

¹ Johnson Eze IGWE, ¹ Ijeoma F. IKECHUKWU, ¹ Tochukwu F. OKEOMA

DESIGNING AN EFFECTIVE SOLAR PHOTOVOLTAIC SYSTEM FOR SMALL AND MEDIUM ENTERPRISES (SME) IN URBAN AREAS OF UMUAHIA ABIA STATE, NIGERIA

¹ Mechanical Engineering Department, Michael Okpara University of Agriculture, Umudike, Abia State, NIGERIA

Abstract: Due to the unstable grid supply, this study focuses on developing an efficient solar photovoltaic (SPV) system specifically designed to suit the energy needs of small and medium-sized enterprises (SMEs) in metropolitan Umuahia, Abia State, Nigeria. It was discovered that the daily energy requirement was 78.8 kWh, and the total wattage was 10.2 W. For the SPV design, 72 solar panels and 43 batteries were obtained, respectively. The selected single solar panel was 435 W, and the battery was 250 Ah. For the SPV design, the solar charge controller's current and power ratings were 428 A and 31.3 kW, respectively. The inverter's input power was found to be 13.4 kW. The SPV system has a maximum DC direct current of 711.6 A and a maximum voltage of 24 V. The SPV system's maximum alternating current and voltage were 44.7 A and 230 V, respectively. Since the highest power output (287.4 kWh) and average (127.9 kWh) per day over a month were greater than the load of the appliances (76.8 kWh) per day, the proposed SPV system will satisfy the energy needs of SMEs. It was found that the performance ratio was 85.5%.

Keywords: Design; Solar energy photovoltaic system; Small and medium enterprises; Module, Charge controller, Battery; Inverter; Output power; Solar radiation; Performance ratio

1. INTRODUCTION

The energy challenges faced by Small and Medium Enterprises (SMEs) in urban areas of Nigeria are multifaceted and significant. These challenges include unreliable grid electricity supply, high energy costs, frequent power outages, and limited access to modern energy services (Okonkwo et al., 2021). SMEs in Nigeria often struggle with inadequate and unstable power supply from the national grid, leading to disruptions in their operations and increased costs due to the need for alternative power sources such as diesel generators (Okonkwo et al., 2021). Additionally, the lack of access to affordable and reliable energy services hinders the growth and productivity of SMEs in urban areas (Nwokocha and Madu, 2020). In addressing these energy challenges, the use of cost-effective solar photovoltaic (PV) systems has emerged as a promising solution for SMEs in urban areas of Nigeria. Solar energy is abundant in Nigeria, with high levels of solar radiation throughout the year, making it a viable renewable energy source for power generation (Okonkwo et al., 2021). The installation of solar PV systems on the rooftops of urban buildings can help SMEs reduce their reliance on the unstable grid electricity supply and mitigate the impact of high energy costs (Delponte & Schenone, 2020). Solar PV systems can provide a reliable and sustainable energy solution for SMEs, allowing them to operate more efficiently and competitively in the market. Research has shown that solar power can be optimized in urban areas by utilising thermal solar panels and PV systems on rooftops, maximizing the use of available space for energy generation (Aldhshan et al., 2021). The potential for building solar PV roofs in urban areas is significant, especially on rooftops with minimal open areas, making urban settings ideal for the deployment of PV systems (Ihsan, 2023). Furthermore, rooftop-mounted PV systems have been identified as a promising way for urban environments to generate electricity sustainably, contributing to the overall energy mix of urban areas (Fakhraian et al., 2021). Studies have highlighted the economic advantages of implementing renewable technologies like solar PV systems in various locations, emphasizing the cost-effectiveness and sustainability of such systems, particularly in rural settings (Odetoye, 2023). The integration of solar PV panels in urban areas, whether distributed on buildings or as part of grid-connected systems, offers a practical solution to meet the energy demands of SMEs and urban communities (Adesanya and Pearce 2019). The use of photovoltaic systems has been recognized as an energy-acceptable solution for both urban and rural areas, enabling energy savings and promoting sustainability (Abubaka 2024).

Solar PV technology has evolved over the years, with advancements in multijunction PV cells increasing power conversion efficiency and expanding the potential for solar energy utilization globally Lin et al., (2022). The development of innovative PV technologies, such as micro-concentrators and bifacial modules, has further enhanced the efficiency and electricity generation capacity of solar PV systems, making them more attractive for urban applications (Chen et al., 2022). Additionally, the implementation of maximum power point tracking (MPPT) control methods for PV cells optimizes energy output, ensuring that solar panels operate at their maximum efficiency levels (Meng, 2024). In conclusion, the adoption of cost-effective solar PV systems presents a viable solution to the energy challenges faced by SMEs in urban areas of Nigeria. By harnessing the abundant solar resources available in the country, SMEs can improve their energy reliability, reduce costs, and contribute to sustainable development. The integration of solar PV technology in urban settings not only addresses energy needs but also promotes environmental sustainability and economic growth for SMEs in Nigeria.

