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EFFICIENCY OPTIMIZATION OF SOLAR PHOTOVOLTAIC SYSTEMS FOR NKATA PRIMARY HEALTHCARE CENTER, IBEKU, ABIA STATE, NIGERIA

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Abstract: This research presents the analysis and efficiency optimization of a solar photovoltaic (SPV) system tailored for Nkata Primary Healthcare Center, in Umuahia, Abia state, Nigeria. Using solar radiation data, the study evaluates the solar resource potential of the region and simulates the system's performance ratio from January to December 2023. The design analysis was conducted on the component part of the SPV system such as the solar panel, charge controller, battery and inverter. The major findings of the solar photovoltaic system design are the energy requirement per day was found to be 21 kWh, and the total wattage becomes 2.6 kW. The number of solar modules or panels obtained was 25. The SunPower solar panel of 435 W was selected for the design of the SPV system. The current amperage of the solar charge controller realized was 107A for the SPV design, and the power rating for the charge controller was 11 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 3.3 kW for the SPV system design. The maximum direct current DC and voltage for the proposed SPV system were 197 A and 24 V, respectively. At the same time, the maximum alternating current AC and voltage for the SPV system were 11.2 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.

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The proposed SPV system will meet the energy needs of the Nkata Primary Health Center, since the minimum (57.8 kWh) and maximum theoretical energy output (272.2 kWh) per day in a month were higher than the actual estimated energy requirement of the appliances (21 kWh) per day. The average solar performance ratio of the solar system was determined to be 66 %.

Key words *Design; solar photovoltaic system; panel, charge controller, battery; inverter; actual output energy; theoretical output energy; solar radiation; performance ratio*

INTRODUCTION

In recent years, the utilization of renewable energy sources has become increasingly crucial, especially in regions where conventional electricity supply is unreliable or insufficient [1]. This is particularly relevant in the context of healthcare facilities in rural areas, such as those in Abia State, Nigeria [11]. Rural health center's play a pivotal role in providing essential healthcare services to communities. These services range from basic medical care and emergency response to more complex procedures that require reliable power for medical equipment. The importance of consistent and sustainable energy sources in these settings cannot be overstated [10]. The World Health Organization (WHO) emphasizes the critical role of energy in healthcare delivery, noting that access to reliable power is fundamental to preserving life, reducing morbidity, and enhancing the quality of healthcare services [33]. In the context of Abia State, the challenges are accentuated by the region's geographical and infrastructural constraints, which hinder the consistent supply of electricity.

This issue of unsteady power supply is particularly problematic given the critical nature of healthcare services and the need for consistent power to operate is essential to medical equipment [2,3]. The central research problem of this work revolves around the design of solar photovoltaic (PV) systems as a solution to this challenge. The focus is on enhancing the efficiency of these systems to ensure a reliable and sustainable energy source [14]. This involves addressing the unique energy requirements of medical equipment and overcoming the rural infrastructural constraints in Abia State [21]

The theories and models related to solar photovoltaic systems encompass a wide range of topics, including photovoltaic reciprocity theory, electroluminescence, quantum efficiency, artificial neural network models, solar tracking systems, and maximum power point tracking [20]. The photovoltaic reciprocity theory establishes a relationship between the electroluminescence spectrum of a solar cell and the external photovoltaic quantum efficiency of the device [1].

Additionally, the detailed balance theory of fluorescent collectors has been shown to be compatible with conventional solar cells [29].

Furthermore, artificial neural network models have been developed to estimate the energy efficiency of photovoltaic systems using meteorological parameters such as temperature, humidity, wind, and solar radiation [20]. Solar tracking systems have been designed to automatically orient photovoltaic plants to the sun, thereby improving their efficiency [2]. Moreover, maximum power point tracking techniques have been explored to optimize the power output of solar photovoltaic systems [8].

In addition to these, the literature also covers the use of mathematical and simulation models for solar photovoltaic plants, the development of adaptive devices to enhance energy harvesting in solar photovoltaic tracking systems, and the application of model reference adaptive control to assure optimum operating conditions for solar photovoltaic systems [9,13]. Furthermore, the study of distributed knowledge dynamic integration and fusion for solar concentration photovoltaic systems has been proposed to facilitate in-depth research in this area [34]. The impact of neighboring photovoltaic systems on power forecasting has been assessed using artificial neural networks [32]. Additionally, the role of optical elements in holographic solar energy systems has been investigated [15]. Moreover, the use of dual-axis solar trackers to improve the performance of photovoltaic panels has been simulated [4]. The efficiency of different types of solar photovoltaic (PV) systems has been a subject of extensive research. Various studies have investigated the performance and optimization of solar PV systems, including maximum power point tracking (MPPT) techniques, concentrated solar power (CSP), photovoltaic-thermal hybrid systems, and PV levelized cost of electricity (LCOE) generation.

