Univerzitet u Beogradu	University of Belgrade
Poljoprivredni fakultet	Faculty of Agriculture
Institut za poljoprivrednu tehniku	Institute of Agricultural Engineering
Naučni časopis	Scientific Journal
POLJOPRIVREDNA TEHNIKA	***AGRICULTURAL ENGINEERING***
Godina L	Year L
Broj 3, 2025.	No. 3, 2025.
Strane: 27 – 45	pp. 27 – 45

Original Scientific paper
Originalni naučni rad
DOI: 10.5937/POLJTEH2503027J

DESIGN MODELLING OF STAND-ALONE SOLAR PHOTOVOLTAIC SYSTEMS FOR A THREE-ROOM BUNGALOW IN UMUAHIA CITY, ABIA STATE, NIGERIA

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Abstract: This study looks at the layout, operation, and feasibility of a stand-alone solar photovoltaic (PV) system for a three-room bungalow in Umuahia, Abia State, Nigeria. The solar panel, charge controller, battery, and inverter are the primary design elements of the solar photovoltaic system. It was found that the daily energy usage was 21 kWh, which translated into a total wattage of 2.4 kW. Twenty (20) solar panels with a 435 W capacity each were chosen for the SPV system. The actual current amperage of the solar charge controller was 102 A, and its power rating was 8.7 kW, as per the SPV design. The solar system was anticipated to require twelve (12) batteries, and the SPV system design chose one battery with a 250 Ah capacity. It was discovered that the inverter's input power was 3.2 kVA. The maximum DC direct current and voltage are 192 A and 24 V, respectively.

The maximum alternating current and voltage for the SPV system were 11 A and 230 V, respectively. The highest number of solar panels was observed in August, when the sun's output was at its lowest.

Since the estimated actual energy output per day (21 kWh) and monthly average output energy (630 kWh) were below the monthly minimum (1620 kWh) and maximum theoretical output energy (5980 kWh), the solar photovoltaic energy will meet the energy requirement of the three-room bungalow.

The solar performance ratio came out to be 85.5%.

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Key words: *Design; solar energy photovoltaic system; module, charge controller, battery; inverter; output power; solar radiation; performance ratio.*

INTRODUCTION

Urban areas in Abia State, Nigeria, are grappling with significant energy challenges. The electricity supply in these regions is characterized by its unreliability, high cost, and frequent outages, which significantly impact residential buildings. Despite efforts to enhance electricity consumption, urbanization, and economic growth [26]. The allocation of electricity remains skewed, and about 91% of the electricity supply is directed to urban areas, leaving rural areas with minimal access due to constraints in the electrical grid [38]. This disparity exacerbates the difficulties faced by both urban and rural dwellers in accessing stable and reliable electricity [20]. Consequently, approximately 80% of those connected to the grid resort to using fossil fuel generators as an alternative source of electricity [29], highlighting the persistent imbalance between electricity demand and supply. The exploration of renewable energy sources has been proposed as a potential solution to the inadequate electricity supply in Nigerian urban center's, including Abia State [35]. Research has been conducted to assess how households adapt to insufficient electricity supply, their use of renewable energy facilities, and their perceptions of renewable energy sources [35]. However, the use of solar energy has become an alternative solution to free from irregular power supply to commercial buildings in Umuahia city [34]. In addition, the transition to renewable energy sources is challenged by infrastructure development, cost implications, and policy frameworks. The historical context of Nigeria's electricity supply sector reveals persistent issues such as gas shortages, power asset insecurity, high operational costs, and insufficient capital for consistent performance [30]. These challenges hinder the efficiency and reliability of the sector, affecting both urban and rural areas. Privatization of Nigeria's energy sector has not fully addressed these issues, with investors facing numerous obstacles that impede sector growth and development [30]. There is a clear need for modernization and prioritization of the electricity sector to ensure a sustainable and reliable supply [20]. Innovative approaches, including the use of machine learning for modelling electricity supply dynamics, have been explored to enhance understanding and address challenges within the sector [3]. Electricity is a critical driver of economic growth in developing countries, emphasizing the importance of ensuring an efficient and sustainable supply [3]. Despite these efforts, the gap between electricity demand and supply persists, necessitating innovative solutions to meet the growing energy needs of urban areas like Abia State.

In urban Abia State, the inadequate electricity supply impacts not only residential buildings but also small-scale industries, where reliable power is essential for operations [33]. Cost-effective solutions such as stand-alone power generation systems have been proposed to address the electricity needs of these industries, highlighting the importance of consistent and affordable power sources [33]. Additionally, the design and evaluation of solar electricity systems for administrative buildings reflect ongoing efforts to enhance energy access and reliability in urban settings [19]. Compounding these challenges are issues such as electricity theft, distribution inefficiencies, and inadequate power generation [28]. These long-standing issues have led to frequent outages and unreliable electricity supply for urban residents [28].

