) as shown in "Table 2". These values will determine the amount of energy produced, efficiency, losses, and other important values.

Determining the tilt angle of the solar panels at an angle of 33 degrees towards the south, which is the optimal angle that makes the losses zero, as shown in Figure 3. This number was chosen based on the

lowest losses relative to the ideal output power. We note that the transposition factor is 1.16, meaning that the efficiency of the panels in receiving solar

radiation is 16% more based on this angle compared to horizontal radiation.

Table 2: Definition of a Geographical Site & Weather Data.

Geographical site														Mosul /Iraq	
Source Data (Meteoronorm 7.2)															
Longitude 43.14E, Latitude 36.39N															
Month	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.	year		
Hor. Global	2.24	3.13	4.14	5.15	6.70	7.17	6.92	6.38	5.31	3.87	2.82	2.18	4.68	kWh/m ² .day	
Hor. Diffuse	0.95	1.40	2.13	2.32	2.51	2.67	2.81	2.46	1.88	1.59	1.15	1.00	1.91	kWh/m2.day	
Amb. Tep	6.9	8.8	13.5	17.6	24.3	30.8	34.5	33.4	28.2	23.0	14.0	8.9	20.3	°C	
Wind. Velocity	2.9	3.0	2.9	3.0	3.0	3.4	3.0	2.5	2.7	2.4	2.5	2.9	2.8	m/s	

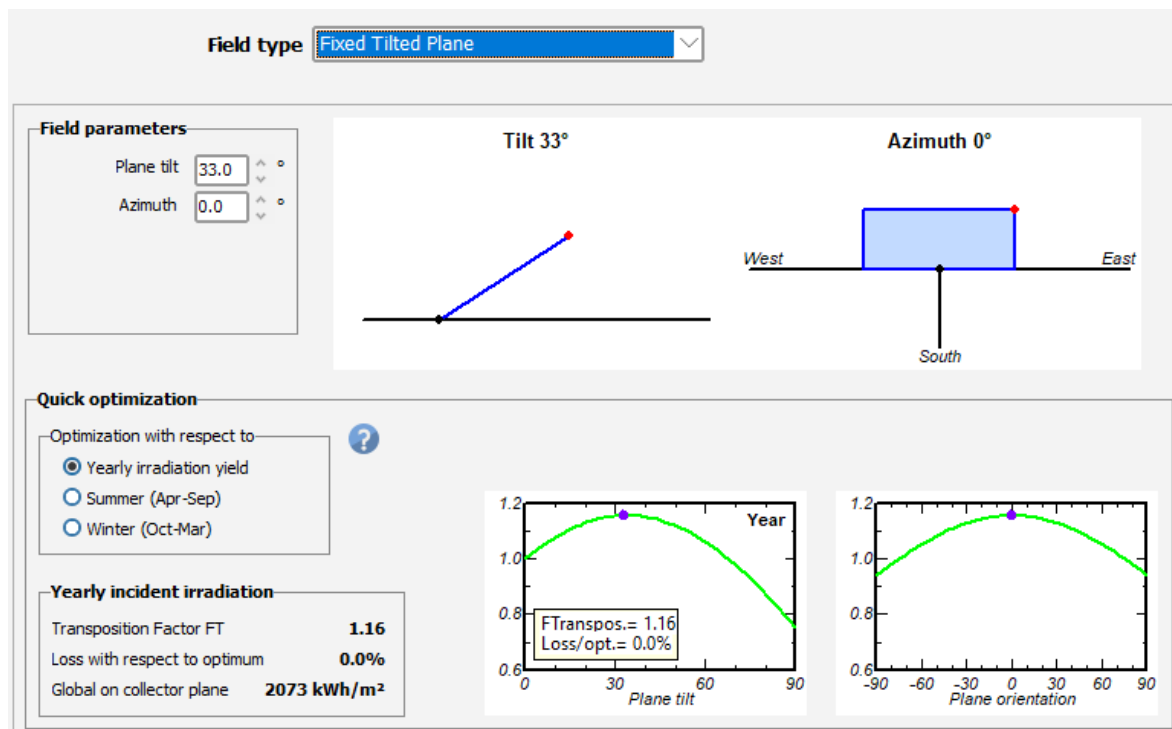


Figure 3: Orientation and Azimuth for solar cell

The available area for design is 1700 m², which is the result of summing the surface areas that can be used for the four buildings mentioned in Table 1 and considering it as a single area for design and entering this value into the PVSyst program. Choosing Huasun DS700 solar panels. The solar panel capacity is 700W, bifacial type, characterized by its ability to absorb solar radiation from both directions, increasing the efficiency of the solar array. The number of solar panels is 546, consisting of 39 strings in parallel, with each string containing 14 solar panels connected in series. Choosing 10 inverters of type Deye with a capacity