Author [14] compared the effectiveness and accuracy of Perturb & Observe (P&O) and Constant Current (CC) MPPT methods for solar PV systems, highlighting the importance of MPPT techniques in enhancing system efficiency.

Additionally, considered the performance of solar PV systems in rural areas, emphasizing the significance of solar PV and CSP in harnessing renewable energy resources [26]. Furthermore, [24] developed a model for a concentrated solar spectrum splitting PV cell-gas turbine hybrid system to evaluate and predict maximum efficiency, demonstrating the potential for optimizing system performance [24]. Moreover, [17] conducted experimental research on photovoltaic-thermal hybrid solar systems, achieving thermal efficiencies ranging from 51% to 67%, indicating the potential for high efficiency in heating water using PV/T solar systems. Additionally, discussed the economic feasibility of PV projects using LCOE generation, providing insights into the economic aspects of solar PV systems [12]. Furthermore, highlighted the potential of PV panels in contributing to the UK's energy policy goals, emphasizing the regional distribution and determinants of PV deployment [10]. Efficiency analysis of storage-type solar PV/thermal hybrid systems, the impact of temperature on PV panel efficiency, and the efficiency of PV systems in water pumping applications have also been studied [5,7]. Additionally, studies have explored the total efficiency of PV/T systems, the performance of PV systems in different geographical locations, and the influence of solar incentives on the efficiency of residential PV systems [18,23,35].

The use of solar photovoltaic (PV) systems in the healthcare sector has been a subject of interest due to its potential economic and environmental benefits. [3] conducted a case study in Riyadh, the capital of Saudi Arabia, to assess the cost-benefit perspective of solar-assisted power generation systems in hot desert climates.

The study focused on the ambitious goals of the country in the field of solar energy, providing insights into the economic viability of implementing solar PV systems in such regions. This case study is particularly relevant for healthcare facilities located in similar climatic conditions, as it offers valuable information on the economic impact and potential benefits of solar PV systems in hot desert climates. Furthermore, [22] undertook a case study in Sanoder village, Bhavnagar district, Gujarat, India, to optimize solar PV systems and analyze the tilt angle for enhanced performance.

This case study provides valuable insights into the practical implementation of solar PV systems in a specific geographical location, offering lessons that can be applied to healthcare facilities in similar regions. Understanding the optimization of solar PV systems and the impact of tilt angle on their performance is crucial for healthcare facilities seeking to maximize energy generation and efficiency. Moreover, [6] investigated the economic impact of 300 kWp PV rooftop penetration on soy sauce companies, emphasizing the cost-saving potential of solar PV systems in industrial settings. While the study focused on industrial applications, the findings are relevant to healthcare facilities seeking to assess the economic implications of integrating solar PV systems into their energy infrastructure. Understanding the economic impact of solar PV rooftop penetration can provide valuable insights for healthcare facilities aiming to reduce operational costs and enhance sustainability. These case studies collectively contribute to the understanding of solar PV energy use in healthcare by providing insights into the economic viability, performance optimization, and cost-saving potential of solar PV systems in diverse geographical and industrial settings. By synthesizing these case studies, it is evident that the economic viability, performance optimization, and cost-saving potential of solar PV systems are crucial considerations for healthcare facilities aiming to integrate sustainable energy solutions into their infrastructure [12]. The implementation of solar photovoltaic (PV) systems in healthcare settings in Africa faces several challenges but also presents opportunities for improvement.

