International Journal of Information, Engineering & Technology
Volume 12, Issue 6, PP 124-133, ISSN: 2360-9194, May, 2024
DOI: 4272-1454-381-2169
Double Blind Peer Reviewed International Research Journal
Journal Series: Global Academic Research Consortium (garc)
arcnjournals@gmail.com
https://arcnjournals.org

Assessment of PV Stand-alone System for School of Engineering, Federal Polytechnic Monguno

A.B. Musa[1*], A.B. Muhammad, M.Shuwa and M.B Maina
[1]Department of Mechanical Engineering, School of Engineering, Federal Polytechnic Monguno, Borno State, Nigeria
[2]Department of Mechanical Engineering, Faculty of Engineering, University of Maiduguri, Borno State, Nigeria

Abstract: *This paper presents the development of an independent photovoltaic (PV) system tailored for the School of Engineering at the Federal Polytechnic Monguno in Nigeria. The system aims to fulfill the daily energy demand of the Department, which stands at 218.83 kWh. Key components of the system include a 42.5 kW PV array, a 48.1 kWh battery bank, 34 charge controllers, and a 4.9 kW inverter, totaling N60,605,000 in cost. The implementation of this system will offer the school a sustainable, reliable energy source, reducing their reliance on grid electricity and cutting down on energy expenses. Designed to align with local climate conditions and energy requirements, the PV array generates sufficient energy to meet daily demands, while the battery bank ensures uninterrupted power supply during periods without sunlight. The integration of charge controllers and inverters facilitates efficient energy management and conversion. Anticipated benefits include cost savings, enhanced energy reliability, environmental sustainability, and bolstered energy security. Professional installation and regular maintenance are planned to ensure optimal and safe system operation.*

Keywords: *Solar system; power supply; energy source; electricity*

1. Introduction

Nigeria is faced with energy crisis and this has been going on for the past five decades. The consequence of this is that many industrial and commercial activities are being affected negatively. There is a significant increase in the number of households, commercial ventures, and industries that consume electricity. This is due to the rapid increase in population and development in industrial and commercial activities. As a result, the demand for electricity has outstripped the supply capacity. The Council for Renewable Energy of Nigeria reports that power outages have caused a loss of about 126 billion naira annually. Firms spend about 25% to 40% of their initial investment on acquisition of facilities to enhance electricity supply (Nnanna & Uzorh, 2011). Aside this negative economic impact, this situation also exposes people to carbon emissions due to the frequent use of generators in different households and business enterprises.

Due to the increasing daily energy demand, it is imperative to explore additional and innovative energy sources to meet this growing need. Solar energy has emerged as one of the prevailing energy sources in today's world, gaining prominence over other forms of energy production on a global scale (Chauhan & Ghandat, 2015). Renewable energy sources have been given less priority compared to non-renewable energy sources in Nigeria. Despite the abundance of renewable energy resources, Nigeria is only able to generate less than 30 % (3,200 MW) effectively out of 12,500 MW of installed generating capacity. This fact is unsurprising considering the vast gas and petroleum resources available in Nigeria. Globally, the harmful effects of pollution and greenhouse gas emissions by non-renewable sources become clearer and the need for sustainable and clean energy takes on a more central role in the global energy conversion. However, all renewable energy sources have some drawbacks that depend on unpredictable factors such as weather and climatic conditions, but this weakness can be overcome by the complementary nature of both the wind and solar energy sources and this brings us to the development of hybrid solar-wind power plant concept (Dalwadi & Mehta, 2012).

Epileptic power supply and grid cut off is a commonplace in Maiduguri Metropolis, Borno State, Nigeria. For instance, the state capital experienced was completely cut off from the national grid for several months when insurgents attacked the Damaturu-Maiduguri Transmission Line in January 2021. To meet their energy needs, there is an increasing attention to the use of backup generators for self-generation and this has become the stopgap measure. These generators powered by diesel or petrol are deployed across every corner of the city at homes, schools, businesses and production sites, and are used for long hours in a day. Continual dependence on these backup generators does not come without revelatory monetary costs to the populace. The financial cost of operating petrol or diesel for long hours in a day is very high (Opeoluwa, 2021). Power outages can have a significant and detrimental impact on academic activities, including the School of Engineering at the Federal Polytechnic Monguno. Engineering education heavily depends on practical laboratory experiments. Power interruptions can halt ongoing experiments, potentially causing data loss and delaying coursework. Engineering laboratories require constant power for safety measures, such as ventilation, emergency lighting, and equipment shutdown protocols. Power outages can compromise safety. To address these challenges, the Federal Polytechnic Monguno may consider investing in backup power sources like utilization of renewable energy sources: solar, wind, biogas, tides, geothermal and water and uninterruptible power supplies (UPS) for critical areas such as laboratories and computer facilities. Developing contingency plans for dealing with power interruptions and promoting energy-efficient practices can also help minimize disruptions and ensure a more consistent learning and research environment in the School of Engineering. Solar energy and wind energy were shown to be clean, available and inexhaustible which are also eco- friendly, these characteristics have made them more attractive and the energy sector is focusing on how to use these sources on a larger scale