The ramifications are extensive, affecting not only residential buildings but also businesses, industries, and overall economic productivity in urban areas. In conclusion, the background of electricity supply in urban Abia State, Nigeria, underscores a complex interplay of factors, including disparities in supply allocation, reliance on alternative power sources, exploration of renewable energy, infrastructure limitations, and policy challenges. Addressing these issues requires a multifaceted approach that integrates renewable energy solutions, infrastructure development, policy reforms, and investment in modernising the electricity sector to ensure a sustainable, reliable, and cost-effective electricity supply for residential buildings and urban areas. Solar photovoltaic systems are based on the direct conversion of solar irradiation into electrical energy through the photovoltaic (PV) method [8]. These systems are composed of micro- and nanostructured electrodes that facilitate solar energy conversion, either in the form of photovoltaics or direct photo-electrolysis cells [41]. The principles and composition of solar photovoltaic systems have been applied in various settings, including maritime vessels, buildings, and apartment buildings, to harness renewable energy for power generation [24,25,36]. Additionally, research has focused on optimising the performance of photovoltaic solar electric power through intelligent systems using light-dependent resistors and servo motors for automatic solar tracking [14]. Furthermore, numerical simulations have been conducted to study heat transfer in concentrating solar photovoltaic systems, aiming to enhance their efficiency [39]. The integration of solar photovoltaic systems with thermoelectric generators has also been explored to improve energy generation and efficiency [23]. Moreover, the application of solar thermal power generation technology has been investigated as a complementary approach to solar photovoltaic systems, contributing to the overall development of renewable energy technologies [22]. Solar photovoltaic systems harness sunlight and convert it into electricity through the photovoltaic effect, where photovoltaic cells, typically made of semiconductor materials, directly convert solar radiation into electrical energy [37]. When sunlight strikes the photovoltaic cells, the energy of the photons in the sunlight is transferred to the electrons in the semiconductor material, causing the electrons to be expelled and creating an imbalance of charge that results in the generation of an electric current [37]. This direct conversion of sunlight into electricity is a fundamental principle of solar photovoltaic systems and has been the focus of technological advancements aimed at increasing efficiency and performance. One significant technological advancement in the field of solar photovoltaics is the development of solar cells with higher conversion efficiencies. Research has shown that increasing the efficiency of solar cells is crucial for improving the overall performance of photovoltaic systems [13].

This has led to the exploration of innovative approaches, such as splitting sunlight into spectral bands and directing each band to a dedicated solar cell with an appropriate energy bandgap to maximize conversion efficiency [13]. Additionally, advancements in semiconductor materials and the design of photovoltaic cells have contributed to improving the efficiency of solar energy conversion [37]. Another area of technological advancement in solar photovoltaic systems is the development of intelligent systems for solar tracking and energy extraction improvement. Research has focused on the implementation of automatic solar tracking systems using light-dependent resistors and servo motors to optimize the energy produced from photovoltaic cells, making the overall systems more efficient and cost-effective [32].

Furthermore, the reconfiguration strategies for electrical PV arrays have been investigated to improve energy extraction and adapt to external operating conditions, enhancing the overall performance of grid-connected PV systems [32]. Moreover, the integration of solar photovoltaic systems with grid-connected inverters and the development of advanced control techniques have been significant technological advancements in the field. These advancements aim to improve the power quality, efficiency, and reliability of grid-connected photovoltaic systems, contributing to their seamless integration with existing electrical distribution systems [9,16].

[1] emphasizes the broad applicability of solar energy in Nigeria, spanning across agriculture, engineering, medical sciences, power generation, and recreation, showcasing its versatility and potential impact on various sectors. [12] delves into the adoption of renewable energy and green technology in Nigeria, specifically noting the increasing trend of solar PV adoption in cities like Kano, where 60% of adopters installed their systems between 2015 and 2016, indicating a growing interest in solar energy among residents. [2] focused on the determinants of solar energy use by small and medium enterprises in Lagos State, pointing out that factors such as the cost of grid electricity, poor utility services, and government policies significantly influence the adoption of solar energy as an alternative power source. Moreover, [27] have explored the geospatial assessment of suitable sites for utility-scale solar PV farms in Nigeria, revealing the untapped potential for solar energy generation in the country, with locations capable of producing significant amounts of solar electricity annually. [31] conducted a viability assessment of a grid-integrated solar PV system in Idofian, Nigeria, showcasing practical applications of solar technology in enhancing electric power supply in specific regions. These studies collectively underscore the growing interest and practical implementations of solar energy solutions in Nigeria, particularly in urban areas where the demand for reliable and sustainable power sources is increasing. Furthermore, the challenges and serviceability of solar power in Nigeria have been addressed by [40], who suggest solutions to the energy crisis by incorporating solar energy into the country's energy mix, highlighting the potential gains that Nigeria can achieve through solar energy integration. Factors influencing solar PV utilization among residents in specific urban areas like Akure have also been investigated by [18], shedding light on the determinants that impact the adoption and utilization of solar energy technologies in different regions. These studies provide valuable insights into the practical implications, challenges, and opportunities associated with solar energy adoption in residential buildings within urban areas of Nigeria. In conclusion, recent research on solar energy in residential buildings in urban areas of Nigeria reflects a growing trend towards the adoption and integration of solar power as a viable solution to the country's energy challenges.

From exploring the diverse applications of solar energy to assessing the factors influencing its adoption and conducting geospatial assessments for optimal solar PV farm locations, these studies collectively contribute to the body of knowledge aimed at promoting sustainable and renewable energy practices in Nigeria's urban settings. As the country continues to grapple with energy issues, the findings from these studies serve as valuable resources for policymakers, urban planners, and stakeholders seeking to leverage solar energy for a more sustainable and resilient energy future in Nigeria.

MATERIAL AND METHODS

Geographical and Climatic Profile

Figure 1 shows that Umuahia, the capital city of Abia State, Nigeria, is approximately 5.53°N latitude and 7.49°E longitude. Its location close to the equator endows it with a tropical rainforest climate characterised by substantial rainfall and consistently high temperatures. The average annual temperature in Umuahia ranges from 24°C to 28°C, with relative humidity levels often exceeding 80%. This climate profile is essential for understanding the region's solar energy potential. The significant solar irradiance levels in Umuahia make it an advantageous area for solar photovoltaic (PV) applications. High temperatures and humidity must be factored into the design and efficiency calculations for solar PV systems to ensure they can withstand local climatic conditions.