Challenges include the lack of guaranteed funding, weak infrastructure, and limited resources, as evidenced by experiences in resource-limited countries such as the Democratic Republic of Congo (DRC) [28]. Additionally, the transition to clean energy security in Africa, including the implementation of solar PV systems, requires coordinated efforts of people, industry, and governments [11]. Furthermore, unequal societies, such as South Africa, face resistance and protest when relying solely on technical solutions to address access and inequality in electricity legitimacy dynamics [30]. In the context of healthcare, the challenges of implementing solar PV systems are compounded by the specific features of medicine safety and pharmacovigilance in Africa, which require resources, infrastructure, and expertise [21]. Moreover, the integration of mental healthcare into primary healthcare in South Africa has faced challenges despite efforts to align health-related policy development with international trends [19]. Access to biomedical healthcare services for Black South Africans living in low socio-economic settings remains limited and poor, indicating broader challenges in healthcare access and infrastructure [25]. However, amidst these challenges, there are opportunities for improvement. Lessons learned from the experiences of resource-limited countries, such as the DRC, demonstrate that it is possible to implement PV systems to promote patients' safety in sub-Saharan African countries with limited funding [28].

Additionally, South Africa has opportunities to adapt successful strategies from other areas of public health to improve healthcare, which could be extended to the implementation of solar PV systems in healthcare settings [16]. Furthermore, the potential for solar energy utilization in Africa is underscored by the long-term historical changes in solar irradiance in West Africa and the implications for photovoltaic systems [27]. In conclusion, the challenges in implementing solar PV in healthcare settings in Africa are multifaceted, encompassing funding, infrastructure, and societal dynamics.

However, there are opportunities for improvement, including lessons learned from other healthcare initiatives, the potential for solar energy utilization, and the need for coordinated efforts to achieve clean energy security. Addressing these challenges and leveraging the opportunities for improvement can contribute to the successful implementation of solar PV systems in healthcare settings in Africa. While there is extensive literature on solar energy applications in healthcare, there is a noticeable gap in studies focused on the specific energy needs and infrastructural constraints of rural health center's in regions like Abia State, Nigeria.

MATERIAL AND METHODS

The Nkata Primary Healthcare Centre is in Ibeku, a rural area within Abia State, Nigeria. This healthcare facility is situated at the geographical coordinates of 5.5376014 latitude and 7.5096301 longitude. Figure 1 provides a detailed map of the centre's location, highlighting its proximity to key roads, neighbouring buildings, and the surrounding natural landscape.

Figure 1. Map showing Nkata Primary Healthcare Centre

This center plays a vital role in the local healthcare system, primarily serving the rural population in and around Ibeku. The geographical setting of Ibeku presents unique opportunities and challenges for solar energy utilization.

The region benefits from significant solar exposure, making it an ideal candidate for solar photovoltaic (PV) systems. However, these benefits are countered by challenges such as variable weather conditions, limited infrastructure, and resource constraints typical of rural settings. The solar PV system currently in use at the healthcare center is a critical component of its infrastructure, designed to provide a reliable source of electricity. This system's specifications, such as its capacity, panel type, and configuration, are crucial for understanding its current efficiency levels and potential for optimization. The study of this system, set against the backdrop of Ibeku's unique geographical and infrastructural context, is expected to yield valuable insights into the optimization of solar PV systems in similar rural healthcare settings. The focus on the Nkata Primary Healthcare Centre not only addresses the immediate need for reliable and efficient energy solutions in this specific location but also contributes to a broader understanding of renewable energy applications in rural healthcare environments across Nigeria and similar regions.

Data Collection Methods

Data collection for this study involves a combination of primary and secondary methods to gather comprehensive information on the solar PV system's performance and the healthcare centre's energy needs.

Primary Data Collection: Energy Usage and Solar Irradiance Data: Direct measurements of energy consumption at the healthcare center and solar irradiance levels will be recorded. Energy consumption data will be collected using energy meters attached to key equipment and overall facility metering. Solar irradiance will be measured using a pyranometer installed at the site.

Secondary Data Collection: Local Climate Data: Historical climate data for Ibeku will be obtained from local meteorological stations to analyze the impact of weather conditions on solar PV performance.

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 [4,31].

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:

(1) Estimating total load of all appliances in the three rooms 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 mostly 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, η_p which is a function of average panel temperature as given by [4,2] 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 is the temperature coefficient for module efficiency. The value of $\eta_r$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 [2,7] is given in eqn. (2).

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

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 ºC). NOCT is the Nominal operating cell temperature (45 ºC).

