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Original Research Article

Design of Off-Grid Hybrid Energy for Residential Buildings in Rural Areas : A Case Study of Arogbo Community in Ondo State

ABSTRACT

This paper developed an off-grid hybrid energy system for residential buildings in rural areas. The Arogbo community in Ese-Odo Local Government Area of Ondo State, Nigeria, was used as case study. Energy Audit of the selected residential buildings was carried out through the administration of structured questionnaires and oral interaction with occupants. Information obtained was used to evaluate the total power estimate and actual consumption over a period of 6 hours per day. The total energy demand for the study area based on the number of appliances used per day was estimated as 4981.684 kW. The energies required for three different categories of accommodation: [three-bedroom (Luxury), three-bedroom (Convenience) and room with parlour living apartment] in the area were estimated as 10.015 kWh, 3.216 kWh, and 1.736 kWh respectively. Their total photovoltaic (PV) energy system capacities were estimated as 13.53 kWh (16.91 kVA), 4.342 kWh (5 kVA), and 2.344 kWh (2.93 kVA) with power factor of 0.8 respectively. The PV solar modules for the three-bedroom (luxury), three-bedroom (convenience) and room with parlour living apartment were estimated as (3.38, 1.08 and 0.59) kW with installation areas of (31, 10 and 5.5) m^2; and inverter rating of (6, 1 and 1) kVA were selected respectively. The deep cycle batteries selected were (4, 2 and 2) at 12 V of (150, 150 and100) AH. Electricity generator capacities selected were (6, 1 and 1) kVA respectively.

Keywords: Off-grid, photovoltaic, hybrid energy, electricity generator, inverter system

1. INTRODUCTION

Energy played an essential role in the development and evolution of human society, and in alleviating world poverty. The real potential of electricity/energy lies not in providing social amenities but in stimulating long-term economic development. Energy is used to produce electricity which affects every area of people's lives and it is important to the free flow of a healthy economy and in ensuring a healthy population growth. Energy is a vital factor in all the sectors of any country's economy. Security, climate change, and public health are closely interrelated with energy [1, 2, 3]. Modern economies and ways of life have made life almost impossible without massive, reliable, constant and affordable supplies of energy and therefore, the standard of living of a given country can be directly connected to the per capita energy consumption. Energy resources are required for electrical power generation, and this depends on the availability, security and environmental impact of these resources. The energy resources can be classified as renewable and non-renewable energy sources. Non-renewable sources are those which exist in a fixed or limited quantity on earth and their rate of replenishment is far lower than the rate of consumption. These include fossil fuels such as coal, petroleum, natural gas and nuclear fuels such as uranium. They are expensive and scare and their use are responsible for environmental problems such as global warming and air pollution, which cause health problems and affect the quality of life of populations [4].

Renewable energy on the other hand, is energy obtained from inexhaustible sources like the sun, wind, tidal waves, geothermal, biomass source etc. The use of renewable energy ensures that no additional carbon dioxide is released into the atmosphere. Renewable energy sources are good and wonderful options because they are limitless and will never be depleted as the fossil fuels do. Also, it is not only the declining levels of fossil fuels that is the only major concern that will make Nigeria to adapt and switch to the use of renewable energy sources. Supplying electricity to consumers takes a long and cumbersome process; starting from how to generate, transmit and distribute electrical power from the power generation plant to the consumers. As a result of its complex processes, providing electricity to consumers requires high investment, operational and maintenance cost, and high technology requirement as well as sufficiency of well-trained manpower [5].

Rural electrification remains a common challenge for many developing countries, and is a huge development challenge in Nigeria, to reach out to the rural communities that do not have access to electricity and modern energy services. Renewable energy technology is a promising solution to the energy crisis in Nigeria. There is an extreme electricity deficiency in Nigeria and the causes of this deficiency are related to financial, socio-political, and structural issues which lead to high energy losses and high billing from the power sector. These factors result in insufficient cash generation and poor power supply [6, 7]. An estimated 60-70% of the country population does not have access to electricity; while only 10 % of rural households and 30- 40% of the country's total population has access to electricity [8]. Most houses in the rural area obtain their electricity from petrol- and diesel-powered generators which results in noise pollution and increase in global warming or greenhouse gas emission that has a negative effect on the surrounding. Aside the environmental problems, the financial implication for running them every day is very high. To alleviate the problems generated using petrol and diesel generators has forced people to look for alternative energy source that is reliable, sustainable and environmentally friendly.

Renewable energy as source is an alternate energy source that will solve the problem of pollutant formation, climate change and imbalance between energy demand and supply that affect humankind [9]. Hybrid energy system is a system designed to integrate two or more renewable energy sources to generate electricity that is clean, affordable and environmentally friendly. Research has shown that more efforts have been made to combine the electricity generated by the solar with other sources so as to build hybrid power system. In the design and sizing of hybrid power system, the combination of wind and solar energy sources could be used for example as the main source while utility line is used as a backup. This requires the selection and sizing of the most suitable combination of energy sources, distribution and storage systems [10, 11]. In India, the design of hybrid generation system includes a 4.8 kW PV arrays, 2.5 kW wind turbine, and 1200 Ah battery. This provided electricity to base transceiver stations (BTS) with an average power demand of 4 kW. Therefore, by using this power system, about 90% of the required power can be supplied by renewable energy sources [12]. Also, in Iraq, [13] reported the design and performance analysis of stand-alone PV system aimed at providing continuous lighting for laboratories and car parking garage for the purpose of generating green energy.

