

Feasibility Study of an Off-Grid Solar PV System for a Residential Application in Model Town, Lahore

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ABSTRACT

This study presents a feasibility of the off-grid solar photovoltaic system proposed for a residential property in Model Town, Lahore, Pakistan. The system offers a sustainable and reliable energy solution in view of high solar irradiance and frequent grid outages in the region. Using HOMER Pro software, simulation of a hybrid microgrid consisting of a 12.6 kW PV array, 89 kWh of battery storage, and an 11-kW inverter is presented. It meets loads of 25 kWh per day. The system showed favorable economic and technical perspectives, with an IRR of 228%, a payback period of 0.491 years, and a 91% reduction in net present cost compared to second-best diesel generator-based systems. The system is also documented for zero CO₂ emissions and almost no energy disruptions, declaring it environment-friendly, as well as being favorable to include in similar regions for residential purposes.

Keywords: Grid-tied PV, Photovoltaic system, renewable energy, solar energy.

Submitted: June 08, 2025

Published: October 23, 2025

 10.24018/ejenergy.2025.5.5.171

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1. INTRODUCTION

Strategically located and endowed with abundant solar irradiance throughout the year, Pakistan can tap solar energy as a sustainable and economically viable solution to fulfill household energy requirements [1], [2]. With the growing electricity demand and continuing issues related to energy security and affordability, solar energy appears to be a potential alternative to traditional fossil fuel-based energy sources [3], [4]. Household solar energy technologies empower consumers with an alternative during the times when the national grid is often deemed irregular and the blackouts affect a lot of areas [5]. Rooftop solar PV systems were, and are still, being installed at an accelerated pace in Pakistan, especially after utility companies went ahead in promoting net metering policies [6]–[8]. This setup facilitates the generation of clean, uninterrupted electricity at home while discharging the surplus into the grid for energy credits, thereby helping homeowners reduce their electricity payments and avoid the cost of battery storage. Besides capacity-building from the perspective of costs, these arrangements also contribute toward developing a sustainable and resilient energy infrastructure [9]–[11].

In Pakistan, multiple studies have been done to assess technical, economic, and environmental feasibility of PV

systems. For example, Ali *et al.* [12] investigated component optimization for grid-connected microgrids, reporting cost reductions of 92.47% for residential and 48.52% for commercial applications. Majid Gulzar *et al.* [13] reviewed solar energy deployment in Tharparkar from the socio-technical perspective, emphasizing the capacity of the technology to enhance affordability and equality in energy access. Likewise, a solar-biomass hybrid system was studied by Mahmood *et al.* [14] in the Hattar Industrial Estate, which was shown to considerably reduce carbon emissions and have a payback time of 4.6 years. The study conducted by Zeb *et al.* [15] looked at barriers to solar adoption in Pakistan and proposed policy interventions for bridging accelerated clean energy transitions. In comparison, Habib *et al.* [16] presented a comparative study of hybrid systems for remote areas and concluded grid-connected systems are more reliable and cost-effective.

Further, Hakim *et al.* [17] proposed a hybrid energy model tailored to the electricity demands of educational institutions, demonstrating the cost-effectiveness of integrating PV, wind, and fuel cell technologies. Life cycle assessments such as Shompa and Hoque [18] validated the environmental sustainability of multi-Si PV systems in Pakistan, estimating energy payback times between 2.5



Fig. 1. Site location on google maps.

to 3.5 years. User behavior and acceptance were investigated in Effendi *et al.* [19] using the UTAUT2 framework, identifying environmental awareness, social influence, and cost perception as key adoption drivers. In Rehman and Iqbal [20], performance metrics of a 150.7 kW grid-tied system at a Pakistani university were analyzed, showing a high-performance ratio of 79.64%.

Additionally, Pachauri *et al.* [21] used design optimization and decision-tree models to evaluate residential solar integration, highlighting synergies between PV systems and battery or grid configurations. Franklin *et al.* [22] explored institutional resistance to distributed solar PV, pointing to financing hurdles and misaligned incentives as critical bottlenecks. Economic viability assessments like Sesa and Mahmuddin [23] focused on Faisalabad, confirming favorable financial returns due to Pakistan's high solar radiation. Battery technology comparisons in Basheer *et al.* [24] evaluated depth-of-discharge profiles for various chemistries in cement plant applications, while Basheer *et al.* [25] investigated hybrid energy solutions for industrial sectors.