The total area S_A of the PV panel array can be presented in eqn. (3) as stated by [20].

$$S_A = \frac{E_p}{\eta_{p\,G}} = \frac{E_p^{!}}{\eta_c\eta_b\eta_{p\,G}} \qquad \text{………(3)}$$

Where E_p is the energy provided by the PV array. $E_p^{!}$is the energy provided by the PV array after battery bank ($E_p^{!}$equals the daily load demand 21225 Wh). G is the daily irradiance (5kWh/m^2/day),$\eta_{c,}$ $\eta_b$and η_i are the efficiencies of 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 panel as stated by [1,20] is given in eqn. (4)

$$N_{p1} = S_A/S_p \qquad \text{………(4)}$$

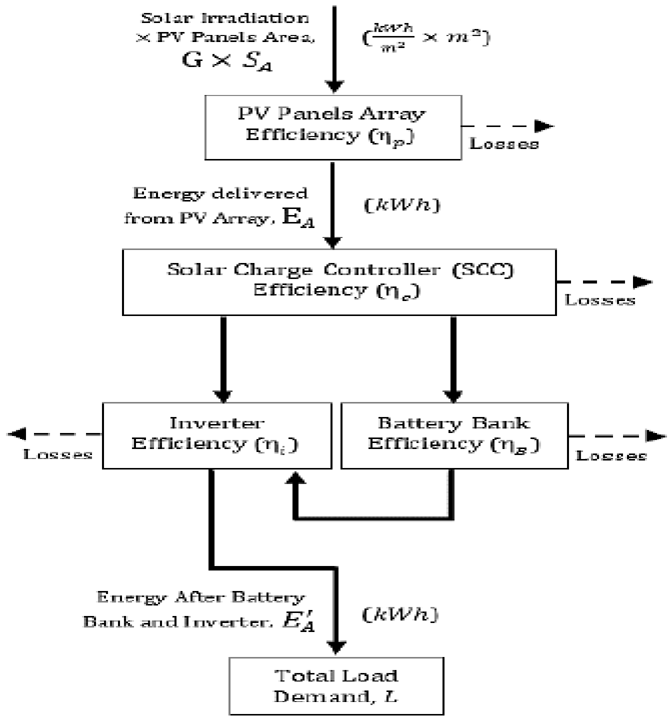

Fig. 2: Solar PV system design flow-chart.

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

The total electricity demand of 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 [23] is presented in eqn. (5).

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

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

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

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

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) = **21,225** Wh/day

Total PV panels energy needed (TPEN)

$$TPEN = ECPD \times ELS \quad (7)$$

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).

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

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 the angles are calculated by Omni calculator in Fig. 3.

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

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

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). 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 d ≈ 2m.

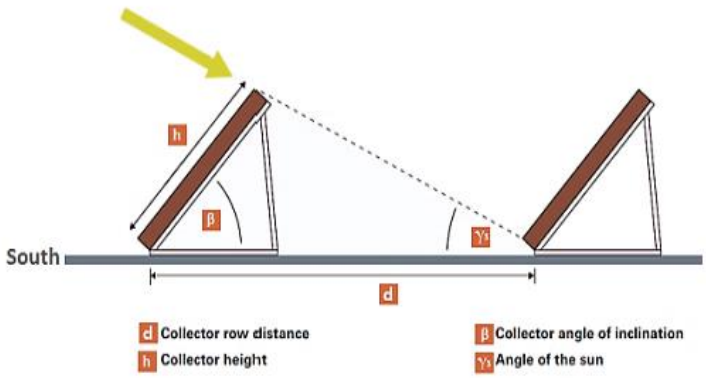

Plate 1. Clearance Between Collectors or PV Panels Rows.

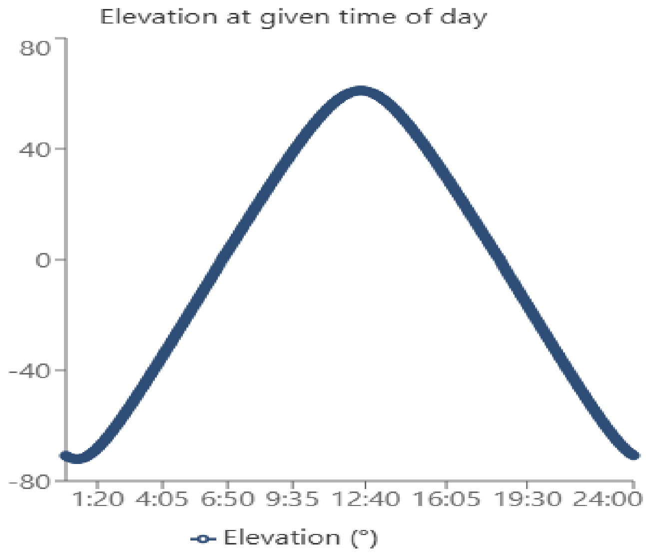

Fig.3. The angle γ_s of the sun at mid-day in the shortest day of the year 2023 (21st December) for Umuahia area (by Solar elevation angle Omni calculator).

