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Design and Performance Evaluation of an Off-Grid Solar-Powered System

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Abstract: *Electricity is the most general form of energy used across the world. The gap between the demand and supply of electricity for the masses has highlighted the exploration of alternative sources of energy and their sustainable use. Thus the need for the Design and Performance Evaluation of An Off-Grid Solar-Powered System. This project work presents the load demand estimation of a building in northern Nigeria and designing of the solar power capacity that can generate the amount of power assessed from the building. The methodology of this project has been done by knowing the total load estimate. Thus, the load demand assessment shows that the amount of power required by the house is 31522.5Wh per day at maximum and 16,557.3Wh per day when the diversity factor was applied. The most important elements of the off-grid PV system that was designed in this work are Solar panels, charge controllers, battery banks, and inverters. According to the design, the rating of the solar panel, charge controller, battery bank, and inverter needed to produce or generate the required power are 6000w_p, 48V/100A, 25kWh/48V, and 5000VA respectively. Lastly, the designed solar system when compared with the amount of power generated through the PV and the load demand, was observed to be balanced.*

Keywords: Nigeria electricity supply**,** Off-grid solar design, load demand estimation, renewable energy, energy storage, photovoltaic system performance, renewable power generation

1. INTRODUCTION

The design of an effective and efficient system is essential to the optimum utilisation of solar power via photovoltaic or PV cells to generate electricity, especially considering the power fluctuations resulting from environmental conditions such as solar irradiance, temperature, and other weather-induced factors (Mohammad, 2020). The epileptic nature of electricity supply is a drawback in any institute, whether big or small organization. Almost all the day-to-day running facilities to aid the proper execution of one's daily work are currently consuming electric loads such as photocopiers, air-conditioners, computer systems, lighting systems, etc (Manjor *et al.,* 2021). Therefore, energy is a necessity like food and water. Everything around us requires energy. Over the years there has been an increase in the earth's population which is directly proportional to the energy used as well. All the possible gadgets and equipment need some or the other kind of energy to function. With depleting fossil fuel reserves it becomes necessary to identify viable renewable energy resources that can decrease the dependency on fossil fuels (Ayaz, 2018). Photovoltaic (PV) systems (or PV systems) convert sunlight into electricity using semiconductor materials. One good thing about a solar system is that a photovoltaic system does not need bright sunlight to operate. It can also generate electricity on cloudy and rainy days from reflected sunlight. PV systems can be designed as Stand-alone or grid-connected systems. A "stand-alone or off-grid" system means they are the sole source of power to your home, or other applications such as remote cottages, telecom sites, water pumping, street lighting, or emergency call boxes on highways. Stand-alone systems can be designed to run with or without battery backup. Battery backup systems store energy generated during the day in a battery bank for use at night. Stand-alone systems are often cost-effective when compared to alternatives such as utility line extensions (Bhatia, 2022). In this research, the design of an off-grid solar-powered system will be considered.

2. LITERATURE REVIEW

The design and performance evaluation of an off-grid solar-powered home system are the subjects of this research project. The solar panel, inverter, secondary batteries, charge controller, service box, combiner box, and LCD battery monitor are all used in this design. Figure 1 depicts the most well-recognized schematic view of solar home systems (SHS) that has been approved globally (Zain *et al*., 2019).

Figure 1: Schematic diagram of a typical domestic solar system (Zain *et al*., 2019)

The cost and dimensions of the SHS's parts are influenced by one another as well as by the amount of power that glowing lamps and mini-TVs demand. The scarcity of main fuels, such as natural gas, is limiting the advancement of power. Some of the developments that indicate the rapid rise of SHS are the knowledge of the smart grid (Zain *et al*., 2019).

Before the invention of PV generators, the primary focus of research was to offer diesel or gasoline-powered generators as an alternate source of power for systems. A Design and Performance Evaluation of An Off-Grid Solar-Powered System was created to stray from these approaches. However, the research's unreliability constituted a concern. To provide complete system reliability, a gasoline-powered generator and utility supplies were integrated. This study effort focuses on a few documented field works, together with their critiques, suppositions, and conclusions. Table 1 is a tabulation of the review literature summary:

Table 1 gives the summary of relevant literature on alternative power systems showing weaknesses, strengths, and contributions to knowledge of each work reviewed.

