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Techno-Economic Optimization of a Grid-Supported Solar PV-Battery System for Residential Electricity Supply in Saburi Estate, Abuja, Nigeria

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***Abstract:** This study evaluates the technical and economic performance of a grid-supported solar photovoltaic (PV)-battery system for residential electricity supply in Saburi Estate, Abuja, Nigeria, using HOMER Pro optimization. The system model comprises a PV array, $LiFePO_4$ battery storage, inverter, utility grid and residential AC load. The adopted average daily electricity demand is 19.441 kWh/day with an estimated peak demand of approximately 4.5 kW. HOMER Pro optimization, subject to zero capacity shortage, a minimum renewable fraction of 80%, a minimum battery state of charge of 20% and a 25-year project lifetime, produced an 8.18 kW PV array, 32 kWh battery storage and a 4 kW inverter. The optimized configuration generated 12,645 kWh/year from PV, representing 89.2% of gross electricity production, while the grid supplied 10.8%. The renewable fraction was 85.5%, with zero unmet load and zero capacity shortage. Annual excess electricity was 2,457 kWh/year, or approximately 17.3% of gross electricity production. The initial capital cost was ₦6,898,763.01, net present cost was ₦12,654,460, and cost of energy was ₦127.82/kWh against an adopted grid reference of approximately ₦209.8/kWh. The resulting payback period, return on investment and internal rate of return were four years, 18.8% and 23.9%, respectively. The findings indicate that integrated optimization can reduce battery and inverter capacities while increasing PV capacity relative to conventional sizing, producing a technically reliable and economically attractive grid-supported residential configuration under the stated assumptions.**

***Keywords:** Solar PV; Battery storage; HOMER Pro; Techno-economic analysis; Residential electricity; Grid-connected system; Abuja; Nigeria.**

I. INTRODUCTION

Reliable electricity remains important for residential welfare and socioeconomic development. In Nigeria, limitations in grid electricity supply have increased dependence on alternative power sources. Solar PV offers a promising solution because of the country's favourable solar resource, although its intermittency requires appropriate integration with energy storage and backup electricity supply.

Battery storage improves the utilization of solar electricity by storing surplus generation for use during periods of low or zero PV production [1]. However, excessive storage capacity increases system cost, making proper coordination of PV generation, battery storage and power-conversion equipment essential.

HOMER Pro is widely applied to hybrid renewable-energy system planning because it simultaneously evaluates technical performance and lifecycle economics [11]. Optimization-based component sizing can differ substantially from conventional engineering calculations because component interactions, resource availability, load demand and backup supply are considered simultaneously [12], [13].

Despite increasing research on hybrid renewable-energy systems in Nigeria, limited attention has been given to direct comparison between conventional engineering sizing and HOMER optimization for grid-supported residential PV-battery systems in Abuja. This study therefore evaluates the optimized residential PV-battery-grid system in Saburi Estate and compares its component capacities and performance with the conventional design baseline.

II. OBJECTIVES

- Optimize the PV-battery-grid configuration using HOMER Pro.
- Evaluate the technical performance of the optimized configuration.

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- Assess the lifecycle economic indicators of the optimized system.
- Compare HOMER-optimized capacities with conventional engineering capacities for the same residential load.

III. LITERATURE REVIEW

HOMER-based optimization has been widely used because it compares alternative component combinations under technical and economic constraints. Reviews by Bahramara et al. [11] and Al-Falahi et al. [12] show that integrated optimization can produce component sizes that differ from deterministic sizing. Nigerian applications have also demonstrated the value of sensitivity and lifecycle analysis [13], [14], [15].

Salisu et al. [6] and Esan et al. [7] reported the importance of technical feasibility and reliability in hybrid systems, while Udeani et al. [8] assessed residential rooftop solar-battery systems in grid-connected Lagos households. Odetoye et al. [9] examined multi-year techno-economic assessment of a zero-emission hybrid community microgrid in Nigeria. These studies provide a basis for applying optimization and lifecycle metrics to residential renewable-energy systems.

The present study extends this body of work by directly comparing a conventional engineering design with a HOMER-optimized grid-supported residential configuration in Abuja.

IV. MATERIALS, EQUIPMENT AND METHODS

1. Study Area, Load and Resource Basis

The study was conducted in Saburi Residential Estate, Dei-Dei, within the Federal Capital Territory, Abuja, Nigeria. Solar radiation data covering 2022–2024 were obtained from the Nigerian Meteorological Agency (NiMet), Abuja. Monthly average solar radiation ranged approximately from 3.9 to 6.3 kWh/m²/day, with generally lower values during the rainy season. The appliance-based household energy audit produced an adopted average daily electricity demand of 19.441 kWh/day and an estimated peak demand of approximately 4.5 kW.

2. HOMER Pro System Configuration

The modeled configuration consisted of a PV array, $LiFePO_4$ battery storage, inverter, utility grid and residential AC load. HOMER Pro was used to determine the preferred configuration based on technical performance and lifecycle economic criteria.

3. Optimization Constraints and Performance Indicators

The principal constraints included zero capacity shortage, a minimum renewable fraction of 80%, a minimum battery state of charge of 20%, and a project lifetime of 25 years. Technical performance was evaluated using annual PV production, grid contribution, renewable fraction, excess electricity, unmet load and capacity shortage. Economic indicators included initial capital cost, net present cost (NPC), cost of energy (COE), payback period, return on investment (ROI) and internal rate of return (IRR).