The Batteries Sizing of the solar panel (Method 1), according to [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 volt 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 Batteries 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; Battary loss-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 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 [31] is represented in equation (13)

Solar Charge controller (SCC_{1cu}) is given bellow

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

The system volt used is 24 V.

The Solar charge controller sizing: Method 2, according to [20] is given in eqn. (14).

According to standard practice, the sizing of solar charge controller is to take the short circuit current (Isc =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} = panels in Series array x total short circuit current of PV array x 1.3 ….(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 [20] 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)

The Inverter Capacity Selection for the solar panel as stated by [18] is in eqn. (17) for Method 1.

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

The inverter sizing for Method 2 as presented by [20] is stated in eqn. (18).

For safety, the inverter should be considered 25-30% bigger of 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).

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

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).

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

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

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

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

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

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

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

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. AC Load for Nkata Health Center

S/N	Appliances	Watts (W)	Quantity	Total Watt (W)	Hour	Energy (Wh)
1	Led light bulb	18	10	180	12	2,160
2	Fan	70	8	560	12	6,720
3	Inverter Refrigerator	250	1	250	12	3,000
4	Inverter Refrigerator	125	2	250	24	6000
5	Inverter Air-condition	500	1	500	3	1500
6	Inverter Sumo pump	760	1	760	2	1,520
7	Computer	65	1	65	5	325
				2,565		21,225

Table 2. Weather parameters from Metrological Unit at (NRCRI)

Monthly average solar radiation and ambient temperature from Jan. to Dec. 2023.					
S/N	Daily Solar Radiation (G_r) ($W/m^2/d$)	Ambient temperature (Ta) (°C)	Monthly Theoretical Output Energy (kWh)	Monthly Actual Output Energy (kWh)	SPR (%)
1	5192	27.61	4206	658	39.01
2	6508	29.76	5271	594.3	30.55
3	4588	28.94	3716	658	47.76
4	4384	28.38	3551	636.8	64.64
5	3536	28.74	2861	658	70.64
6	2512	27.41	2035	636.8	91.77
7	2432	27.11	1970	658	89.03
8	1780	27.24	1442	658	100
9	2300	27	1863	636.8	93.86
10	2528	27.76	2048	658	84.98
11	4120	27.32	3337	636.8	48.88
12	4980	29.11	4034	658	39.08

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 Module	25
Efficiency	20.1 %
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 Nkata health center in Umuahia, while Table 4 reveals the actual results from the design analysis of the proposed solar photovoltaic system. The environmental weather parameters used in the SPV design, 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. The results from the proposed SPV design of a three-room bungalow in Umuahia

	Total energy hour (kWh)	Watt (kW)	Number of solar compon ents	Capac. of the single product	Input power (kW)	Ampere (A)	Volt (V)	Effic. (η %)
		2.6	20, 19.7 & 19	435 (W)				20.1
Charge controller		11				107, 42 & 42	428	95
Battery (Ah)			12 & 28	250				90
Inverter					2.5 & 3.2			96
Max. DC.						197	24	
Max. AC.						11.2	230	
SPV system	21 & 121							
SPR								68

Discussion of results in Table 3.

Table 1 displays the Nkata Health Center energy estimate, while Table 4 shows a summary of the determined design outcomes. The analysis found a wide range of energy-consuming appliances with different power ratings and operating times. It was determined that the facility (solar panel) would use 21225 Wh (21 kWh) of actual energy each day while the theoretical energy per day is 121 kWh. For the solar photovoltaic panel, the estimated module peak power was 2.6 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 that there were 20, 19.7, and 19 solar panels, respectively. Method 1 was chosen for the design of the solar photovoltaic system since it has the most panels number of 20, but it is approximated to 25 panels due to factor of safety to accommodate future improvement. The efficiency of the solar panels was found to be 20.1%. Methods 1, 2, and 3 all yielded solar charge controller amperages of 107 A, 42 A, and 42 A, respectively. For the SPV system design, the best result is 107 A from method 1 was chosen. 11 kW was determined to be the solar charge controller's wattage. There were 12 batteries from method 1 and 28 batteries from method 2. Even though method 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 2.7 kW for method 1 and 3.3 kW for method 2. Method 2 is used for the design of the SPV system because it has the largest inverter input power (3.3 kW). The suggested SPV system has a maximum direct current (DC) of 197 A and a maximum voltage of 24V. The SPV system's maximum voltage and alternating current (AC) were 230V and 11.2 A, respectively. The solar system's average solar performance ratio was found to be 68 %, indicating that it effectively transforms sunlight or solar irradiance into electrical power.