Table 1: Summary of relevant literature

S/N	Author	Contribution	Strength	Deficiency	Research Gap
1	Marias (2020)	Design of a Small Scale Off-Grid Solar Energy Plant	Compared to conventional electricity supply, in the long-term off-grid PV system, is cost-effective for the consumer	There was no provision for a service box for maintenance and repairs in case the need arises	Provision was made for the service box
2	Ogbekwe (2010)	3kva Hybrid Power Supply System for 18-unit Computer Laboratory	Compared to other source of electricity supply, it increases the reliability of the power to the consumer.	The configuration was not a match to the load in question and it cannot charge the batteries sufficiently in a day.	The proposed configuration was a match to the load in question and it can charge the batteries sufficiently in a day with back for night use.
3	Allouhi *et al.* (2016)	Grid-Connected PV systems	Findings indicate that the grid-tied PV	The design is not 100% reliable as	The proposed design is 100%

		installed on institutional buildings: technology comparison, energy analysis and economic performance	system has the potential to decrease carbon emission by 5.01 tons of CO2 concerning the selected cases.	there was no provision for back in case of an eventuality.	reliable as there was provision for back in case of eventuality: grid and petrol-driven generator steps in if the system fails.
4	Chaudhry (2021)	Design and Analysis of Off-Grid Solar System for DC Load of a House in Pakistan	It was established that the unit cost of off-grid solar PV electricity is less than grid electricity if the carbon tax and current oil price are Considered	Designed purely for DC loads	Designed for both AC and DC loads
S/N	Author	Contribution	Strength	Deficiency	Research Gap
5	Ghenai (2019)	Grid-tied solar PV/fuel cell hybrid power system for the university building	Findings indicate the integration of A local utility grid with renewable power is an efficient approach to achieving renewable energy targets along with affordable cost of energy.	It was discovered that the percentage of fuel cells was to the tune of 32% which is still harmful to the immediate environment due to the gas emission produced from the fuel cells.	This is different from the new design because the percentage of gas emissions was less than 5%.
6	Obi *et al.*, (2019)	The Use of Renewable Energy as an Alternative Power Supply to New Faculty of Management Science Building Rivers State University, Port Harcourt Nigeria	The research helps in planning and harnessing energy demand (PHED), and cost of energy supply by PHED.	This combination shows that there is still a larger percentage of gas emissions to the immediate environment which may be hazardous to the immediate inhabitants.	The new design has less gas emission.
7	Kehinde *et al.*, (2021)	Design of Grid-connected and Stand-alone Photovoltaic Systems for Residential Energy Usage: A Technical Analysis.	The design happened to be cheap and reliable because of the PVGIS software used	The depth of discharge was 20% and for this reason, the backup time is very low.	The depth of discharge was 80% and for this reason, the backup time is very high.
8	Mahamed (2020)	Self-Sufficient Off-Grid Energy System for a Rowhouse	The low charging issue was solved by combining PV panels with different energy storage systems to have a large harvest	The produced energy from the PV panels is unpredictable due to changes in radiation throughout the day	Sufficient PV was made available in the new research.

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3 MATERIALS AND METHODS

3.1 System Configurations

There are four main configurations of Solar PV systems you can choose from when creating a solar electricity installation. These are Grid-connected (or grid-tied), Off-grid (or standalone), Grid-tie with backup (or grid interactive), and Grid fallback solar PV systems. In this research, an off-grid system was considered.

3.2 Stand-alone/off-grid

A stand-alone small solar electric or photovoltaic (PV) system operates off-grid – in other words, it isn't connected to an electricity distribution grid operated by a utility (figure 2). A stand-alone PV system makes sense if any of the following apply: You live in a remote location where it's more cost-effective than extending a power line to a grid. You're considering a hybrid electric system – one that uses both a PV (solar electric) system and a small wind electric system. You need minimal amounts of power; e.g., for irrigation control equipment and remote sensors. Anyone can take advantage of outdoor solar lighting – a stand-alone PV application. Even if you are planning on something much bigger and grander, it is often a good idea to start with a very small and simple stand-alone system first. Learn the basics and then progress from there (Michael, 2012). Examples where standalone systems are applicable are vending machines, recreational vehicles, homes, and rural areas.

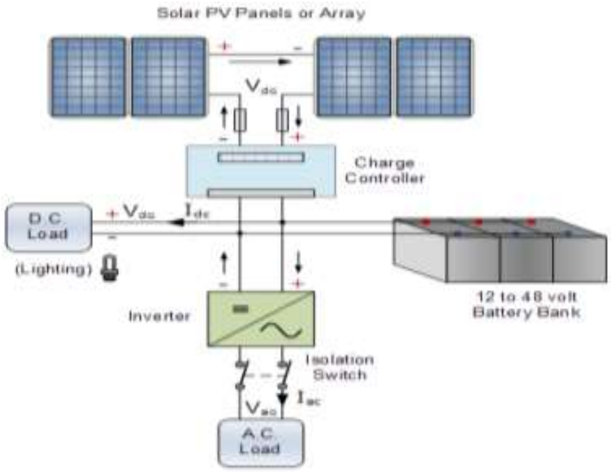

Figure 2: Off-Grid PV system (Bhatia, 2022)

