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Original Research Article

Design of a Standalone Photovoltaic Inverter System for Selected Load Centres in the Faculty of Engineering, University of Benin

***Uwuigbe, E.O. and Omoze, L.E.**

Department of Electrical/Electronic Engineering, Faculty of Engineering, University of Benin, PMB 1154, Benin City, Nigeria.
*emmanuel.uwuigbe@uniben.edu; edirin.omoze@uniben.edu

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ABSTRACT

This study details the design and comprehensive economic analysis of a standalone photovoltaic inverter system tailored for selected load centres within the Faculty of Engineering, University of Benin. It addresses the necessity for a cleaner and cheaper power source amid rising costs, proposing a resilient renewable energy alternative. Methodology began with a load survey to quantify consumption patterns and peak demand. Components were sized using mathematical equations. Optimization was conducted using the Hybrid Optimization of Multiple Energy Resources Pro software. Lifecycle cost was compared against the utility grid energy cost. Simulation and economic assessment confirmed the viability and financial advantage of the designed system. The levelized cost of energy was calculated to be ₦143.47 per kilowatt-hour, demonstrating significant cost benefit when compared to utility grid supply rate of ₦209.5 per kilowatt-hour. This result shows that the photovoltaic solution is cheaper and more sustainable over the 25-year project lifetime. With a payback period of 13.4 years, the study concludes the proposed system represents a financially stable and economically competitive investment.

1. INTRODUCTION

Energy is the driving force behind social and economic development, influencing almost every aspect of human existence. It is broadly classified into renewable and non-renewable forms. Non-renewable energy sources, such as coal, petroleum, and natural gas, have powered economies for decades but are finite and contribute significantly to environmental degradation through the release of greenhouse gases (Abdallah and Odeleke, 2023). Renewable energy, derived from naturally replenished resources such as solar, wind, hydro, and biomass, offering cleaner alternatives that align with global climate change mitigation efforts (Abdallah and Odeleke, 2023). According to the International Renewable Energy

Agency (IRENA, 2025), approximately 91% of newly commissioned renewable energy projects are now cheaper than most fossil fuel alternatives, a trend driven by decreasing technology costs, especially for solar and wind, alongside increasing fossil fuel prices.

In many developing nations, including Nigeria, energy insecurity is a critical challenge. The national grid suffers from frequent outages, low generation capacity, and inefficient distribution, forcing institutions to depend heavily on diesel-powered generators (Golobish et al., 2025). This dependency leads to escalating operational costs and pollution (Omeiza et al., 2022). Solar photovoltaic (PV) technology is the most abundant and feasible source for institutional environments in southern Nigeria, where solar irradiance is consistently high (Okonkwo et al., 2021).

The Faculty of Engineering at the University of Benin has experienced unreliable power supply due to grid instability and high operational costs. Following the April 2024 tariffs increase for Band A consumers (NERC, 2024), this study aims to design a PV inverter system for selected load centres in the Faculty. The energy demand was assessed through an audit, the PV system was designed and sized, technical and economic feasibility was simulated and evaluated using HOMER Pro software, and a cost-benefit analysis was carried out.

The study promotes renewable energy adoption in line with Nigeria's Energy Transition Plan and Sustainable Development Goal 7 (Federal Government of Nigeria, 2022; United Nation, 2015), improves energy security by reducing reliance on the unstable national grid and costly diesel generators, supports academic continuity by ensuring uninterrupted power supply to critical facilities, and fosters technical competence in solar technology by serving as a learning platform for engineering students. The study is limited to the Metallurgical and Materials Engineering Department and laboratory, and the Petroleum Engineering Department, excluding high-power loads such as air-conditioning and heavy-duty laboratory machines.

2. MATERIALS AND METHODS

2.1. Load Assessment and Peak Load Estimation

The design process commenced with a comprehensive load assessment of the selected load centre. This involved identifying some electrical appliances (light, socket, and fan), recording their respective power ratings, and estimating their daily usage at 8hours. From this data, the total daily energy demand was used to serve as the foundation for sizing the PV array, battery bank, inverter, and charge controller. System losses and derating factors were also used to enhance accuracy and reliability under real-world operating conditions (Tamoor et al., 2023).

