

# Design And Installation Of A Stand-Alone Photovoltaic System For A Sustainable Renewable Energy Solution In Nigerian Tertiary Institutions

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**Abstract:** In Nigeria power supply from the grid is unreliable and leads to incessant failure, this has necessitated the need for a large portion of the Nigerian population to relies on alternative sources, particularly self-generated power from diesel, petrol generators and renewable energy power like solar photovoltaic (PV) system. The aim of this work was to 'Design and Install a Stand-Alone Photovoltaic System for a Sustainable Renewable Energy Solution in Nigerian Tertiary Institutions'. The purpose of this work was to design and install a 2.5 kVA solar PV system in the Department of Mechanical Engineering of the Niger Delta University, Bayelsa State. The methodology involves: estimating the amount of solar energy available in Bayelsa State; estimating the power consumption of the department; sizing and selection of solar power components and also to carry out the installation and performance test of the solar power system. The data show that among the greatest solar insolation was measured during the dry sea, at 5.22 kWh/m<sup>2</sup>/day. The daily energy usage of 1,680kWh was computed by considering each of the appliances that will be powered by the PV system. The design estimate for the number of panels necessary yields 5.48 panels, which falls between 5 and 6 solar panels. Installing six panels suggests that the system will function better and the battery's lifespan will be extended. PV systems may be cost-effective because they have no running costs and little to no maintenance costs. Furthermore, it is an excellent option for isolated places that have no access to the grid.

**Keywords**— Lithium-ion battery, Inverter, Solar array, Charge controller, Irradiance, Photons, Cells.

## 1. INTRODUCTION

A solar photovoltaic (PV) system converts sunlight directly into electricity via solar panels which comprise of photovoltaic cells that release electron when targeted by photons (the photovoltaic effect), resulting in direct current (DC) which is converted to functional alternating current (AC) through an inverter for individuals, companies or the grid. Off-grid systems frequently include batteries for storage, resulting in a clean sustainable energy solution (Beshada & Waldenmaier, 2012)[1]. A PV system is made up of numerous components, such as solar panels that absorb and transform sunlight into electric power, an inverter that converts the output from direct to alternating voltage; mounting, wiring, and various electrical components to complete an operational system. Solar power systems are becoming increasingly popular in Nigeria as a way to provide electricity, especially in off-grid areas.

Nigeria has seen a significant increase in solar energy capacity, with a 2,700% increase from 2014 to 2023 (Shubham et al., 2025)[2]. These types of systems vary from small Solar Home Systems (SHS) powering individual homes to enormous mini-grids that serve entire towns (Ogbaka et al., 2021)[3]. They offer a sustainable alternative to traditional power sources and can lead to cost savings and energy independence. Interest in alternative

energy sources including renewable energy stems from growing oil prices, increased global energy demand, and

environmental concerns. West Africa accounts for around 25% of global major hydropower currently operational capacity (Muyiwa & Samuel, 2017)[4].

Nigeria has twenty-three (23) power-generating facilities connected to the national grid, with a combined capacity of 11,165.4 MW, which is much less than what is required to service basic home and commercial requirements (Olayinka, 2011)[5]. In 2012, the industry worked hard to distribute 5,000 MW, which was far short of the 40,000 MW required to meet the population's fundamental demands. This deficit is worsened by unscheduled load shedding, complete and total breakdowns of the system, and power outage. To meet demand, numerous families and companies purchase generating sets for powering their properties; during 2008, this form of energy generated 6,000 MW.

The Tertiary Education Trust Fund (TETFUND) has been an intervention agency established by Nigeria's federal government that offers additional assistance to all kinds of public tertiary institutions within Nigeria, with the primary goal of using funds in conjunction with management of projects to restore, consolidate, and revitalize tertiary education in the country. Part of TETFUND's mission is to address power supply concerns and

provide appropriate money to resolve them (Ndubizu et al., 2022)[6].

Ngala et al. (2013)[7], designed and modeled a PV solar farm to improve power system stability at the Federal University of Kashere in Gombe State, Nigeria. They asserted that solar energy involves radiant light and heat via the sun which has been

harnessed through a variety of ever-changing technologies. There is an urgent need to adopt the use of solar power for generating electricity in the science faculty building, as well as model the execution across other faculty buildings along with the University as a whole. This is to make sure that the electricity is not interrupted, as a blackout would impede the advancement of many critical pro-academic activities such as education, research, laboratory operations, and so on.

Oni and Bolaji (2021)[8], used two modeling tools to assess the financial and ecological advantages of establishing a PV system in DHA Lahore: The Systemic Advisor Model (SAM) as well as HOMER Pro. The report presents a detailed financial analysis through contrasting the PV system's parameters for performance across both models. SAM analysis finds a leveled cost of energy of 6.22 c/kWh notional and 2.95 c/kWh real, resulting in a \$1269 annual electricity bill reduction and a 2.7-year payback.