3.3 Load Estimation

According to Table 2, the amount of total load needed per day is equivalent to 31,522.5Wh/day. Applying the diversity factor and selecting the most frequent load in use we have 16,557.3Wh /day. That means the following loads are not frequently used by the client;

AC = 6,000Wh, 2 fans are not always used =4800Wh, 60 lamps not always used =3,600Wh, Pump = 565.2Wh. Total load not always in use = 14965.2Wh. Overall load estimated = 23,820Wh

Design load is therefore = 31,522.5 – 14,965.2= 16,557.3Wh

Table 2:Load Schedule

S/N	Appliances	Appliance Categories	Quantity	Actual Load (W)	Operating Time (Hours/day	Watts-Hour Per day
1	LED Lights	Night Use	120	5	12	7,200
2	Cell Phone Charger	15 Hours	8	5	15	600
3	TV Set	20 Hours	1	50	20	1,000

4	Pumping Machine (Borehole)	0.75Hours (45 mins)	1	750	0.75	562.5
5	Fans	20 Hours	4	120	20	9,600
6	Washing Machine	3 Hours	1	320	3	960
7	Fridge	14 hours	1	400	14	5,600
8	AC	8 Hours	1	750	8	6,000
	Total Watt-hour per day				31,522.5	

An off-grid solar-powered system consists of several key components that work together to generate, store, and utilise solar energy efficiently. The performance of this system is evaluated based on the interconnection of these components. Figure 3 is an explanation of the system design and how each component contributes to its performance:

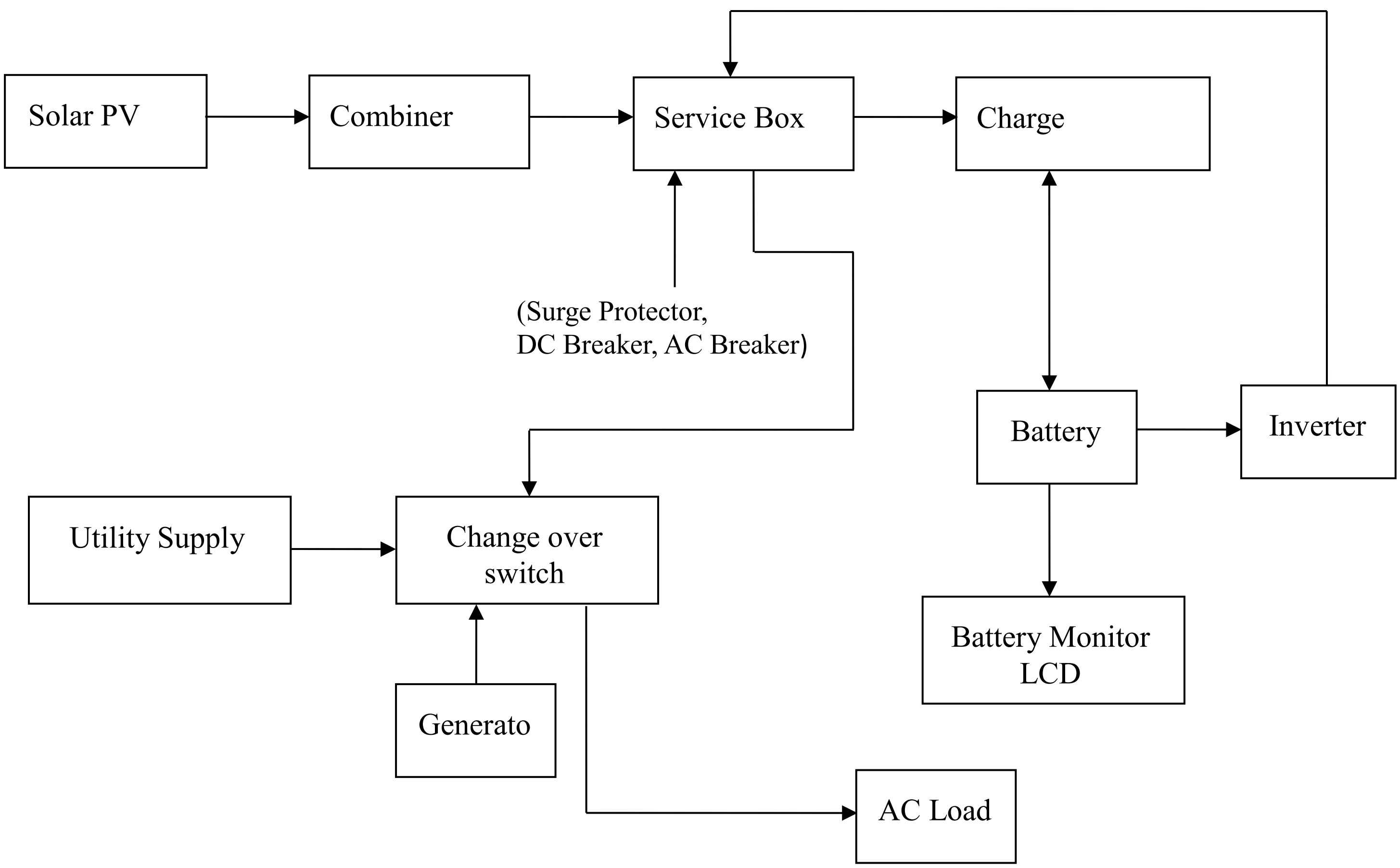

Figure 3: Block Diagram of an Off Grid Solar Powered

3.4 Project Schematic Diagram

Figure 4 depicts a Schematic Diagram of an Off Grid Solar Powered System and Figure 3 explains the design process. The wiring diagrams are shown in the schematic diagram, it also shows the type of combination done (series and parallel), the combination was done to boost voltage and current respectively.

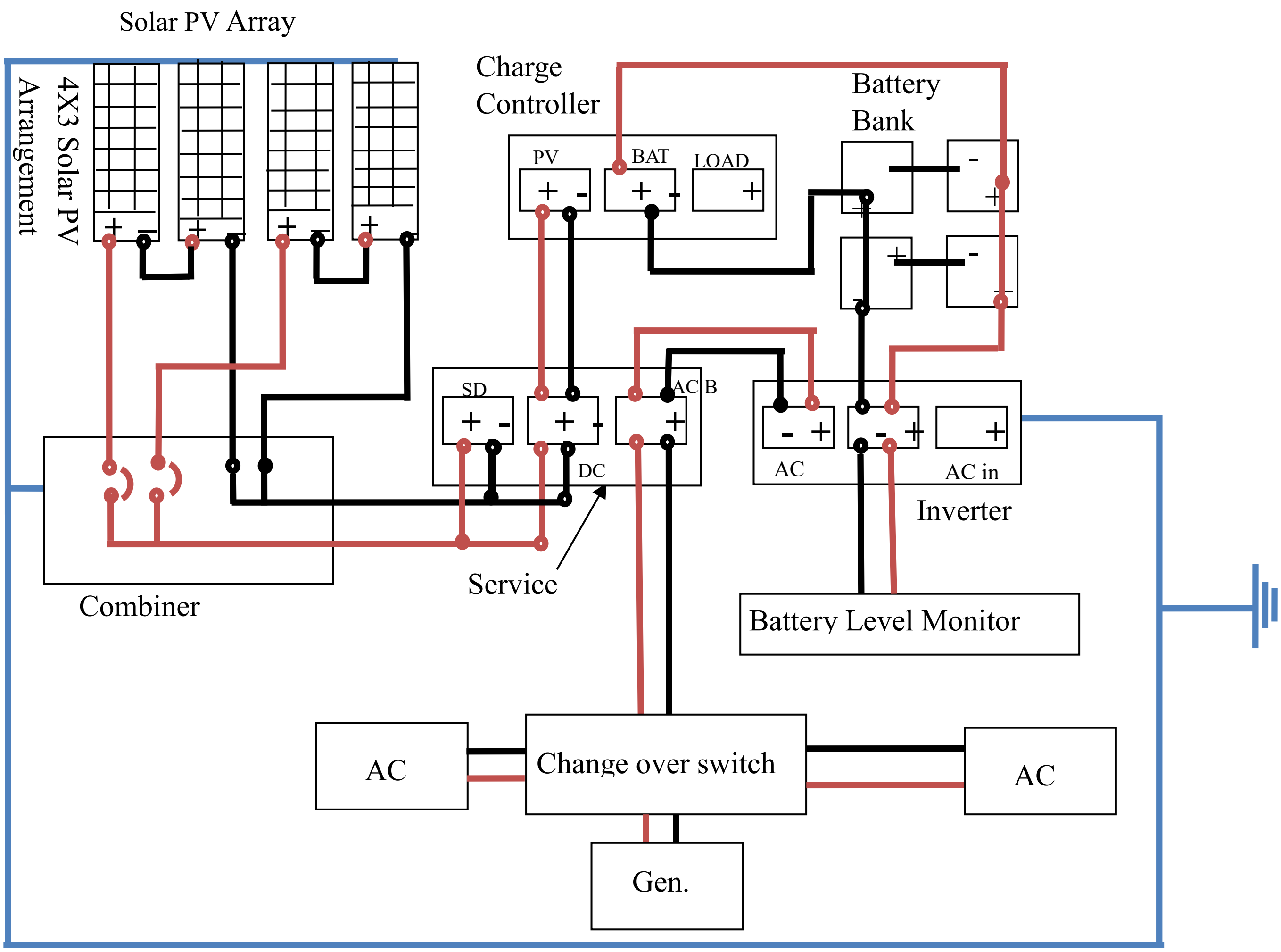

Figure 4: Schematic Diagram of an Off Grid Solar Powered System

i. **Solar Panels (PV Array)**:

The system begins with photovoltaic (PV) panels, which convert sunlight into direct current (DC) electricity. These panels are the primary source of energy for the system. Their performance depends on the sunlight availability, which fluctuates based on geographic location, weather, and time of day.

To calculate the Wattage of the Solar Panels, the method adopted by Moien was used.

$$P_{PV} = \frac{E_d}{PSH \times \eta_{CR} \times \eta_{inv}} \quad (\text{Moien, 2019}) \qquad 1$$

Where,

E_d = is the daily energy consumption of the residential building (kWh/day) = 16,557.3Wh/day (Table 2).

η_{CR} = Charge regulator efficiency = 95%

η_{inv}= Inverter efficiency = 95% (1.0 if there is no inverter)

PSH = Average annual peak sunshine hours (PSH) for Kwara State between 2016-2021 gives 6.3kwh/m^2 (NiMet, 2022).

$$P_{PV} = \mathbf{5491.82W}$$

The total panel capacity used was 6000W

$$Total\ DCCurrent, I_t = \frac{Average\ Peak\ Power\ (Watts)}{System\ Voltage(V_{SP})} \quad 2$$

$$Number\ of\ Series\ Module, N_S = \frac{System\ Voltage(V_{SP})}{Max. Panel\ Voltage\ (Panel\ Short\ Circuit\ Voltage)} \quad 3$$

$$Number\ of\ Paralle\ Module, N_P = \frac{I_t}{I_m} \quad 4$$

Where I_m = Module Current or PV Current

$$N_t = \quad N_S \times N_P \quad 5$$

The formula in Equations 3 to 5 was used to calculate the total number of series and parallel panels used for the design (Zulhelmi, 2018).

Therefore,

$I_t = 48A$

System voltage Vsp, here is the panel design voltage which was 125.6 (short-circuit voltage) and it has an open circuit voltage of 139.2VDC.

$N_S = 4$

$N_P = 3$

$$N_t = 12$$

Therefore, the total number of panels used was 12 Panels rated 500W each

ii. Inverter:

An inverter's performance directly affects the quality and stability of the power supplied to the load. From Table 2, the total connected load to the PV system = 3390W = 3.392Kw = 3.4Kw, therefore the choice of inverter size will be 3.4/0.8 = 4.25KVA and an inverter of 5KVA was selected for future expansion. The inverter converts the stored DC power in the battery bank to alternating current (AC) so that household appliances can use it.

iii. Battery Bank:

Extra energy produced by the solar panels is stored in the battery bank. When solar generation is low, as it is at night or on cloudy days, this stored energy is crucial for keeping the system running. The battery bank's capacity dictates how long the system can run on electricity when it's not sunny. The capacity, the load duration, and the depth of discharge are used to inform the battery selections. They are made to withstand hundreds or thousands of discharges and recharges. Both kWh and amp hours (Ah) are used to rate the batteries. Batteries can connected in series and parallel to raise the voltage to the required level and increase amp hours, just as solar panels. Like solar panels, batteries can be wired in series and parallel to increase voltage to the desired level and increase amp hours. In selecting the battery bank within the time frame per day, the formula in equation 6 was used.

$$\mathrm{C_{BAh}} = \frac{\mathrm{E_{db}} \times \mathrm{DOA}}{\mathrm{DOD} \times \eta_{\mathrm{BA}} \times \mathrm{V_B}} \quad (\text{Moien}, 2019) \quad 6$$

Where

E_{db} = Daily energy required from battery = 16,557.3 (applying diversity factor)

C_{Bah} = Battery capacity

AD = DOA = Autonomy days or Days of autonomy =1

DOD = Depth of discharge for lithium battery = 80%

η_{BA}= Ampere efficiency of battery = 280%

V_B = Selected nominal DC Voltage of the battery =48V

$$\mathrm{C_{BAh}} = \mathbf{538.95AH}$$

Therefore, a 25kWh/51.2V lithium battery was selected.

iv. Charge Controller:

The DC electricity generated by the solar panels is regulated by a charge controller. This device ensures that the power from the solar

panels is properly managed to prevent overcharging of the battery bank. It plays a crucial role in maintaining the longevity and performance of the batteries by optimizing the charge and discharge cycles.
To calculate PV Array Current (Minimum Controller Input Current)
PV Array Current = I_{SC} x P_{VP} x Safety Factor
I_{SC} = Module short circuit current = 14.7 amps
P_{VP} = PV modules in parallel = 3 no.
Safety Factor = 1.25
PV Array Current = 14.7 x 3 x 1.25 = 55.125A
Therefore, a 48V/80A charge controller was sufficient but because of the number of panels in a string, a 48V 100A MPPT charge controller was selected.

v. Combiner box

Individual PV modules or string wires are installed to lead to the combiner box, which is typically located on the roof. These cables may have been single conductor pigtails that required attaching to the solar PV modules. The PV solar system combiner box outputs a single, larger, conduit-mounted two-wire. Each string in a combiner box often has a security circuit or breaker, and it may also include surge protection.

vi. Service box –This box has DC and AC breakers for overloads as well as a surge protector (XLSDP) to reroute any surges. These AC and DC breakers can also be utilized in situations where future repairs or an electrical short occurs. When power from the utility and renewable energy source enters the building, this box acts as the primary control point. It contains circuit breakers that safeguard different electrical circuits within the house.

vii. Surge protectors help to absorb or divert excess voltage, preventing damage to the solar equipment. They are an essential safety feature in solar installations, designed to protect sensitive components like inverters, charge controllers, and battery banks from electrical surges.

viii. The battery monitor LCD unit serves as a critical tool for monitoring the status and performance of the battery bank. Its primary function is to provide real-time information about the state of the batteries, helping users manage and optimize the battery's performance.

ix. AC loads refer to electrical devices or appliances that run on **alternating current (AC)**, the form of electricity typically supplied by the power grid or converted by an inverter in off-grid systems. In a solar power system, DC (direct current) generated by the solar panels or batteries must be converted to AC using an **inverter** to power AC loads. Examples of such loads are Refrigerators, Washing machines, Air conditioners, Microwaves, Electric ovens, TVs and so on.

x. Generator- In solar power systems, particularly **off-grid** or **hybrid systems**, a generator is often used as a backup power source when solar power is insufficient, such as during prolonged cloudy periods, at night, or when energy demand exceeds solar generation.

xi. Change over switch- This is an electrical device that allows a smooth transition between two power sources, such as between the main power supply (grid or generator) and an alternative power source (like solar power or backup generator). It ensures that one power source is safely disconnected before another source is connected, preventing back feed, which can damage electrical equipment or pose safety risks.

xii. Utility supply- Electricity from a public or private **utility company** to homes, businesses, or other facilities. In the context of solar power systems, the utility supply often serves as a backup or supplementary power source.

xiii. The grounding is an essential safety mechanism in electrical systems, including solar power installations. It involves connecting parts of the electrical system, like solar panels, inverters, and metal components, to the earth (ground) to ensure safety and proper functioning. Grounding prevents electrical faults, reduces the risk of electric shock, and protects equipment from damage caused by surges, such as lightning strikes. Grounding likewise balances out voltages and gives a typical reference point.

xiv. Array DC disconnect is an essential safety device used in solar photovoltaic (PV) systems. It is designed to disconnect the solar array (or multiple arrays) from the rest of the electrical system, particularly the inverter and other downstream equipment. This allows for safe maintenance, troubleshooting, or emergency shutdowns.

xv. Inverter AC disconnect is a safety device used in solar photovoltaic (PV) systems to isolate the inverter from the alternating current (AC) side of the electrical system. This disconnect is crucial for ensuring safety during maintenance, troubleshooting, or emergencies.

3.2 Selection of Cable Size

When the size and type of cable are well selected this improves the reliability and performance of the PV system that is why cable sizing is a very important step. In this system, a copper wire was used.

The cable cross-sectional area is determined by the following equation:

$$\text{CT} = \frac{(\text{L} \times \text{I} \times 0.04)}{(\text{V} \div 20)} \quad (\text{Michael}, 2012) \tag{7}$$

Where CT = Cable thickness
L = length of run of cable = 30m
I= system current = Array current =55.125
V= system voltage = Array voltage = 139.2

$$\text{CT} = \mathbf{9.5mm^2}$$

The available cable size closer to $9.5mm^2$ is $10mm^2$; therefore a $10mm^2$ was selected.

3.5 Pictures of the Constructed Work

Before the work started, a lot of preparation was done, ranging from getting the best position of installation using the compass, and the tilt angle, measuring the position of best fit for the ray-less mounting structures, cutting flash bands to cover areas of possible leakages after installation as shown in plate1. Thereafter the mounting, earthing, and installation process followed and this can be seen in plate 2 to plate 4 respectively.