Vincent, (2016), designed a hybrid (Photovoltaic (PV)/Diesel) power system with energy storage in batteries for remote residential home located in the Southern Nigeria. The hybrid system was designed to overcome the problem of climate change, to ensure a reliable supply without interruption, and to improve the overall system efficiency. The system was sized using conventional simulation tool and representative insolation data. This system includes a 15 kW PV array, 21.6 kW (3600 Ah) worth of battery storage, and a 5.4 kW (6.8 kVA) generator. Photovoltaic/wind-based hybrid power system connected to a common bus with battery storage and conventional backup source to supply 2 kW telecommunication load was proposed for use in Malaysia [14]. Tang and Bhamra, [15], (2008) presented an innovative wind/PV/diesel hybrid system implemented in three remote islands in the Republic of Maldives. In the micro-grid system, twenty-four 1.8 kW wind turbines are coupled to the micro-grid, and 2.5 kW of amorphous silicon PV modules to alternating current (AC) grid through single phase grid connected inverter. They undertook renewable system planning using the software tool HOMER to analyze the various options paying particular attention to the cost per unit of electricity consumed, fuel saved and initial capital requirements.

Photovoltaic systems (PV) contain photovoltaic cells that convert light energy directly into electricity [16]. They offer consumers the ability to generate electricity in a clean, quiet and reliable way due to its high energy density [17, 18]. The future of solar photovoltaic systems as a viable alternative to fossil fuel non-renewable sources seem promising, but is yet to make meaningful contribution in the rural areas of developing countries [19].

This study is therefore aimed at designing an autonomous hybrid (PV/Battery/Generator) energy system to generate electricity for residential buildings in the rural area at an affordable price and secure energy services, to alleviate the problems associated with the use of fossil fuels and also improving the standard of living of people of the area.

2. MATERIALS AND METHODS

2.1 Study Area

The study area in this paper is Arogbo Community and is located in Ese-Odo Local Government Area of Ondo State in the South-western part of Nigeria. Arogbo is Northeast of Fiabrasite and Southwest of Safarogbo with Latitude of 6^o 15' 36.1" (6.26^o) North and Longitude of 4^o 59' 48.1" (4.9967^o) East and elevation of 5 meters. Arogbo falls under the tropical climate region which is of two seasons; rainy season between April and October and dry season between November and March. The map of Arogbo is shown in Figure 1

2.2 Population of Study Area

The population of the Arogbo community as recorded in the population census conducted by National Population Census in the year 2006 is 13,857 [20]. The community has a total number of 4,500 to 5,000 houses, but for the purpose of this paper 3,803 houses were covered which represents 80% of the total number of houses in the community. The information on energy consumption pattern obtained from these houses was used to determine the total energy demand of the community. This was used to design the autonomous hybrid (PV/battery/generator) energy system in the area based on the three classes of residential buildings in consideration.

