World Journal of Advanced Engineering Technology and Sciences

eISSN: 2582-8266

Cross Ref DOI: 10.30574/wjaets

Journal homepage: https://wjaets.com/

(Research Article)

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Design and installation of 2kW solar photovoltaic system for sustainable power supply at Taraba state polytechnic (Siwes unit), Nigeria

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World Journal of Advanced Engineering Technology and Sciences, 2026, 19(02), 153-160

Publication history: Received on 12 April 2026; revised on 16 May 2026; accepted on 19 May 2026

Article DOI: https://doi.org/10.30574/wjaets.2026.19.2.0276

Abstract

Reliable electricity supply remains a major challenge in many Nigerian tertiary institutions.

This study presents the design, installation and performance assessment of a 2kW solar photovoltaic (PV) system implemented at the Students Industrial Work Experience Scheme (SIWES) unit of Taraba State Polytechnic, Nigeria. The objective was to provide a sustainable alternative to unreliable grid electricity and diesel generators. Load assessment, system sizing, component selection and installation procedures were carried out using standard PV design methods. The system consists of photovoltaic modules, charge controller, battery bank, inverter and protection devices. The estimated daily energy demand of the facility was approximately 6kWh. Based on local solar irradiance conditions, a 2kW PV array with battery storage was designed to meet the demand with additional reliability margin. Results from the installation demonstrate that the system is capable of meeting the office load requirements while reducing dependence on fossil fuel generators. The study demonstrates the technical feasibility of small-scale solar PV systems for institutional applications in Nigeria. The findings provide a practical framework for similar renewable energy installations in educational institutions and public facilities.

Keywords: Solar photovoltaic system; Renewable energy; System design; Rural electrification; Nigeria

1. Introduction

Energy access remains a critical factor for socio-economic development. In many parts of Nigeria, electricity supply from the national grid is unreliable, particularly in educational institutions located outside major urban centres. Renewable energy technologies, particularly solar photovoltaic systems, offer a viable solution to this challenge due to the high solar irradiance available across the country.

Solar photovoltaic systems convert solar radiation into electrical energy using semiconductor materials working in the principle of the block diagram in figure 1. A typical small-scale PV system in the range of 1–5kW are widely deployed to supply residential loads, reduce dependence on fossil fuels, and enhance energy security. A proper system design is therefore essential to ensure efficiency, cost-effectiveness, and long operational life. The design must consider load demand, solar resource availability, system losses, and component compatibility [1],[2].

Countries in the sub-Saharan Africa have long struggled with the issue of erratic electricity supply, a challenge that continues to hinder economic growth and national development. Nigeria in that region has a power generation capacity estimated at about 13,000 megawatts (MW) of installed capacity, with less than 6,000MW typically available to consumers remains grossly insufficient for its growing population and infrastructural demands [3]. This shortfall is

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particularly felt in the education sector, where access to stable electricity is critical for learning, research, digital innovation, and administrative which builds up the future of that region.