Finally, Ramaprabha and Al [26] assessed risks associated with large-scale PV systems in Pakistan, categorizing user complaints and proposing mitigation strategies to enhance reliability and acceptance. In this context, our study presents a detailed site-specific analysis and simulation of a rooftop PV system for a residential house in Model Town, Lahore. Using HOMER Pro, we model and evaluate the system's performance to validate its technical and economic feasibility under real-world conditions.

2. SITE LOCATION

The location of the study is a building in Lahore, Pakistan. The city of Lahore is the second most heavily

populated one in the country. It is a metropolitan division and its population is around 22 million [27]. The coordinates of the place are 74.3156 degrees of latitude and 31.482982 degrees of longitude. These numbers indicate that the location is in the vicinity of Fig. 1, which is a screenshot of the site taken from Google Maps.

3. LOAD PROFILE

Fig. 2 shows the typical electric load diagram of the house. In the summer months in Pakistan, the temperatures can be as high as 45°C. Therefore, the air conditioning systems are used to create comfortable indoor conditions. It is seen from the past energy consumption records that the family consumes an average daily electricity of 25.06 kWh, with a significant rise during the summer period. The maximum electricity consumed by the house is about 7.0 kW. It is the sum of the two loads, one house load and the other the AC load (Deferrable load), which are usually used in summer.

4. RESOURCES

4.1. Model Components

The system model comprises a photovoltaic (PV) array, a generator, an inverter and battery system, as illustrated in Fig. 3.

4.2. Solar Panel

This project utilizes solar panels manufactured by Jinko Solar. The panels are of model number JKM540M-72HL4-V, each with a rated capacity of 585 watts. These modules feature a half-cut cell configuration, which provides several performance benefits, including increased power output, improved efficiency under high temperatures, reduced impact from shading, a lower risk of hot spots, and enhanced mechanical load tolerance. The detailed specifications of the solar panels are presented in Table I.

The panel is designed to operate with a maximum system voltage of 1500V DC and supports an operating temperature range from -40°C to 85°C . Additionally, it has a maximum series fuse rating of 25A [3].

4.3. Inverter

The system incorporates a Growatt MOD 11KTL3-X, an 11 kW pure sine wave hybrid inverter. It is rated for operation on 230 VAC, 50 Hz systems, aligning with

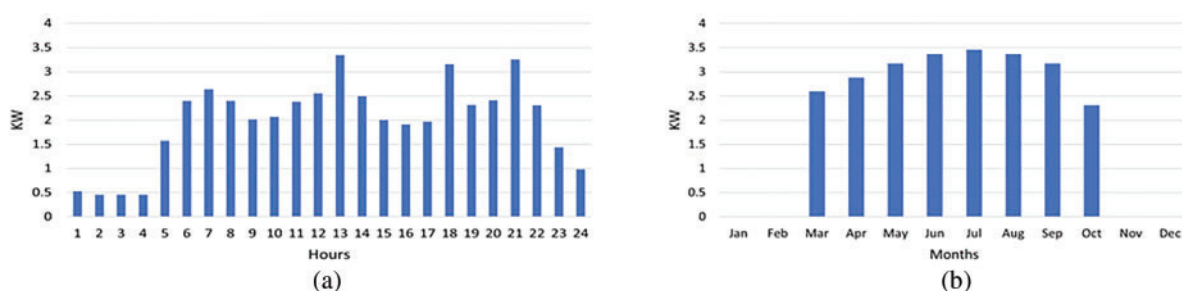


Fig. 2. Daily electrical load profiles: (a) Load and (b) Deferred load.

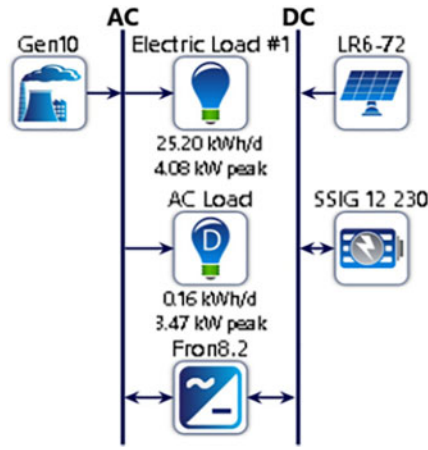


Fig. 3. System layout.