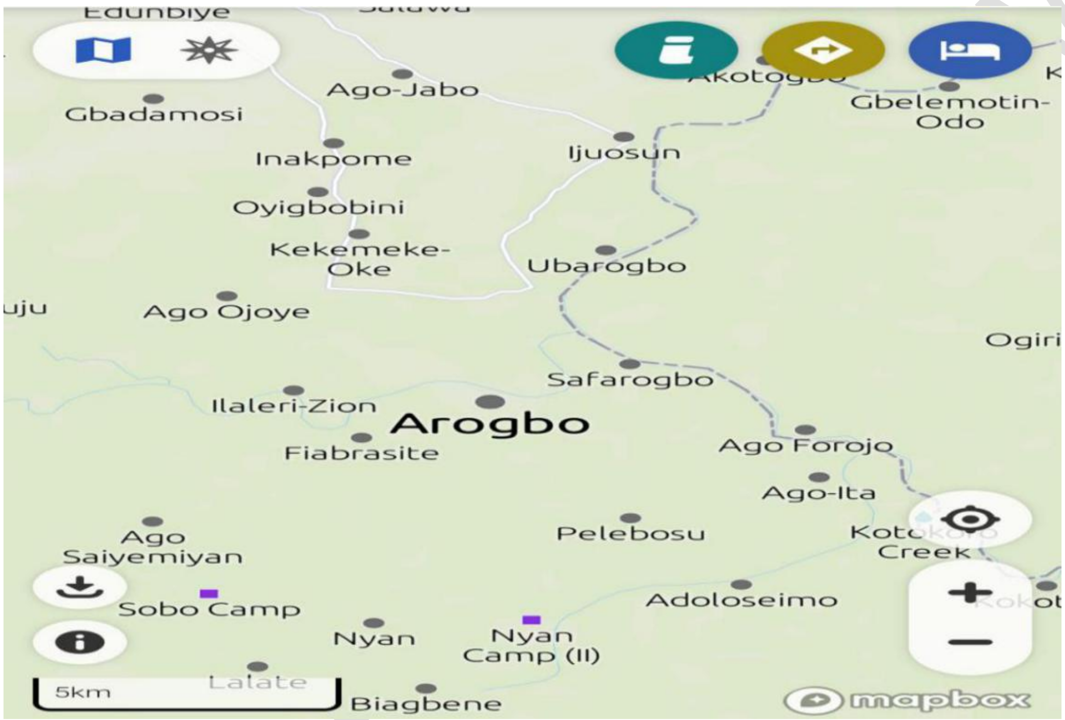
2.3 Research Questionnaire

A well-structured questionnaire was distributed and administered to obtain the required information on energy consumption patterns of the community. Responses from the questionnaire and oral interaction were used to estimate the energy audit of the area.

2.4 Methods

2.4.1 Solar PV Potential of Arogbo Community

The average sunshine per year with an average of 7:16 hours of sunlight per day globally is 2656 hours. This shows that 60.6% of the daylight is sunny and 39.4% of the daylight is likely cloudy or with shade or low sun intensity [21]. The average temperature of Arogbo is 26.9^{o}C while the sunshine hour in the community ranges between 3 - 9 hours per day. Therefore, the average sunshine hour in Arogbo community is 6 hours per day. This makes it a relatively sun-rich region with an annual solar irradiation of about 2190 kWh/m^{2}/year.



LEGEND

	Communities
---------------	State Boundary
	Greeks

Figure 1: Google Map showing Arogbo Community

2.4.2 Energy Demand of Arogbo Community

Arogbo is an Off-grid community and the energy demand was evaluated from the data collected from the appliances in the residential homes through the research questionnaire distributed. The energy demand was determined based on the following information obtained from the area: type of appliances available in the house; number of the appliances in each house; power rating of each appliances in Watts (W) and time of usage of each appliances in hour per day.

2.4.3 Determination of PV Energy Required by each Appliances

The photovoltaic energy required by each equipment in each building was estimated using Equation 1

$$P_D = P_A \times H_D \quad (1)$$

where:
P_A is the total power consumption of each appliances in Watts (W); P_D is the amount of energy needed by each appliances per day in Watts -hour (Wh) or kWh and H_D is the average number hours used by each appliances per day.
The total energy needed to power the area under study was estimated from Equation 2, [22]..

$$S_n = \sum_{j=1}^{j=n}(P_D) \quad (2)$$

where:
S_n is the total energy needed to power the area.
The total power loss in the design of photovoltaic (PV) system for any appliance due to dirt, heat dissipation, resistance in the wire, inverter loss, losses in the battery and PV modules was estimated using Equation 3

$$PL = PL_{PV} + PL_H + PL_D + PL_W + PL_I + PL_B \quad (3)$$

where:
PL_{PV} are the power losses due to PV modules, PL_H is the power losses due to heat dissipation, PL_D is the power losses due to dirt and dust in the solar panel, PL_W is the power losses due to wiring and mismatch, PL_I is the power losses in the inverter and PL_B is the power loss in the battery system.
The PV energy (E_{PV}) required by each appliance in the area was estimated using Equation 4

$$E_{PV} = \sum_{j=1}^{j=n}(P_D) + PL \quad (4)$$

2.5 Photovoltaic (PV) System Equipment Sizing

The sizing of the PV system equipment was based on the total PV energy estimated in Equation (4) and the following equipment were selected based on the total PV energy of the study area:

i. one off-grid solar inverter system
ii. mono-crystalline solar PV arrays rated 500 W of 48 V and 300 W of 24 V
iii. MPPT series Type Micro-controller (MPPTM)
iv. Deep Cycle (DC) batteries
v. Circuit breakers
vi. Combiner boxes

The solar PV array of 48 V and 24 V were selected for the study area being an off-grid location. Based on this, the Green Sun Solar (GSM500-96) model and Felicity (FL-M300-72) model were used.

2.6 Sizing of PV arrays System

The size of the solar arrays needed for each building in the study area was estimated using Equation (5), [23]. The PV arrays were positioned in the right tilt angle in order to receive direct sunlight intensity.

$$S_{PV} = \frac{E_{PV}}{R_H} \times \varepsilon_f \quad (5)$$

where:
S_{PV} is the size of the PV arrays, E_{PV} is the required total PV energy, R_H is the required average sunshine hour per day and ε_f is the efficiency factor (for effectiveness, efficiency factor of 1.5 is assumed in this work).
The Panel Generation Factor (PGF) is an important factor in the design of solar PV module and was estimated based on the above-mentioned factors using Equation (6)

$$PGF = S_{irrad} \times T_{cf-pv} \quad (6)$$

where:
S_{irrad} is the average irradiation of the study area and T_{cf-pv} is the total correction factor for the PV arrays
The total watt-peak for the PV panel capacity needed was determined using Equation (7).

$$P_{Wp} = \frac{E_{PV}}{PGF} \quad (7)$$

where:
P_{Wp} is the total watt-peak for the PV panel capacity.