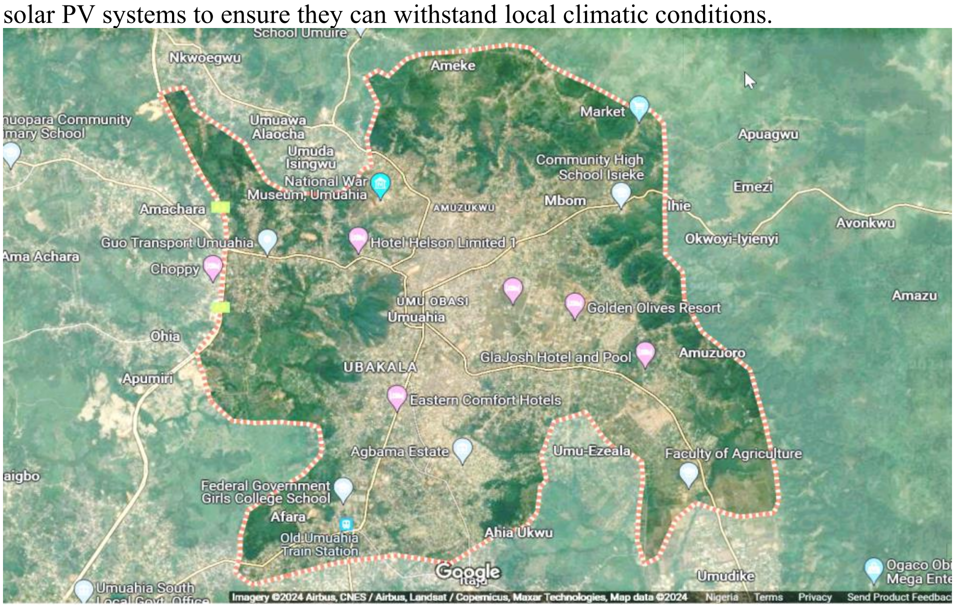

Figure 1. Map showing Umuahia, Abia State, Nigeria

Demography of Umuahia

Umuahia, the capital city of Abia State, Nigeria, exhibits a complex demographic profile crucial for understanding the potential implementation of hybrid solar photovoltaic systems in residential areas.

The city is divided into two Local Government Areas (LGAs): Umuahia North and Umuahia South, comprising urban and rural communities [15]. The population of Umuahia is characterized by a high proportion of individuals in their reproductive years. According to a study on socioeconomic factors in Umuahia, the majority of women of childbearing age fall within the 25-29 age group (30.0%), followed by those under 25 (23.8%) and those aged 30-34 (21.9%) [15]. This age distribution suggests a relatively young population, which could affect energy consumption patterns and the adoption of solar technologies. Education levels in Umuahia are notably high, with 45.2% of the studied population having tertiary education and 44.0% having secondary education [15].

This high level of education could facilitate residents' understanding and acceptance of solar energy technologies.

The Methodology

In this section, we will give a technical overview of the system components. Also, design methods and mathematical calculations for sizing these components are presented [4].

The solar photovoltaic system's primary parts are:

(1) Solar PV panel array, (2) Batteries, (3) Solar charge controllers (SCC), and
(4) Inverter

PV System Design

The following steps conduct the system design calculations:

(1) Estimating the total load of all appliances in the three-room bungalow.

(2) Sizing the solar PV system. This includes selecting the type of PV panels, number of panels, arrangement of PV array, and the orientation of panels (i.e. tilt angle).

(3) Sizing the battery bank, (4) Sizing the Inverters, (5) Sizing the solar charge controller.

Estimating Total Daily Load

The total load includes all electrical appliances, such as lighting and equipment, that are used daily in the bungalow. The average daily solar insolation is mainly taken as 5 kW/m^2/day.

PV array Sizing:

Standard Testing Conditions (STC) involve 1 kW/m^2 of irradiation and a PV cell temperature of 25°C.

The Exact Design -Method 1.

The PV panel is characterized by its average efficiency, ηp, which is a function of average panel temperature as given by [4], and is presented in eqn. (1).

$$\eta_p = \eta_r \left(1 - \beta_p \left(T_p - T_r\right)\right) \quad \text{.....................................(1)}$$

where η_r Is the panel efficiency at T_r. T_r Is the reference temperature (25 ^{0}C). β_p It Is the temperature coefficient for module efficiency. The value of η_r and β_p Appendix A shows 20.1% and -0.38%/K, respectively.

T_P is a function of the ambient temperature, as stated by [4], and is given in eqn. (2).

$$T_p = T_a + \left(219 + 832\bar{k}\right)\left(\frac{NOCT - 20}{800}\right) \quad \text{..............................(2)}$$

Where $\bar{k}$ It is the clearness index. It ranges from 0.3 for cloudy areas to 0.8 for sunny areas. T_a is the ambient temperature of the solar panel (30 ^{o}C). NOCT is the Nominal operating cell temperature (45 ^{o}C).

The total area S_A Of the PV panel array can be presented in Eq. (3) as stated by [10]

$$S_A = \frac{E_p}{\eta_p\, G} = \frac{E_p^{!}}{\eta_c \eta_b \eta_p\, G} \quad \text{..............................(3)}$$

Where: E_p Does the PV array provide the energy?

$E_p^!$Is the energy provided by the PV array after the battery bank

($E_p^!$Equals the daily load demand 20,690 Wh).