After getting all the needed parameters, the peak load for the selected load centre was determined from Equation (1).

$$P_{peak} = P_{connected} \times Diversity\ Factor \times (1 + Loss\ Allowance) \tag{1}$$

Therefore, the design peak load for the Faculty of Engineering load centre was calculated. This value serves as an important baseline for sizing the PV array, inverter, and battery bank components of the standalone PV inverter system (Duffie and Beckman, 2013).

The selected load centre was operated for eight hours daily. The daily energy demand was given by Equation (2).

$$E = Pxt \tag{2}$$

Where E= energy consumed (Wh/day), P= power rating (W), and t= average hours of the use per day

Figure 1 presents a block diagram of the overall system configuration.

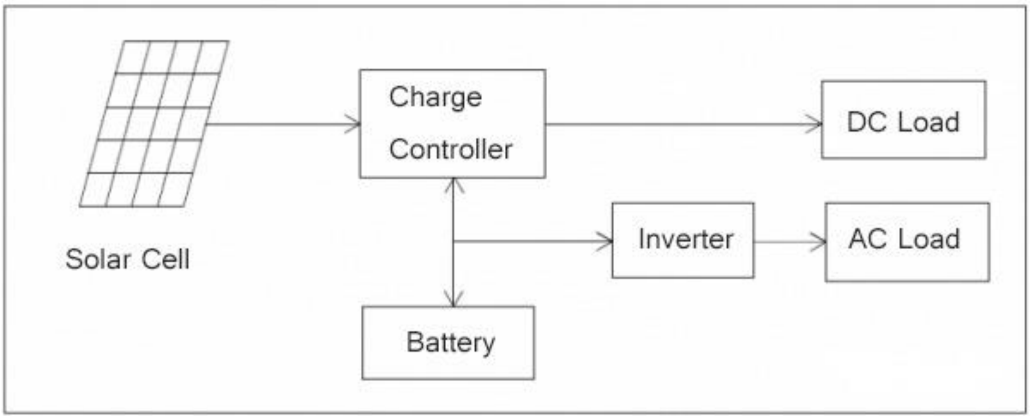


Figure 1: The block diagram of the system

2.2. Inverter Sizing

Inverter sizing is essential to ensure that the system could meet the total load demand efficiently and reliably (Burdick and Schmidt, 2017). The inverter capacity (P_{inv}) can be determined from Equation (3).

$$P_{inv} = P_{load} \times F_s \tag{3}$$

Where P_{inv}= inverter rated power (kW), P_{load}= total load demanded (kW), and F_s= safety factor (1.25-1.30)

For this design, a safety factor of 1.25 is used to accommodate surge power and inverter losses. The required inverter capacity is approximately 95 kW. However, to ensure robustness and future expansion, a 100 kW inverter was selected. Ten FELICTY 10KVA pure sine wave inverters operating at 48V were connected in parallel to meet the required power, each with an efficiency of 95%.

2.3. Battery Sizing

The total battery capacity required depended on the daily energy demand(E_{load}), the system voltage (V_{sys}), the depth of discharge (DOD), the battery efficiency (η_{bat}), and the days of autonomy (D_{aut}) (Khatib and Muhsen, 2020). The general equation for sizing the battery capacity is given by Equation (4).

$$C_{bat} = \frac{E_{load} \times D_{aut}}{V_{sys} \times DOD \times \eta_{bat}} \tag{4}$$

Where C_{bat}= required battery capacity (Ah).

2.3.1. Battery charge modeling for 3-hour full charge

To model the system, the battery and MPPT charging inefficiencies were first calculated using Equation (5) and Equation (6).

$$E_{bat,input} = \frac{E_{load}}{\eta_{bat}\ x\ \eta_{MPPT}} \tag{5}$$

$$E_{bat,input} = \mathrm{P}_{load}\ x\ \mathrm{t_c} \tag{6}$$

Accounting for the inverter losses to supply the alternating current (AC) load, the effective load energy is given by Equation (7).

$$E_{load,eff} = \frac{E_{load,3h}}{\eta_{inv}} \tag{7}$$

The total PV energy required over the three hours was the sum of battery charging energy and load energy.