Plate 1: Construction of ray-less mounting structures

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Plate 2: Mounted panel on the mounting rays

Plate 3: Installation of Battery, Inverter, Controller, and Service box in Progress

Plate 4: Construction and Installation of earth mat

4 TESTING AND RESULTS

After mounting and completing the installation, Table 3 shows the results obtained while Figure 5 shows the plot of the results obtained from the aforementioned table.

Table 3 shows the average sun hour data obtained between January to December 2023.

Table 3: Average Solar Cell result obtained for the hourly current generated

Tilt angle 15^0 Mounting Position: South West Lat. $8^0$28'40" N Long. $4^0$30'0" E

SOC = 95% at 7am DOD =5% at 7am Sun hours/day = 7-9hrs Temperature 28^0C-41^0C

Date In Months	Time (Hours)	PV Rating (W)	PV Voltage (V)	PV Current (A)	Power Generated (W)	Battery Voltage (V)
January to December	7:00 am	6000	80	4.0	196	49.0
	7:30 am		100	4.5	223	49.5
	8:00 am		105	4.6	230	50.0
	8:30 am		110	10.0	500	50.0
	9:00 am		120	12.0	606	50.5
	9:30 am		120	11.5	575	50.0
	10:00 am		125	14.0	707	50.5
	10:30 am		100	18	918	51.0
	11:00 am		100	22	1144	52.0

11:30 am	98	25	1300	52.0
12:00 pm	90	28	1456	52.0
12:30 pm	90	32	1664	52.0
1:00 pm	88	48	2496	52.0
1:30 pm	85	43	2322	54.0
2:00 pm	82	48	2592	54.0
2:30 pm	80	35	1908	54.5
3:00 pm	75	40	2200	55.0
3:30 pm	70	35	1925	55.0
4:00 pm	100	18	1008	56.0
4:30 pm	90	15	855	57.0
5:00 pm	80	12	690	57.5
5:30 pm	80	12	696	58.0
6:00 pm	60	10	580	58.0
6:30 pm	50	7	392	56.0

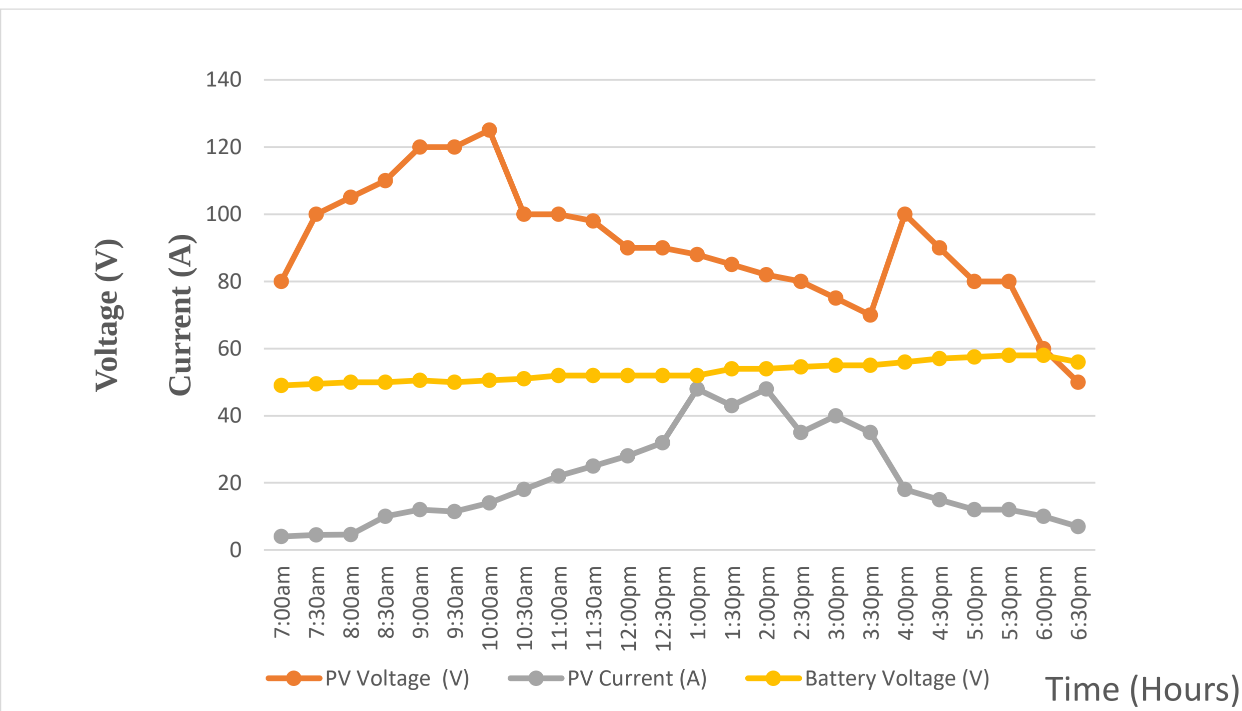

Figure 5: Solar Cell curves for PV voltage, Battery voltage, and PV current against time between January to December 2023.