The total number of PV panel needed for the PV array system is given in Equation (8)

$$N_p = \frac{P_{Wp}}{P_{max}} \quad (8)$$

where:
N_p is the number of panels needed for the PV arrays and P_{max} is the rated maximum power of the solar panel.

2.7 Sizing of the Inverter System and the Micro-controller

The inverter system was sized based on the size of PV array, with power surplus of between 20-30% according to Equation (9). The micro-controller selected was based on the nominal voltage of the PV array.

$$S_{inv} = \frac{R_P}{P_F} \quad (9)$$

where:
S_{inv} is the System inverter; R_p is the real power. (It is given as 1.3 of total wattage of all the appliances in W) and P_F is the power factor. (P_F of 0.8 is adopted for efficiency of the system).

2.8 Sizing of Generator and Battery of the System

The battery capacity was determined according to Equation (10) and the battery load in (kW) was obtained using Equation (11).

$$B_{CAP} = \frac{E_{PV}}{B_{DD} \times Nominal\ Voltage} \times Number\ of\ Days \quad (10)$$

$$Battery\ Load = \frac{N_B \times (V \times A)}{1000} \quad (11)$$

where:
B_{CAP} is the battery capacity, B_{DD} is the battery depth of discharged (taken as 0.5 for 50% of depth of discharge), N_B is the number of batteries used, V is the battery voltage and A is the charging current of the battery.
The size of generator used was determined based on the total loads (loads of all the appliances + battery loads) and power factor according to the Equation (12).

$$G_{SIZ} = \frac{Total\ Loads}{Power\ Factor} \quad (12)$$

2.9 Sizing of Solar Charge Controller and other Accessories

The solar charge controller was determined according standard practice using equation (13).

$$S_{scc} = I_{sc} \times M_{par} \times SF \quad (13)$$

where:
$I_{sc}$is the short circuit current of the PV panel, S_{scc} is the solar charge controller; M_{par} is the modules arranged in parallels and SF is the safety factor.

3. RESULTS AND DISCUSSION

3.1 Arogbo Community Energy Demand

The total energy demand for Arogbo community is shown in Table 1. The total power rating of all the appliances in all the buildings covered was computed to be 4,981.684 kW using standard equations. The total energy demand of the community over a specified period of average usage hours per day, per appliance was estimated to be 19,143,858 which is equivalent to 15315 kVA with power factor of 0.8 and 15% tolerance of the maximum load

3.2 Average Losses in the Design of the PV System

The average losses in the PV system designed is estimated as shown in Table 2. It can be seen from the table that most of the losses occurred at battery (PL_B) and the inverter (PL_I) and the least losses occurred from the wiring (PL_W).

3.3 Hybrid Energy System for Three-bedroom Flat (Luxury)

The total power and energy cosumption per day for all the appliances in three-bedroom flat (Luxury) is shown in Table 3. They were computed as 3.44 kW and 10.015 kWh respectively.

Table1: Energy Demand of Arogbo Community

S/N	Facilities/Appliances (F/A) Captured	Total Quantity of each F/A	Number of Houses	Average Power Rating (P_R) of F/A in (Watt)	Average Hour Usage per day $h_{D,}$ (h)	Total power Rating of F/A. $P_A= P_R$ X Qty, in (Watt)	Power Need per Day. $P_D=P_A$ X $h_D$in (Wh)
1	Tv LCD/LED/Plasma	2514	915	40	8	100560	2133880
	B/W & Coloured	1955	1413	85	8	166175	
2	DSTv	1404	1154	25	8	35100	280800
3	Startime	2531	1321	24	8	60744	485952
4	Air Conditioner	309	87	1010	3	312090	936270
5	Refrigerator	889	767	100	8	88900	711200
6	Deep Freezer	602	541	220	10	132440	1324400
7	Sound System	1891	1089	95	4	179645	718580
8	Single LED Bulb	26087	1739	10	7	260870	
	40W Build	8153	2064	40	7	326120	4108930
9	Ceiling Fan	3385	1315	75	6	253875	1523250
10	Standing Fan	6443	2481	60	6	386580	2319480
11	Electric Pressing Iron	1062	708	850	1.5	902700	1354050
12	Water Pump	198	198	1300	1.5	257400	386100
13	Washing Machine	78	69	400	1.5	31200	46800
14	Electric Stove	27	18	1000	2	27000	54000
15	Microwave	353	207	1200	0.5	423600	211800
16	Security Light	1101	222	10	11	11010	121110
17	Play Station Games	18	10	85	4	1530	6120
18	Phone Charger	15408	3602	5	3	77040	231120
19	Water Heater	38	25	1200	0.5	45600	22800
20	Transistor Radio	12830	2627	6	8	76980	615840
21	Rechargeable Light	13596	2766	5	2	67980	135960
22	DVD Player	2878	2003	35	6	100730	604380
23	Laptop	1367	672	45	4	61515	246060
24	Electrical Blender	159	157	350	0.1	55650	5565
25	Electrical kettle	120	115	500	0.08	60000	4800
26	Electrical boiling ring	215	208	1500	0.17	322500	54825
Total Energy Demand for Arogbo in Watts and Watts-hour						4,981,684	19,143,858
Total Energy Demand for Arogbo in kW and kWh						4,981.684	19143.858
Total Number of Facilities/Appliances Captured						106,260	