The required PV power in kW was determined using Equation (8).

$$P_{PV} = \frac{E_{load}}{H_s \times \eta_{sys}} \tag{8}$$

The computed PV capacity was approximately 250.7kW, which was rounded up to 251kW to ensure adequate energy generation and to allow for possible system losses, dust accumulation, and component aging. Therefore, the PV array capacity required to meet the energy demand was 303kW.

To determine the number of PV modules required, 500W rated modules were selected. Hence, a total of 502 PV panels rated at 500 W each will be required to supply the load demand effectively under the given site conditions.

2.3.2. Charge controller sizing

The charge controller regulated the flow of electrical energy between the PV array and the battery bank. The required charge controller current capacity was calculated from Equation (9).

$$I_C = \frac{P_{PV}}{V_{system}} \tag{9}$$

2.4. System Configuration in Hybrid Optimization of Multiple Energy Resources (HOMER) Pro

The standalone PV system was modeled using HOMER Pro, incorporating a PV array, battery storage, inverter, and load profile. The system was simulated using NASA solar data with 4.66 kWh/m²/day irradiance. Optimization was performed to evaluate system performance, cost, and reliability (Ikechukwu and Chibueze, 2022; Ohajianya, 2023). The system configuration consisted of a 303 kW PV array, 15,700 Ah (48 V) battery bank, 100 kW inverter, and a 76 kW load.

2.5. Protection and Cabling

To ensure safe and reliable operation, several protection devices were integrated into the PV power system. These devices guarded the system against short circuits, overcurrent, and voltage surges. All direct current (DC) circuits used DC-rated breakers and fuses, while AC-rated devices protected the inverter output (Quaschning, 2016; Messenger and Ventre, 2010). DC circuit breakers were installed between the PV combiner box and the MPPT charge controller, and between the battery bank and inverter, sized with 25% safety margins. AC breakers were installed at the inverter output and distribution boards, sized per load demand. Surge protection devices were installed at the PV combiner, battery bank, and AC distribution board per manufacturer specifications (Quaschning, 2016). Proper cable sizing minimized voltage drop, power loss, and heating in DC circuits. The required cross-sectional area was calculated from Equation (10).

$$A = \frac{I\,x\,L\,x\,\rho\,x\,2}{k\,x\,Vd} \tag{10}$$

where A = cross-section (mm²), I= current (A), L = length (m), ρ = 0.0175 Ω·mm²/m (resistivity of copper), and Vd= allowable voltage drop (V) (Duffie and Beckman, 2013).

3. RESULTS AND DISCUSSION

The load estimation was carried out in three main areas within the Faculty of Engineering: the Metallurgical and Materials Engineering Department, the Metallurgical and Materials Engineering Laboratory, and the Petroleum Engineering Department. The equipment considered included lighting, 13A sockets, and ceiling fans, which were the major electrical loads in these locations. Each load category was analyzed based on the quantity, rated power, and load factor which helped in calculating the total power consumption in watts. The geographical location of the study area is shown in Figure 3.

Figure 3: Geographical location of the study area

The key specifications of the inverter are summarized in Table 1. The design parameters used for the battery design are presented in Table 2.

Table 1: Inverter specification

Parameter	Symbol	Value	Unit
Total Load Demand	P_{load}	76	kW
Safety factor	F_s	1.25	-
Inverter Capacity	P_{inv}	100	kW
System DC Voltage	V_{DC}	48	V
AC Output Voltage	V_{AC}	230/400	V
Frequency	f	50	Hz
Inverter Type	-	Pure Sine Wave	-
Effciency	η_{inv}	≥0.95	-

Table 2: Battery design parameters

Parameter	Symbol	Value	Unit
Daily Load Demand	E_{load}	608,000	Wh/day
Days of Autonomy	D_{aut}	1	days
System Voltage	V_{sys}	48	V
DOD	DOD	0.95	-
Battery Efficiency	η_{bat}	0.85	-

Substituting the values into Equation (4), the total required battery capacity was approximately 15,700Ah at 48V DC. Using selected 48V, 250Ah Felicity deep-cycle batteries, the number of parallel strings required was 63 units. The battery design summary is presented in Table 3. The selected protection and cable components are summarized in Table 4. The load audits are shown in Tables 5–7, with a summary in Table 8.