2. LITERATURE REVIEW

The energy demand and consumption landscape for small and medium-scale businesses in Nigeria is a critical aspect that intertwines with economic growth, environmental sustainability, and overall business performance. Nigeria, like many other developing nations, faces challenges in ensuring a stable and reliable energy supply for businesses, which impacts their operations and competitiveness in the global market (Okafor et al., 2020). The energy sector in Nigeria has been plagued by issues such as poor electricity supply, leading to disruptions in production, increased costs of goods and services, closure of industries, and loss of competitive advantage for businesses (Okafor et al., 2020). These challenges have hindered the industrialization process and undermined efforts to achieve sustained business and economic growth in the country (Nnaemeka et al., 2022). In Nigeria, traditional energy sources still dominate the energy consumption landscape, with modern energy sources accounting for a smaller percentage (Abubaka 2024). This reliance on traditional energy sources poses challenges in terms of sustainability and environmental impact, highlighting the need for a transition towards cleaner and more efficient energy sources (Abubaka 2024). The country's energy consumption patterns are intricately linked to economic growth, with studies indicating a complex relationship between energy consumption and economic development (Ekeocha, et al., 2020). While energy consumption plays a role in driving economic growth, the impact has not been fully realized in the Nigerian economy, suggesting the need for further interventions to optimize the energy-economic growth nexus (Ekeocha, et al., 2020). The COVID-19 pandemic has also had implications for energy consumption patterns in Nigeria, as seen in global trends where reduced office space usage and limited commercial activities have influenced energy balances towards renewable energy sources (Strielkowsk et al., 2021). This shift underscores the importance of adapting energy management strategies to changing economic conditions and leveraging information and communication technology solutions to optimize energy consumption (Strielkowsk et al., 2021). Moreover, the energy transition in Nigeria, particularly towards renewable energy sources, has implications for the country's oil and gas exports, with studies indicating a negative impact on revenue generation from these sectors (Waziri et al., 2018). This highlights the interconnectedness of energy consumption, economic activities, and international trade dynamics in Nigeria's energy landscape (Waziri et al., 2018). Efforts to enhance energy efficiency and sustainability in Nigeria's business sector have been explored through various studies focusing on factors such as energy intensity, industrial energy mix, and the potential of carbon tax policies to mitigate CO₂ emissions (Nduka, 2020). These initiatives aim to address the environmental impact of energy consumption and promote more sustainable business practices in the country (Nduka, 2020). Studies have highlighted the importance of monitoring and managing energy consumption at a granular level to identify inefficiencies and optimize resource utilization (Nikbay et al., 2023). By implementing real-time monitoring solutions and energy-efficient practices, businesses can reduce operational costs and enhance their sustainability profile (Nikbay et al., 2023). Furthermore, the integration of energy management strategies into business processes is essential for improving energy efficiency and reducing overall consumption (Reiter et al., 2014). This integration enables businesses to track and analyse energy usage patterns, leading to informed decision-making and resource optimization (Reiter et al., 2014). The adoption of low-energy materials and sustainable building practices in public housing delivery projects reflects a broader trend towards promoting energy efficiency and environmental sustainability in the country (Emezue 2024). These initiatives

not only contribute to reducing energy consumption but also align with global efforts to mitigate the impacts of climate change and promote sustainable development (Emezue 2024). In conclusion, the background of energy demand and consumption for small and medium-scale businesses in Nigeria is multifaceted, encompassing economic, environmental, and social dimensions. Addressing the challenges associated with energy supply, consumption patterns, and sustainability is crucial for enhancing business competitiveness, driving economic growth, and mitigating environmental impact. By leveraging technological innovations, policy interventions, and sustainable practices, Nigeria can transition towards a more energy-efficient and resilient business sector that supports long-term development goals.

Solar photovoltaic (PV) adoption by Small and Medium Enterprises (SMEs) facing energy challenges in Nigeria is a critical area of study due to the potential benefits it offers in addressing energy needs, reducing costs, and promoting sustainability (Nwankwo and Kanyangale 2019). Several studies have highlighted the importance of renewable energy sources like solar PV in Nigeria. Adesanya & Pearce (2019) demonstrated the economic viability of solar PV systems for the Nigerian private sector, showcasing high returns on investment and the potential for cost savings compared to traditional energy sources like diesel. This economic feasibility is crucial for SMEs facing energy challenges in Nigeria.

Abdullahi et al. (2022) identified financial constraints and lack of technical skills as obstacles to ICT adoption among SMEs in Nigeria, which could also be relevant to understanding barriers to solar PV adoption. Emezue (2024) explored various renewable energy options for electrifying Nigeria, including solar PV, indicating the importance of considering different renewable energy technologies in addressing energy challenges. Jesuleye et al. (2020) highlighted the need for cooperation between private enterprises and government agencies to promote factors influencing solar PV utilization in Nigeria, emphasizing the role of policy and collaboration in driving solar PV adoption.

Enongene et al. (2019) pointed out the potential of solar PV systems for residential homes in Lagos, aligning with the focus on SMEs in urban areas facing energy challenges. Nduka, 2020 discussed the challenges related to upfront costs hindering widespread solar PV adoption in Nigeria, which is crucial for SMEs with limited financial resources. Diemuodeke et al. (2021) presented the status of solar PV electrification in Nigeria, emphasizing the need for aggressive PV penetration, especially in rural communities, which could benefit SMEs operating in such areas.

Diyoke et al. (2023) highlighted the anticipated role of solar PV in Nigeria's future energy mix, emphasizing the importance of supportive policies and financing mechanisms for driving solar PV adoption. Nwankwo & Kanyangale (2019) recommended integrative Entrepreneurial Marketing (EM) for SMEs in Nigeria to reduce business failure rates, suggesting strategies that could also be relevant for promoting solar PV adoption.

In conclusion, the literature review on solar PV adoption by SMEs facing energy challenges in Nigeria reveals a complex landscape influenced by factors such as economic viability, financial constraints, technical skills, policy support, and collaboration between stakeholders. Understanding these factors is crucial for promoting solar PV adoption among SMEs in Nigeria, addressing energy challenges, reducing costs, and fostering sustainability in the business sector by the government.

