Design and Analysis of Photovoltic System for a House in Model Town Lahore using Homer Pro

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***Abstract*— This paper presents a detailed performance evaluation of an 11 kW grid-connected photovoltaic (PV) system installed at a residential site in Lahore, Pakistan. The study focuses on assessing the system's economic, environmental, and operational benefits, offering insights into its viability for reducing energy costs and carbon emissions. The analysis shows that the PV system achieves a penetration level of 89.6%, providing nearly 90% of the site's energy demand from solar power. Annual energy cost savings amount to 65%, with a favorable payback period of 1.97 years and an internal rate of return (IRR) of 50.7%. Additionally, the system reduces CO2 emissions by 42.4%, aligning with global sustainability goals. These results suggest that rooftop solar PV installations in urban residential areas in Pakistan offer significant financial and environmental advantages.**

Keywords*— *Photovoltaic system, grid-tied PV, solar energy, renewable energy

I. Introduction

This Pakistan's geographical location, characterized by abundant sunlight throughout the year, presents a unique opportunity to harness solar energy, transforming it into a sustainable and cost-effective solution for households across the country [1], [2]. With the ever-increasing demand for electricity coupled with the challenges of energy security and affordability, solar energy emerges as a beacon of hope, offering a viable alternative to traditional fossil fuel-based power generation [3], [4]. By embracing solar power, Pakistani households can generate electricity, reducing their reliance on the often-unreliable grid and mitigating the impact of frequent power outages [5].

The adoption of rooftop solar photovoltaic (PV) systems in Pakistan has gained significant traction, particularly following the introduction of a green metering system by utility companies [6]–[8]. This approach allows homeowners to generate clean and uninterrupted electricity and sell excess generated energy back to the grid, eliminating the need for battery storage. This mutually beneficial arrangement reduces household electricity bills and contributes to a more sustainable and resilient energy infrastructure [9]–[11].

Several studies have explored the viability and long-term impact on environmental, economic, and social aspects of PV systems in Pakistan. For instance, the study [12] explores optimal component planning for a grid-connected microgrid in Pakistan. The objective is to reduce the cost of energy, increase the renewable share, cut greenhouse gas emissions, enhance power supply reliability, and make electricity generation sustainable. Results show a 92.47% reduction in the cost of energy for residential applications and a 48.52% reduction for commercial applications. This study [13] assesses the socio-technical aspects of implementing solar power in Tharparkar, Pakistan, focusing on equitable energy access. It discusses the potential for solar power to replace current energy sources at lower costs and improve gender-related energy access. The analysis emphasizes long-term planning for the lowest prices, emissions reduction, and equitable outcomes. This study [14] evaluates a solar-biomass on-grid hybrid system for the Hattar Industrial Estate in Pakistan. The study aims to provide cost-effective and uninterrupted power supply by considering available resources. The optimal system combines solar PV and biogas generation, reducing energy costs, achieving a payback period of 4.6 years, and significantly cutting carbon emissions. This paper [15] examines the barriers and potential for solar energy development in Pakistan. It highlights the need for cleaner energy sources and identifies solar energy as a promising option. The study proposes policy recommendations to overcome barriers and promote solar energy use. This research [16] evaluates the techno-economic effectiveness of grid-connected and standalone integrated hybrid energy systems for remote electricity supply. The study considers factors like net present cost, cost of energy, and payback time, concluding that grid-connected hybrid systems are best for reliable energy supply in remote areas. This work [17] proposes a hybrid energy model for fulfilling Pakistan's educational institute's power requirements. It considers various stand-alone and grid-connected energy systems and shows that PV, wind, and fuel cells are cost-effective for energy production and storage. This study [18] conducts a life cycle assessment of multi-Si PV systems in Pakistan. It evaluates environmental impacts and energy payback time, concluding that these systems have an EPBT of 2.5 to 3.5 years, making them a viable option for energy production. This research [19] employs the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) to understand the acceptance of solar technology in Pakistan's southern region. Environmental beliefs, social influence, and price value influence consumers' intention to use solar technology. This study [20] evaluates a 150.7 kW grid-connected PV system in a public university in Pakistan. It analyses energy generation, performance ratios, and annual energy yields, concluding that the system is efficient and has a performance ratio of 79.64%. This study [21] focuses on integrating solar photovoltaic (PV) energy into the residential sector. It uses a decision tree and design parameters optimization to assess sustainability and electrification requirements. The

