Design and Optimization of a Solar–Battery–Grid Hybrid Power System for a Mosque in Dhaka City

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Abstract–*This paper presents the design and techno-economic optimization of a hybrid solar–battery–grid power system for a mosque located in Dhaka City, Bangladesh. Due to frequent load shedding and rising grid electricity costs, renewable-based hybrid systems have become a promising alternative for ensuring a reliable and sustainable power supply for religious and community facilities. The study analyzes the electrical demand pattern of a medium-sized mosque and proposes a hybrid configuration integrating photovoltaic (PV) panels, a battery storage unit, and the national grid. Using HOMER Pro software, configurations were simulated to minimize the Net Present Cost (NPC) and Levelized Cost of Energy (LCOE). The optimization process was subject to constraints ensuring 100% load coverage and a maximum annual capacity shortage of 0%. The optimized PV–Battery–Grid system achieves a levelized cost of energy (LCOE) of 7.33 BDT/kWh and a net present cost (NPC) of BDT 2,280,000, with a renewable energy fraction of 82%. Furthermore, the proposed system reduces CO_2 emissions by approximately 45%, demonstrating its potential as a cost-effective and environmentally sustainable energy solution for the selected mosque in Dhaka City.*

Keywords: *HOMER, hybrid, PV, renewable energy*

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I. Introduction

Bangladesh continues to experience rising electricity demand due to rapid urbanization and increased reliance on electrical appliances in both residential and community facilities. In Dhaka City, many areas still face load shedding and voltage instability, which disrupt essential services in institutions such as mosques. Reliable power is particularly important for mosques to operate lighting, fans, sound systems, and water pumps during daily prayers, Jummah gatherings, and Ramadan nights. As a result, hybrid renewable systems have become an attractive option for ensuring stable and cost-effective power supply.

Dhaka receives average daily irradiation 4.5–5.0 kWh/m²/day [1], making rooftop solar PV systems highly suitable for urban buildings. However, PV alone cannot provide continuous power during nighttime or cloudy conditions. Integrating battery storage with the grid enhances reliability, improves system stability, and reduces dependence on expensive grid electricity. With the support of national policies—such as net metering and renewable energy expansion—solar–battery–grid hybrid systems offer a practical solution for urban mosques aiming to reduce energy costs and improve system reliability in locations such as well as across Bangladesh.

Previous studies in Bangladesh have successfully applied hybrid systems in rural, remote, and challenging environments. Research on off-grid settlements, islands, refugee camps, and hilly regions demonstrates that HOMER [2]-optimized hybrid configurations can significantly reduce energy cost and enhance system reliability like Bhasan Char [3]; St Martin's Island [4]; Nijum Dwip [5]; Sandip para [6]; Cox's bazar [7]; Bandarban [8],[9], and also as whole Bangladesh [10]-[14]. Additionally, HOMER Pro has been used to design and optimize hybrid energy systems [15].

While these studies provide a robust foundation for hybrid system design, most existing literature focuses on residential or industrial loads in remote areas, largely neglecting the unique intermittent load profiles of urban religious institutions. There is a notable research gap regarding the techno-economic feasibility of net-metered hybrid systems for mosques, which experience high-magnitude, short-duration peak loads aligned with prayer times—a pattern distinct from typical household or commercial energy consumption.

A mosque-specific study is novel because it addresses these specific load fluctuations while considering the limited rooftop space and high density of urban Dhaka. This study fills this gap by evaluating how a solar–

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battery–grid configuration can specifically cater to the operational needs of religious facilities under current national net-metering policies.

Building on these findings, this paper makes several key contributions by developing a customized load profile that represents the estimated electrical demand of a medium-sized urban mosque, accounting for unique consumption spikes during daily prayers, Jummah, and religious observances. It provides a techno-economic optimization tailored for religious institutions, identifying the most cost-effective system configuration in terms of Net Present Cost (NPC) and Levelized Cost of Energy (LCOE) within an urban grid-connected environment.

Furthermore, the study performs a reliability and sustainability analysis to quantify the impact of battery storage on maintaining uninterrupted services during load shedding while measuring the potential for CO_2 emission reductions. Finally, the research demonstrates policy alignment by showing the practical application of net metering guidelines for non-residential, community-based urban facilities to promote the adoption of clean energy in Bangladesh.

II. System Description

The selected mosque is a four-story building located in Dhanmondi, Dhaka, with a typical load profile including lighting, fans, a sound system, and a water pump during prayer hours. The average daily electricity demand is approximately 25.9 kWh/day, with a peak load of approximately 3.65 kW during evening prayer times. Table I summarizes appliance ratings, operating hours and estimated daily energy consumption.