4. Baseline

For comparison, engineering calculations for the same load produced a 4.86 kW PV array, a 54.0 kWh battery bank and an approximately 5.6 kW inverter. The conventional battery calculation used two days of autonomy, 80% depth of discharge and 90% battery efficiency, while PV sizing used five peak sun hours and 80% overall efficiency. These values are treated as the deterministic baseline rather than as the optimized solution.

V. RESULTS AND DISCUSSION

1. Conventional and HOMER Pro Optimized Capacities

Component	Conventional	HOMER Pro	Change
PV array	4.86 kW	8.18 kW	+68.3%
Battery	54.0 kWh	32.0 kWh	−40.7%
Inverter	5.6 kW	4.0 kW	−28.6%

HOMER optimization increased PV capacity by 68.3% while reducing battery and inverter capacities by 40.7% and 28.6%, respectively. Conventional battery sizing was based on a predefined two-day

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autonomy requirement, whereas HOMER considered the interaction among PV production, battery storage, residential demand, grid availability and lifecycle costs.

The larger optimized PV array increases direct solar-energy supply and battery charging opportunities, while grid support reduces the need for prolonged battery autonomy. Similar optimization behaviour has been reported in previous hybrid-energy studies [6], [10]–[12], [14], [15].

2. Technical Performance

Parameter	Value
PV capacity	8.18 kW
Battery storage	32 kWh
Inverter	4 kW
Annual PV generation	12,645 kWh/year
PV contribution	89.2%
Grid contribution	10.8%
Renewable fraction	85.5%
Excess electricity	2,457 kWh/year
Excess fraction	17.3%
Unmet load	0%
Capacity shortage	0%

The optimized system generated 12,645 kWh/year from PV, representing 89.2% of gross electricity production, while the utility grid contributed 10.8%. The renewable fraction was 85.5%. Zero unmet load and zero capacity shortage indicate that the modeled electricity demand was satisfied under the imposed simulation conditions.

Annual excess electricity was 2,457 kWh/year, corresponding to approximately 17.3% of gross electricity production. This surplus could support future load growth or flexible household energy uses.

3. Economic Performance

Indicator	Value
Initial capital	₦6,898,763.01
Net present cost (NPC)	₦12,654,460
Cost of energy (COE)	₦127.82/kWh
Grid reference	≈ ₦209.8/kWh
Payback	4 years
Return on investment (ROI)	18.8%
Internal rate of return (IRR)	23.9%
Project lifetime	25 years

The optimized system had an initial capital requirement of approximately ₦6.90 million and an NPC of approximately ₦12.7 million. The COE was ₦127.82/kWh compared with the adopted grid reference of approximately ₦209.8/kWh.

$$Cost\ reduction = \frac{209.8 - 127.82}{209.8} \times 100 = 39.1\% \quad (1)$$

The modeled system COE was therefore approximately 39.1% lower than the adopted grid electricity reference. The four-year payback period, ROI of 18.8%, and IRR of 23.9% indicate favourable economic performance under the assumptions used in the study [8], [9], [10], [14], [16], [17].

4. Interpretation

The central result is that the optimized system does not simply scale every component upward or downward from the conventional design. Instead, it reallocates system capacity: PV capacity increases substantially, while storage and inverter capacities decrease. This configuration reflects the value of allowing the grid to provide residual support while using additional PV generation to reduce reliance on both grid electricity and large battery reserves.

The zero unmet load and zero capacity shortage indicate strong modeled reliability under the imposed constraints. At the same time, the presence of 2,457 kWh/year of excess electricity shows that the optimized system has generation beyond the modeled load in some periods. The economic results should therefore be interpreted together with the technical results and the underlying assumptions, particularly tariff, component cost, replacement, degradation and resource representations.

VI. CONCLUSION AND RECOMMENDATIONS

1. Conclusion

This study evaluated the techno-economic performance of a HOMER Pro-optimized solar PV-battery-grid system for residential electricity supply in Saburi Estate, Abuja. For an adopted electricity demand of 19.441 kWh/day, HOMER produced an 8.18 kW PV array, 32 kWh battery and 4 kW inverter, compared with conventional capacities of 4.86 kW, 54.0 kWh and approximately 5.6 kW, respectively.

Optimization increased PV capacity by 68.3% while reducing battery storage by 40.7% and inverter capacity by 28.6%. The optimized system generated 12,645 kWh/year from PV, achieved an 85.5% renewable fraction, and recorded zero unmet load and zero capacity shortage.

The system had an initial capital cost of approximately ₦6.90 million, NPC of approximately ₦12.7 million and COE of ₦127.82/kWh. The COE was approximately 39.1% lower than the adopted grid reference of ₦209.8/kWh. A four-year payback period, 18.8% ROI and 23.9% IRR further demonstrated favourable economic potential under the stated assumptions.

2. Recommendations

- Future studies should use measured high-resolution household load profiles to capture hourly and seasonal variations in electricity demand.
- Longer-term meteorological datasets should be incorporated to improve representation of interannual solar-resource variability.
- Battery degradation, component replacement and alternative economic scenarios should be included in sensitivity and uncertainty analyses.
- The optimized configuration should be validated through field installation and long-term performance monitoring.

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