3. MATERIALS AND METHODS

Study Area Description

Figure 1 is the actual area in Umuahia, the capital city of Abia State, Nigeria, is situated at approximately 5.53°N latitude and 7.49°E longitude. Its geographical location close to the equator endows it with a tropical rainforest climate characterized by substantial rainfall and consistently high temperatures. The average annual temperature in Umuahia ranges from 24°C

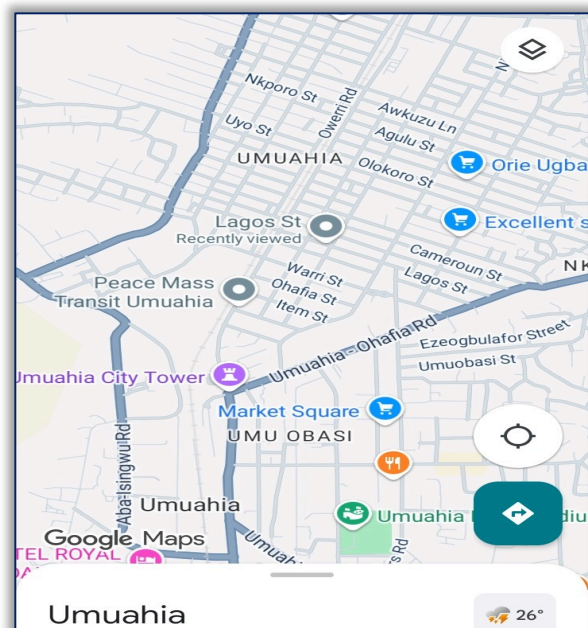


Figure 1: Map showing Lagos Street Umuahia, Abia State, Nigeria

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. The high temperatures and humidity must be factored into the design and efficiency calculations for solar PV systems, ensuring they can withstand the local climatic conditions.

— Description of the project function

The small and medium enterprise business is all about setting up a shop of 15 feet x 15 feet. The shop is located at Lagos Street Umuahia city with zip code 440236. In this shop there will be barbing unit and hair dressing unit. In barbing unit, men's hair will be cut with the desired hair design or shape using a wireless clipper or battery storage clipper. In the hair dressing unit, the women's hair will be packaged or given a desired shape design as directed by the customer using hairdryer machine, hair hydration and other supporting equipment. Other women's fashion services like fixing of nails etc, is done in the shop.

— The Data Collection

The data used in this research work were collected from the meteorology unit inside the National Root Crops Research Institute Umudike (NRCRI) for 12 months. The two weather parameters collected were daily solar insolation and daily temperatures. Secondly, electricity consumption records of all the appliances of every unit in small and medium enterprise saloon shop (SME) at Lagos Street Umuahia were captured. This dataset is critical for estimating the size and capacity of the required SPV system. Finally, data parameters were extracted from selected single solar panel manufacturer's technical specification.

■ 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 also presented (Bakheet, 2023).

The solar photovoltaic system's primary parts are: (1) Solar PV panels array (2) Batteries (3) Solar charge controllers (SCC), and (4) Inverter PV System Design

The system design calculations are conducted by the following steps:

- Estimating total load. The total load of SME (including lighting, equipment, and air conditioning) are to be calculated.
- 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).
- Sizing the battery bank,
- Sizing the Inverters
- 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 SMEs. The average daily solar insolation is mostly taken as 5 kW/m²/day.

PV array Sizing: Standard Testing Conditions (STC) involve 1 kW/m² of irradiation and a PV cell temperature of 25°C.

— The Method 1: Exact Design

The PV panel is characterized by its average efficiency, η_p which is a function of average panel temperature as given by Bakheet (2023) is presented in eqn. (1).

$$\eta_p = \eta_r (1 - \beta_p (T_p - T_r)) \quad (1)$$

where η_r is the panel efficiency at T_r . T_r is the reference temperature (25 °C). β_p is the temperature coefficient for module efficiency. The value of η_r and β_p are taken from Appendix A as 20.1% and -0.38%/K, respectively.

T_p is a function of the ambient temperature as stated by Bakheet, (2023) is given in eqn. (2).

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

where \bar{k} 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 °C). NOCT is the Nominal operating cell temperature (45 °C). $T_p = 57.6$ °C and $\eta_p = 20$ %.

The total area S_A of the PV panel array can be presented in eqn. (3) as stated by Chen et al., (2022).

$$S_A = \frac{E_p}{\eta_p G} = \frac{E_p'}{\eta_c \eta_b \eta_p G} \quad (3)$$

where E_p is the energy provided by the PV array. E_p^1 is the energy provided by the PV array after battery bank (E_p^1 equals the daily load demand 76,848 Wh). G is the daily irradiance (5kWh/m²/day), η_c , η_b and η_i are the efficiencies of controller, batteries, and inverter, respectively ($\eta_c = 95\%$; $\eta_b = 90\%$; $\eta_i = 96\%$). There for the total area of solar panels $S_A = 2634.3$ m². The area of a SunPower 435W single solar panel S_p is equal to (2.067m × 1.046m = 2.16 m²). The number of SPV panel as stated by Bakheet (2023) is given in eqn. (4)