Table 3: Battery design summary

Parameter	Symbol	Value	Unit
Required Energy Storage	$E_{load} \times D_{aut}$	608,000	Wh
System Voltage	V_{sys}	48	V
Battery Capacity	C_{bat}	15,700	Ah
Battery Rating	-	48V, 250Ah	-
Battery Product	-	Felicity	-
Parallel Strings	$N_{parallel}$	63	-
Total Batteries	N_{total}	63	-
Recommended Type	-	Deep-cycle LiFePO4	-

Table 4: Summary of selected protection and cable components

Location	Device	Rating	Type/Specification	Installation Point
PV Combiner → MPPT	DC Breaker	50A	PV-rated	Between combiner and MPPT
Battery → Inverter	DC Breaker	200A	Battery-rated	On battery positive line
Inverter Output	AC Breaker	500A	AC MCB	Inverter output
PV Array	SPD (AC)	100–150 V DC, 10 kA	Type II	Combiner box
Battery Bank	SPD (AC)	Optional	Type II	Near battery
AC Distribution	SPD (AC)	230/275 V AC, 10–20 kA	Type II	Distribution board
PV Trunk Cable	Cable	$10mm^2$	PV-rated Copper	Combiner → MPPT
Battery Cable	Cable	$16mm^2$	Flexible Tinned Copper	MPPT → Battery

Table 5: Load audit for Metallurgical and Materials Engineering Department

S/N	MET and MAT Department	Quantity	Ratings	Load Factor	Consumption (W)
1	Lightings	172	40	0.9	6,192.00
2	13A Sockets	146	200	0.6	17,520.00
3	Fans	58	165	0.9	8,613.00
	Subtotal				32,325.00
	Load @ 220V				146.93A

Table 6: Load audit for Metallurgical and Materials Engineering Laboratory

S/N	MET and MAT Department	Quantity	Ratings	Load Factor	Consumption (W)
1	Lightings	154	40	0.9	5,544.00
2	13A Sockets	108	200	0.6	12,960.00
3	Fans	24	165	0.9	3,564.00
	Subtotal				22,068.00
	Load @ 220V				100.31A

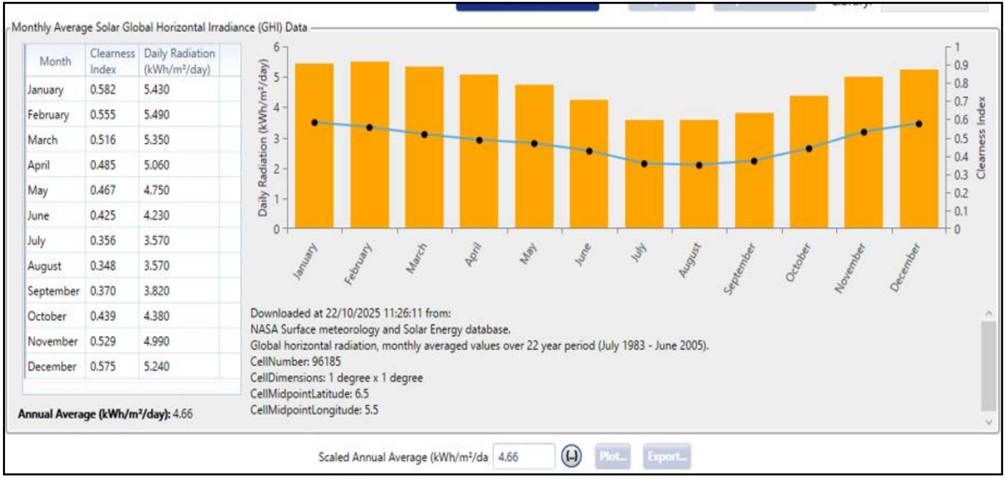
Table 7: Load audit for Petroleum Department