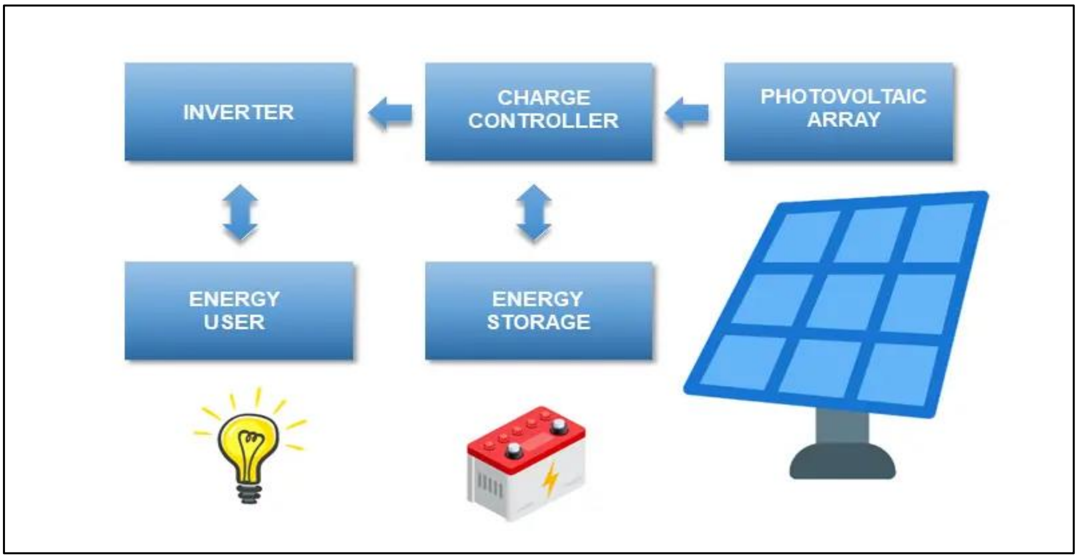

Figure 1 Block diagram of a solar system

2. Problem statement

Public institutions in the northeastern part of Nigeria like many public institutions across Nigeria, is plagued by persistent power supply challenges resulting from the country's inadequate and unreliable national electricity grid. The institution experiences frequent blackouts, voltage fluctuations, and prolonged outages that severely disrupt academic and administrative activities. These interruptions affect the functionality of laboratories, computer rooms, and internet-based learning platform resources that are critical to delivering quality education in today's digital age.

The cumulative effect of these energy challenges is a decline in academic productivity, administrative inefficiency, and a reduction in the overall quality of service delivery. Students and staff alike face difficulties in accessing power-dependent educational tools, conducting laboratory experiments, and performing ICT related tasks. These limitations compromise the Polytechnic's ability to meet modern educational standards and fully implement e-learning and research-based curricula.

3. Literature review

Previous studies have highlighted the growing importance of solar PV technology in developing countries. Solar photovoltaic systems convert solar radiation directly into electricity using semiconductor materials. According to renewable energy research, solar PV has become one of the fastest-growing sources of electricity generation globally [4].

Tertiary institutions across the country, including universities, polytechnics, and colleges of education, rely heavily on continuous power to facilitate laboratory experiments, operate ICT infrastructure, access online learning platforms, and maintain administrative services. Unfortunately, the national grid is plagued with frequent outages, voltage fluctuations, and limited coverage, especially in rural and semi-urban areas [5]. These power challenges have forced many institutions to depend on diesel-powered generators, which are not only expensive to operate and maintain but also environmentally unsustainable.

In Nigeria, several researchers have investigated the feasibility of solar PV installations for rural electrification and institutional power supply. Studies show that decentralized PV systems can significantly improve energy reliability while reducing greenhouse gas emissions. Recent work has also focused on hybrid systems, battery storage integration and cost optimization for small-scale installations. These studies demonstrate that properly designed PV systems can meet the energy demand of small offices and laboratories when supported with adequate storage [6],[7].

Solar energy presents a highly viable and sustainable alternative to conventional fossil-fuel-based power sources [8]. The steadily rising cost of diesel, coupled with its adverse environmental impacts has made generator-based electricity generation increasingly unsustainable for the various department of the institution. By leveraging solar photovoltaic (PV) technology, institutions can significantly reduce their carbon footprint, lower long term energy costs, and ensure a more stable and reliable power supply for critical academic and administrative functions.

Institutions located in northeastern part of Nigeria experiences recurrent power supply interruptions that disrupt academic and administrative activities. Laboratories are often non-functional during blackouts, ICT centers remain underutilized, and digital learning is frequently halted due to unstable power. These challenges undermine the quality of education and limit the Polytechnic's capacity to provide modern, technology-driven instruction and research. Moreover, the reliance on diesel generators results in high operational costs and carbon emissions, further straining the institution's already limited budget and contributing to environmental degradation.

Given the high solar radiation levels within this region, it receives an average solar radiation between 4.5 and 6.5kWh/m^2/day, this makes solar photovoltaic systems suitable for decentralized electricity generation. Several studies have demonstrated the potential of solar PV for powering small facilities such as offices, laboratories and residential buildings.

The proposed installation of a 2kW solar photovoltaic (PV) system is strategically designed to serve as a practical living laboratory for students in the department. It will provide students with experiential learning opportunities, bridging the gap between theoretical knowledge and real-world application. The practical exposure gained through interaction with the installed system will significantly enhance students understanding of renewable energy technologies, foster technical skills development, and position graduates to effectively contribute to the rapidly expanding renewable energy sector in Nigeria and globally

By embedding practical renewable energy infrastructure within the academic environment, the project not only strengthens the department capacity for technical training but also aligns with the national and global priorities for sustainable energy development and workforce readiness.

The deployment of a 2kW solar PV system aligns with Nigeria's commitment to achieving sustainable development and expanding its renewable energy capacity, as outlined in the nation's Renewable Energy Master Plan (REMP). This initiative not only supports the country's energy diversification strategy but also reinforces global efforts to mitigate climate change [9].

4. Methodology and implementation

The study followed a systematic design methodology consisting of load assessment, system sizing, component selection and installation.

Load assessment was conducted at the SIWES unit to determine the total daily energy demand of electrical appliances.