(Muhammad, et al., 2015). As a result, the aim of the study is to design a PV stand-alone system for department of Mechanical Engineering, School of Engineering, Federal Polytechnic Monguno.

2. Materials and Methods

2.1 Study Area

The site meteorological data is required to predict the performance of the PV system of the site under consideration. The School of Engineering is located on the main campus of the Federal Polytechnic Monguno (see Figure 1). The campus is located at the coordinates of 12.6831° N, 13.5873° E. The mean annual daily global solar radiation of the region is approximately 5.5 kWh/m^2/day and the mean annual sunshine hours is approximately 2800 hours. The mean yearly temperature and relative humidity of the region are 28°C and 45%, respectively. The specific potential of the region is characterized by the high intensity of solar radiation of 6.176kW/m^2/day and the average sunshine hour in the arid region is about 9 hours (Ngala, et al., 2013).

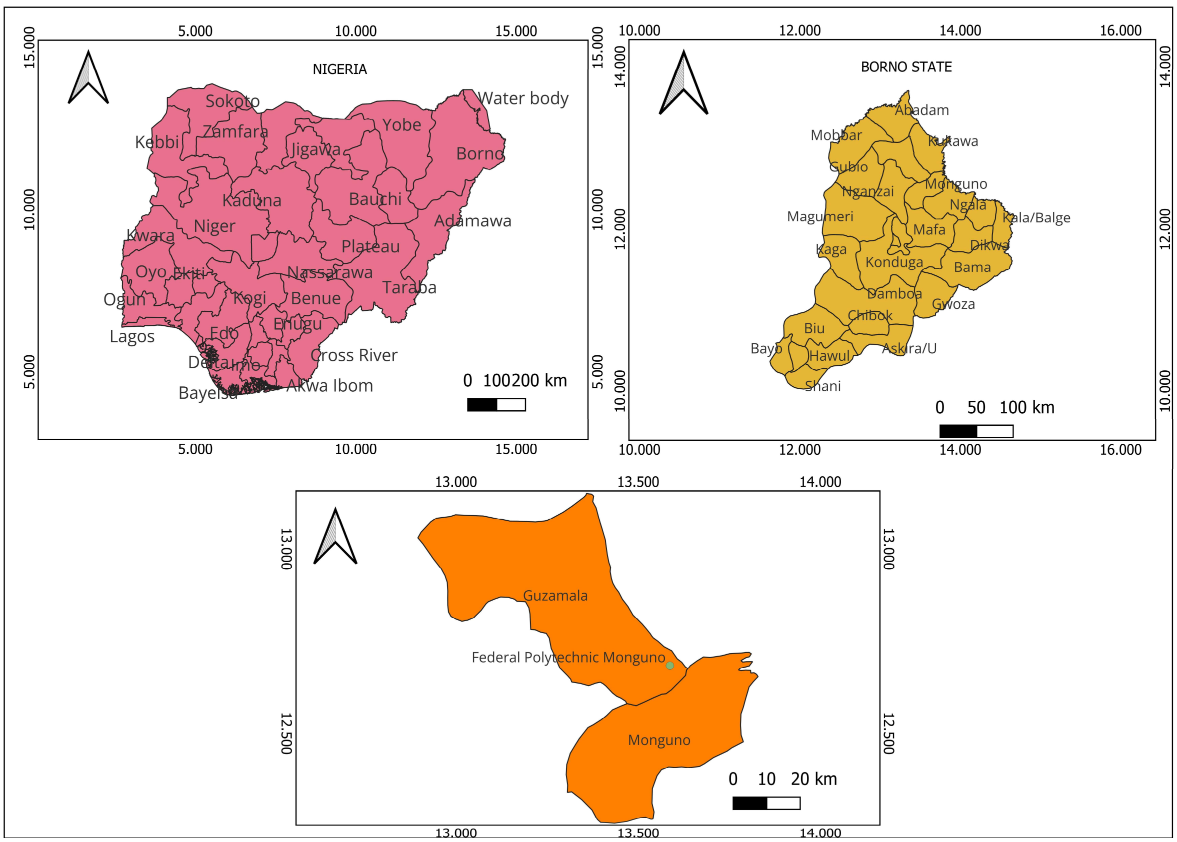

Figure 1: Map of the study area

2.2 System Design

2.2.1 Photovoltaic Array

The photovoltaic array is the heart, and therefore indispensable, component of any stand-alone PV system. It is responsible for the conversion of sunlight into electricity. The fundamental power conversion units are the solar cells, which typically produce less than 2 Watts of power. In order to produce increased power output, the solar cells are normally connected in series and parallel to form modules (Guda & Aliyu, 2015). Modules are then also connected in series and parallel architecture to form an array so as to meet the desired power output. The determination the size of the PV array is given in Table 1.

Table 1: PV Array Module specification

Model	**Sunshine solar AP-PM-265W**
Voltage at Pmax (V_{mp})	37.60V
Current at Pmax (I_{mp})	7.05 A
Short cirtuit current (I_{sc})	7.54 A
Maximum power (PMax)	265 W
Open circuit voltage (VOC)	46.25 V
Maximum System voltage	DC 1000V
Maximum series fuse rating	15A
Unit cost of a panel	N70, 000

The required daily energy demand can be obtained from Equation 1.

$$EN_{rd} = \frac{EN_d}{\lambda_b \lambda_i \lambda_c} \quad (1)$$

Where EN_{rd}= required daily energy demand, EN_d= load profile, λ_b= battery efficiency, λ_i= inverter efficiency, λ_i= charge controller efficiency.
The required average peak power (P_{peak}) can be obtained from Equation 2.

$$P_{peak} = \frac{EN_{rd}}{T_{sh}} \quad (2)$$

Where T_{sh} = Average sun hours for Monguno. The total DC Current (I_{DC}) can be obtained from Equation 3.

$$I_{DC} = \frac{P_{peak}}{V_{DC}} \quad (3)$$