S/N	MET and MAT Department	Quantity	Ratings	Load Factor	Consumption (W)
1	Lightings	87	40	0.9	3,132.00
2	13A Sockets	144	200	0.6	13,680.00
3	Fans	30	165	0.9	4,455.00
	Subtotal				21,267.00
	Load @ 220V				96.67A

Table 8: Summary of the load analysis

S/N	Subtotal	Consumption (W)
1	Metallurgical and Materials Engineering Department	32,325.00
2	Metallurgical and Materials Engineering Laboratory	22,068.00
3	Petroleum Engineering Department	21,267.00
	Total	75,660.00

In designing the standalone PV system, the total power consumption of the selected load centre was calculated to be 76,000watts and its operation to be eight hours daily. The design of a reliable standalone PV system relied fundamentally on the monthly average solar global horizontal irradiance (GHI) data for the site (latitude 6.5° N, longitude 5.5° E) (Duffie and Beckman, 2013; Messenger and Ventre, 2010; Sharma and Chandel, 2013). The location demonstrates a strong overall resource with an annual average GHI of 4.66 kWh/m²/day, confirming system viability. The monthly average solar GHI data are shown in Figure 4.



Monthly Average Solar Global Horizontal Irradiance (GHI) Data

Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.582	5.430
February	0.555	5.490
March	0.516	5.350
April	0.485	5.060
May	0.467	4.750
June	0.425	4.230
July	0.356	3.570
August	0.348	3.570
September	0.370	3.820
October	0.439	4.380
November	0.529	4.990
December	0.575	5.240

Annual Average (kWh/m²/day): 4.66

Downloaded at 22/10/2025 11:26:11 from:
NASA Surface meteorology and Solar Energy database.
Global horizontal radiation, monthly averaged values over 22 year period (July 1983 - June 2005).
CellNumber: 96185
CellDimensions: 1 degree x 1 degree
CellMidpointLatitude: 6.5
CellMidpointLongitude: 5.5

Scaled Annual Average (kWh/m²/da 4.66

Figure 4: Monthly average solar GHI data

The critical design month was August, which registered the lowest daily radiation at 3.570 kWh/m²/day. This minimum peak sun hour value showed that the system battery could only be charged to 89.25% of the total capacity during this month, which was still good for the system. The standalone PV system was modeled using HOMER Pro software. The schematic diagram illustrating the configuration and energy flow for the selected load centre within the Faculty of Engineering is shown in Figure 5. On the DC side, the Jinko solar panels captured solar radiation and converted it into DC electricity, which was then stored in LGChem9.8 batteries for backup power, during periods were there was no sunlight. At the centre of the system, a converter transformed the stored DC energy into AC power, making it suitable for the use of standard electrical equipment. On the AC side, the generated power was supplied to the selected load centre.

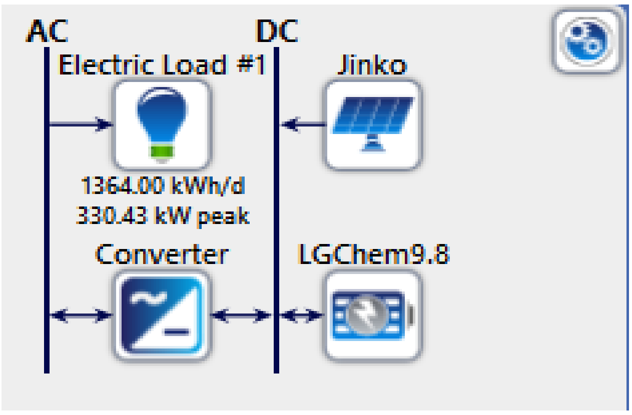


Figure 5: Schematic diagram

An economic evaluation was carried out to assess the capital cost, replacement cost, operation and maintenance cost, and salvage value of the major components. The cost breakdown summary is presented in Table 9.