The major loads included computers, lighting systems, fans and office equipment.

System sizing involved determining the required photovoltaic array capacity, inverter rating, charge controller capacity and battery storage. Solar radiation data for the region were considered in estimating expected energy production. Standard photovoltaic design equations were applied to determine the required number of panels and battery capacity.

The installation included mounting the solar modules, wiring connections, inverter installation and safety protection devices.

4.1. Site Analysis and Load Assessment

A comprehensive site survey was conducted at the site of installation to assess its suitability for solar PV installation. This will involve determining the available solar insolation using a solarimeter to collect real-time data on solar irradiance levels and determining the system type which can either be an off-grid system that is independent, a hybrid system combining the grid and battery storage or the grid-tied that is connected to utility supply. This paper will focus primarily on an off-grid or hybrid configuration which required energy storage.

In addition, load analysers and data loggers will be used to evaluate the building's electrical consumption patterns over a typical 24-hour cycle, including peak demand and average load.

Table 1 Table of Load analysis

Load Name	Load Power (W)	Quantity	Total Power (W)	Hours/day	Total Energy (Wh/day)
Computers	120	5	600	6	3600
LED Lights	10	10	100	8	800
Ceiling Fans	70	3	210	6	1260
Printer	100	1	100	2	200
TOTAL			715		6000

The total daily energy demand for the system is 6000Wh/day (6kWh/day). The structural integrity of rooftops will be inspected to confirm compatibility with the weight and layout of solar panels and mounting structures. Environmental factors such as shading, roof orientation (azimuth), tilt angle, and weather conditions will be considered to optimize solar capture and system efficiency

4.2. System Design and Simulation

Based on the data obtained from the site analysis, system design will be carried out using specialized photovoltaic system design tools. The tools that will be employed to model a 2kW hybrid solar PV system includes solar panels, an inverter, deep-cycle batteries, a charge controller, and other balance-of-system (BoS) components.

4.3. Solar Resource Considerations

Solar panel output depends on peak sun hours (PSH).

Assume average:

$$PSH = 10\ hours/day$$

Accounting for system losses (temperature, wiring, inverter losses ≈ 25%):

$$Required\ PV\ energy = \frac{6000 \times 0.75}{10} = 450\ W$$

To ensure reliability and future expansion, design margin is added:

$$System\ rating \approx 500W$$

4.4. Panel Selection

Using 250W panels:

$$\frac{500}{250} = 2\ panels$$

Two panels of 250W would be sufficient to give us the required energy for the system but while considering room for expansion of the system, six panels of 300W was installed for future system capacity expansion.

The panel configuration will depend on the system voltage (12V, 24V, or 48V), for efficiency, a 48V system is always recommended.

4.5. Battery Bank design

The battery capacity must be designed in such a way to be able to supply sufficient energy during low sunlight periods, but northeast Nigeria have an all-year-round sunlight emission.

We assume a one-day battery autonomy, a 50% depth of discharge (DOD) and a system voltage of 48V.

$$Bettery\ capacity\ (Ah) = \frac{6000}{48 \times 0.5} = 250Ah$$

Thus, four 12V 250Ah batteries are connected in series or an equivalent lithium battery bank can be used.

4.6. Charge Controller Selection

In selecting a charge controller, the rating must exceed the panel current.

$$I = \frac{P}{V} = \frac{500}{12} \approx 42A$$

A safety margins is recommended for the charge controller, therefore a 60A MPPT charge controller is installed because the MPPT controllers increase energy harvest by optimizing panel voltage.

4.7. Inverter Sizing

The inverter majorly converts DC to AC supply. The estimation at peak load in simultaneous appliance demand $\approx 1500W$ and a surge load (motor startup) $\approx 2\ \times$.

Therefore, the recommended inverter rating for the system is a 3kVA pure sine wave inverter.

$$Required\ Inverter\ Power = \frac{715 \times 1.25}{0.9} = 993.1 \approx 1000W$$

4.8. Data Analysis

The solar system energy production can be estimated using the total system capacity

Total system capacity: 2kW

Daily energy generation: 2kW × 10 sun hours × 0.75 efficiency = 15kWh/day

Annual generation: 5475kWh

4.9. System design

The proposed system consists of a photovoltaic array rated at approximately 2 kW. The array converts solar radiation into direct current electricity which is regulated by a charge controller and stored in a battery bank for later use.

An inverter converts the stored DC energy into alternating current suitable for powering office equipment.

Protection devices including circuit breakers and fuses were incorporated to ensure safe operation.

The design considered factors such as peak sun hours, system losses, inverter efficiency and battery depth of discharge.