G is the daily irradiance (5kWh/m^2/day),$\eta_{c,}$ $\eta_b$and η_i Are the efficiencies of the controller, batteries, and inverter, respectively (η_c = 95%; η_b = 90%; η_i = 96%). The area of a SunPower 435W single solar panel S_p is equal to 2.067m ×1.046m =2.16 m^2 as in Appendix A.

The number of SPV panels as stated by [4] is given in Eqn. (4)

$$N_{p1} = S_A/S_p \quad \text{.................................(4)}$$

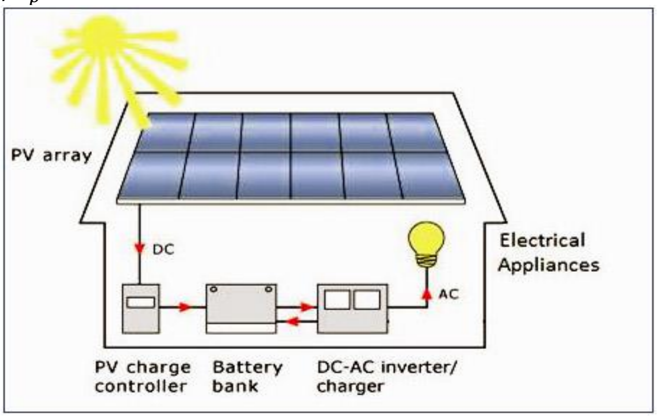

Fig. 2. Solar PV system design.

The size of the solar panel and module estimation for method 2.

The total electricity demand of the bungalow in Umuahia from the gathered data in Table 1 is used to determine the size of the PV system (in Wp).

The SPV Module Peak Wattage Estimation (Wp) according to [5] is presented in Eqn. (5).

The total watt hour (Energy) using battery efficiency (η_b) of 90%.

$$\text{Module Peak wattage (Wp)} = \frac{\Sigma(\text{Daily Energy Demand Wh})}{PSH \times \eta_b} \quad \text{.......(5)}$$

Where PSH is peak sunshine hours and η_bIs the battery efficiency.

$$\text{Number of Modules or panels} = N_{P2} = \frac{\text{SPV Module Wattage Estimation}}{\text{Value of Each Panel}} \quad \text{.......(6)}$$

The SunPower panel of 435 W was selected for the solar design.

The size of the solar panel for method 3

The total appliances used per day = energy consumed per day (ECPD) = **20,690** Wh/day

Total PV panels energy needed (TPEN)

$$TPEN = ECPD \times ELS \quad \text{......................(7)}$$

Total Peak Wattage (Wp) of PV panel capacity needed (PWSP)= PGF x WSP

The total number of solar panels (N_{P3}) according to [21] is given in Eqn. (8).

$$N_{P3} = \frac{\text{Energy watt hour per day x Energy loss in the system}}{Panel\ generation\ factor\ (PGF)\times Wattage\ of\ single\ panel(WSP)} = \frac{TPEN}{PWSP} \quad \ldots\ldots\ldots..(8)$$

The energy loss in the solar system (ELS)= 1.3

Panel generation factor (PGF) = 3.596 for Nigeria.
The minimum clearance (distance) required between each row of panels is represented by distance (d) as seen in Plate 1 and Omni calculator calculates the angles in Fig. 3.

This distance can be calculated using the equation. (9) as stated by [4].

$$d = h[(\sin(180^o - \beta - \gamma_s))/(sin\gamma_s)] \quad \ldots\ldots\ldots\ldots\ldots..(9)$$

Determining this clearance requires the angle γ_s Of the sun at midday (12 Noon) in the shortest day of the year 2023 (i.e., 21st December). The angle (γ_s) is 60.27 ° (see Fig. 3). The collector height used is ≈ 1.8 m. The tilt angle used is β = 15 °.

Hence, the distance is ≈ 2m.

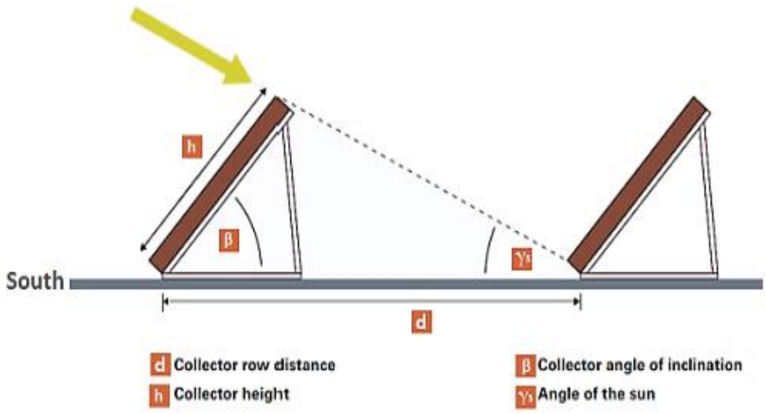

Plate 1. Clearance Between Collectors or PV Panels Rows

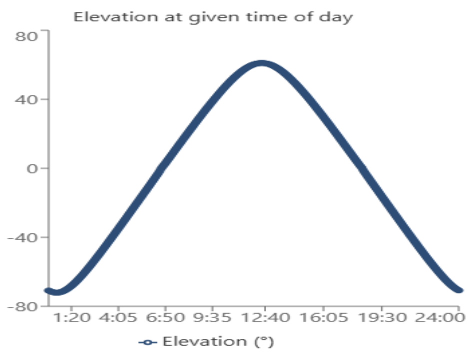

Fig.3. The angle γ_s of the sun at midday in the shortest day of the year 2023 (21st December) for the Umuahia area (by Solar elevation angle Omni calculator).