While the average daily energy consumption is calculated at 25.90 kWh/day, the optimized system utilizes a 26 kW PV array to ensure technical reliability and economic efficiency. This sizing ratio is justified by the need for load shedding resilience, as the oversized array allows the 25 kWh battery bank to recharge rapidly during limited daylight hours even when the grid is unavailable.

Furthermore, the capacity aligns with the Bangladesh Net Metering Guideline, enabling the mosque to export significant surplus energy during off-peak hours to offset nighttime grid costs. The design also ensures full peak demand coverage during high-occupancy events like Friday Jummah prayers and accounts for system losses, including a 92% derating factor and inverter efficiencies, to maintain required AC output over the 20-year project lifetime.

TABLE I.
CONSIDERED LOAD CALCULATION TO PREPARE THE LOAD PROFILE

Appliances	Number of Units	Rated power per unit (W)	Power Consumption per hour (Wh)	Energy for continuous 24-hour operation (kWh/day)	Daily operating time (h/day)	Daily energy consumption (kWh/day)
LED tube lights	60	20	1200	28.8	7	8.4
Ceiling Fan	40	50	2000	48	7	14
Sound system (mic, speakers, amplifier)	1	400	400	9.6	5	2
Water pump	1	750	750	18	2	1.5
Total daily energy consumption (kWh/day)						25.9

III. Components

The suggested hybrid power system, which combines solar, battery, and grid technologies, comprises several main components that collaborate to provide a dependable, sustainable, and economical electricity supply for the mosque. Every component serves a distinct function in energy generation, storage, transformation, and distribution. Below, the essential elements of the system are outlined.

A. Solar PV Array

The PV array is the primary renewable energy source of the hybrid system. It converts solar irradiation into direct current (DC) electricity using crystalline silicon modules. Dhaka receives an average solar irradiation of 4.5–5.0 kWh/m²/day, making rooftop solar PV highly effective for daytime load support. The PV array reduces the mosque's dependency on grid electricity, reduces operating costs, and contributes to environmental sustainability by generating clean, emission-free energy.

The size of the PV array is selected based on the daily load demand, available rooftop area, and economic optimization results from HOMER Pro. We have used Canadian Solar MaxPower CS6X-325P PV modules, each rated at 325 W [16], an efficiency of 16.94% with temperature coefficient of -0.41%/°C. To maximize solar harvesting in Dhaka, the panels are modeled at an optimal

tilt angle of 23.5° (matching the latitude) with a south-facing orientation (0° azimuth). The design incorporates a total system loss assumption of 14%, which accounts for soiling, wiring losses, and shading, in addition to the 92% derating factor specified in the HOMER Pro configuration.

TABLE II.
PARAMETERS OF PV MODULE

Parameter	Unit	Value
Rated capacity	watt	325
Capital cost	BDT	22,654
Replacement cost	BDT	22,654
O&M cost	BDT	0
Lifetime	yr	25
Derating factor	%	92

B. Battery Bank

The system uses a 25 kWh lithium-ion battery bank [17]. Its capital cost is BDT 1,224,532.

TABLE III.
PARAMETERS OF BATTERY

Parameter	Unit	Value
Nominal voltage	V	48
Nominal capacity	kWh	25
Capital cost	BDT	1,224,532
Replacement cost	BDT	9,79,625
O&M cost	BDT	0
Lifetime	yr	20
Throughput	kWh	1,752,000

C. Grid Connection

The system remains connected to the national utility grid, which acts as a secondary power source and a sink for excess energy under net metering. Given the urban context of Dhaka, the model assumes a grid reliability profile characterized by an average outage frequency of 2–3 times per day, with a mean repair time of 1 hour, reflecting local load-shedding conditions. This necessitates the integration of storage to maintain critical mosque operations.

D. Hybrid Configuration

The system architecture integrates the DC and AC components through a centralized hub. A bidirectional converter is used for AC–DC power conversion and battery charging, ensuring that energy flows efficiently between the PV array, battery bank, and mosque loads. The converter capacity is optimized to handle the peak mosque demand of 3.65 kW while managing the 26 kW PV input during peak generation.

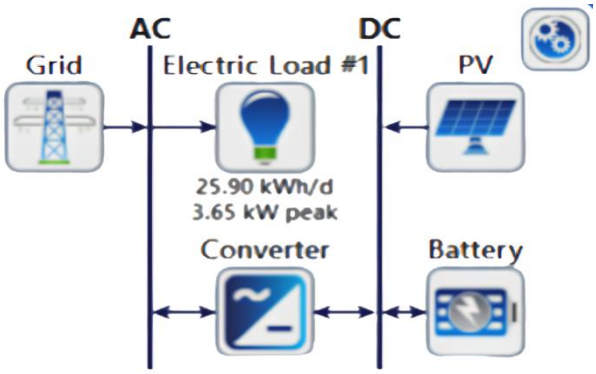


Fig. 1. Schematic diagram of proposed system

This structure allows the mosque to primarily rely on solar energy during the day, store surplus energy in the battery, and draw from the grid during night hours or cloudy conditions.