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research quantifies synergies and trade-offs between design parameters, evaluates the impact of solar PV systems on energy sustainability, and analyses the competitiveness of various solar PV integrated energy systems. The findings suggest that combining solar PV systems with grid power has a greater impact, while combining them with battery energy storage systems is more competitive, providing valuable insights for encouraging renewable solar integration. This paper [22] investigates the challenges hindering the adoption of distributed solar photovoltaics (PV) in Pakistan. It finds resistance from incumbent actors due to misaligned institutional logics, focusing on difficulties in acquiring finance and insufficient incentives for distribution companies to facilitate distributed generation. This misalignment leads to user preferences for fossil-fuel backup energy systems, under-facilitation of distributed generation, restricted lending behaviour, and limited coordination between system actors. The findings have generalizable implications for regions facing similar challenges. This study [23] explores the economic viability and feasibility of installing photovoltaic (PV) solar energy systems in Pakistan, specifically in Faisalabad. It highlights Pakistan's favourable solar radiation characteristics and assesses the cost-benefit analysis of installing PV systems in households. The research shows that the true financial cost of a PV module decreases significantly when energy cost savings are considered in generating conventional electricity, emphasizing the potential for solar energy in Pakistan. In [24] the researchers study the the depth of discharge (DOD) for four battery technologies—lead-acid (LA), lithium-ion (Li-ion), vanadium redox (VR), and nickel-iron (Ni-Fe)—in five cement plants in Pakistan. In [25] the authors investigated the possibility of delivering hybrid energy to Pakistani cement plants. This work [26] focuses on the risk assessment and mitigation strategies for large-scale solar PV systems in Pakistan. It collects data on complaints related to PV systems from reputable companies and presents insights into potential risks and their severity. The study also provides risk mitigation strategies to address these complaints, aiming to reduce risks associated with large-scale solar PV installations in developing countries. In this paper, we present site details, and the software used to simulate the PV setup on a house in Lahore, Pakistan.

II. Site Location

The site chosen for this research is a residential house located in Lahore, Pakistan. Lahore is the second most densely populated city and the largest division in the country, with a population of approximately 22 million [27]. The precise coordinates of the site are longitude 31.482982 and latitude 74.3156. Fig 1 presents a Google Maps image of the location.

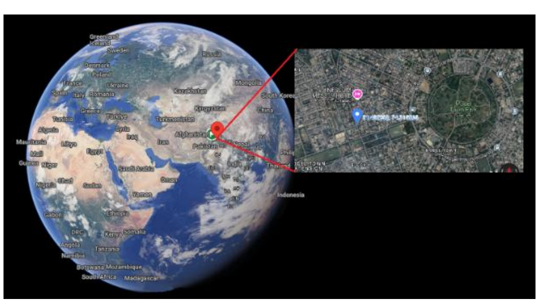

Fig.1. Site Location on Google Maps

III. Load Profile

Fig 2 shows average load of the house. Temperature rises to 45°C during summers in Pakistan, so air conditioning units are used to maintain indoor temperature. Historical energy trend of the house shows that average daily energy consumption of this house is around 58 kWh with peak consumption in summer. The peak load of this house is around 7.6 kW.

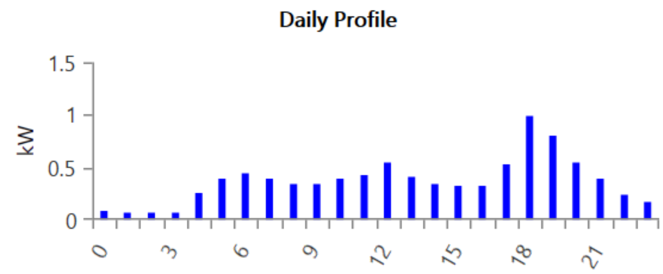

Fig.2. Daily Electrical Load Profile.

IV. Resources

A. Model Components

The model consists of a PV system, an inverted and grid-tied system as shown in fig 3.

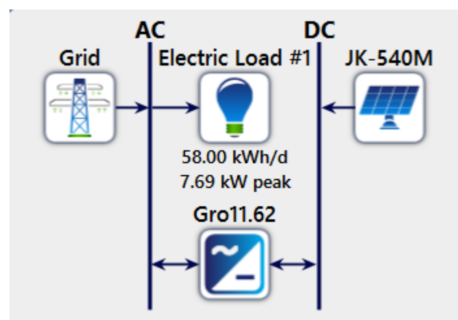

Fig.3. System Layout

B. Solar Panel

A total of 23 Monocrystalline solar panels manufactured by Jinko Solar are being used in this project. The model number of the solar panel is JKM540M-72HL4-V, and the total rated power of each solar panel is 540 watts. Jinko Solar used half-cut configuration of the modules which offers advantages of higher power output, better temperature-dependent performance, reduced shading effect on the energy generation, lower risk of hot spot, as well as enhanced tolerance for mechanical loading. The solar panel Specification is illustrated in Table 1.