The battery sizing of the solar panel (Method 1), according to [11], is presented in Eqn. (10).

The actual battery capacity = $B_{C1} = \frac{\text{Total Energy (Wh)}}{\text{Depth of Discharge} \times \text{System Volt}}$ …...(10)

The system voltage used for this system is 12 volts and 0.5 depth of discharge.

Number of batteries = $N_{B1} = \frac{\text{Actual Battery Capacity}}{\text{Value of Each Piece}}$

The battery sizing of the solar panel (Method 2) as given by [21] is presented in Eqn. (11).

The actual battery capacity = $\frac{\text{Total Energy (Wh) x Days of autonomy}}{\text{Battery loss x Depth of Discharge} \times \text{System Volt}}$ …… (11)

The nominal battery voltage is 12 volts; Battery loss is 0.85; depth of discharge is 0.6, and Battery days of autonomy is 2.

Number of batteries = $N_{B2} = \frac{\text{Actual Battery Capacity}}{\text{Value of Each Piece}}$ …………….(12)

Since 250Ah batteries can be easily found in the market and have more storage capacity, the final calculation is selected to determine the actual number of batteries for the solar panel design.

The Charge Controller Selection for Method 1.

To obtain the needed charge controller as given by [7] is represented in equation (13) Solar Charge Controller (SCC_{1cu}) is given below.

$SCC_{1cu} = \frac{\text{Total Wattage}}{\text{Voltage}}$ ………………………(13)

The system voltage used is 24 V.

The Solar charge controller sizing: Method 2, according to [21], is given in eqn. (14).

According to standard practice, a solar charge controller sizing is to take the short circuit current (Isc =6.43 A from Appendix A) of the PV array and multiply it by the Energy panel loss (ELS-1.3).

Solar charge controller rating (SCC_{2cu})

SCC_{2cu} = panels in Series array x total short circuit current of PV array x 1.3 …...(14)

The solar charge controller sizing SCC_3cu for Method 3.

The charge controller's rated power is greater than the maximum power the PV array could produce, since a safety factor 1.3 is used.

The following are the steps to determine the SCC_{3cu} by [4] presented in Eqn. (15).

(1). Wattage of the PV array = (number of PV panels)×(PV panel rated power) .....(15)

(2). Rated voltage of SCC_{3v} = (number of panels in series) × (Voc of panel) ………(16)

(3) Rated current of SCC_{3cu}=(number of strings of panels)×(Isc of PV panel)×(safety factor)

3.2.9. The Inverter Capacity Selection for the solar panel as stated by [7;8] is in eqn. (17) for Method 1.

Therefore, Input Power = $\frac{\text{Output Power}}{\text{Efficiency of inverter } (\eta_i)}$ ………………………(17)

The inverter sizing for Method 2 as presented by [21] is stated in Eqn. (18).

For safety, the inverter should be considered 25-30% bigger than the total wattage of all appliances.

$$Inverter\ Input\ power = 30\% \times total\ wattage + total\ wattage \quad ......(18)$$

3.3.1. The Output Power from the SPV system according to [5]is given in Eqn. (19).

$$P_{out} = G \times S_{tp} \times \eta_{sys} \quad ....(19)$$

Where (S_{tp}) Is the area of the SPV panel array, (η_{sys}) Is the panel system efficiency; G is the solar radiation.

The maximum direct/alternating current and voltage of wire of the solar photovoltaic system as given by [6,7] are represented in eqns. (20) and (21).

$$\text{The maximum direct current (DC)} = \frac{Max\ DC\ wattage\ (W)/module\ \ wattage}{DC\ system\ voltage\ (V)} \quad .....(20)$$

The maximum DC voltage and current are 24V and 711.6A.

$$\text{The maximum alternating current (AC)} = \frac{Max\ AC\ wattage\ (W)/Total\ \ wattage}{AC\ system\ voltage\ (V)} .....(21)$$

The maximum AC voltage and current are 230V and 44.7 A.

Solar Performance Ratio (SPR%) according to [16;17;18] is stated in equation (23)

$$SPR(\%) = \frac{Actual\ Energy\ Output}{Theoretical\ Maximum\ Energy\ Output} \times 100 \quad ....(22)$$

$$SPR(\%) = \frac{Daily\ Energy\ Demand\ (Wh)}{total\ solar\ area\ (m^2) \times panel\ efficiency(\eta_r) \times Insolation\ \ G\ (\frac{kwh}{m^2})} \times 100 \quad ......(23)$$

G Solar insolation on tilted panel (kWh/m^2/day):

η_r = Total solar panel efficiency (%).

S_A =Total solar area (m^2).

Table 1**.** Energy Consumption of a Typical Three-room Bungalow in Umuahia City.

S/N	Appliances	Power Rating (W)	Quantity	Total Power (W)	Hours of Daily Usage	Daily Energy Consumption (Wh)
1	LED light bulb	5	10	50	12	600
2	Fan	75	5	375	7	2625
3	Refrigerator	760	1	760	12	9120
4	Television	110	2	220	5	1100
5	Air conditioner	1,20	1	1,200	5	6000
6	Sound system	250	1	250	3	750
7	DSTV	20	2	40	5	200
8	Phones	1	5	5	5	25
9	Power Bank	18	3	54	5	270
Total				2,439		20,690

Table 2. Weather parameters from the Meteorological Unit at NRCRI.