Where V_{DC}=system voltage. The number of series modules (N_{sm}) can be obtained from Equation 4

$$N_{sm} = \frac{V_{DC}}{V_{rm}} \quad (3)$$

The number of parallel modules (N_{pm}) can be obtained from Equation 5.

$$N_{pm} = \frac{I_{DC}}{I_{rm}} \quad (5)$$

The total number of modules (N_{tm})can be obtained from Equation 6.

$$N_{tm} = N_{pm} \times N_{sm} \quad (6)$$

The total cost of array in Naira (A_{cost}) can be obtained from Equation 7.

$$A_{cost} = N_{tm} \times M_{cost} \tag{7}$$

where M_{cost}= cost of a single module

2.2.2 Storage Batteries

Storage batteries are employed to power devices when there is no sunlight available, and they are charged by the solar panel system during periods of intense solar radiation. It's advised to utilize deep-cycle lead-acid batteries in standalone solar power systems due to their superior performance, as suggested by Abu-Jasser (2010). The appropriate size of the battery bank can be determined using the guidelines provided in Table 2.

Table 2: Battery module specification

Model	Nexus solar C10 200Ah tabular battery
Days of Autonomy (D_{au})	4
Maximum allowable depth of discharge	90%
Capacity of battery	200Ah
Rated Dc voltage of battery	12V
Battery efficiency	85%
Battery cost	₦185,000

The Estimated Energy Storage (E_{Est}) can be obtained from Equation 8.

$$E_{Est} = E_d \times D_{aut} \tag{8}$$

where D_{aut}= number of days of autonomy. The safe energy storage (E_{safe}) can be obtained from Equation 9.

$$E_{safe} = \frac{E_{Est}}{D_{disch}} \tag{9}$$

Where D_{disch}= allowable depth of discharge. The total Capacity of Battery Bank (C_{th}) can be obtained from Equation 10.

$$C_{th} = \frac{E_{safe}}{V_h} \tag{10}$$

The total Number of Batteries in Bank (N_{th}) can be obtained from Equation 11.

$$N_{th} = \frac{C_{th}}{C_b} \tag{11}$$

Where C_b = capacity of battery. The Number of Batteries in Series (N_{sb}) can be obtained from Equation 12.

$$N_{sb} = \frac{V_{DC}}{V_b} \tag{12}$$

The number of Batteries in Parallel (N_{pb}) can be obtained from Equation 13.

$$N_{pb} = \frac{N_b}{N_{sb}} \tag{13}$$

Cost of battery bank (B_{bcoct}) can be obtained from Equation 14.

$$B_{bcoct} = N_{th} \times B_{cost} \tag{14}$$

2.2.3 Charge Controller

The charge controller, also referred to as a voltage regulator, manages the power distribution among the system components and the load, maintaining the system voltage within a designated range. Its primary role is to prevent both overcharging and over discharging of the storage battery. Table 3 provides guidance on determining the capacity of the charge controller.