of 33 kW per inverter to achieve a total output capacity of 330 kW. Figure 4 shows the area entered in the simulation and the number of panels and inverters. After entering all the previous requirements, we proceed to simulate the proposed photovoltaic system to open the economic evaluation window and input the component costs, which include the costs of solar panels, inverters, structures, installation, accessories, and maintenance and operation costs. The selling price of electricity to the grid and purchasing from it is set at 0.06 USD. "Table 3" shows the component

costs according to the market price in the city of Mosul.

Figure 4: Global system configuration

Table 3: The components' cost [from the local market]

Components	Price(\$/Wp)
PV module	0.25
Chassis and installation	0.07
Inverter	0.07
Accessories and wires	0.02
Maintenance and cleaning	0.01
Inverter Replacement	0.01

4. Results and discussion

The results obtained from the PVsyst program are varied between values, tables, and graphs, through which the performance of the proposed solar system can be determined.” Table 4” shows the electrical characteristics and number of solar panels and inverters, as well as the amount of nominal energy that can be obtained from the solar panel array. We also note that the nominal conversion ratio is 1.16, which is a value resulting

from the ratio of energy output from the solar panels to the energy output from the inverter set, and it is a good indicator of design efficiency and the compatibility of the panels and inverters.

Table 4: PV Module and Inverter Characteristics

PV module		Inverter	
Manufacturer	Huasun Solar	Manufacturer	deye
Model	DS700	Model	SUN-33K-G04
(Original PVsyst database)		(Custom parameters definition)	
Unit Nom. Power	700 Wp	Unit Nom. Power	33.0 kWac
Number of PV modules	546 units	Number of inverters	10 units
Nominal (STC)	382 kWp	Total power	330 kWac
Modules	39 string x 14 In series	Operating voltage	200-1000 V
At operating cond. (50°C)		Pnom ratio (DC:AC)	1.16
Pmpp	357 kWp	Power sharing within this inverter	
U mpp	548 V		
I mpp	652 A		
Total PV power		Total inverter power	
Nominal (STC)	382 kWp	Total power	330 kWac
Total	546 modules	Number of inverters	10 units
Module area	1696 m ²	Pnom ratio	1.16

TABLE 5-a. The main results of the simulation

System Production			
Produced Energy	670455 kWh/year	Specific production	1754 kWh/kWp/year
Used Energy	1997446 kWh/year	Perf. Ratio PR	85.06 %
		Solar Fraction SF	29.64 %
Economic evaluation			
Investment		Yearly cost	LCOE
Global	156,702.00 USD	Annuities	0.00 USD/yr
Specific	0.41 USD/Wp	Run. costs	9,172.80 USD/yr
		Payback period	5.0 years
		Energy cost	0.02 USD/kWh

TABLE 5-b. The main results of the simulation

Month	GlobHor kWh/m ²	DiffHor kWh/m ²	T- Amb °C	E-Array kWh	E_User kWh	E- Grid kWh	EFR_G rid kWh	Solar fraction ratio	P.R ratio
January	78.8	35.34	6.88	43753	180792	1458	139217	0.230	0.905
February	91.0	43.08	8.70	43027	191520	415	149659	0.219	0.895
March	136.0	67.96	13.34	55381	163680	5056	114298	0.302	0.877
April	170.4	81.44	17.83	61114	113040	16922	69886	0.382	0.862
May	191.8	94.77	24.64	60788	171864	3867	116026	0.325	0.842
June	221.3	86.52	31.13	65466	198720	376	134761	0.322	0.823
July	226.0	82.03	35.17	67294	266352	0	200237	0.248	0.811
August	211.8	70.40	34.34	69298	186000	3963	121865	0.345	0.812
September	174.8	48.66	29.14	66550	168480	7501	110570	0.344	0.824
October	127.6	49.34	23.26	57422	139872	10358	93766	0.330	0.854
November	89.8	35.57	14.34	47922	70560	22812	46258	0.344	0.882
December	74.9	28.15	8.96	44155	146568	5686	108861	0.257	0.899
Year	1794.1	723.26	20.71	682170	1997448	78415	1405406	0.296	0.851