Table 1 shows that appliances with large energy demands, including refrigerators and fans dominate the consumption profile. Their respective energy demands are 9,000 and 6,000 Wh. Other appliances, including, computer, and LED lightbulbs, use less energy on their own, but because of their longer use hours, they add to the total demand. However, it can usually be optional. The availability of solar energy is in good alignment with the peak energy demand, which usually happens during the day when operating activities are at their highest [4;10;11;12].

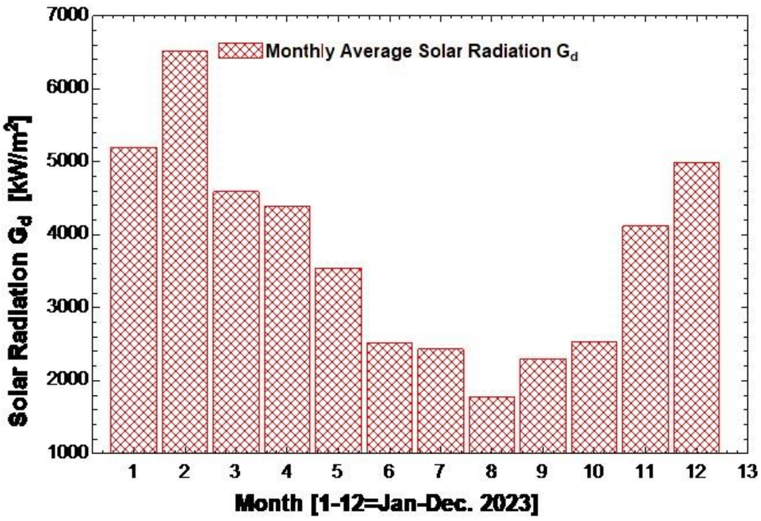

Fig.4. The solar radiation for the photovoltaic system

The solar radiation bar chart for the photovoltaic system from January to December 2023 is shown in Fig. 4. Solar radiation was at its lowest in August and then rose from September to February. In August, the sun radiation summary, average, minimum, and maximum were 44300, 1780, 800, and 3800, respectively. In February, the solar radiation summary, average, minimum, and maximum were 162700, 6508, 3200, and 8400, respectively. Accordingly, February 2023 revealed the maximum amount of solar radiation (8400 W/m2/day) 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 theoretical output energy of 121 kWh per day compared to Table 1's Actual consumption energy of 21 kWh per day.

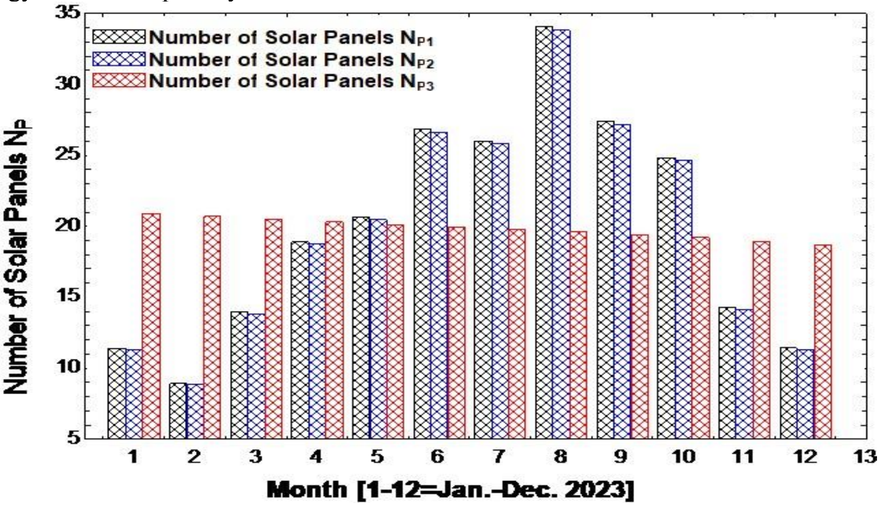

Fig. 5: The Number of panels of the solar photovoltaic system.