Daily average solar radiation and ambient temperature from January to December. 2023, and Theoretical Output Power				
S/N	Solar Radiation (G_r) (W/m^2)	Ambient temperature (Ta) (°C)	Theoretical Monthly Output Energy (kWh)	Actual Monthly Output Energy (kWh)
1	5192	27.61	4626	642
2	6508	29.76	5980	580
3	4588	28.94	4001	642
4	4384	28.38	4149	621
5	3536	28.74	3040	642
6	2512	27.41	2258	621
7	2432	27.11	2202	642
8	1780	27.24	1620	642
9	2300	27	2060	621
10	2528	27.76	2295	642
11	4120	27.32	3677	621
12	4980	29.11	4611	642

Table 3. The Characteristics of The SPV System

Solar Photovoltaic Panel Capacity	435 W
Type	E 20/435 Solar Panel
Manufacturer	SunPower
Model	SPR-435NE-WHT-D
Number of Modules	20
Efficiency	20%
Nominal operating cell temperature	45%
Temperature coefficient	-0.38%/K
Solar collector area	2.16 m^2

RESULTS AND DISCUSSION

The design results from the SPV system.

Table 1 shows the collected data from a bungalow in Umuahia city, while Table 4 reveals the actual results from the design analysis of the proposed solar photovoltaic system. The environmental weather parameters, such as solar radiation and ambient temperature, were collected from the meteorology unit inside the National Root Crops Research Institute (NRCRI) for 12 months in 2023

Table 4. shows the results from the proposed SPV design of a three-room bungalow in Umuahia.

	Total energy in Watt-hours (kWh)	Wattage (kW)	Number of solar components	Capac. of the single product (W)	Input power (kW)	Ampere (A)	Volt (V)	Efficien. (η %)
Solar panel	21	2.4	20, 19 & 18	435				20

Contin. Table 4.								
Charge contr.		9				428,75 &75	684.8	95
Battery (Ah)			12& 27	250				90
Inverter					2.5 &3.2			96
Max. DC.						192	24	
Max. AC.						11	230	
SPR								85.5

Discussion of results in Table 3.

Table 1 displays the three-room bungalow's energy estimate, while Table 4 summarizes the determined design outcomes. The analysis found various energy-consuming appliances with different power ratings and operating times. It was determined that the facility (solar panel) would use 20,690 Wh (21 kWh) of electricity each day.

The estimated module peak power for the solar photovoltaic panel was 4,598 W (4.6 kW). For the SPV design, a SunPower single solar panel with a wattage of 435 W was chosen. The results of methods 1, 2, and 3 showed 20, 19, and 18 solar panels, respectively. Method 1 was chosen to design the solar photovoltaic system since it has the most panels (20). The efficiency of the solar panels was found to be 20%. Methods 1, 2, and 3 all yielded solar charge controller amperages of 102 A, 41.8 A, and 33.1 A, respectively. For the SPV system design, the best result (102 A) from approach 1 was chosen. 8.7 kW was determined to be the solar charge controller's wattage. There were 12 batteries from method 1 and 27 batteries from method 2.

Even though procedure 2 produced the maximum number of batteries, the number of batteries from method 1 (12) was chosen for the SPV system design. While method 2's outcome is required in situations when high energy storage is crucial, method 1's result is economically feasible. The 250 Ah single solar lithium-ion battery was used for the design because it was readily available and had a good product storage capacity. The inverter's input power was 2.5 kW for method 1 and 3.2 kW for method 2. Method 2 is used to design the SPV system because it has the largest inverter input power (3.2 kW). The suggested SPV system has a maximum direct current (DC) of 192 A and a maximum voltage of 24V. The SPV system's maximum voltage and alternating current (AC) were 230V and 11 A, respectively. The solar system's solar performance ratio was 85.5%, indicating that it effectively transforms sunlight or solar irradiance into electrical power. Table 1 shows that appliances with large energy demands, including air-conditioners and refrigerators, dominate consumption. Their respective energy demands are 6,000 and 9,120 Wh. Other appliances, including fans, TVs, and LED lightbulbs, use less energy on their own, but they add to the total demand because of their longer use hours. However, it can usually be optional. The availability of solar energy is aligned with the peak energy demand, which usually happens during the day when operating activities are at their highest [4;10;11;12].

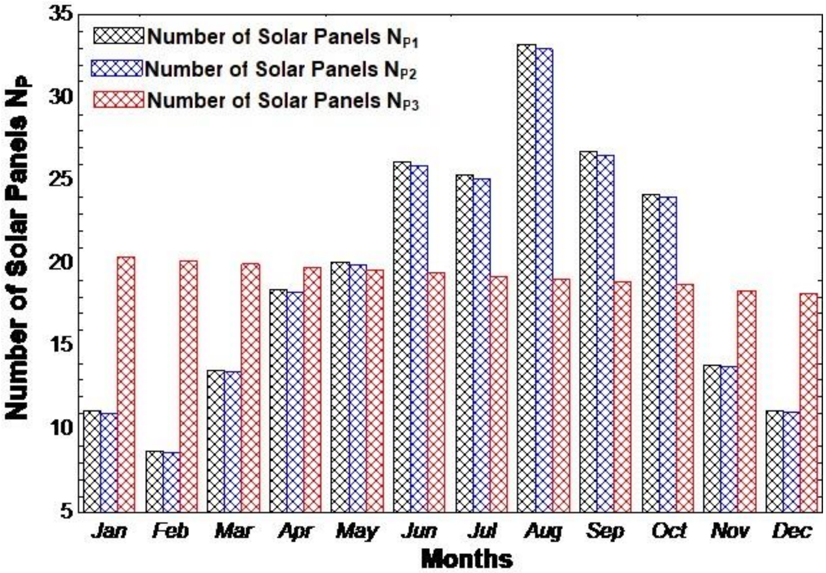

Fig. 4. The Number of panels of the solar photovoltaic system

Fig. 4 shows the number of solar panels calculated from three methods, and they were simulated by the Engineering Equation Solver (EES) software. The total summation, average, minimum, and maximum number of panels (N_{P1}) from method 1 are 232.7, 19.39, 6.7, and 33.24, respectively. The number of solar panels obtained from method 2 was also simulated, and the total summation, average, minimum, and maximum number of panels (N_{P2}) are 230'6, 19.22, 8.625, and 32.94, respectively.