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

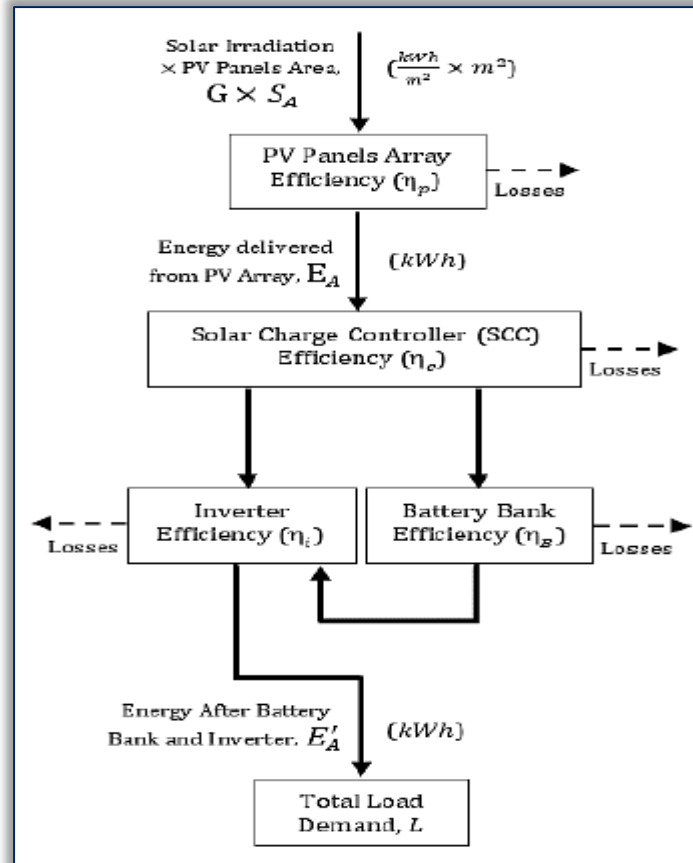


Figure 2: Solar PV system design flow-chart.

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

The total electricity demand of SME 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 Bhatia (2008) is presented in eqn. (5).

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

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

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

$$\text{Number of Modules or panels} = N_{p2} = \frac{\text{SPV Module Wattage Estimation}}{\text{Value of Each Panel}} \quad (6)$$

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) = 76,848Wh/day

Total PV panels energy needed (TPEN)

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

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

The total number of solar panels (N_{p3}) according to Leonics (2009), is given in eqn. (8).

$$N_{p3} = \frac{\text{Energy watt hour per day} \times \text{Energy loss in the system}}{\text{Panel generation factor (PGF)} \times \text{Wattage of single panel (WSP)}} = \frac{\text{TPEN}}{\text{PWSP}} \quad (8)$$

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

Panel generation factor (PGF) = 3.596 for Nigeria.

The method 1 has the highest number of panels of 72, and it is selected for the design.

The 72 PV panels will be arranged in 8 strings (parallel rows), and 9 panels in series. The minimum clearance (distance) required between each row of panels is represented by distance (d) as seen in Plate 1 and the angles are calculated by Omni calculator in Figure 3. This distance can be calculated using eqn. (9) as stated by Bakheet (2023).

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

Determining this clearance requires the angle γ_s of the sun at mid-day (12 Noon) in the shortest day of the year 2023 (i.e., 21st December). In SMEU, the angle (γ_s) is 60.27° (see Figure 3). The collector height used is ≈ 1.8 m. The tilt angle used is $\beta = 15^\circ$. Hence, the distance $d \approx 2$ m.

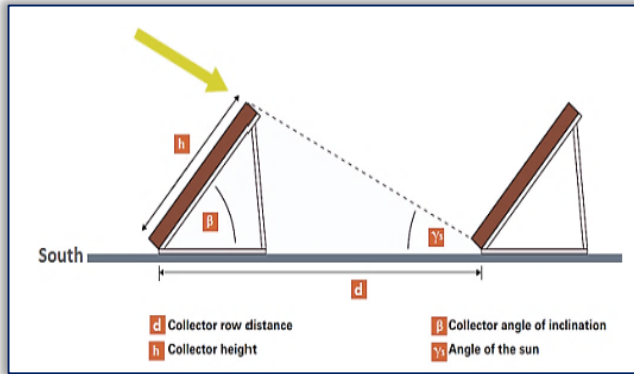


Plate 1. Clearance Between Collectors or PV Panels Rows.



Figure3: The angle γ_s of the sun at mid–day in the shortest day of the year 2023 (21st December) for Umuahia area (by Solar elevation angle Omni calculator).

- The Batteries Sizing of the solar panel (Method 1), according to Diyoke, et. al., (2023) is presented in eqn. (10).

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

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

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

- The Batteries Sizing of the solar panel (Method 2) as given by Leonics (2009) is presented in eqn. (11).

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

The nominal battery voltage is 12 volts; Battery loss-0.85; depth of discharge is 0.6 and Battery days of autonomy is 3.

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

Since 250Ah batteries can be easily found in the market, and has more storing capacity, it is selected for the final calculation to know 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 Chetan (2014) is represented in equation (13) Solar Charge controller (SCC_{1cu}) is given bellow

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

The system volt used is 24 V.

- The Solar charge controller sizing: Method 2, according to leonics (2009) is given in eqn. (14).

According to standard practice, the sizing of solar charge controller is to take the short circuit current ($I_{sc} = 6.43$ A from Appendix A) of the PV array and multiply it by Energy panel lose (ELS-1.3).

Solar charge controller rating (SCC_{2cu}):

$$SCC_{2cu} = \text{panels in Series array} \times \text{total short circuit current of PV array} \times 1.3 \quad (14)$$

In 72 panels calculated, there are 8 strings to be arranged in parallel while 9 panels will be arranged in series connection as a single string.

— 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 of 1.3 is used.