Fig. 5 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 239, 19.9, 8.9, and 34.1, 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 236, 19.7, 8.85, and 33.8, respectively. The total summation, average, minimum, and maximum number of solar panels (N_{P3}) from method 3 are 238, 18.79, 18.7, and 20.9, 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 25 for the SPV design, which is in line with the findings of [4,5]. Another observation can be seen from the bar chart 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 maximum number of solar panels of 34.1.

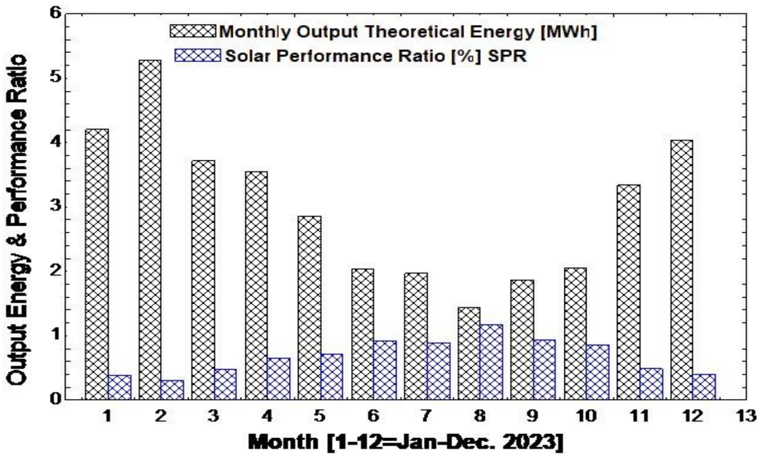

Fig.6. The output Energy and Performance ratio of the solar photovoltaic system

Fig. 6 is the output theoretical energy of the solar photovoltaic system. Fig. 6 illustrates show the output energy fluctuates based on the influence of daily solar radiation, with a minimum output energy of 26.16 kWh in August and a maximum output energy of 210.9 kWh in February. With an average monthly energy production of 3028 kWh, the system generates 36,330 kWh of energy for the site annually. The Nkata Health Center in Umuahia will have its daily energy needs met by the solar photovoltaic system because the projected energy requirement per day is 21225 kWh (21 kWh) from Table 1, which is less than the minimum theoretical energy output (57.7 kWh) and maximum energy output (272.2 kWh) per day in a month in February. The findings regarding the highest energy output in February and the lowest in August are consistent with [11,20,28]'s observations. The solar performance ratio (SPR) spread across the bar chart from January to December with average of 68 %. This results of SPR shows that sunlight energy was totally converted throughout the year.

CONCLUSION

The proposed design of solar photovoltaic system for Nkata Health Center in Umuahia, Abia State, Nigeria, has been completed. The major findings of the solar photovoltaic system are: The energy requirement per day was found to be 21 kWh, and the total wattage becomes 2.6 kW. The number of solar modules or panels obtained was 25. The SunPower solar panel of 435 W was selected for the design of the SPV system. The current amperage of the solar charge controller realized was 107 A for the SPV design, and the power rating for the charge controller was 11 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 3.3 kW for the SPV system design. The maximum direct current DC and voltage for the proposed SPV system were 197 A and 24 V, respectively.

At the same time, the maximum alternating current AC and voltage for the SPV system were 11.2 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 Nkata health center , since the minimum (57.8 kWh) and maximum theoretical energy output (272.2 kWh) per day in a month were higher than the actual estimated energy requirement of the appliances (21 kWh) per day. The average solar performance ratio of the solar system was determined to be 66 %.

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Appendix A.