4.1 Discussion of Results

Solar Cell I-V Characteristics Curves are a graphical representation of the operation of a solar cell or module summarising the relationship between the current and voltage at the existing conditions of irradiance and temperature. I-V curves provide the information required to configure a solar system so that it can operate as close to its optimal peak power point (MPP) as possible. The above graph (figure 5) shows the current-voltage (I-V) characteristics of a typical silicon PV cell operating under normal conditions. The power delivered by the solar module was obtained as the product of its output current and the battery voltage (I x V).

With the solar cell being open-circuited, that is, not connected to any load, the current was at its minimum (zero) and the voltage across the cell is at its maximum, known as the solar cell's open circuit voltage, or Voc (figure 5). At the other extreme, when the solar module was short-circuited, that is the positive and negative leads connected, the voltage across the module was at its minimum but the current flowing out of the module reached its maximum, known as the solar cells/module short circuit current, or Isc. The Photovoltaic panels were wired or connected in series and parallel combinations, to increase the voltage and current capacity of the solar array. When the solar panels are connected in a series combination, the voltage increases, and when they are connected in parallel then the current increases. It was observed that when the system was loaded the excess voltage was converted into current up to the tune of 48A. That is, voltage drops from 139.2VDC to 70 and 82VDC and current appreciates from 4.5A to 48A respectively for a load of 1500W upward.

Table 3 and Figure 6 typically represent the performance of the system over 12 months. Each plot tracks the behavior of different components in the system, providing insights into how the solar panels (PV), batteries, and the overall system are functioning. PV voltage represents the voltage generated by the solar panels based on the amount of sunlight received. This plot (figure 5) typically shows how the voltage varies throughout the day as sunlight intensity changes. In the morning**,** as the sun rises, the PV voltage begins to increase, reaching its peak around midday when sunlight is strongest. At midday, the voltage is generally highest around noon or early afternoon, during the hours of maximum sunlight. Finally, in the evening, as the sun sets, the PV voltage decreases and eventually drops to zero after dark. It was observed that, in the morning, as the PV panels begin generating power, the battery voltage rises as the batteries start charging. The battery voltage increases gradually until it reaches full charge. When the batteries are fully charged, the voltage remains steady at a high level, indicating that no more charge is being stored. Also as the sun rises, the current generated by the PV panels increases, following the increase in sunlight intensity.

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The design and performance analysis of a 5kVA off-grid solar-powered system has demonstrated that such systems can effectively meet the energy demands of households and small businesses, especially in areas with limited or unreliable access to the utility grid. The project showed that the key components of the system, including solar panels, charge controllers, battery banks, and inverters, work in tandem to provide continuous power, particularly in locations like Nigeria, where sunlight is abundant.

Through the load demand assessment, it was determined that the energy consumption for the building was approximately 32,000Wh per day at peak, with a reduced demand of 17,000Wh per day after applying the diversity factor. The design of the solar system, consisting of solar panels rated at 6000Wp, a 48V/100A charge controller, a 25kWh/51.2V battery bank, and a 5000VA inverter, was able to meet these requirements effectively.

The system's performance, when compared to the load demand, indicated a balance between energy generated and energy consumed, ensuring reliable off-grid operation. The integration of efficient components, alongside proper design considerations, provided a sustainable solution for energy independence and reduced reliance on fossil fuels.

5.2 Recommendations:

1. **System Sizing and Expansion**:

For future installations, it is recommended to carefully assess the specific energy consumption patterns of users to appropriately size the system. If there is a potential increase in load demand, the system should be designed to allow for easy expansion, such as adding more solar panels or increasing battery capacity.

2. **Battery Management and Maintenance**:

The battery bank is a critical component in off-grid systems. It is recommended to implement an effective **battery management system (BMS)** to prolong battery life and ensure optimal performance. Routine maintenance and monitoring of the state of charge (SOC) should also be conducted to prevent overcharging or deep discharge.

3. **Use of Energy-Efficient Appliances**:

To maximize the performance of the solar-powered system, users should be encouraged to utilise energy-efficient appliances. Reducing the overall load demand can lead to increased autonomy of the system and reduced battery wear.

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