“Table 5.a” shows the main results from the simulation of the photovoltaic system using the PVsyst program, which indicates how efficient the design is and how well it meets the required load. It was found that the system produces 670,455 kWh of energy each year (1754 kWh/kWp/year), while it uses 1,997,446 kWh annually, resulting in a performance ratio of 85.06%. This shows how efficient the system is and its capacity factor. We also note that solar energy covers about one-third of the load compared to the electrical grid, with a total investment of USD 156,702.00 spent at the start of the project to set up the solar system and all its components, Total investment amount: USD 156,702.00, which is the amount that was spent at

the beginning of the life of the project on the establishment of the solar system with all its details and components. Operational cost includes maintenance, replacement, and wages, 9,172.80 USD/year. The cost of energy produced is 0.02 USD/kWh. The payback period is 5 years of the project's life of 25 years.

“Table 5.b” shows the annual rate of energy injected into the grid (78415 kWh), the energy withdrawn from it (1405406kWh), the energy supplied to the user (1997448 kWh), and the energy produced by the solar panel array (682170 kWh). It also shows the system's efficiency (performance ratio 0.851) as shown in

Figure 5. the solar system's contribution (solar fraction 0.296), and the monthly values for each.

Figure 6 shows the monthly energy production as well as losses as follows: Yf (red column) is the amount of energy produced and utilized. We express the inverter output as 4.81 kWh/kWp/day, this output is highest during the summer (June to August) due to the increased hours of solar radiation. Lc (purple bar) represents the losses due to solar panel performance (e.g., reflection, shading, etc.) and is about 0.76 kWh/kWp /day, these losses are almost constant throughout the year. Ls (Green column) represents system losses (such as inverters and storage devices), which are about 0.08 kWh/kWp /day, and remain constant throughout the year. We conclude that productivity is high in sunny months with a reduced impact of losses. Factors such as heat and dirt lead to a decrease in productivity, but they are evenly distributed throughout the year.

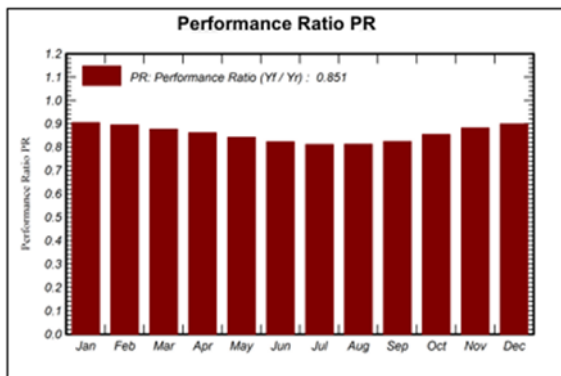


Figure 5: Performance ratio

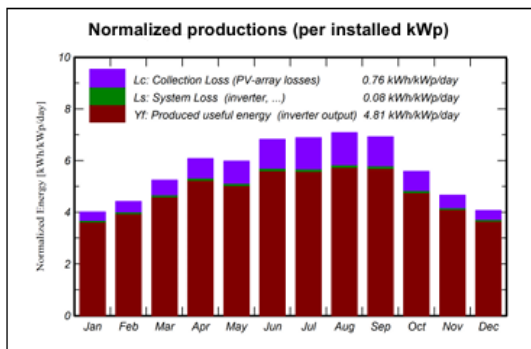


Figure 6. Normalized production

Figure 7 shows the relationship between the temperature of the solar panels and the intensity of the corrected effective solar radiation according to the effects of the angle of incidence and shadow for a full year from 1/1 to 31/12. The horizontal axis represents the corrected effective radiation due to shadows and reflection during the passage of radiation through the layers of the atmosphere, and the vertical axis represents the average

temperature of the solar panels. When the effective solar radiation locations increase, the temperature of the solar panels increases due to their absorption of solar energy, which may reduce their efficiency. The red dot represents the STC (Standard Test Conditions) conditions, i.e., the standard radiation intensity (usually 1000 W/m²) and the reference temperature of 25°C.