Table 1. Electrical Specification of Solar Panel

Type	Rating
Maximum Power (Pmax)	540 W
Open Circuit Voltage (Voc)	49.2 VDC
Maximum Power Voltage (Vmp)	40.70 VDC
Short Circuit Current (Isc)	13.85 A
Maximum Power Current (Imp)	13.27 A
Module Efficiency	20.94%
Power Tolerance	0 – 3%
Temperature Coefficient of Isc (α_Isc)	0.048% °C
Temperature Coefficient of Voc (β_Isc)	-0.28% °C

Temperature Coefficient of Pmax (γ_Isc)	-0.35% °C

This panel is rated for 1500V DC maximum system voltage and operating temperature range is -40C to 85C. The maximum series fuse rating of this solar panel is 25A [3].

C. Inverter

Growatt MOD 11KTL3-X 11 kW pure sine wave hybrid inverter is used in this system. This inverter is rated for 230 VAC and 50Hz systems as per the local demand of the utility supply company. Table 2 shows the specification of the inverter. Inverter can be used with or without a battery, in the current setup no battery is used.

Table IV. Technical Specifications of inverter.

Type	Rating
Rated Output Power	12100VA/1100W
Rated Voltage	230/400 VAC
Frequency range	50Hz/60Hz
PV Voltage range	140-1000 dc V
PV I_{sc}	16 dc A*2
Maximum input Current	13 dc A*2
Maximum output Current	18.3 ac A
Operating Temperature	-25 °C – +60 °C

V. RESULT AND DISCUSSION

The integration of an 11 kW photovoltaic (PV) system at the site offers significant improvements in both energy cost savings and environmental impact. The following sections provide a detailed analysis of the system's economic, operational, and environmental performance.

A. Energy and Cost Savings

The electric demands of the site are currently met using grid-supplied energy, resulting in annual operating costs of $3,129. As shown in fig 4. The proposed addition of an 11 kW PV system drastically reduces these costs to $1,086 per year, a decrease of nearly 65%. This significant reduction in energy expenses translates to annual savings of $2,043.

Additionally, the financial analysis of the investment shows

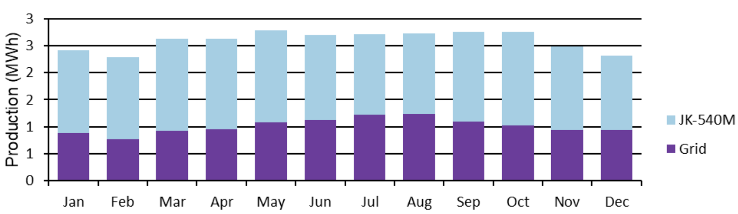

Fig. 4. Production of Electricity

a favorable payback period of 1.97 years. The internal rate of return (IRR) is estimated to be 50.7%, making the PV system a highly attractive investment. These figures indicate that the capital invested in the solar installation will be recovered in less than two years, after which the system will generate free or low-cost electricity for the remainder of its lifespan.

B. System Specifications and Performance

The Jinko PV system installed at the site has a nominal capacity of 11.0 kW. Its annual energy production is expected to reach 18,978 kWh as shown in Table 3, which covers a substantial portion of the site's electricity needs. The specific yield of the system is 1,725 kWh per kW installed, reflecting the system's efficiency in converting solar energy into electricity.

Table 3. Electricity Generation from PV

Rated Capacity	11.0 kW	Total Production	18,978 kW
Capital Cost	$3,259	Maintenance Cost	143 $/yr
Specific Yield	1,725 kWh/kW	LCOE	0.0208 $/kWh
PV Penetration	89.6 %		

- The PV system achieves a penetration level of 89.6%, meaning nearly 90% of the site's energy demand can be supplied by solar power. This minimizes reliance on grid electricity, especially during peak solar production hours.

- The LCOE for the PV system is extremely low at $0.0208 per kWh. This reflects the long-term cost-effectiveness of the solar installation, making it a financially viable solution for reducing energy expenses over the system's lifetime.

- The system is expected to operate for approximately 4,384 hours per year, with an average power output of 2.07 kW. The maximum recorded output is 10.7 kW, very close to its rated capacity, indicating high system efficiency as shown in Table 4.