TABLE I: ELECTRICAL SPECIFICATION OF SOLAR PANEL

Type	Rating
Nominal output power	585 W
Voltage (No load)	49.2 VDC
Voltage at peak power	40.70 VDC
Current (Short circuit)	13.85 A
Current at peak output	13.27 A
Conversion efficiency	20.94%
Output deviation range	0%–3%
Temp. effect on short circuit current	0.048% °C
Temp. effect on open circuit voltage	–0.28% °C
Temp. effect on power output	–0.35% °C

the standard requirements of the local utility provider. The inverter specifications are detailed in Table II. While this model supports both battery-backed and battery-less configurations, the current setup operates without battery storage.

4.4. Battery

The storage system in this study is simulated by the Kinetic Battery Model for creating realistic charge-discharge cycles and energy efficiencies. The battery rated voltage is 12 V, and the battery rated energy capacity is 2.78 kWh. Of this size, it has a high energy output for small installations (Table III).

5. RESULTS AND DISCUSSION

The electric needs of Plot 92 F, Block F Model Town, Lahore, Punjab, Pakistan, are met with 10 kW of generator capacity. The operating costs for energy are currently \$12,399 per year. We propose adding 13 kW of PV and 89 kWh of battery capacity. This would reduce your operating costs to \$400.56/yr. Your investment has a payback of 0.491 years and an IRR of 228%.

5.1. Electric Consumption

This microgrid requires 25 kWh/day and has a peak of 3.349 kW. In the proposed system, the following generation sources serve the electrical load as shown in Fig 4.

TABLE II: TECHNICAL SPECIFICATIONS OF INVERTER

Type	Rating
Nominal power output	12100 VA/1100 W
Output Voltage (Rated)	230/400 VAC
Supported frequency range	50/60 Hz
Acceptable PV voltage range	140–1000 dc V
PV short-circuit current (Input side)	16 dc A*2
Highest allowable input current	13 dc A*2
Peak output current	18.3 ac A
Permissible operating temperature range	–25°C – +60°C

TABLE III: BATTERY SPECIFICATIONS

Parameter	Value
Nominal voltage (V)	12
Nominal capacity (kWh)	2.78
Maximum capacity (Ah)	232
Capacity ratio	0.486
Rate constant (1/hr)	0.409
Roundtrip efficiency (%)	80
Maximum charge current (A)	41
Maximum discharge current (A)	300
Maximum charge rate (A/Ah)	1

TABLE IV: TECHNICAL DETAILS OF PV SYSTEMS

Nominal capacity	12.6 kW	Total output	18,120 kWh/year
Capital investment	\$2540	Maintenance cost	86.1 \$/yr
Specific output	1439 kWh/kW	LCOE	0.0165 \$/kWh
PV input to the system	197%		

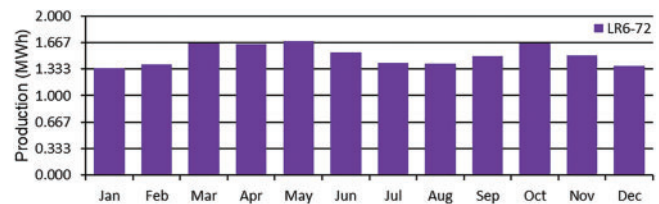


Fig. 4. Electrical consumption.

TABLE V: TECHNICAL DETAILS OF BATTERY

Nominal capacity	89.0 kWh	Expected life	13.1 yr
Annual throughput	5566 kWh/yr	Capital costs	\$5,888
Maintenance cost	96.0 \$/yr	Losses	1243 kWh/yr
Autonomy	67.4 hr		

TABLE VI: TECHNICAL DETAILS OF CONVERTER

Capacity	11.0 kW	Hours of operation	8756 hrs/yr
Mean output	1.06 kW	Energy out	9252 kWh/yr
Min output	0 kW	Energy in	9588 kWh/yr
Max output	3.35 kW	Losses	336 kWh/yr
Capacity factor	9.60 %		

5.1.1. PV System

Table IV shows that the LONGi Solar Technology Co., Ltd. PV system has a nominal capacity of 12.6 kW. The annual production is 18,120 kWh/yr.