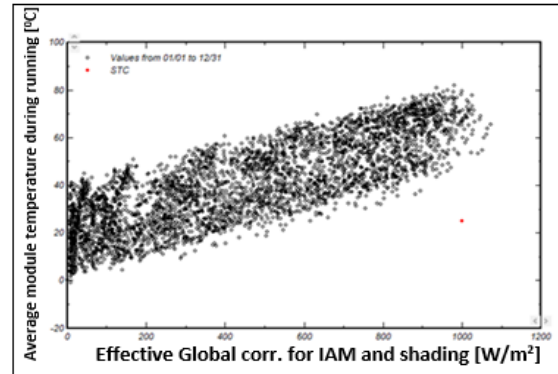


Figure 7: Array temperature vs effective irradiance

Figure 8 shows the performance of the photovoltaic system over a full year. The horizontal axis represents the radiation falling on the solar panels daily and is measured in [kWh/m²/day]. The vertical axis represents the electrical energy produced by the solar system daily, which is injected into the grid and utilized, and its unit is [kWh/day]. These points represent the relationship between the solar radiation falling on the solar panels and the useful energy output over the year. From the figure, we observe that these points are distributed almost linearly, indicating a direct relationship between the solar radiation entering the solar panels and the energy produced by the photovoltaic system. Each point represents a specific day of the year. The other points we see at the bottom of the graph indicate that the radiation was weak due to weather conditions or clouds, which consequently led to low energy production. Through the analysis of this form, it is possible to verify the system's performance and efficiency, identify the days of the year when performance is low, and thus propose appropriate solutions to improve design and operation.

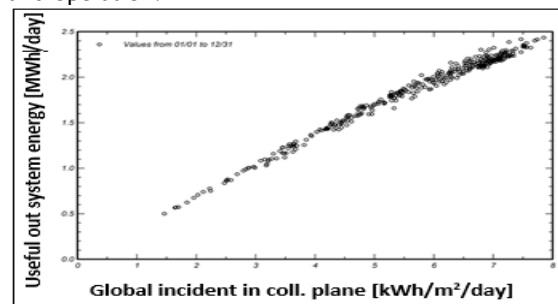


Figure 8: Daily input /output diagram

Over a certain period (in this case, January 1–December 31), Figure 9 displays the frequency of each temperature (number of events) within the range of various temperatures for solar panels. The horizontal axis represents the average temperature of the solar panels during operation in degrees Celsius ($^{\circ}\text{C}$), ranging from 0 to 100 degrees Celsius. The vertical axis represents the number of events for each temperature, i.e., the number of times the solar panels were at a certain temperature during the operating period. The distribution appears as an asymmetric curve. It starts with very few at low temperatures ($<10^{\circ}\text{C}$), indicating that there are few times when the temperature of the panels is low. The number of incidents gradually increases until it peaks at around 40°C , which is the most frequent temperature range during operation. After the peak, the number of incidents begins to gradually decrease with the temperature rise, indicating that periods of high temperatures ($>60^{\circ}\text{C}$) are less frequent. Benefits of this analysis, Thermal design: It helps in designing an efficient cooling system or determining the need for it, especially if high temperatures ($>60^{\circ}\text{C}$) affect the system's efficiency. Efficiency and productivity (high temperatures reduce the efficiency of solar cells, and thus understanding the heat distribution can help improve system performance). Reliability (understanding the heat distribution helps in assessing the lifespan of solar panels, as continuous exposure to high temperatures can cause faster deterioration). We conclude that most operations occur within a relatively ideal temperature range ($\sim 40^{\circ}\text{C}$). This distribution can be useful for understanding the solar system's annual performance and making decisions to improve the efficiency of solar panels and reduce heat-related wear.