According to Abdelsalam (2023)[9], electricity is one of the most important basic necessities for every human being nowadays because it drives a country's socioeconomic activity. More than 1.3 billion people worldwide lack access to energy. The shortage of accessibility to electric power for this population created a significant gap in existing energy sources, affecting the development of that population, which is largely concentrated in isolated regions of developing countries. Electrical energy is a critical component for economic and advancement in every country. Despite the abundance of different energy sources (conventional and non-conventional) throughout the world, including in Nigeria, there are still access issues related to power generation, transportation, and distribution. These issues hamper a country's socioeconomic growth.

The aim of the work was to 'design and install a 2.5 kVA photovoltaic system for use in a tertiary institution. The specific objectives of this work are to: i) Carry out the estimation of solar insolation in Bayelsa State; ii) Carry out the estimation of power consumption in the Mechanical Engineering Department of NDU; iii) Carry out sizing and selection of solar power components and iv) Carry out installation and performance test of the solar power system. units (in parentheses). An exception would be the use of English units as identifiers in trade, such as "3.5-inch disk drive."

## 2.1 Schematic diagram

A schematic diagram of a PV system shown in Figure 1 illustrates how sunlight is converted into usable electricity and distributed to the load.

The main components of a PV system are:

- 1) PV Solar Panels: The primary source where solar cells absorb sunlight to generate DC electricity.
- 2) Charge Controller: Regulates the voltage and current coming from the panels to prevent overcharging batteries.
- 3) Battery Bank : Stores excess energy for use at night or during power outages, common in off-grid setups.
- 4) Inverter: Converts the DC power generated by panels or stored in batteries into AC for household appliances.
- 5) DC & AC Loads: Represents the final destination of the power, such as LED lights (DC) or refrigerators and TVs (AC).

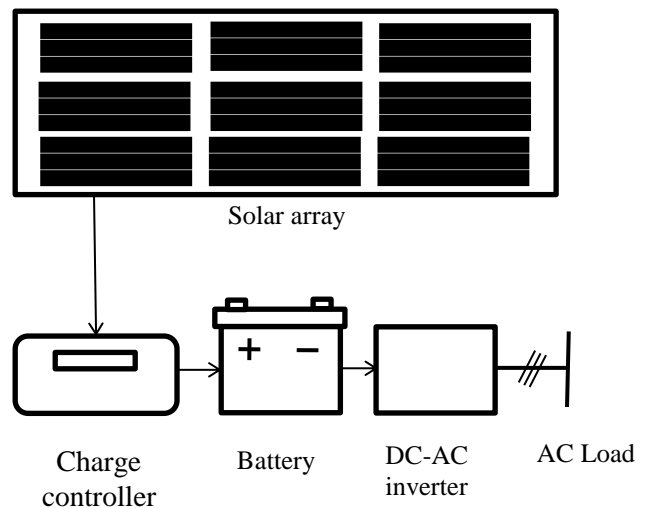


Figure 1: Solar PV system

## 2.2 Daily Sunshine Hours Availability in Bayelsa State, Nigeria

The average daily sun hour in Bayelsa State, Nigeria is approximately 6.4 hour, this figure can fluctuate between 4 and 8 hours depending on the specific month and season, with more sunshine during the dry season and less during the wet season. Sunshine hours vary by month, with an average of about 8 hours in January and decreasing to around 6 hours in June. The average daily sun hours for each month is provided in Table 1.

Table 1: Seasonal Breakdown of Average Daily Sun Hours

S/N	Month/Season	Average Daily Sun Hours (approx.)
1	May	5 – 8 hours
2	July	4 – 7 hours
3	August	3 – 7 hours
4	Dry season (Nov. – Jan)	Up to 6 – 7 hours

5	Wet season (Jun. – August)	As low as 3 hours
6	Annual average	5.4 hours

(Source: Nigerian Meteorological Centre, 2024)

### 2.3 Calculation of Solar Insolation

Solar insolation can be calculated by multiplying the solar constant (S) by the cosine of the zenith angle (Z), using the formula in equation 1

$$I = S \times \cos(Z) \quad (1)$$

where

I: Solar insolation (in Watts per square meter, (W/m<sup>2</sup>))

S: Solar constant (approximately. 1000 W/m<sup>2</sup>)

Z: Zenith angle, the angle between the sun and the vertical (overhead) position

For daily insolation as shown in equation 2

This formula accounts for the change in the sun's angle (h) throughout the day,

Where

RE: Earth's radius

φ: latitude

δ: solar declination

### 2.4 Estimation of Typical Domestic Power Consumption

A typical power consumption of various appliances is given in Table 2.