The following are the steps to determine the SCC_{3cu} by Bakheet (2023) presented in eqn. (15).

$$(1). \text{ Wattage of the PV array} = (\text{number of PV panels}) \times (\text{PV panel rated power}) \quad (15)$$

$$(2). \text{ Rated voltage of } SCC_{3v} = (\text{number of panels in series}) \times (\text{Voc of panel}) \quad (16)$$

$$(3) \text{ Rated current of } SCC_{3cu} = (\text{number of strings of panels}) \times (\text{Isc of PV panel}) \times (\text{safety factor})$$

The capacity of the solar charge controller in method 1 is higher, therefore 428 A is approved for the SCC selection.

— The Inverter Capacity Selection for the solar panel as stated by Chetan (2014) is in eqn. (17) for Method 1.

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

■ **The inverter sizing for Method 2 as presented by Leonics (2009) is stated in eqn. (18).** For safety, the inverter should be considered 25-30% bigger of total wattage of all appliances.

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

— The Output Power from the SPV system according to Bhatia (2008) is given in eqn. (19).

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

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

Table 1: Energy Consumption Data of the appliances.

S/N	Appliances	Watts (W)	Quantity	Total Watt	Hour	Energy (Wh)
1	Led light bulb	5	5	50	12	600
2	Fan	60	3	180	12	720
3	Refrigerator	500	1	500	12	6000
4	Television	100	3	300	8	2400
5	CCTV	18	3	54	24	1296
6	GoTV	6	1	6	8	42
8	Computer	65	1	65	6	390
9	Hair dryer	1,600	3	4,800	8	38,400
10	Hair curler	30	1	30	8	240
11	Hair hydration	1,500	2	3000	5	15000
12	Hair clipper	20	10	200	8	1600
13	Sanitizer	30	3	90	24	2160
14	Air conditioner	1000	1	1000	8	8,000
	Total			10,275		76,848

Table 2: The weather parameters from metrological unit at (NRCRI)

Monthly average solar radiation and ambient temperature from Jan.–Dec. 2023.		
S/N	Solar Radiation (G_a) (kW/m ²)	Ambient temperature (T_a) (°C)
1	5400	27.61
2	6000	29.76
3	5100	28.94
4	3420	28.38
5	4160	28.74
6	2460	27.41
7	2240	27.11
8	1580	27.24
9	2310	27
10	2380	27.76
11	4270	27.32
12	4440	29.11

— The maximum direct/alternating current and voltage of wire of the solar photovoltaic system as given by Chetan (2014) are represented in eqns. (20) and (21).

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

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

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

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

— Solar Performance Ratio (SPR%) according to Jara et al., (2020) is stated in equation (23)

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

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

G= Solar insolation on tilted panel (kwh/m²/day): η_r = Total solar panel efficiency (%).
 S_A=Total solar area (m²).

Table3: 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 panels	72
Efficiency	20 %
Nominal operating cell temperature	45 %
Temperature coefficient	-0.38 %/K
Solar collector area	2.16 m ²

4. RESULTS AND DISCUSSION

■ The design results from SPV system.

The Table 1 showed the computed collected data from SME Umuahia, while the table 4 revealed the actual results from the design analysis of proposed solar photovoltaic system in SME Umuahia.

Table 4. Results from proposed SPV design of SME Umuahia

	Total energy per-hour (kWh)	Wattage (kW)	Number of solar components	Capacity of the single product	Input power (kW)	Ampere (A)	Volt (V)	Efficiency (η %)
Solar panel	76,848	17.1	72, 71.6 & 68	435 (W)				20
Charge controller		31				428, 75 & 75	684.8	95
Battery (Ah)			43& 100	250				90
Inverter					10.7 & 13.4			96
Max. DC.						711.6	24	
Max. AC.						44.7	230	
SPR								85.5

■ Discussion of results

The energy estimation of the small and medium enterprise (SME) is presented in Table 1, while the summary of the calculated design results is indicated in table 4. The analysis revealed a diverse set of energy-consuming appliances with varying power ratings and operational durations. The total energy requirement for the facility (solar panel) was calculated to be 76848 Wh (76.8 kWh) per day. The module peak wattage estimation of the solar photovoltaic panel was determined to be 17,077 W (17.1 kW). The SunPower single solar panel wattage was selected for the SPV design to be 435 W. The number of solar panels determined from method1, method2 and method3 were 72, 71.6 and 68 respectively. The method1 has the highest number of panels (72) and it was selected for the solar photovoltaic system design. The solar panel efficiency was obtained to be 20 %. The solar charge controller amperage realized from method1, method2 and method3 were 428.1 A, 75 A and 75 A respectively. The highest result from method1 was selected (428 A) for the design of SPV system. The wattage of the solar charge controller was calculated to be 31.3 kW. The number of batteries from method1 and method2 were 43 and 100 respectively. The number of batteries from method1 was selected for the SPV system design despite the highest number emerged from method2. The result from method1 is economically visible while that of method2 is needed where high energy storage is essential mostly. The single solar lithium-ion battery chosen for the design due to their availability in the market and good product storage capacity was 250 Ah. The input power of the inverter from method1 and method2 were 10.7 and 13.4 kW. The method2 has the highest inverter input power of 13.4 kW and it is selected for SPV system design. The maximum direct current (DC) and voltage for the proposed SPV system were 711.6 A and 24V respectively. While the maximum alternating current (AC) and voltage for the SPV system were 44.7 A and 230V respectively. The solar performance ratio of the solar system was determined to

be 85.5 %, which signifies that the solar system converts sunlight or solar irradiance into electricity efficiently. From table 1, there are high-energy-demand appliances, such as air conditioners and refrigerators are 8000 and 6000 Wh respectively, while the hair dryer and hair hydration are 38,000 and 15,000 Wh respectively dominate the consumption profile than any appliances. Sanitizers, are also significant contributors, emphasizing the need for energy-efficient solutions. Other appliances such as, computers, and televisions, take less energy-consumption individually, collectively contribute to the overall demand due to their extended usage hours but most times can be optional. The peak energy demand typically occurs during daytime hours when operational activities are at their peak, aligning well with the availability of solar energy (Bakheet 2023; Diyoke et al., 2023; Diemuodeke et al., 2021; Fakhraian et al., 2021).