Table 3: Charge controller specification

Model	**SCCM10048**
Maximum battery current (I_{cc})	45 A (DC)
Nominal system voltage of charge controller (V_{cc})	24 V
Product weight (kg)	5.1 Kg
Storage temperature	-40°C to 75°C
Charge controller efficiency	98%
Charge controller price	₦120,000

The required charge controller current (I_{rcc}) can be obtained from Equation 15

$$I_{rcc} = I_{sc} \times N_{pm} \times F_{safe} \tag{15}$$

Where I_{sc}= open circuit current, F_{safe} = safety factor. The number of charge controllers (N_{cc}) can be obtained from Equation 16.

$$N_{cc} = \frac{I_{rcc}}{I_{cc}} \tag{16}$$

The cost of charge controller can be obtained from Equation 17.

$$C_{tcost} = N_{cc} \times C_{cost} \tag{17}$$

2.2.4 Inverter

An inverter, which is also called a power conditioning system, is crucial for fulfilling the load demands. Since the power generated by the PV array is in direct current (DC) form, an inverter that converts dc to alternating current (AC) is required if the load needs an ac power supply. Table 4 provides steps on determining the capacity of the inverter.

Table 4: Inverter sizing and specification

Model	**FL-IVPS1512-1500VA**
DC voltage	48 V
AC voltage	220 V
Inverter Power (P_i)	5000 W
Nominal output frequency	50Hz / 60 Hz ±0.3Hz
Inverter efficiency	95%
Unit inverter cost (I_{cost})	₦460,000

The power of non-inductive Appliances (P_{nia}) can be obtained from Equation 18.

$$P_{nia} = \sum_{i=1}^{1} P_{niai} \tag{18}$$

The power of inductive appliances scaled by 3 ($3P_{ia}$) is given by the Equation 19.

$$3P_{ia} = 3\sum_{k=1}^{1} P_{iak} \qquad (19)$$

The total inverter power (P_i)can be obtained from Equation 20.

$$P_i = 1.25(P_{nia} + 3P_{ia}) \qquad (20)$$

2.2.5 System Wiring Size

The design of a PV power system is incomplete until the correct size and type of cable is selected for wiring the components together (Guda & Aliyu, 2015). The following cables links in the PV system must be appropriately selected:

i. The dc cable from the PV array to the battery bank through the charge controller.

ii. The ac cable from the inverter to the distribution board (DB) of the residence. The system wiring and specification is given in Table 5.

Table 5: Specification and system wiring size

Selected Cable Size and Type	3x35 mm^2 insulated flexible copper cable
Selected Cable Size and Type	3x4 mm^2 insulated flexible copper cable

The cable current rating (I_{cab}) can be obtained from Equation 21.

$$I_{cab} = I_{rcc} \times I_{sc} \times N_{pm} \times F_{safe} \qquad (21)$$

The current produced by inverter output can be obtained from Equation 22.

$$I_{oi} = \frac{P_i}{V_{oi} \times pf} \qquad (16)$$

2.3 Load Specification

2.3.1 Data Collection

An energy audit was conducted by walking through the Department to collect information on the power ratings of electrical equipment and appliances that were in use. The total energy consumption of each device was calculated by multiplying its power rating by the total number of hours it was in use. However, the actual energy consumed might be less than what was indicated by the manufacturer's power rating, which Could be up to 50-70% lower, as reported by (Joseph, et al. 2004). Alternatively, actual energy consumption could be higher than expected if the equipment was used for longer than the officially organized duration, as pointed out by Bordass (2001). In addition, large variable loads for cooling (AC) and hot water requirements are normally not part of the PV design, in most cases they are eliminated or operated from another power source (Guda & Aliyu, 2015).