The total summation, average, minimum, and maximum number of solar panels (N_{P3}) from method 3 are 232.2, 18.31, 16.89, and 20.41, respectively. It can be observed that method 1 has the highest average number of solar panels of 19.39, and it is approximated to be 20 for the SPV design, which aligns with the findings of **[4,5].** Another observation from the bar chart is that the results from method 3 are higher from January to April and become lowest from May to October. The results from methods (1 and 2) are higher during the rainy season, while method 3 is higher in the dry season. It can also be seen in the bar chart that during the rainy season, there is always poor solar radiation or sunshine; therefore, a greater number of solar panels will be needed, as observed in August, which recorded 125.7 maximum number of solar panels.

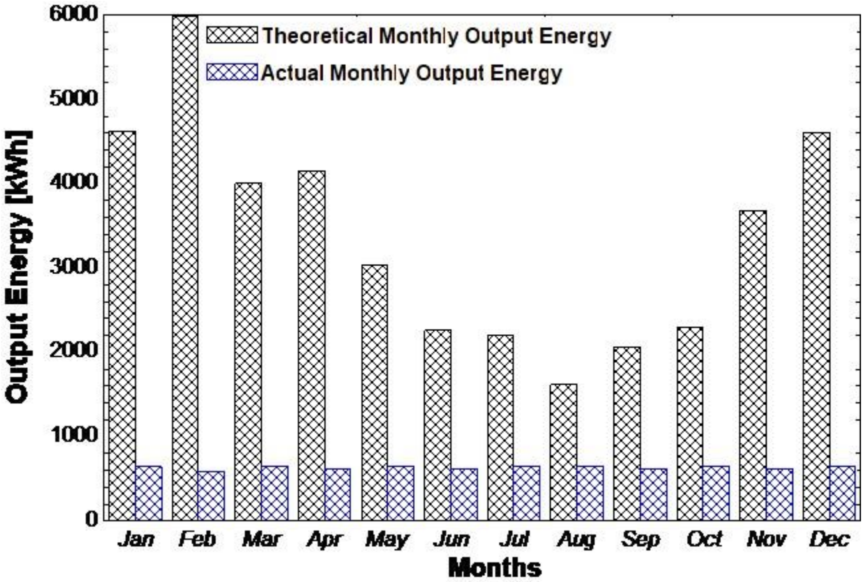

Fig.5. The output power from the solar photovoltaic system

Fig. 5 is the output energy from the solar photovoltaic system. The summation, average, minimum, and maximum theoretical output energy were 40519, 3377, 1620, and 5980 kWh, respectively, while the summation, average, minimum, and maximum actual output energy from the appliances were 7558, 630, 580, and 642 kWh, respectively. The overall theoretical energy generated by the system in a year is 40519 kWh, with an average monthly energy production of 3377 kWh. Since the estimated actual energy output per day (21 kWh) and monthly average output energy (630 kWh) were below the monthly minimum (1620 kWh) and maximum theoretical output energy (5980 kWh), the solar photovoltaic energy will meet the energy requirement of the three-room bungalow.

The findings regarding the highest output energy in February and the lowest in August are consistent with [11,19,28]'s observations.

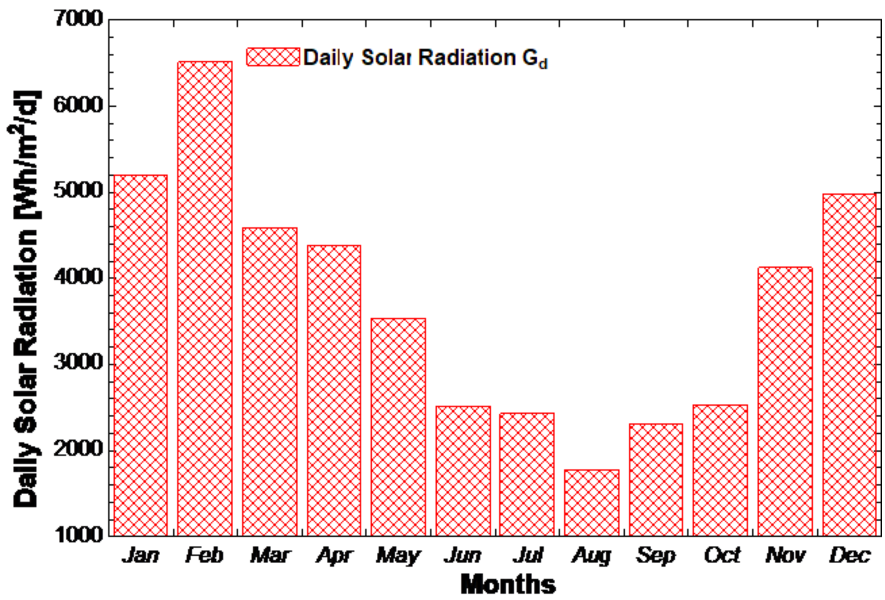

Fig.6. The solar radiation for the photovoltaic system

The solar radiation bar chart for the photovoltaic system from January to December 2023 is shown in Fig. 6. Solar radiation was at its lowest in August and then rose from September to February. In August, the average, minimum, and maximum sun radiation summary were 44300, 1780, 800, and 3800, respectively. In February, the average, minimum, and maximum solar radiation summary were 162700, 6508, 3200, and 8400, respectively. Accordingly, February 2023 saw the highest amount of solar radiation in Umuahia, Abia State, while [8,9,10] found a similar outcome. This is because February had the highest solar radiation, resulting in a maximum output energy of 239.2 kWh per day compared to Table 1's Actual consumption energy of 21 kWh daily.