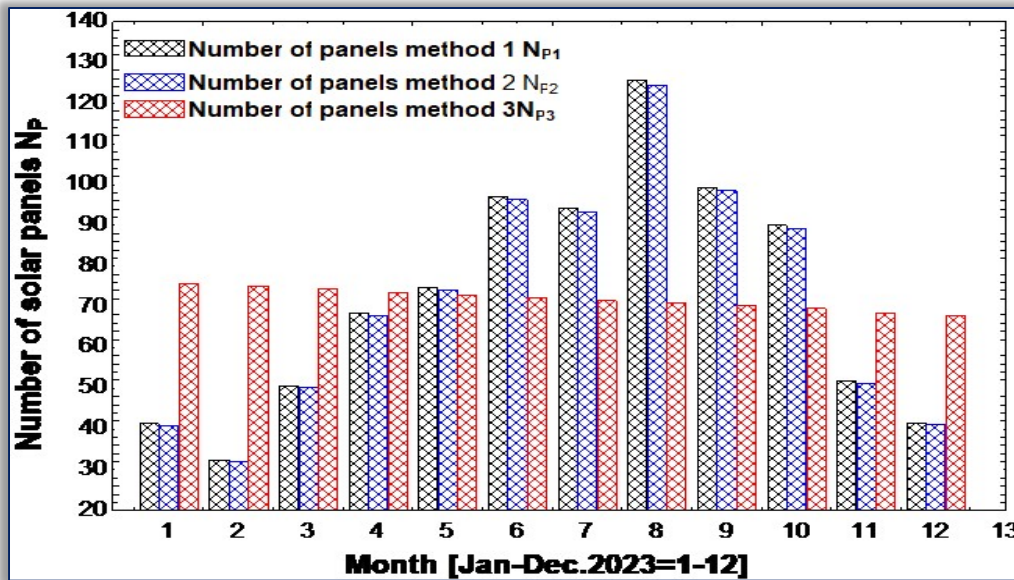


Figure 4: The Number of panels of solar photovoltaic system

Figure 4 is the number of solar panels calculated from three methods, and they were simulated by Engineering Equation Solver (EES) software. The environmental weather parameters such as solar radiation or solar irradiance and ambient temperature were collected from the meteorology unit inside the National Root Crops Research Institute (NRCRI) for 12 months, 2023. The total summation, average, minimum and maximum number of panels (N_{P1}) from method 1, are 866.7, 72, 32.3 and 125.7 respectively. The number of solar panels obtained from method 2, were also simulated and the total summation, average, minimum and maximum number of panels (N_{P2}) are 858.8, 71.8, 32.03 and 124.5 respectively. While the total summation, average, minimum and maximum number of solar panels (N_{P3}) from method 3 are 862.3, 68.02, 67.75 and 75.8 respectively. It can be observed that method 1, has the highest average number of solar panels which is in line with findings of Bakheet (2023). Another observation can be seen from the bar chart, that the results from method 3 is higher between January to April and became lowest from May to October. The results from method (1 and 2), are higher during raining season while method 3 is higher in dry season. It can also be seen in the bar chart that during raining season, there is always a poor solar radiation or sunshine, there for a greater number of solar panels will be needed as observed in the month of August which recorded 125.7 number of solar panels.

Figure 5 is the output power from the solar photovoltaic system. The average daily solar radiation on a horizontal surface is 3,738 kWh/m²/year through the year. The monthly average solar radiation on a horizontal surface varies from 1,772 kWh/m²/day in August to 6,508 kWh/m²/day in February. It can be seen from Figure 3 that the power output varies according to the prevailing meteorological parameters of the site for a given month, with a maximum output of 287.4 kWh occurring in February and a minimum output power of 60.63 kWh occurring in August. The overall power generated by the system in a year for the site is 1,535 kWh with an average monthly energy production of 127.9 kWh. Since the estimated energy requirement per day is 76,848 kWh (76.8 kWh) from Table 1, is below the average monthly (127.9 kWh) and maximum power output (287.4 kWh) per day in a month, therefor the solar photovoltaic system will meet the daily energy demand in SME Umuahia. The above results concerning the maximum power output occurring in February while lowest in August are in accordance with the observations of Diyoke et al., (2023).