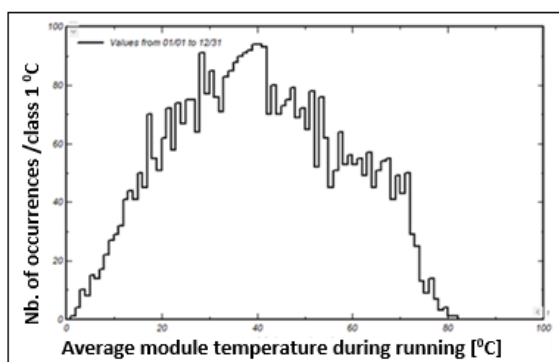


Figure 9: Array Temperature Distribution during running

The system losses are distributed between solar radiation, high temperature, panels, inverters, ohmic losses, and other connections, as shown in Figure 10, which illustrates the following details.

Losses from solar radiation, the total horizontal solar radiation is 1794 kWh/m^2 . Moreover, the tilt and orientation of the panels lead to an increase of $+14.9\%$ in the incident solar radiation on the array. The losses brought on by the angle at which sunlight strikes the panels, which lowers the effective radiation, are represented by the Angle of Incidence Modifier (IAM), which is -2.42% . With a photovoltaic unit efficiency under standard test conditions (STC) of 22.54% , to reach 2012 kWh/m^2 on the solar panel array. As a result, an energy of 769253 kWh is obtained under STC conditions. Photovoltaic array losses: Other losses occur within the photovoltaic array and include Photovoltaic energy loss due to a radiation level of 0.50% , loss of photovoltaic energy due to temperature effects of 6.60% , unit quality loss of $+1.50\%$, loss of mismatch in units and strings 2.05% , losses in the wires of 1.08% . After these losses, the virtual array's energy at the maximum power point (MPP) is 682321 kWh . Inverter losses, during the operation of the inverter, a power loss of 1.71% occurs. Inverter Loss over nominal inverter power is 0.02 . After all the losses, the output power from the inverters is $670,459 \text{ kWh}$, the power injected into the grid is $78,419 \text{ kWh}$, and the power supplied to consumers is $592,040 \text{ kWh}$. After conducting the simulation and entering all the required costs for the components, installation, maintenance, operation, and connection to the grid as shown in 'Table 3', and determining the cost of selling electricity to the grid and purchasing it for $0.06 \text{ \$/kWh}$, the simulation results showed that the total cost of installing the photovoltaic system is $156,702\text{\$}$ with an annual operating cost (OPEX) of $9,172.80 \text{ \$/year}$, and the levelized cost of energy (LCOE) is $0.0219 \text{ \$/kWh}$, which is much lower than the cost of electricity purchased from the grid, reflecting the economic feasibility of the project. "Table 6" shows the costs obtained from the simulation.

The payback period for the initial investment amount is 5 years from the project's 25-year lifespan, as shown in Figure 11, where the red color represents the payback period. We notice that in the early years of the project's life, around 5 years, the cumulative cash flow is negative (in red). The reason for the negative value is the high initial costs. The cumulative cash flow starts to rise at the break-even point, which occurs around the year 2030. Then the cumulative cash flow begins to rise gradually until it reaches significantly positive values at the end of the project's life in 2050, where the net profit is $669,452.77 \text{ USD}$. The return on investment (ROI) is 427.2 .

Table 6: Financial analysis

Total installation cost	156,702 USD
Operating costs (OPEX)	9,172.80 USD/year
Produced energy	670,459 kWh/year
Cost of produced energy (LCOE)	0.0219 USD/kWh
Payback period	5 years
Net present value (NPV)	669,452.77USD