3.3.2 Load

Loads are the power consuming units of the PV system. There are two types of loads (AC and DC) depending on the type of electrical power that they require for their operation. For the purpose of this design, electrical loads may be broadly classified as either resistive or inductive. Resistive loads do not have any significant inrush of current when energized. Examples of resistive loads include light bulbs and electric heaters. Inductive loads on the other hand, pull a large amount of current (in rush) when first energized and examples include transformers, electric motors and coils. The load profile for the Department of Mechanical Engineering, is determined by itemizing all the residence appliances with their corresponding power ratings and hours of operation to obtain the total average energy demand in watt-hours (residence load profile) per day as indicated in Table 6.

Table 6: Load profile of the Department of Mechanical Engineering

S/N	Appliance	Quantity	Load Power (Watt)	Operational hours per Day	Energy consumption per Day
1	Laptop	94	65	5	6500
2	Printer	10	720	0.5	3600
3	Ceiling fan	23	70	7	11270
4	Photocopy machine	4	800	0.5	1600
5	Cell phone	25	2.5	4	250
6	Lighting bulb	28	9	7	1764
7	Fridge	5	90	0.5	225
	Total		1768.5		173171

3. Results and Discussion

The result of the design from Table 7 shows that we selected the Sunshine solar AP-PM-265W panels for their reliability and efficiency. The total cost of array is estimated at ₦11, 480,000. These panels are expected to efficiently harness solar energy and convert it into electricity.

Table 7: Determined parameters and size of PV array (Sunshine solar AP-PM-265W)

Determined parameters	**Unit**	**Value of parameter**
Required Daily Energy Demand	KWh/Day	218.83
Average Peak Power	W	27805.59
Total DC Current	A	1158.57
Number of Series Modules	-	1
Number of Parallel Modules	-	164
Total Number of Modules	-	164
Total Cost of Array	₦	11, 480,000

To store excess energy for use during night time or cloudy days, the Nexus solar c10 200Ah tabular batteries were chosen as shown in table 8. The estimated energy storage was calculated to be

519.513 kWh, ensuring a reliable energy reserve. The total cost of the battery bank is ₦44, 585,000, reflecting the importance of energy storage in this off-grid system.

Table 8: Determined size of the Battery Bank and cost estimate (Nexus solar c10 200Ah tabular battery)

Determined parameters	Unit	Value of parameter
Estimated Energy Storage	KWh	519.513
Safe Energy Storage	KWh	577.24
Total Capacity of Battery Bank	Ah	48103.06
Total Number of Batteries in Bank	---	241
Number of Batteries in Series	---	2
Number of Batteries in Parallel	---	121
Cost of Battery Bank in Naira	₦	44,585,000

Efficient charge controllers are essential for regulating the flow of electricity from the PV array to the battery bank. We determined that 34 SCCM10048 charge controllers were needed as shown in Table 9 to manage the energy flow effectively, with a Cost of Charge Controllers of ₦4, 080,000.

Table 9: Charge Controller Sizing and Cost Estimate (SCCM10048)

Determined parameters	Unit	Value of parameter
Required Charge Controller Current	A	1545.7
Number of Charge Controllers	---	34
Cost of Charge Controllers	₦	4,080,000

The Total Inverter Power was calculated to be 4936.5 W, considering the power requirements of both non-inductive and inductive appliances. We selected an inverter with this capacity, and the Cost of Inverter was estimated at N460,000 as shown in table 10. Inverters are critical for converting stored DC energy into usable AC power for the Department’s devices.

Table 10: Inverter sizing procedure and cost estimate

Determined parameters	Unit	Value of parameter
Power of Non-inductive Appliances	W	166.5
Power of Inductive Appliances Scaled by 3	W	4770
Total Inverter Power	W	4936.5
Cost of Inverter in Naira	₦	460,000

4. Conclusion

In conclusion, the results of the design of the standalone PV system for the Department of Mechanical Engineering, School of Engineering at the Federal Polytechnic Monguno demonstrate a thorough and well-planned approach to meeting the energy needs of the facility. The selection of appropriate components, including the PV array, battery bank, charge controllers, and inverters, has been carefully considered to ensure compatibility and efficiency. Additionally, the cost estimates provide valuable information for budget planning and procurement, ensuring the successful implementation of the PV system to support the Department's energy requirements. This project serves as a model for sustainable energy solutions in regions with abundant sunlight, contributing to energy independence and environmental conservation.

Overall, the results of the study show that a 42.5 kW PV solar power system with 164 solar panels, 34 charge controllers, 241 batteries, and a 4.9 kW inverter would be sufficient to meet the daily energy demand of the Department of Mechanical Engineering, School of Engineering. The total cost of the system would be approximately ₦60, 125,000.

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