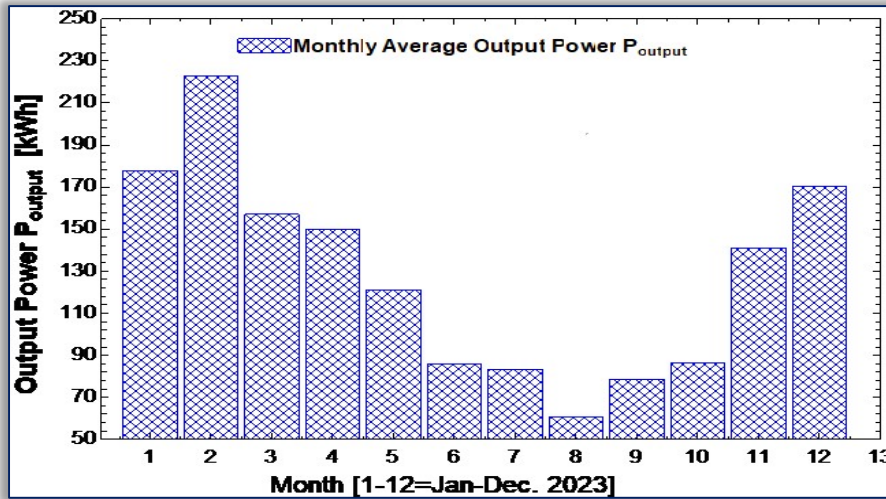


Figure 5: The output power from the solar photovoltaic system

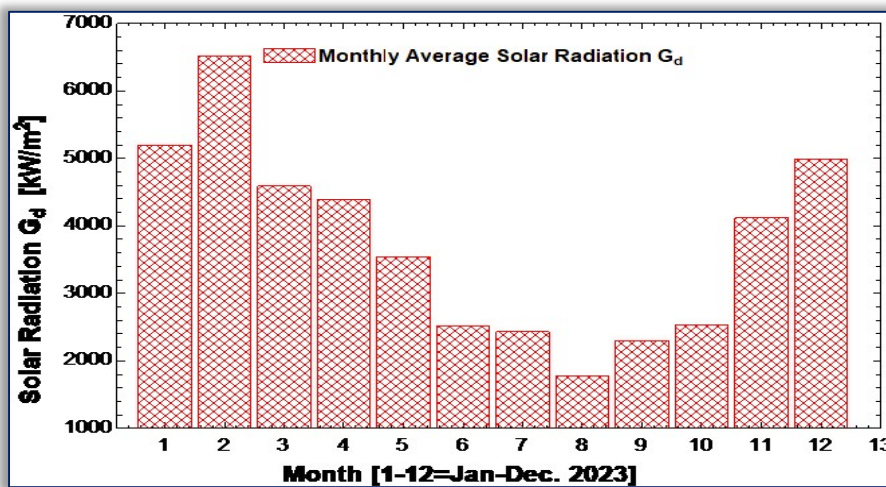


Figure 6: The solar radiation for the photovoltaic system

Figure 6 is the bar chart of solar radiation for the photovoltaic system, from January - December 2023. The month of August recorded the lowest solar radiation and increased from September to February. The summation, average, minimum and maximum of solar radiation in August were 44300, 1772, 800, and 3800 respectively, while the summation, average, minimum and maximum of solar radiation in February were 162700, 6508, 3200, and 8400 respectively. So, the month of February recorded the maximum solar radiation in the year 2023 in Umuahia Abia State and Diemuodeke et al., (2021) has similar result. It is because February recorded the maximum solar radiation, the output power was maximum [of 287.4 kWh per day as against the consumption power of 78.8 kWh per day from Table 1.

5. CONCLUSION

The proposed design of an effective solar photovoltaic system for small and medium enterprise saloon shop in urban areas of Abia State, Nigeria, has been completed. The major findings of the solar photovoltaic system are:

The energy requirement per day was found to be 78.8 kWh and the total wattage becomes 10.2 kW. The number of the solar modules or panels obtained were 72. The SunPower solar panel of 435 W, was selected for the design of SPV system. The current amperage of solar charge controller realized was 428 A for the SPV design and the power rating for the charge controller was gotten to be 31.3 kW.

The number of batteries calculated for the solar system was 43 and 250 Ah for single battery was chosen for the SPV system design. The input power of the inverter determined was 13.4 kW for the SPV system design. The maximum direct current DC and voltage for the proposed SPV system were 711.6 A and 24 V respectively. While the maximum alternating current AC and voltage for the SPV system were 44.7 A and 230 V respectively.

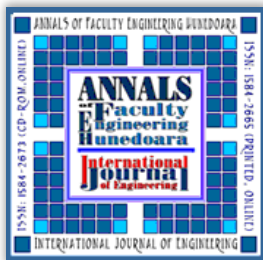
It was observed that the highest number of solar panels occurred in the month of August at the period of minimum solar radiation.

The proposed SPV system will meet the demand of energy of the SMEs, since the average (127.9 kWh) and maximum power output (287.4 kWh) per day in a month were higher than the estimated energy requirement of the appliances (76.8 kWh) per day. The solar performance ratio of the solar system was determined to be 85.5 %.