Table 2: Average Losses in the System Design

Losses	PL_{PV}	PL_H	PL_D	PL_W	PL_I	PL_B
Average Values (%)	2	5	2	1	10	15
TOTAL Losses (%)	35					

Table 3: Three Bed Room Apartment with High Load Consumptions (Luxury)

S/N	Facilities/Appliances (F/A) Captured	Total Quantity of each F/A	Average Power Rating (P_R) of F/A in (Watt)	Average Hour Usage per day h_D, (h)	Total power Rating of F/A. $P_A = P_R$ X Qty, in (Watt)	Power Supply per Day. $P_D = P_A$ X h_D, in (Wh)
1	Television	2	50	8	100	800
2	Sound System	1	95	4	95	380
	Ceiling Fan	3	75	6	225	
3	Standing Fan	2	60	6	120	2070
4	DVD	1	35	6	35	210
5	DSTV/StarTimes	1	25	8	25	200
6	Single LED Bulb	19	10	7	190	1330
7	Refrigerator	1	100	10	100	1000
8	Iron	1	850	1.5	850	1275
9	Water Pump	1	1300	1.5	1300	1950
10	Washing Machine	1	400	2	400	800
	Total Power Requirement in Watts and Watts-hour				3,440.0	10,015.0
	Total Energy Requirement in kW and kWh				3.44	10.015
	Total Number of Facilities/Appliances Considered				33	

The autonomous hybrid energy system for three-bedroom flat (luxury) was designed based on the energy information on Table 3. It was established that this requires a minimum of seven (7) solar panels rated 500 W at voltage rating of 48 V each, four (4) batteries each being 150AH at 12 V, a 6 kVA inverter, a charge controller rated 95A and a 6 kVA generator as shown in Table 4.

Table 4: Design of Hybrid Energy System for Three Bedroom Flat (Luxury) Summary

Parameter	Equations	Values Obtained
Power consumption per day	$Sn = \sum_{j=1}^{j=10}(PD)$	10.015 kWh
Solar PV Power requirement per day	$E_{pv} = \sum_{j=1}^{j=10}(PD) + PL$	13.53 kWh
Sizing of the PV Arrays	$Spv = \frac{Epv}{RH} \times \varepsilon_f$	3.38 kW
Arrays Area	$A_M = Spv \times 100ft^2$	31 m^2
Panel generation factor	$PGF = S_{irrad} \times T_{cf-pv}$	4.1
Total watt-peak of PV panel capacity needed	$P_{Wp} = \frac{E_{PV}}{PGF}$	3300 W
Total number of PV panels needed	$Np = \frac{PWP}{PMax}$	6.6 ≈ 7 solar PV modules
Inverter sizing	$S_{INV} = \frac{\text{Real Power (Rp)}}{\text{Power Factor (PF)}}$	6 kVA
Sizing of Battery	$B_{CAP} = \frac{E_{PV}}{BDD \times VNom} \times ND$	564AH (4 batteries each being 12 V @ 150AH)
Solar charge controller sizing	$Sscc = I_{SC} \times M_{par} \times SF$	95.11 ≈ 95 Amperes.
Generator Sizing	$G_{SIZ} = \frac{Total\ Loads}{Power\ Factor}$	6.1≈ 6 kVA@ 0.8 PF

The schematic diagram of the Off-grid Hybrid (PV/battery/generator) energy system designed for three-bedroom flat (Luxury) in Arogbo community is shown in Figure 2