SUNPOWER E20/435 SOLAR PANEL

MODEL: SPR-435NE-WHT-D

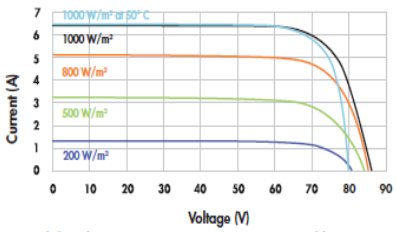
ELECTRICAL DATA
Measured at Standard Test Conditions (STC): Irradiance 1000W/m², AM 1.5, and cell temperature 25° C

Nominal Power (+/-5%)	P_{nom}	435 W
Cell Efficiency	η	22.4%
Panel Efficiency	η	20.1 %
Rated Voltage	V_{mpp}	72.9 V
Rated Current	I_{mpp}	5.97 A
Open-Circuit Voltage	V_{oc}	85.6 V
Short-Circuit Voltage	I_{sc}	6.43 A
Maximum System Voltage	IEC	1000 V
Temperature Coefficients	Power (P)	– 0.38%/K
	Voltage (V_{oc})	-235.5mV/K
	Current (I_{sc})	3.5mA /K
NOCT		45°C +/– 2°C
Series Fuse Rating		20 A
Limiting Reverse Current (3 strings)	I_R	16.1 A
Grounding		Positive grounding not required

ELECTRICAL DATA
Measured at Nominal Operating Cell Temperature (NOCT): Irradiance 800W/m², 20° C, wind 1 m/s

Nominal Power	P_{nom}	323 W
Rated Voltage	V_{mpp}	67.2 V
Rated Current	I_{mpp}	4.81 A
Open-Circuit Voltage	V_{oc}	80.1 V
Short-Circuit Voltage	I_{sc}	5.20 A

I-V CURVE



Current/voltage characteristics with dependence on irradiance and module temperature.

TESTED OPERATING CONDITIONS

Temperature	– 40° C to +85° C
Max load	550 kg/m² (5400 Pa), front (e.g. snow) w/specified mounting configurations 245 kg/m² (2400 Pa) front and back (e.g. wind)
Impact Resistance	Hail: 25 mm at 23 m/s

WARRANTIES AND CERTIFICATIONS

Warranties	25-year limited power warranty
	10-year limited product warranty
Certifications	IEC 61215 Ed. 2, IEC 61730 (SCII)

OPTIMIZACIJA EFIKASNOSTI SOLARNIH FOTONAPONSKIH SISTEMA ZA PRIMARNI CENTAR ZDRAVSTVENE ZAŠTITE NKATA, IBEKU, DRŽAVA ABIJA, NIGERIJA

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Abstract: Istraživanje predstavlja analizu i optimizaciju efikasnosti solarnog fotonaponskog (SFS, eng. SPV) sistema prilagođenog za centar primarne zdravstvene zaštite Nkata, grada Umuahija, država Abija, Nigerija.

Koristeći podatke o solarnom zračenju, studija procenjuje potencijal solarnih resursa regiona i simulira odnos performansi sistema od januara do decembra 2023. godine. Analiza dizajna je sprovedena na komponentama SPV sistema kao što su solarni panel, regulator punjenja, baterija i invertor. Glavni rezultati ispitivanja ovog dizajna solarnog fotonaponskog sistema su: utvrđeno da je potrebna energija dnevno 21 kWh, a ukupna snaga 2,6 kW. Broj dobijenih solarnih modula ili panela je 25. Za dizajn SPV sistema izabran je solarni panel SunPower od 435 W.

Ostvarena električna energija solarnog regulatora punjenja bila je 107 A za dizajn SPV-a, a nominalna snaga regulatora punjenja bila je 11 kW. Broj baterija izračunat za solarni sistem bio je 12, a za dizajn SPV sistema izabrano je 250 Ah za jednu bateriju. Ulazna snaga invertera je određena od 3,3 kW za dizajn SPV sistema. Maksimalna jednosmerna električna energija (jačina struje) (DC) i napon za predloženi SPV sistem bili su 197 A i 24 V, respektivno. Istovremeno, maksimalna (jačina struje) naizmenična električna energija (AC) i napon za SPV sistem bili su 11,2 A i 230 V, respektivno.

Najveći broj solarnih panela bio korišćen u avgustu, tokom perioda minimalnog sunčevog zračenja. Predloženi SPV sistem će zadovoljiti energetske potrebe Doma primarne zdravstvene zaštite grada Nkata, jer je minimalna (57,8 kWh) i maksimalna teoretska izlazna energija (272,2 kWh) dnevno u mesecu bila veća od stvarne procenjene dnevne potrebe za energijom uređaja (21 kWh).

Prosečan odnos solarnih performansi solarnog sistema je određen na 66%.

Ključne reči: *Dizajn; solarni fotonaponski sistem; panel, kontroler punjenja, baterija; inverter; stvarna izlazna energija; teoretska izlazna energija; sunčevo zračenje; odnos performansi.*

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