- Annual energy losses are calculated to be 854 kWh, a small fraction of the total production, which further confirms the system's operational reliability and performance.

- The capacity factor, representing the ratio of actual output to maximum possible output, is 18.8%. This is a typical value for solar installations in regions with good sunlight conditions, ensuring reliable performance throughout the year. There is no battery storage. Excess Energy is fed to grid since net-metering is allowed in Pakistan.

Table 4. Inverter Usage

Capacity	11.0 kW	Hours of Operation	4,384 hrs/yr
Mean Output	2.07 kW	Energy Out	18,124 kWh/yr
Minimum Output	0 kW	Energy In	18,978 kWh/yr
Maximum Output	10.7 kW	Losses	854 kWh/yr
Capacity Factor	18.8 %		

C. Economic Performance

A comparison between the base system (current setup without PV) and the proposed PV system highlights significant financial benefits:

- The NPC of the existing system is $40,452, which would drop to $18,097 with the installation of the proposed PV system. This represents a substantial reduction in the overall long-term cost of meeting the site's energy needs.

- The initial CAPEX required for installing the PV system is $4,059. Following installation, the OPEX would decrease from $3,129 (without PV) to just $1,086 per year, reflecting substantial operational cost savings as shown in Table 5.

- The base system currently incurs an LCOE of $0.148 per kWh. This would be reduced to $0.0462 per kWh with the installation of the solar PV system, demonstrating the financial efficiency of switching to solar energy.

Table 5. Comparison with the Base Case Cost

	Base System	Proposed System
Net Present Cost	$40,452	$18,097
CAPEX	$0.00	$4,059
OPEX	$3,129	$1,086
LCOE (per kWh)	$0.148	$0.0462
CO2 Emitted (kg/yr)	13,379	7,704
Fuel Consumption (L/yr)	0	0

D. Environmental Impact

The proposed solar system not only reduces costs but also brings significant environmental benefits. The integration of PV reduces annual CO2 emissions by 42.4%, from 13,379 kg/year to 7,704 kg/year. This substantial decrease in carbon emissions aligns with global efforts to combat climate change by lowering the carbon footprint of energy consumption.

The system maintains zero fuel consumption, as solar energy replaces the need for any conventional fuel-based power generation. This further contributes to the sustainability of the energy solution.

E. Energy Purchased and Sold to the Grid

The bar chart in Fig 5 illustrates the energy purchased and sold to the grid monthly. The blue bars represent the energy purchased (kWh), while the orange bars show the energy sold (kWh).

- During the summer months (May to August), the energy sold back to the grid increases significantly, driven by higher solar irradiance and excess energy generated by the PV system. This surplus energy is fed back into the grid, contributing to the site's overall financial savings.

- In the winter months, solar production drops due to shorter daylight hours and lower sunlight intensity. As a result, the site purchases more energy from the grid than it sells, although the PV system still offsets a considerable portion of the demand.

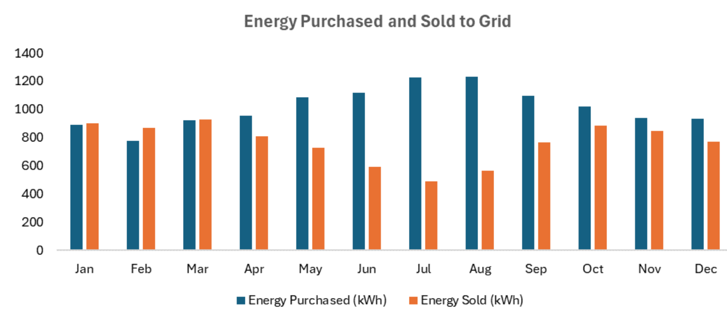

Fig. 5. Energy Purchased and Sold to Grid

VI. Conclusion

The integration of the 11 kW PV system at the Lahore residential site has demonstrated considerable benefits in terms of both energy cost savings and environmental impact. The system meets 89.6% of the site's energy demand through solar generation, reducing reliance on grid electricity. Financial analysis reveals a payback period of less than two years, making the investment economically attractive. Moreover, the system's carbon emissions are reduced by 42.4%, contributing to Pakistan's environmental sustainability goals. With favorable system performance and cost-effectiveness, this study underscores the potential of rooftop PV systems as a scalable solution for residential energy needs across Pakistan. Future work may include expanding the model to include battery storage options for greater energy autonomy and exploring policy frameworks to accelerate solar PV adoption in urban settings.

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