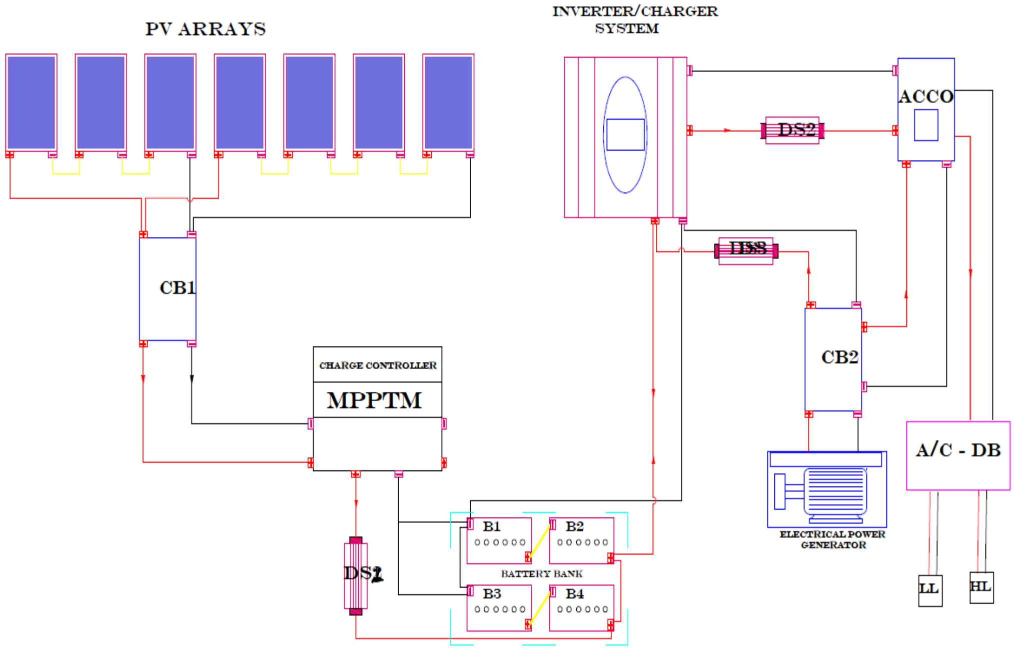


Figure 2: Off-grid Hybrid Energy System for Three-bedroom Flat (Luxury)

3.4 Hybrid Energy System for Three-bedroom Flat (Convenience)

The total power and energy cosumption per day for all the appliances in three-bedroom flat (Convenience) is shown in Table 5, and were computed as 0.51 kW and 3.26 kWh respectively.

The autonomous hybrid energy system for three-bedroom flat (convenience) was designed based on the energy information on Table 5. It was established that it requires a minimum of four (4) solar panels rated 300 W at voltage rating of 24 V each, two (2) batteries each being 150AH at 12 V, a 1 kVA inverter, a charge controller rated 24A and a 1 kVA generator as shown in Table 6

Table 5: Three Bed Room Apartment with High Load Consumptions (Convenience)

S/N	Facilities/Appliances (F/A) Captured	Total Quantity of each F/A	Average Power Rating (P_R) of F/A in (Watt)	Average Hour Usage per day h_D, (h)	Total power Rating of F/A. P_A= P_R X Qty, in (Watt)	Power Supply per Day. P_D=P_A X h_D, in (Wh)
1	Television	1	50	8	50	400
2	DVD	1	35	6	35	210
3	Single LED Bulb	11	10	7	110	770
4	Ceiling Fan	4	75	6	300	1800
5	Transistor Radio	1	6	6	6	36
	Total Power Requirement in Watts and Watts-hour				501.0	3,216.0
	Total Energy Requirement in kW and kWh				0.501	3.216
	Total Number of Facilities/Appliances Considered				18	

Table 6: Design of Hybrid Energy System for Three Bedroom Flat (Convenience) Summary

Parameter	Equations	Values Obtained
Power consumption per day	$S_n = \sum_{j=1}^{j=5} (P_D)$	3.216 kWh
Solar PV Power requirement per day	$E_{TPV} = \sum_{j=1}^{j=5} (P_D) + PL$	4.342 kWh
Sizing of the PV Arrays	$S_{pv} = \frac{E_{Tpv}}{R_H} \times EF$	1.086 kW
Arrays Area	$A_M = S_{pv} \, x \, 100ft^2$	10 m^2
Panel generation factor	PGF = $S_{irrad} \times T_{cf\text{-}pv}$	4.1
Total watt-peak of PV panel capacity needed	$P_{Wp} = \frac{E_{TPV}}{PGF}$	1059 Wp
Total number of PV panels needed	$Np = \frac{P_{WP}}{P_{Max}}$	3.53 ≈ 4 solar PV modules
Inverter sizing	$S_{inv} = \frac{\text{Real Power (Rp)}}{\text{Power Factor (PF)}}$	0.814 ≈ 1 kVA
Sizing of Battery	$B_{CAP} = \frac{E_{TPV}}{B_{DD} \times V_{Nom}} \times ND$	362AH (2 batteries each being 12 V @ 150AH)
Solar charge controller sizing	Sscc = I_{SC} x M_{par} x SF	23.95 ≈ 24 Amperes.
Generator Sizing	$G_{SIZ} = \frac{\text{Total loads in kW}}{\text{Power factor}}$	1.076 ≈ 1 kVA @ 0.8 PF

The schematic diagram of the Off-grid Hybrid (PV/battery/generator) energy system designed for three-bedroom flat (Convenience) in Arogbo community is shown in Figure 3