Table 2: Daily Energy Requirement

S/N	Electrical appliances	Power rating (W)	No. of units	Total load (W)
1	Fans	70	5	350
2	Electric bulbs	10	6	60
3	Projector	150	1	150

### 2.5 Design Calculations and Selection of the PV System Components

#### 1) Solar Panel Requirement

The calculations of the system panel size, power and quantity are given by equation 3, 4 and 5.

#### a) System Size SS (Wh)

$$SS = \frac{\text{Total Daily Energy Demand (Wh)}}{\text{Peak Sun Hours}} \times SE \quad (3)$$

SE: System efficiency

#### b) Solar Panel Power (SPP)

$$SPP = \frac{\text{battery current}}{\text{battery charging time}} \times \text{battery voltage} \quad (4)$$

#### c) Quantity of Solar Panel

$$QSP = \frac{\text{solar panel power}}{\text{solar panel size}} \quad (5)$$

#### 2) Battery Sizing

The required battery capacity is calculated based on the daily energy usage.

Equation 6 gives the sizing of the battery required.

#### 2) Battery Required (BR)

$$BR = \frac{\text{energy required}}{\text{efficiency}} \times \frac{1}{\text{DOD}} \times \frac{1}{V_{\text{sys}}} \times S_f \quad (6)$$

#### 3) Inverter Sizing and Selection

The inverter is calculated based on the capacity that matches the peak power demand as shown in equation 7.

$$\text{Inverter Size} = \text{Total running watt} \times \text{safety factor} \quad (7)$$

Safety factor = 1.25

#### 4) Solar Charge Controller Sizing and Selection

According to standard practice, the sizing of solar charge controller is to take the short circuit current (I<sub>sc</sub>) of the PV array, and multiply it by 1.3 as shown in equation 8

#### a) Charge Controller Rating (CCR)

$$\text{CCR} = \text{total short circuit current of pv array} \times 1.3 \quad (8)$$

#### b) Charge controller efficiency is given by equation 9

$$\eta_{\text{charge controller}} = \frac{\text{output power}}{\text{input power}} \times 100\% \quad (9)$$

### 2.6 Installation of the Solar PV System

Solar panel installation involves electrical work, roof mounting and potentially structural modifications, this must be done professionally to ensure safety and proper system performance.

Panel mounting: The solar panels are mounted outside the building in a location that receives maximum direct sunlight throughout the day, considering factors like tilt angle and potential obstructions. The panels are installed on the East of the roof in the Mechanical Engineering Department of the Niger Delta University, where the sun rises give the best sunlight in peak sunlight hours of the day as shown in Plate 1 while plate 2 shows the installation of the charge controller, battery and the inverter.



Plate 1: Installation of the solar panels

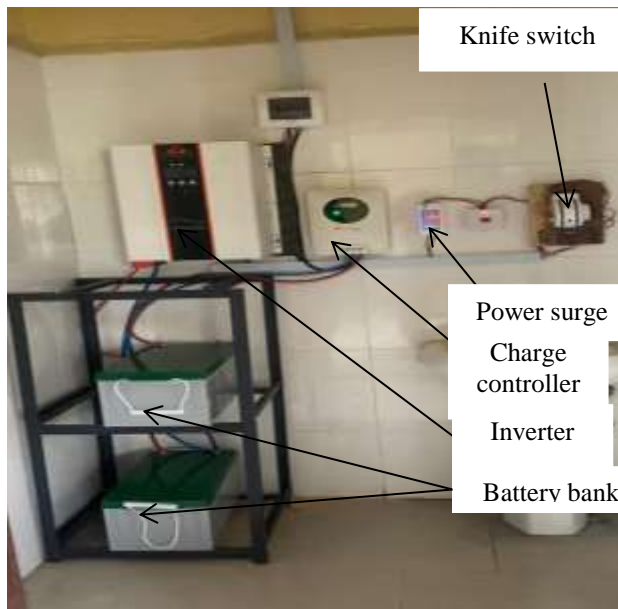


Plate 2: Installation of PV system components

### 2.7 Performance Testing

After installation, the entire system was tested under load to verify it meets the design specifications. This involves measuring the system's output, its lasting capacity when isolated from solar power, and its efficiency with different types of loads. Plate 3 shows the power load of the solar PV system in the Department of Mechanical Engineering, Niger Delta University.