IV. Methodology

A simulation-based optimization approach was employed using HOMER Pro software.

A. Solar Resource

Fig. 2 represents the graphical formation of the clearness index for Dhaka. The average solar GHI [18] is 4.65 kWh/m^2/day. GHI means the total amount of shortwave solar radiation received from above by a surface horizontal to the ground, commonly used in solar energy and meteorology.

B. Load Profile

Fig. 3 shows the hourly electrical load over a 24-hour period.

C. Economic Parameters

Grid electricity tariff – 8.5 BDT/kWh[19]; discount rate – 8%; project lifetime – 20 years.

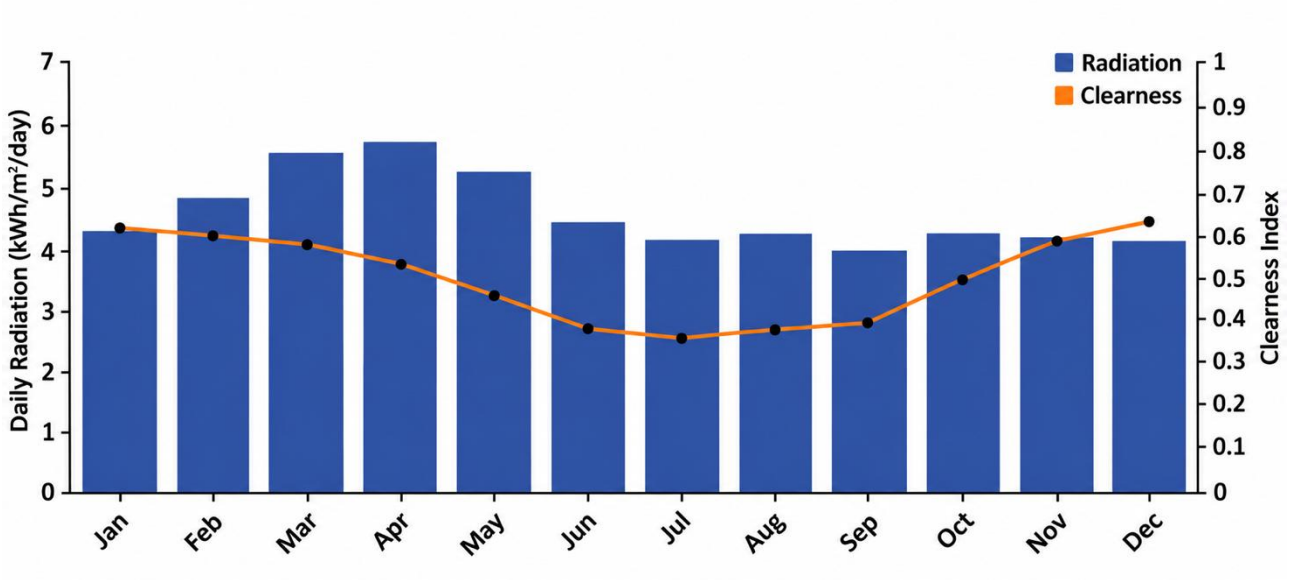


Fig. 2. Daily Clearness Index and Radiation.

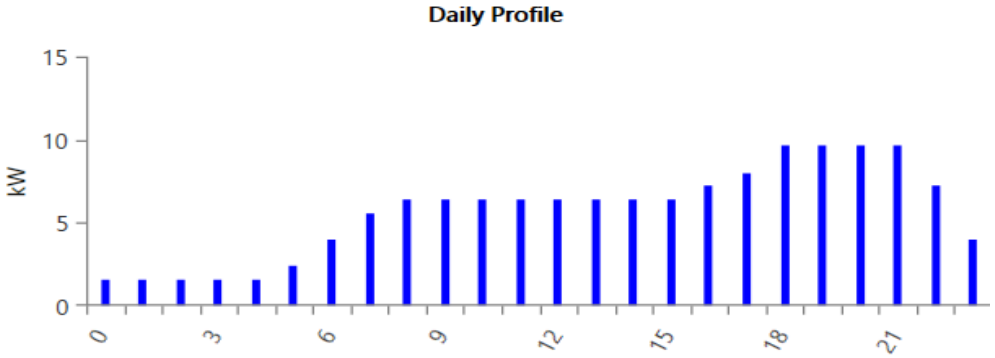


Fig. 3. Daily Load Curve

D. Simulation Scenarios

There are three simulation scenarios, grid only, PV-grid and PV-grid-battery (proposed).

E. Grid-only system

Table IV shows grid purchase and sellback tariffs for the study location. Based on the simulation results from HOMER, the following cost assumptions for the grid, according to the input values provided, are presented in Table V.