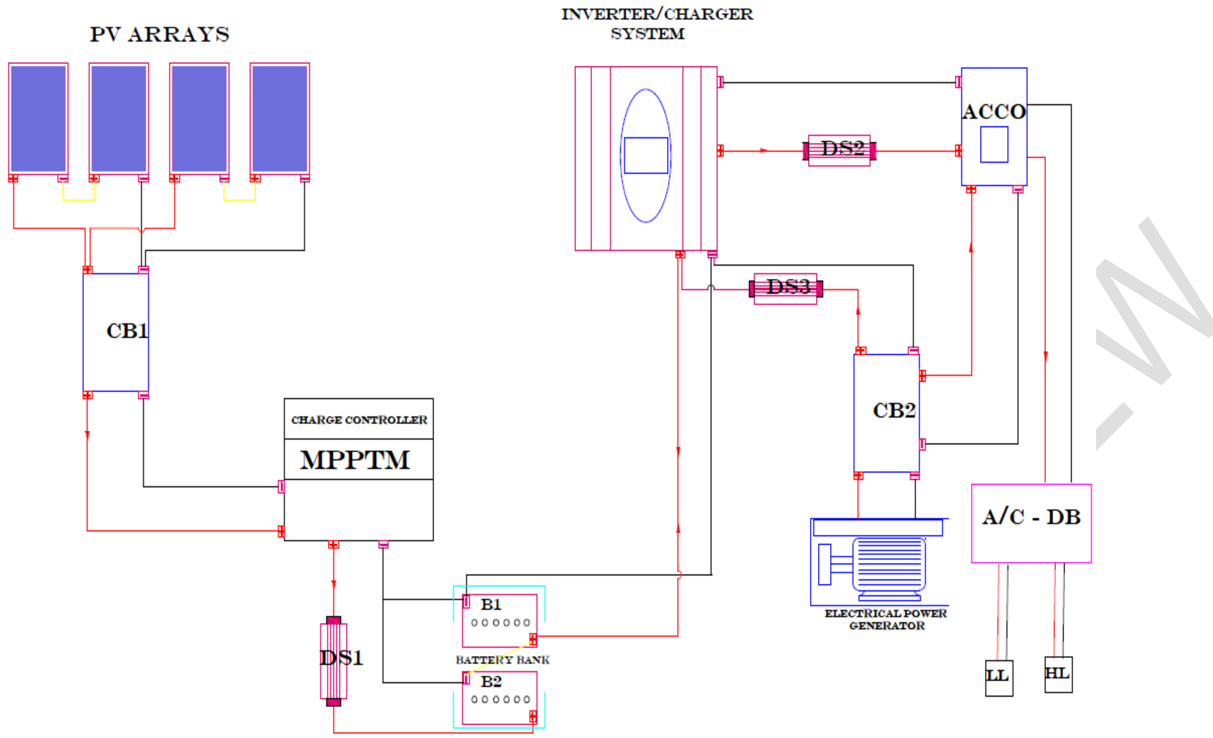


Figure 3: Off-grid Hybrid Energy System for a three-bedroom apartment (Convenience)

3.5 Hybrid Energy System for a Room and Parlour Apartment

The total power and energy cosumption per day for all the appliances in a single room and parlour living apartment is shown in Table 7. These were computed as 0.266 kW and 1.736 kWh respectively.

Table 7: Room and a Parlour Apartment

S/N	Facilities/Appliances (F/A) Captured	Total Quantity of each F/A	Average Power Rating (P_R) of F/A in (Watt)	Average Hour Usage per day h_D, (h)	Total power Rating of F/A. $P_A = P_R$ X Qty, in (Watt)	Power Supply per Day. $P_D = P_A$ X h_D, in (Wh)
1	Television	1	50	8	50	400
2	DVD	1	35	6	35	210
	Ceiling Fan	1	75	6	75	
3	Standing Fan	1	60	6	60	810
4	Single LED Bulb	4	10	7	40	280
5	Transistor Radio	1	6	6	6	36
	Total Power Requirement in Watts and Watts-hour				266.0	1736.0
	Total Energy Requirement in kW and kWh				0.266	1.736
	Total Number of Facilities/Appliances Considered				9	

The autonomous hybrid energy system for a single room and parlour was designed based on the energy information on Table 7. It was established that it requires minimum of two (2) solar panels rated 300 W at voltage rating of 24 V each, one (1) battery of 100AH at 12 V, a 0.43 kVA or 1 kVA inverter, a charge controller rated 24A and a 1 kVA generator as shown in Table 8.

Table 8: Design of Hybrid Energy System for Room & Parlour Apartment Summary

Parameter	Equations	Values Obtained
Power consumption per day	$S_n = \sum_{j=1}^{j=5} (P_D)$	1.736 kWh
Solar PV Power requirement per day	$E_{TPV} = \sum_{j=1}^{j=5} (P_D) + PL$	2.344 kWh
Sizing of the PV Arrays	$S_{pv} = \frac{E_{Tpv}}{R_H} \times EF$	0.59 kW
Arrays Area	$A_M = S_{pv} \text{ x } 100\text{ft}^2$	5.5 m^2
Panel generation factor	PGF = $S_{irrad} \times T_{cf\text{-}pv}$	4.1
Total watt-peak of PV panel capacity needed	$P_{Wp} = \frac{E_{TPV}}{PGF}$	572 Wp
Total number of PV panels needed	$Np = \frac{P_{Wp}}{P_{Max}}$	1.906 ≈ 2 solar PV modules
Inverter sizing	$S_{inv} = \frac{\text{Real Power (Rp)}}{\text{Power Factor (PF)}}$	430 VA (0.43 kVA)
Sizing of Battery	$B_{CAP} = \frac{E_{TPV}}{B_{DD} \times V_{Nom}} \times ND$	195AH (2 batteries each being 12 V @ 100AH)
Solar charge controller sizing	Sscc = I_{SC} x M_{par} x SF	23.95 ≈ 24 Amperes.
Generator Sizing	$G_{SIZ} = \frac{\text{Total loads in kW}}{\text{Power factor}}$	1 kVA @ 0.8 PF

The schematic diagram of the Off-grid Hybrid (PV/battery/generator) energy system designed for a single room and parlour apartment in Arogbo community is shown in Figure 4.