CONCLUSION

The proposed design of a standalone solar photovoltaic system for a three-room bungalow in Umuahia City, Abia State, Nigeria, has been completed. The major findings of the solar photovoltaic system are: The energy requirement per day was 21 kWh, and the total wattage becomes 2.4 kW. The number of solar modules or panels obtained was 20. The SunPower solar panel of 435 W was selected to design the SPV system. The current amperage of the solar charge controller realized was 102 A for the SPV design, and the power rating for the charge controller was 8.7 kW. The number of batteries calculated for the solar system was 12, and 250 Ah for a single battery was chosen for the SPV system design. The input power of the inverter was determined to be 3.2 kW for the SPV system design. The proposed SPV system's maximum direct current DC and voltage were 192 A and 24 V, respectively.

At the same time, the maximum alternating current AC and voltage for the SPV system were 11 A and 230 V, respectively. It was observed that the highest number of solar panels occurred in August, during the period of minimum solar radiation**.** The proposed SPV system will meet the energy needs of the three-room bungalow, since the estimated actual energy output per day (21 kwh) and monthly average output energy (630 kWh) were below the monthly minimum (1620 kWh) and maximum theoretical output energy (5980 kWh), the solar photovoltaic energy will meet the energy requirement of the three-room bungalow. The solar performance ratio of the solar system was determined to be 85.5 %.

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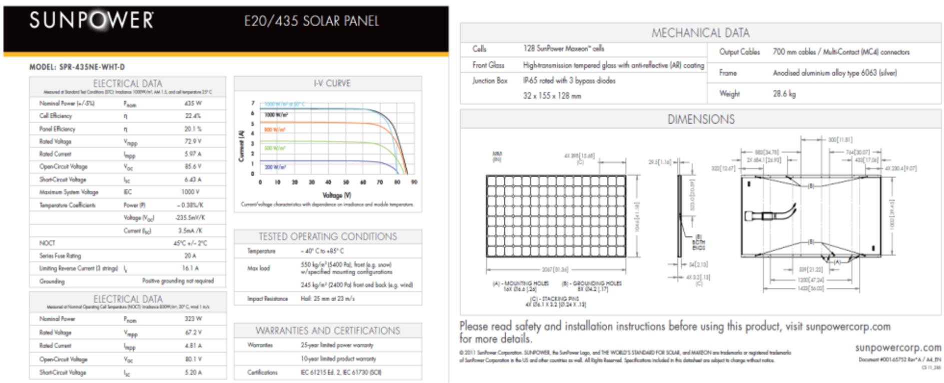
APPENDIX A.



MODELIRANJE PROJEKTA SAMOSTALNIH SOLARNIH FOTONAPONSKIH SISTEMA ZA TROSOBNI OBJEKAT U GRADU UMUAHIA, DRŽAVA ABIA, NIGERIJA

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Apstrakt: Ova studija ispituje raspored, rad i izvodljivost samostalnog solarnog fotonaponskog (PV-Solar Photovoltaic) sistema za trosobni objekat-bungalov u gradu Umuahi, država Abia, Nigerija.
Solarni panel, regulator punjenja, baterija i invertor su glavni elementi dizajna solarnog fotonaponskog sistema. Utvrđeno je da je dnevna potrošnja energije bila 21 kWh, što je prevedeno u ukupnu snagu od 2,4 kW. Za SPV system (Stand-alone Solar Photovoltaic) je izabrano dvadeset (20) solarnih panela kapaciteta 435 W. Stvarni napon kod solarnog regulatora punjenja je 102 A, a njegova snaga 8,7 kW, prema SPV (Stand-alone Solar Photovoltaic) dizajnu.
Predviđeno je da solarnom sistemu treba dvanaest (12) baterija, a za SPV sistem je izabrana jedna (1) baterija kapaciteta 250 Ah. Utvđeno je da ulazna snaga invertora ima vrednost od 3,2 kVA.
Maksimalna jednosmerna struja (AC) i napon su 192 A i 24 V, respektivno, a naizmenična struja (DC) i napon za SPV sistem bili su 11 A i 230 V, respektivno.
Najveći broj solarnih panela bio je postavljen u mesecu Avgustu, kada je sunčeva energija bila najmanjih vrednosti.
Procenjena stvarna dnevna proizvodnja električne energije (21 kWh) i prosečna mesečna proizvodnja energije (630 kWh) su bile ispod mesečnog minimuma (1620 kWh) i maksimalne teorijske proizvodnje energije (5980 kWh). Solarna fotonaponska energija zadovoljava energetske potrebe ispitivanog trosobnog objekta.
Odnos solarnih performansi je na nivou od 85,5%.

Ključne reči: *Dizajn; fotonaponski sistem solarne energije; modul, kontroler punjenja, baterija; inverter; izlazna snaga; sunčevo zračenje; odnos performansi.* [2]

Prijavljen:
***Submitted*: 15.07.2025.**
Ispravljen:
***Revised*: 15.08.2025.**
Prihvaćen:
***Accepted*: 22.08.2025.**