TABLE IV.
INPUT PARAMETERS FOR GRID

Parameters	Rate (BDT/KWh)
Grid Power Price	9.12 [20]
Grid Sellback Price	4.37 [21]

TABLE V.
COST ANALYSIS FOR GRID

Type of Costs	Amount
Total Net Present Cost (NPC)	32,00,000 BDT
Levelized Cost of Energy (LCOE)	9.12 BDT/KWh

F. PV - Grid system

Table VI summarizes the economic performance of the PV-Grid system. The Total Net Present Cost (NPC) of 24,50,000 BDT represents the overall lifetime cost, including installation and future maintenance expenses. The LCOE of 8.50 BDT/kWh indicates the average cost of generating electricity over the system's operational life and shows that the system can produce energy at a competitive rate. The Operating Cost of 249,538 BDT reflects the recurring maintenance and operational expenses required to keep the system functioning.

TABLE VI.
COST ANALYSIS FOR PV-GRID

Type of Costs	Amount
Total Net Present Cost (NPC)	24,50,000 BDT
Levelized Cost of Energy (LCOE)	8.50 BDT/KWh
Operating Cost	249,538 BDT

G. PV - Battery - Grid (Proposed)

Table VII presents the cost evaluation of the PV–Battery–Grid system. The Total Net Present Cost (NPC) is 22,80,000 BDT, representing the complete lifetime expense, including installation, replacement, and maintenance. The system's Levelized Cost of Energy (LCOE) is 7.33 BDT/kWh, indicating that it generates electricity at a lower average cost compared to other configurations. The Operating Cost of 232,223 BDT covers routine maintenance and operational activities throughout the project life.

TABLE VII.
COST ANALYSIS FOR PV - BATTERY - GRID

Type of Costs	Amount
Total Net Present Cost (NPC)	22,80,000 BDT
Levelized Cost of Energy (LCOE)	7.33 BDT/KWh
Operating Cost	232,223 BDT

V. Results and Discussion

Table VIII compares the costs and performance indicators of the three configurations. In table VIII the cost of different systems has shown. The findings are based on simulations and have not been validated against measurements from a physical installation.

The optimized PV generation is approximately 39,000 kWh/year, which is significantly higher than the mosque's annual demand of approximately 9,453 kWh/year; while the system appears oversized at roughly four times the annual load, this is a deliberate optimization result driven by several technical and economic factors.

TABLE VIII.
COST ANALYSIS OF DIFFERENT SYSTEMS

Configuration	NPC (BDT)	LCOE (BDT/ kWh)	Renewable Fraction	CO_2 Reduction
Grid Only	32,00,000	9.12	0%	-
PV-Grid	24,50,000	8.50	61%	37%
PV-Battery-Grid	22,80,000	7.33	82%	45%

Under the 2018 Net Metering Guideline, the surplus energy of approximately 29,500 kWh/year is exported back to the grid, generating credits that significantly reduce the Total Net Present Cost (NPC) and Levelized Cost of Energy (LCOE), making the 26 kW system more economically favorable than a smaller installation. Additionally, the high PV-to-load ratio functions as a mechanism for peak-shaving and reliability, ensuring that the system meets critical needs and maintains battery charge even during periods of heavy cloud cover or low irradiation. Finally, this oversized array facilitates rapid battery recovery, allowing the 25 kWh battery bank to be fully recharged within a narrow window of sunlight which plays a vital feature for maintaining autonomy during Dhaka's frequent load-shedding season.

VI. Conclusion

This study successfully developed and optimized a solar–battery–grid hybrid power system tailored for a mosque in Dhaka City. The optimal configuration, consisting of 26 kW of solar PV and a 25-kWh battery bank supported by the utility grid, achieved an LCOE of 7.33 BDT/kWh and reduced CO_2 emissions by 45% compared to grid-only operation.

The system provides reliable power coverage for daily and peak prayer-time loads, lowers dependence on the national grid, and improves long-term economic performance. The design framework and optimization approach demonstrated here can be effectively applied to similar urban mosques, educational institutions, and community facilities across Bangladesh to promote cleaner and more resilient energy solutions.

Despite the promising results, this study has certain limitations. The findings are based on simulations and have not been validated against measurements from a physical installation. The load profile was estimated based on appliance ratings and typical usage patterns rather than measured smart-meter data.

Future work will focus on experimental validation through the implementation of a pilot project to compare actual performance with simulated results. Additionally, a detailed sensitivity analysis will be conducted to evaluate the system's robustness against fluctuating component costs, varying grid tariffs, and the long-term impact of climate change on solar irradiation patterns in urban Bangladesh.

Conflict of Interest

The author declares no conflict of interest in the publication process of the research article.

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