Installation site

Following the system design, the solar PV system was installed at the Students Industrial Work Experience Scheme (SIWES) Unit of Taraba State Polytechnic, Nigeria. The location experiences high solar radiation throughout most months of the year, making it suitable for photovoltaic electricity generation.

Solar modules were mounted on a roof structure with appropriate tilt angle facing true south (in the Northern Hemisphere) toward the equator with no shading during peak sun hours to maximize solar energy capture.

Electrical wiring and grounding were implemented according to standard safety practices (such as International Electrotechnical Commission (IEC) and Institute of Electrical and Electronics Engineers (IEEE) standards) ensuring correct cable size, incorporate grounding, surge protection, isolation switches and proper cable management [10],[11].

System commissioning involved configuring the hybrid inverter settings, synchronizing battery management parameters, and conducting operational tests to verify real-time energy flow, load balancing, and system integrity.

5. Results and discussion

The installed system was able to supply electricity to the SIWES office during working hours and provided backup energy during periods of grid outage. The PV system significantly reduced the reliance on diesel generators previously used to power the facility.

The performance of the system indicates that small-scale solar PV installations can effectively meet the electricity demand of institutional offices. The system also contributes to environmental sustainability by reducing carbon emissions associated with fossil fuel generation.

5.1. Expected Output

The daily energy production from the solar system is:

$$2kW \times 10\ hours = 20kWh/day\ (ideal)$$

And then after losses, it will be $\approx 17 - 18kWh/day$

The daily average power generation and usage for the solar power system after installation is monitored and recorded below in table 2 with the graphical representation in figure 2.

Table 2 2kW solar power generation and usage

Hour	Solar Generation (kW)	Usage (kW)
0	0	0.5
1	0	0.5
2	0	0.5
3	0	0.5
4	0	0.5
5	0	0.5
6	0	0.75
7	0.518	1
8	1	1.5
9	1.414	1.76
10	1.732	1.8
11	1.932	1.75
12	2	1.6
13	1.932	1.2
14	1.732	1
15	1.414	0.5
16	1	0.5
17	0.518	0.5
18	0	0.5
19	0	0.5

20	0	0.5
21	0	0.5
22	0	0.5
23	0	0.5

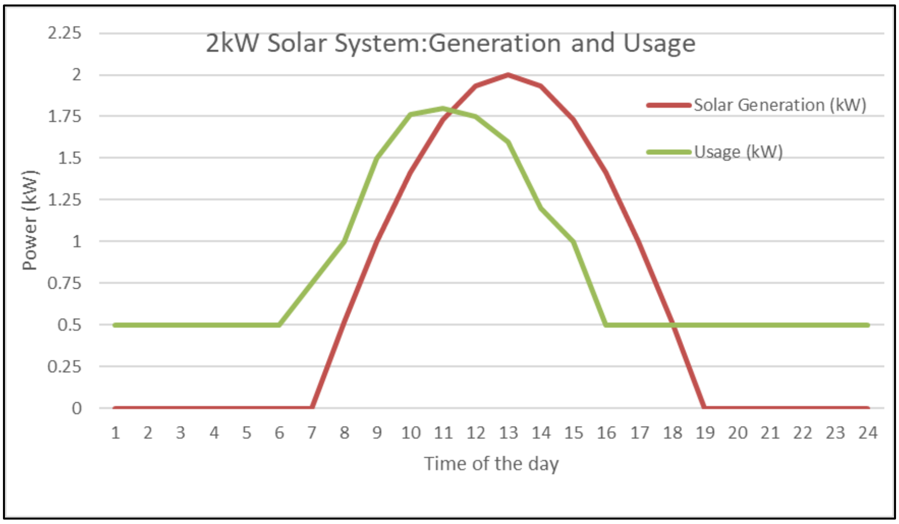

Figure 2 Graphical expression of 2kW Solar system power generation and usage

5.2. Environmental Impact

- Co₂ emissions reduction: 12tons/ year.
- Equivalent trees planted: 300 trees/ year.

Upon conclusion of this research, it is expected that there will be a Reduced use of diesel generators and grid power, Improved energy independence, learning and practical activities due to stable electricity, low operating cost with monthly energy savings estimated at 200l of diesel, a replicable and a scalable solar PV model.

It is expected that there will be a practical training platform for electrical and renewable energy students.

6. Conclusion

This study presented the design and installation of a 2kW solar photovoltaic system at the SIWES Unit of Taraba State Polytechnic. The results demonstrate that solar PV systems can provide reliable and sustainable electricity for small institutional facilities.

The implementation of similar systems across educational institutions in Nigeria could significantly improve energy access while supporting national renewable energy goals.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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