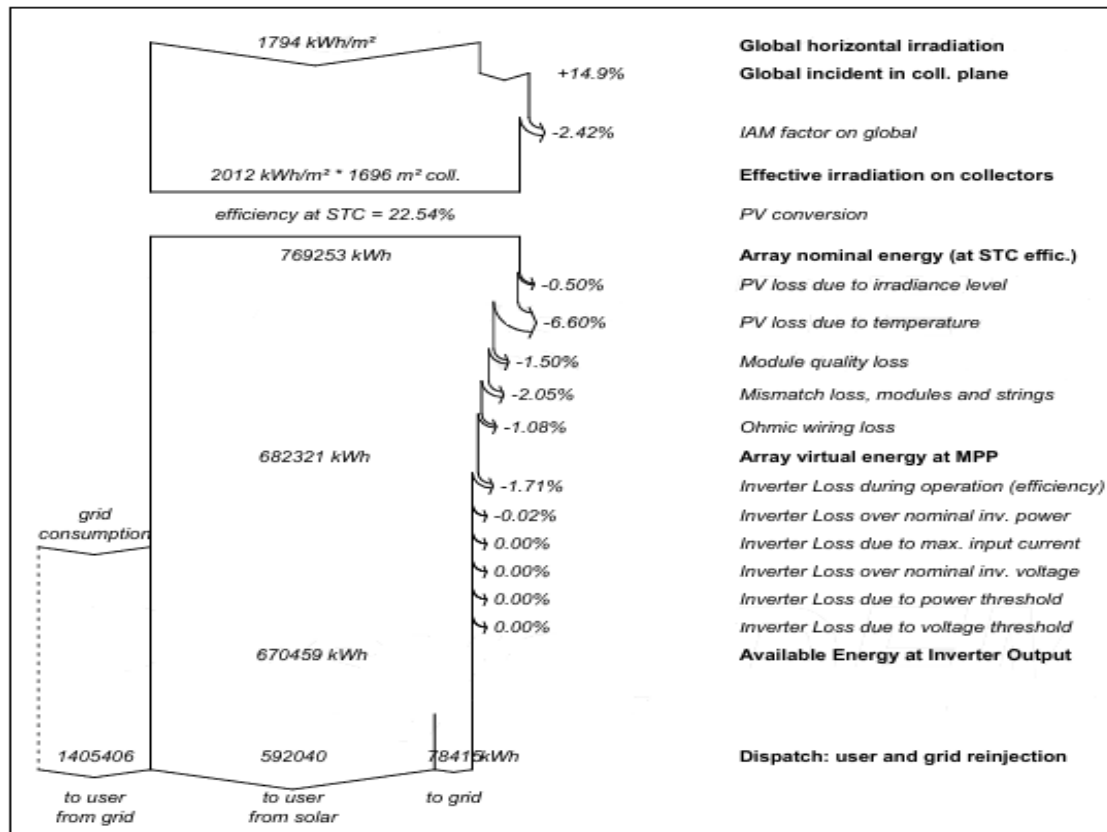


Figure 10. Loss diagram over a whole year

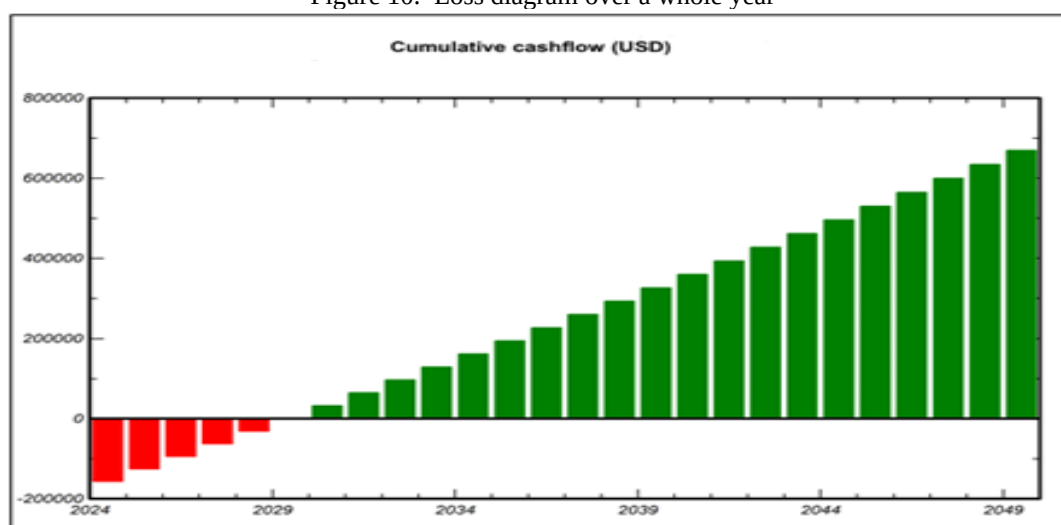
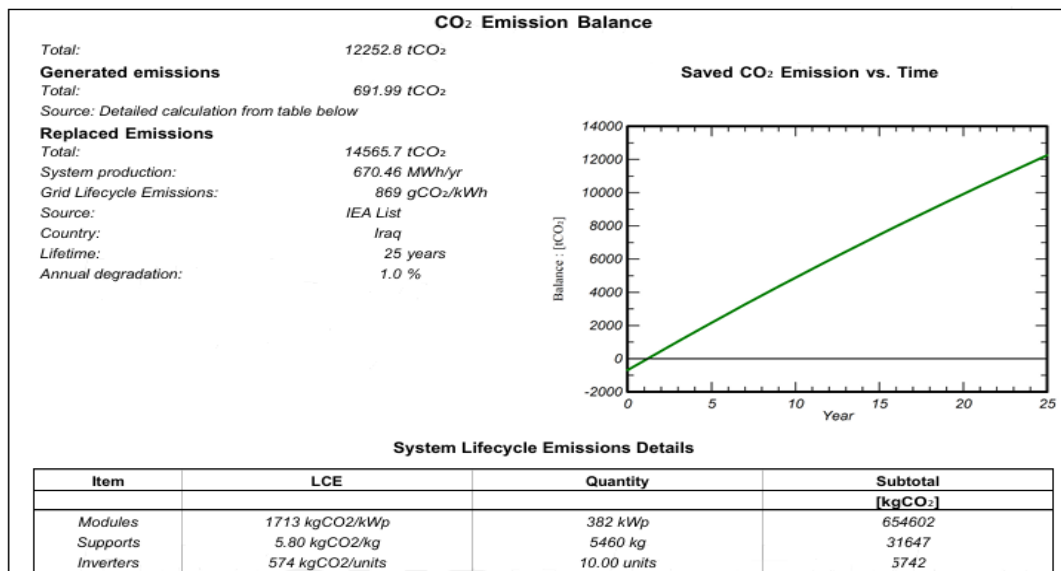


Figure 11. Cumulative cash flow

Figure 12. CO₂ Emission Balance

The shift to renewable energy sources in electricity production has a positive impact on the environment. As we can see in Figure 12, the total CO₂ emissions generated by the solar system were 691.99 tons, while the emissions resulting from fossil fuels to produce the same amount of electricity over the project's lifespan were 14565.99 tons. The graph shows an increase in emissions savings over the system's lifespan (25 years), with the system ultimately saving 12252.8 tons of CO₂. and in the end, the system's lifespan (25 years) with a 1% annual decrease in production demonstrates the system's effectiveness in reducing carbon emissions in the long term compared to relying on electricity from the grid. In short, the system significantly reduces CO₂ emissions compared to relying on the grid in Iraq. We also note that the total emissions resulting from the manufacture of the system are Solar panels produce 654602 kg of CO₂ during manufacturing, and structures and infrastructure produce 31647 kg of CO₂. Electrical inverters produce 5742 kg of CO₂. Total manufacturing emissions: 691.99 tons CO₂.

5. CONCLUSION