Plate 3: Power load of the solar PV system

## 3 Results and Discussion

### 3.1 Result of Solar Insolation

The solar insolation of Bayelsa State is presented in Table 3

Table 3: Solar Insolation of Bayelsa State

S/N	Month	Solar insol. (kW)	Peak period (hours)	Solar insolation (kwh/m <sup>2</sup> /day)
1	Dry season (Nov. – Mar.)	1	5.22	5.22
2	Wet season (Jul. – Aug.)	1	4.16	4.16
3	Apr. – Jun.	1	4.97	4.97
4	Sep - oct	1	4.39	4.39

The solar energy output in Yenagoa shows promising results across all seasons. Interestingly, dry season months yield the highest energy output, followed closely by April – June months. This pattern suggests that the dry season, which typically occurs during these months, offers optimal conditions for solar energy production. The best tilt angle for fixed panel installations in Yenagoa, Bayelsa State, is 6 degrees south to enhance year-round solar production.

### 3.2 Result of the Estimation of Power Consumption

The total energy requirement per day given by equation 10 can be calculated using the data provided in Table 2.

1) Total energy requirement per day (TER/D)

$$TER/D = \sum \text{Total load of appliances} \times \text{backup time} \quad (10)$$

$$\text{Total load of appliances} = 350 + 60 + 150 = 560 \text{ W}$$

$$\text{Backup time} = 3 \text{ hrs/day}$$

hence,

$$\begin{aligned} \text{Total energy requirement per day} &= 560 \times 3 \\ &= 1680 \text{ Wh} \end{aligned}$$

The daily energy consumption of 1,680kWh is the primary factor determining the size of the solar panel system needed, as it directly correlates to the system's capacity and number of panels required.

### 3.3 Results of Components Sizing and Selection

Component sizing for a solar PV system involves calculating daily energy consumption, then sizing the solar panels, inverter, charge controller, and battery bank, with each calculation accounting for system losses and efficiency. Table 5 shows the results of the components sizing and specifications.

Table 5: Components sizing and specifications

S/N	Components	Specification
1	Solar panel	
	a) Specification	80 A/h, 24 V
	b) Power required	1,920 W
	c) Number of solar panels	6 panels
	d) Rated output power per panel	350 W
2	Battery	
	a) Battery capacity	24 V, 200 Ah
	b) Daily power consumption	1,680 Wh
	c) Depth of discharge of battery	50%
	d) Battery efficiency	80%
3	Inverter	
	a) AC power	193 W
	b) AC voltage	220 V
	c) DC power	226.812 W
	d) DC voltage	24.6 V
	e) inverter efficiency	85%
4	Charge controller	
	a) Power input	1,350 W
	b) Power output	1,215 W
	c) Efficiency	90%

The design calculations of the amount of panels necessary yields 5.48 panels, which falls between 5 and 6 solar panels; installing six panels improves system performance and battery life. Nevertheless, if 5 panels are employed, the system might not operate at all amid cloudy conditions, and the battery lifespan would be reduced. A pure sine wave inverter had been selected for this purpose because it provides more consistent power, cleaner power, as well as lower heat and noise to every appliances in homes and offices.

### 3.4 Performance Test

Performance analysis of a solar PV system involves evaluating its efficiency using the following metrics:

a) Performance Ratio (PR) is expressed by the formula in equation 11 indicating overall system efficiency and losses.

$$PR = \frac{\text{Actual energy output}}{\text{Theoretical maximum output}} = \frac{297.5}{350} = 85\% \quad (11)$$

An excellent, well-maintained system can have a PR of 80% to 90% or higher, but this is highly dependent on environmental and system-specific factors.

b) Capacity Utilization Factor (CUF) is expressed by equation 12.

$$CUF = \frac{\text{Actual energy generated (kWh)}}{\text{Rated capacity (kW)} \times \text{Time period}} \times 100\% \quad (12)$$

Time period = 24 hours  $\times$  7days = 168 hours  
 therefore,

$$CUF = \frac{1.68}{0.875 \times 168} \times 100\% = 11.45\%$$

c) Final Yield (YF): The ratio of the useful energy output from the inverter to the installed capacity of the PV array (kWh/kWp).

$$YF = \frac{\text{Total AC energy output (kWh)}}{\text{Installed DC capacity (kWp)}}$$

therefore

$$YF = \frac{1.68}{2.1} = 0.8 \text{ kWh/kWp}$$

Factors affecting performance of the solar PV system are solar irradiance, temperature, shading, installation specifics and system losses.

### 4 CONCLUSION

A 2.5 kW stand-alone solar PV system was designed and successfully installed to provide an alternative power supply for the Department of Mechanical Engineering. This provides a steady power supply especially during dry season when the sun intensity is usually very high, unlike the conventional power supply from the national grid which is unreliable in most part of the country. PV systems run silently without any moving parts or air pollution, and they can be cost-effective because they have no operating costs and little or no maintenance costs. Furthermore, it is an excellent option for isolated places that have no access with the grid.

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