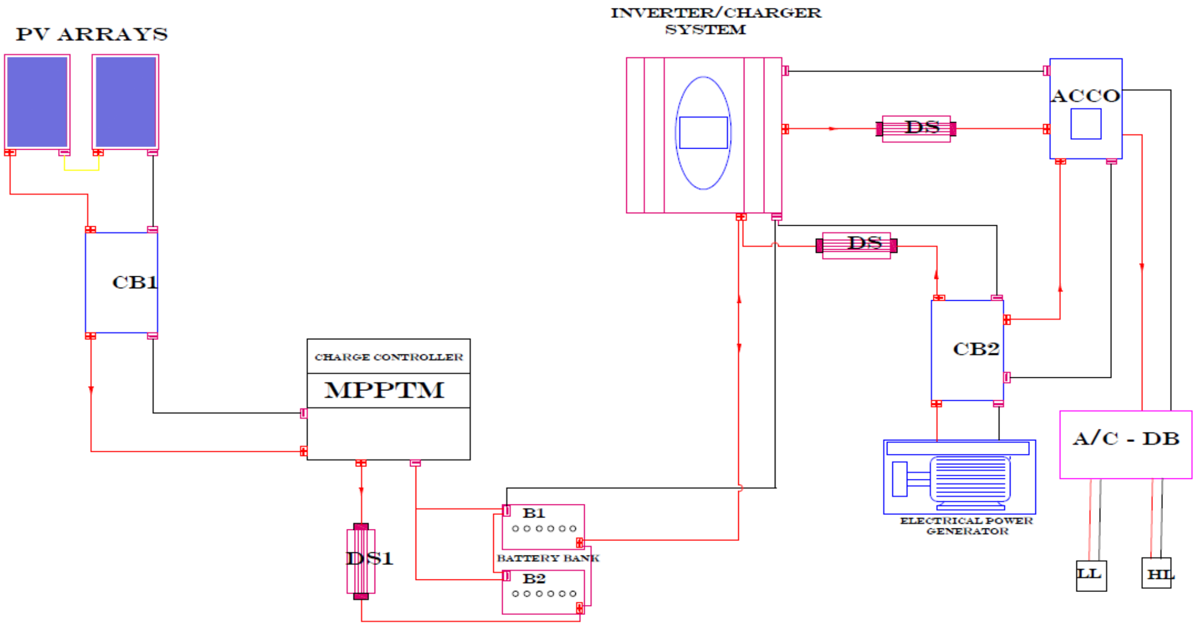


Figure 4: Off-grid Hybrid Energy System for a Room and Parlour Apartment

3.6 Cost Implication

The cost of the various components designed and selected were based on an exchange rate of four hundred Nigerian Naira (₦400.00) to one United State Dollar ($1.00). The summary of the estimated costs are shown in Table 9. This cost was based on unit purchasing of components, and may vary at implimentation due to bulk purchase and state of economy.

Table 9: Summary of Cost Implication

S/No	*Particular*	*Cost in Naira (₦)*	*Cost in Dollar ($)*
1	Three-bedroom (luxury)	2,494,000.00	6,235.00
2	Three-bedroom (convenience)	762,000.00	1,905.00
3	Room and Parlour Apartment	530,000.00	1,325.00

4. CONCLUSION

The design of an off-grid hybrid energy system for residential buildings in rural areas was presented in this paper. The houses were categorized as luxury, convenneice and living apartment, and energy audit was carried out for all. The following conclusions were drawn:

a. The total power rating for all the appliances collated was estimated to be 4981.684 kW (6227.11 kVA) and total electrical energy demands of Arogbo Community over a specified period of six hours usage per day with a power factor of 0.8 and 15% tolerance of maximum load of 6227.11 kVA was estimated to be 19143.858 kWh

b. The total PV energy required for a three-Bedroom apartment (Luxury) was 13.53 kWh (16.91 kVA), at a cost of ₦2,494,000.00

c. The total PV energy required for a three-Bedroom apartment (Convenience) was 4.342 kWh (5 kVA), at a cost of ₦762,000.00

d. The total PV energy required for a Room and Parlour apartment was 2.344 kWh (2.93 kVA), at a cost of ₦530,000.00

e. Though, off-grid, the study showed that electricity can be generated and supplied to rural areas through an hybrid energy system.

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