Table 9: Cost breakdown summary

Component	Capital (₦)	Replacement (₦)	O and M (₦)	Salvage (₦)	Total (₦)
Jinko 500W Solar Panel	3,040,193.71	0.00	2,636,520.69	0.00	215,676,714.40
System Converter	46,625,459.89	7,711,841.58	17,379,918.34	-774,569.08	70,942,650.73
LGChem RESU10 [9.8kWh]	278,200,000.00	46,014,223.41	15,067,624.49	-4,621,619.17	334,660,228.73
Total System Cost	537,865,653.61	53,726,064.99	35,084,063.53	-5,396,188.26	621,279,593.87

The total system cost was estimated at ₦621,279,593.87, which included capital, operation and maintenance, and replacement costs after considering the salvage value.Therefore, we will have a total net present cost of ₦648,349,800.00, a levelized cost of energy (LCOE) of ₦143.47 per kilowatt-hour (kWh), and an operating cost of ₦12,171,830.00.

The payback period is the time required for the total savings generated by the solar system to equal the initial investment. The daily energy consumption was 608 kWh, giving an annual consumption of 221,920 kWh/year. At the grid electricity rate of ₦209.50/kWh, the annual cost per year was ₦46,520,240 and the payback period was determined from Equation (11), which was approximately 13.4 years.

$$Payback\ Period = \frac{\text{Total System Cost}}{\text{Annual Cost per year}} \tag{11}$$

The total 25-year savings amounted to ₦1,163 million which gave a net gain of ₦541,720,406.13. This represents a ROI of 187.19% over the project lifetime. The LCOE of ₦143.47/kWh was significantly lower than the utility grid supply rate of ₦209.50/kWh, which showed that this project was both sustainable and economically rewarding.

The results of this study are consistent with findings from comparable standalone PV system designs reported in the literature, while also presenting distinct characteristics attributable to the scale, location, and economic context of the study site.

A comparative summary of the present study against relevant standalone PV system designs reported in the literature is presented in Table 10.

Table : Comparison with related works

Reference	Location / institution	System scale	Daily energy demand	LCOE (₦/kWh)	Grid tariff (₦/kWh)	Payback period (years)	Battery Type	Simulation tool	Renewable fraction
Present Study	University of Benin (Multiple Depts.)	76 kW / 100 kW inverter	608 kWh/day	143.47	209.50	13.4	$LiFePO_4$	HOMER Pro	100%
Okedu & Uhunmwangho (2019)	University of Port Harcourt (Single dept.)	3.5 kW	Not reported	Not reported	Not reported	Not reported	Not specified	HOMER Pro	Not reported
Akinsanmi et al. (2023)	University broadcasting station	3.5 kVA	Not reported	Not reported	Not reported	Not reported	Not specified	Not specified	Not reported
Omorogiuwa et al. (2021)	University of Benin (Classrooms)	2.5 kW	Not reported	Not reported	Not reported	Not reported	Not specified	Not specified	Not reported
Okakwu (2025)	Olabisi Onabanjo University (Dept. level)	Not stated	Not reported	0.7859	206.80	Not reported	Not specified	Not specified	Not reported
Ishaq et al. (2013)	Bayero University Kano (10% campus)	Pilot scale	Not reported	Not reported	Not reported	3.6	Not specified (likely AGM)	Not specified	Not reported
Ikechukwu & Chibueze (2022)	Michael Okpara University	Not stated	Not reported	Relatively high	Not reported	Not reported	Not specified	HOMER Pro	100%
Hamza et al. (2018)	Nigerian context	Not reported	Not reported	Not reported	Not reported	Not reported	AGM deep-cycle	Not specified	Not reported
Ohanu et al. (2024)	Residential / estate-level	Not reported	Not reported	Not reported	Not reported	Not reported	$LiFePO_4$	Not specified	Not reported
Ohajianya (2023)	Estate-level	Not reported	Not reported	Not reported	Not reported	Not reported	$LiFePO_4$	HOMER Pro	Not reported

In terms of system scale, the 76 kW peak load and 608 kWh/day energy demand designed in this study represent a considerably larger institutional deployment than most comparable works. For instance, Okedu and Uhunmwangho (2019) designed a 3.5 kW standalone PV system for a single department at the University of Port Harcourt, while Akinsanmi et al. (2023) also targeted a 3.5 kVA system for a university broadcasting station. Similarly, Omorogiuwa et al. (2021) reported a 2.5 kW PV design for classrooms at the University of Benin—the same institution as the present study. The larger scale of the current design reflects the multi-departmental scope covering the Metallurgical and Materials Engineering Department, its laboratory, and the Petroleum Engineering Department.