The study presented a grid-connected solar power system for a substation power that supplies four buildings with electrical power by outlining the construction phases, including planning and design, which encompass the available space, the required installation capacity, and the system cost. It has been found that installing a grid-connected solar power system with a capacity of 382 kWp is an effective way to

reduce reliance on traditional energy sources, lower energy costs, and minimize environmental impact. It turns out that over 25 years, the system reduces carbon emissions by 12252.8 tons of carbon dioxide with an annual energy production of 670,459 kWh/year. The payback period for the capital invested in building the station was 5 years, a good period compared to the project's lifespan. The system performance ratio, which reflects the system's efficiency, was approximately 85.06%, and the contribution of the solar system to energy supply (solar fraction ratio) was 29.64%. The performance ratios are 63.9%, 78.63%, 79.6%, and 79.9% when comparing the results of this paper with those of a prior paper [6, 11, 18-19]. Payback periods are 10.8 years, 3 years, 3.4 years, and 11 years. Solar fractions are 0.96, 0.46, LCOE 0.09 \$/kWh, 2.82 BDT/kWh (1 USD = 110 BDT), 0.03 \$/kWh, and 0.094 \$/kWh. The PVsyst simulation confirms the system's excellent efficiency and reliability, with significant potential for expansion in similar geographical and climatic conditions. To improve performance and explore applications on a wider scale, future research may focus on further enhancing system efficiency by using methods to reduce high temperatures and employing a solar tracking system to achieve the best possible productivity.