TABLE VII: TECHNICAL SUMMARY OF HYBRID SYSTEM COMPONENTS

Component	Parameter	Value	Unit	Remarks
PV	Total production	18,120	kWh/year	197% penetration
PV	Capacity factor	16.4	%	Rated 12.6 kW
Battery	Usable capacity	71.2	kWh	Nominal: 89.0 kWh
Battery	Annual throughput	5,566	kWh	Losses: 1243 kWh
Battery	Autonomy	67.4	hr	Long backup time
Inverter	Energy out	9,252	kWh/year	Efficiency ~96.5%
Inverter	Losses	336	kWh/year	Low loss

TABLE VIII: COMPARATIVE ECONOMIC ANALYSIS

Metric	Diesel system	Hybrid system	Change (%)	Unit
Net present cost	\$165,157	\$14,713	-91.1	\$
Capital cost (CAPEX)	\$4867	\$9534	+95.9	\$
Operating cost (OPEX)	\$12,399	\$400.56	-96.8	\$/yr
LCOE	\$1.38	\$0.123	-91.1	\$/kWh
IRR	N/A	228%	N/A	%
Simple payback	N/A	0.491	Fast ROI	yrs

5.1.2. Battery

Table V shows that the Trojan Battery Company storage system's nominal capacity is 89.0 kWh. The annual throughput is 5,566 kWh/yr.

5.1.3. Converter

Table VI shows the output details of converter in the system.

5.2. Discussion

5.2.1. Technical Performance

The hybrid microgrid system comprises a 12.6 kW LONGi Solar PV array, 89.0 kWh of Trojan SSIG 12 230 battery storage, and an 11.0 kW Fronius Primo inverter. The simulated load is 25.2 kWh/day with a peak demand of 3.35 kW. Annual PV production reached 18,120 kWh with a specific yield of 1439 kWh/kW and a capacity factor of 16.4%. The system achieved 197% PV penetration and operated 4384 hours/year.

Battery autonomy was calculated at 67.4 hours with 5,566 kWh/year throughput and 1243 kWh/year losses. The storage system supports 62.5 effective full cycles per year with a projected lifespan of 13.1 years. The inverter maintained full-time operation (8756 hours/year), converting 9588 kWh/year to 9252 kWh/year with 336 kWh of annual loss as shown in Table VII.

5.2.2. Economic Performance

The Net Present Cost (NPC) of the hybrid system was estimated at \$14,713 compared to \$165,157 for the diesel-based system, reflecting a 91% cost reduction over the system's 25-year lifetime (Fig. 5). The Levelized Cost of Energy (LCOE) dropped from \$1.38/kWh (diesel) to \$0.123/kWh (hybrid). The capital cost increased from \$4867 to \$9534 but was offset by annual operating cost savings of over \$11,998. The investment yielded an Internal Rate of Return (IRR) of 228% with a simple payback period of just 0.491 years as shown in Table VIII.

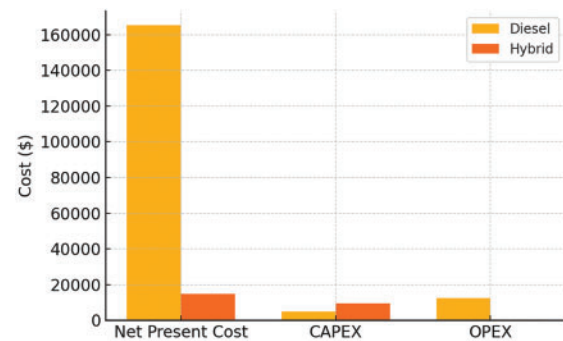


Fig. 5. Cost comparison.

5.2.3. Environmental and Reliability Performance

The hybrid system eliminated diesel fuel usage and reduced annual CO₂ emissions from 27,456 kg to zero. Excess electricity generated was 7302 kWh/year with an unmet load of only 5.76 kWh/year, representing excellent reliability with a capacity shortage of just 8.3 kWh/year. This surplus capacity indicates potential for system expansion or community electrification.

6. CONCLUSION

The feasibility analysis of an off-grid solar PV system for a residence in Lahore confirms the technical, economic, and environmental benefits of renewable energy adoption in urban Pakistan. The proposed system not only satisfies daily electrical needs with high reliability but also drastically reduces operational costs and eliminates greenhouse gas emissions. With an IRR of 228% and a payback period under half a year, the investment proves highly attractive compared to conventional diesel generators. The findings highlight the immense potential of solar energy solutions in addressing Pakistan's energy challenges and support the broader adoption of decentralized, sustainable technologies in residential sectors.

CONFLICT OF INTEREST

The authors declare that they do not have any conflict of interest.

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