Regarding economic performance, the LCOE of ₦143.47/kWh obtained in this study compares favourably with grid tariff benchmarks across the reviewed literature. Okakwu (2025) reported a cost of energy of ₦0.7859/kWh for a department-level PV system at Olabisi Onabanjo University—a figure that, while lower in absolute terms, was evaluated against a grid tariff of ₦206.80/kWh and reflected a smaller system scale. The present study's LCOE of ₦143.47/kWh versus the Band A tariff of ₦209.50/kWh similarly demonstrates a competitive margin, confirming the economic advantage of solar PV over grid electricity. Ishaq et al. (2013) reported a payback period of 3.6 years for a smaller pilot PV system at Bayero University Kano, which benefited from a limited scope covering only 10% of the campus load. The 13.4-year payback period in this study reflects the higher capital investment required by its larger scale, though it remains financially viable given the 25-year ROI of 187.19%.

With respect to simulation methodology, the use of HOMER Pro in this study aligns with the approach adopted by Okedu and Uhunmwangho (2019), Ikechukwu and Chibueze (2022), and Ohajianya (2023), all of whom employed the same tool for techno-economic optimization of standalone PV systems in Nigerian contexts. Ikechukwu and Chibueze (2022) achieved a 100% renewable energy fraction in their HOMER-optimized design for Michael Okpara University, though they reported a relatively high cost of energy. The present study similarly achieves a fully standalone configuration with no grid or diesel generator backup, relying entirely on PV and battery storage, which is consistent with the renewable-only designs reported in the literature.

The solar resource at the study site (annual average GHI of 4.66 kWh/m²/day, latitude 6.5°N) is in line with irradiance values reported for southern Nigerian locations in related studies. Okonkwo et al. (2021) confirmed that solar PV is the most feasible renewable source for institutional environments in southern Nigeria due to consistently high irradiance, a finding directly corroborated by the strong solar resource recorded at the University of Benin site. The critical design month of August (3.570 kWh/m²/day), however, reflects the impact of the rainy season on energy availability—a seasonal constraint that is shared across studies in similar climatic zones.

On battery storage design, the adoption of LiFePO4 deep-cycle batteries in this study reflects the current shift in the literature towards higher-efficiency, longer-life storage technologies. Ohanu et al. (2024) and Ohajianya (2023) also employed lithium-based storage in their residential and estate-level designs, noting that while upfront costs are higher, the superior cycle life and efficiency of lithium batteries improve long-term system economics. In contrast, earlier studies such as Hamza et al. (2018) used AGM deep-cycle batteries, which offer lower efficiency and shorter lifespans.

Overall, the results of this study reinforce the growing body of evidence that standalone PV systems are technically viable and economically competitive for institutional energy supply in Nigeria, particularly under the rising electricity tariff regime introduced by the April 2024 Band A tariff review (NERC, 2024). The scale of this design, combined with its favourable LCOE and strong long-term ROI, positions it as a replicable model for similar institutions seeking to reduce grid dependency and operational costs.

4. CONCLUSION

The design and analysis of the 76-kW standalone PV solar system proved that renewable energy technologies can effectively bridge the power supply gap in academic institutions. The results showed that solar energy is a valuable alternative to grid electricity and diesel-powered generators, offering substantial savings in operational costs, zero carbon emissions, and improved energy reliability. The system's short payback period and high return on investment demonstrated that the project is both sound technically and financially sustainable. It supports uninterrupted academic and research activities while reducing the institution's dependency on the national grid. The project also serves as a model for implementing similar renewable energy systems in other faculties and universities across Nigeria. Overall, this research confirms that solar power systems, when it is properly designed and maintained, it can serve as long-term, cost-effective, and environmentally friendly solutions for institutional energy needs.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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