References

- [1] Abubakar, I. (2024). Investigating the determinants of household energy consumption in Nigeria: insights and implications. *Energy Sustainability and Society*, 14(1)
- [2] Adesanya, A. A., & Pearce, J. M. (2019). Economic Viability of Captive Off–Grid Solar Photovoltaic and Diesel Hybrid Energy Systems for the Nigerian Private Sector. In *Renewable and Sustainable Energy Reviews*
- [3] Aldhshan, S., Maulud, K., Jaafar, W., Karim, O., & Pradhan, B. (2021). Energy consumption and spatial assessment of renewable energy penetration and building energy efficiency in Malaysia: a review. *Sustainability*, 13(16), 9244
- [4] Bakheet M. A., (2023). Design and Modelling of Solar Energy System for Electrification for a Hospital in Saudi Arabia. *European Journal of Energy Research*.
- [5] Bhatia A. (2008). Design and Sizing of Solar Photovoltaic Systems, www.cedengineering.com.
- [6] Chen, H., Yang, H., Shi, Y., Yu, B., & Yang, J. (2022). Experimental and simulation study on bifacial photovoltaic modules integration with buildings. *Thermal Science*, 26(5 Part B), 4413–4422
- [7] Chetan S. S., (2014). *Solar Photovoltaic Technology and Systems*. PHI Learning Private Limited: Delhi–110092.
- [8] Diemuodeke, O., Mulugetta, Y., Njoku, H., Briggs, T., & Ojapah, M. (2021). Solar PV electrification in Nigeria: current status and affordability analysis. *Journal of Power and Energy Engineering*, 09(05), 1–25
- [9] Diyoke, C., Ngwaka, U., & UGWU, K. (2023). A comprehensive analysis on the grid–tied solar photovoltaics for clean energy mix and supply in Nigeria’s on–grid power. *Journal of Energy Systems*, 7(1), 1–17
- [10] Ekeocha, P., Penzin, D., & Ogbuabor, J. (2020). Energy consumption and economic growth in Nigeria: a test of alternative specifications. *International Journal of Energy Economics and Policy*, 10(3), 369–379
- [11] Emezue, D. (2024). Electrification through renewable energy in Nigeria an exploration of viable technology options beyond solar PV. *International Journal of Multidisciplinary Research and Analysis*, 07(02)
- [12] Enongene, K., Abanda, F., Otene, I., Obi, S., & Okafor, C. (2019). The potential of solar photovoltaic systems for residential homes in Lagos city of Nigeria. *Journal of Environmental Management*, 244, 247–256
- [13] Fakhraian, E., Forment, M., Dalmau, F., Nameni, A., & Guerrero, M. (2021). The urban rooftop photovoltaic potential determination. *Sustainability*, 13(13), 7447
- [14] Ihsan, K. (2023). Comparison of potential energy of solar radiation in rooftop modeling using different building levels of detail. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLVIII–M–3, 115–120
- [15] Jara, P. G., Castro, M. T., Esparcia, E. A., & Ocon, J. D. (2020). Quantifying the Techno–Economic Potential of Grid–Tied Rooftop Solar Photovoltaics in the Philippine Industrial Sector. In *Energies*
- [16] Jesuleye, O. A., Arigbede, O. F., & Adepoju, A. O. (2020). Factors Influencing Solar Photovoltaic Utilization for Energy Services Among Residentials in Akure, Nigeria. *Journal of Energy Research and Reviews*
- [17] Leonics (2009). Design of solar Photovoltaic system. https://www.leonics.com/support/article2_12j/articles2_12j_en.php
- [18] Lin, Y., Li, L., Ung, G., Lu, C., Yao, K., Ozbolt, A., & Thon, S. (2022). Diffuse solar micro–concentrators using dielectric total internal reflection with tunable side and top profiles. *Energy Technology*, 10(7)
- [19] Nduka, E. (2022). Reducing carbon footprint by replacing generators with solar PV systems: a contingent valuation study in Lagos, Nigeria. *Environment and Development Economics*, 28(4), 387–408
- [20] Nnaemeka, N., Uzoamaka, N., & Ifeoma, A. (2022). Energy sector and business development in South Eastern Nigeria: 1990 – 2016. *The International Journal of Business & Management*, 10(2)
- [21] Nwankwo, C., & Kanyangale, M. (2019). Market orientation and survival of small and medium enterprises in Nigeria, *Foundations of Management*, 11(1), 291–304
- [22] Nwokocha, V., & Madu, I. (2020). Strategic alliance and its influence on the performance of small– and medium–scale enterprises in Enugu State, Nigeria. *Global Journal of Emerging Market Economies*, 12(2), 199–216
- [23] Nikbay, K., Selçuk, K., & Bilgin, T. T. (2023). Enhancing Energy Efficiency and Real–time Monitoring in Industrial Environments through an Integrated Software Solution: NIGHTWATCH. *Kirklareli Üniversitesi Mühendislik ve Fen Bilimleri Dergisi*, 9(2), 317–329.
- [24] Odetoye, O. (2023). Multi–year techno–economic assessment of proposed zero–emission hybrid community microgrid in Nigeria using homer. *Heliyon*, 9(9), e19189
- [25] Okafor, C., Madu, C., Ajaero, C., Agomuo, K., & Abu, E. (2020). Toward sustainable power supply and consumption of an emerging economy (Nigeria). *Journal of Economic Development Environment and People*, 9(4)
- [26] Okonkwo, C., Edoziuno, F., Adediran, A., Ibitogbe, E., Mahmood, R., & Akinlabi, E. (2021). Renewable energy in Nigeria: potentials and challenges. *Journal of Southwest Jiaotong University*, 56(3), 528–539

- [27] Reiter, M., Fettke, P., & Loos, P. (2014). Towards green business process management: concept and implementation of an artifact to reduce the energy consumption of business processes
- [28] Strielkowski, W., Firsova, I., Lukashenko, I., Raudekiuiene, J., & Tvaronaviene, M. (2021). Effective management of energy consumption during the COVID –19 pandemic: the role of ICT solutions. *Energies*, 14(4),893
- [29] Waziri, B., Hassan, A., & Kouhy, R. (2018). The effect of transitioning to renewable energy consumption on the Nigerian oil and gas exports. *International Journal of Energy sector management*, 12(4), 507– 524



ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665
copyright © University POLITEHNICA Timisoara, Faculty of Engineering Hunedoara,
5, Revolutiei, 331128, Hunedoara, ROMANIA
<http://annals.fih.upt.ro>