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دراسة تحليلية لترتيب نظام هجين للطاقة الشمسية لمحطة قدرة ثانوية في حرم جامعة الموصل

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الملخص

نظراً للاهتمام الواسع النطاق لاستخدام مصادر الطاقة المتجددة والمستدامة لمعالجة مشكلة إمدادات الطاقة الكهربائية، وكذلك محدوديتها وتكاليفها العالية وارتفاع أسعار الوقود الأحفوري، بالإضافة إلى توفر الإشعاع الشمسي المناسب، قدمت هذه الورقة دراسة حالة لتصميم وتقييم جدوى لنظام طاقة شمسية متصل بالشبكة بقدرة 382 كيلوواط/ساعة لتزويد أربعة مباني داخل حرم جامعة الموصل بالطاقة الكهربائية، حيث تم دمج مساحات هذه المباني واعتبارها مساحة واحدة للتصميم. تمت المحاكاة بواسطة برنامج PVSyst وباستخدام ألواح شمسية نوع Huasun DS700 بقدرة 700 واط وعاكس من نوع Deye بقدرة 33 كيلوواط فقد أظهرت نتائج المحاكاة إنتاج طاقة سنوية تبلغ 670,459 كيلوواط/ساعة/سنة بكفاءة نظام 85.06%. وتبلغ تكلفة الطاقة المنتجة 0.02 دولار/كيلوواط ساعة، مما يقلل من الانبعاثات بمقدار 14,473.8 طن. في معالجة قضايا استنزاف الوقود الأحفوري وانبعاثات غازات الاحتباس الحراري، تسلط هذه الاستراتيجية الضوء على الفوائد المالية والبيئية للتحويل إلى الطاقة المتجددة. يمكن تطبيق هذه الدراسة على العديد من المباني والمؤسسات الحكومية التي تنتقل إلى الطاقة المتجددة، خاصة الطاقة الشمسية، في المناطق التي تتوفر فيها موارد شمسية مناسبة من حيث الإشعاع ودرجة الحرارة والمساحة لتحقيق طاقة نظيفة ومستدامة.

الكلمات الدالة:

طاقة شمسية، برنامج PVSyst، نظام متصل بالشبكة، تقييم اقتصادي، انبعاثات الكربون، عداد ذكي.

ABBREVIATIONS

Alternating Current	AC
Ambient Temperature	T_Amb
Direct Current	DC
Effective energy at the output of the array	EArray
Energy supplied to the user	E_User
Energy from the sun	E_Solar
Energy is injected into grid	E_Grid
Energy from the grid	EFR_Grid
Effective Global, corr. for IAM and shadings	GlobEff
Ground Coverage Ratio	GCR
Global horizontal irradiation	GlobHor
Global incident in coll. plane	GlobInc
Horizontal diffuse irradiation	DiffHor
Hybrid Optimization of Multiple Energy Resources	HOMER
Incident Air Mass	IAM
Internal rate of return	IRR
Kilowatt	KW
Kilowatt Hour	KWH, kWh
Levelized Cost of Energy	LCOE
Lifecycle Emissions	LCE
Collection Loss	LC
System Loss	LS
Maximum power point	MPP
Normal Operating Cell Temperature	NOCT
Net Present Cost	NPC
Net Present Value	NPV
Operations And Maintenance	O&M
Operating costs	OPEX
Photovoltaic	PV
Performance Ratio	PR
Renewable Energy	RE

Renewable Energy System	RES
Return on investment	ROI
Standard Test Condition	STC
Solar Fraction	SF
Net balance (income-expenses) for the year (t)	Rt
A discount rate that could be earned in an alternative investment	i
Electricity production for the year (t)	Et
The lifetime the system	n
Investment and expenditures for the year (t)	It
Operational and maintenance expenditures for the year (t)	Mt
Produced useful energy	Yf
Reference system yields	Yr