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DESIGN OF A HYBRID OFF-GRID SOLAR SYSTEM FOR RESIDENTIAL BUILDINGS IN REMOTE BENJA VILLAGE

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ABSTRACT

Reasonable access to energy is an important factor in eradicating energy poverty. In South-West Nigeria, individuals living in remote areas lack access to the electricity from the grid, resulting to the use of generators as primary or back-up source of electricity. This brings about some challenges which include high cost of using a generator as a primary source of electricity in remote areas in Nigeria, depletion of the ozone layer (Air pollution) among others. Solar energy is a fast and easy way of overcoming energy poverty in some of these remote areas. A solar power system, through direct conversion of solar irradiance into electricity, can provide electrical power for households to meet their daily load or energy requirements. This paper designs a stand-alone solar photovoltaic system for a typical residential building. It also outlines in details the procedures involved in choosing each components of the standalone photovoltaic power system. A residence in Benja Village in Ado/odo-Ota Local Government, Ogun State, Nigeria with typical energy consumption was selected and used as a case study for the design. The consideration of alternative current appliances was taken. The total load power of these appliances is 289W having a daily 712Wp energy demand. The result of the design shows that though the initial investment cost is high, but on the long run, the maintenance cost is almost free over a long period of time compared to when the electricity is from the utility.

Keywords: Photovoltaic PV energy yield, Solar System, Residential
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1. INTRODUCTION

Nigeria, Africa's most populous country, having about approximately 197 Million individuals living in the country, has been facing electricity shortage for many years, in last few years this problem has exceeded the common people's patient. Nigeria is located in tropical region of the world. In this modern world, electricity is the main and fundamental demand for the growth of a developing community, nation or continent. It is impossible to have access to 24 hours supply of electricity in our nation, Nigeria. According to Power Company Holding of Nigeria (PHCN), the country's peak electric demand in February 2017 was 7,600 megawatts (MW), but actual generation capability was 3,600 MW. The discrepancy between electricity demand and actual generation is mostly due to low water levels and inadequate plant maintenance. During 2010, electricity generation capacity fluctuated between 2,600 MW and 3,600 MW. The hydropower stations Kainji, Jebba, and Shiroro have seen generation affected by insufficient water, and the Lagos Egbin, Delta, and Port Harcourt Afam plants are also operating at below capacity due to poor maintenance.

According to the official statistics, Nigeria generates 6,700MW and demands 41,133MW (DISCOs 2016). Only 40 percent of Nigerians have access to electricity, the majority of these individuals who have access to electricity are concentrated in urban areas, leaving the individuals in rural areas to suffer and lack access to electricity, depriving these individuals from the benefits of electricity.

This research seeks to proffer a solution to access of energy by designing a model that can be used to in electrification for small businesses in rural communities in Nigeria. About approximately 60% of individuals living in Nigeria has no access to electricity; these individuals are located at rural areas [1] [2]. This brings about a challenge because a lot of rural communities are not connected to the grid and can be characterized by high installation cost, low income generated due to the low population in rural areas [3].

2. PREVIOUS WORK

Review of papers and research has been done on renewable energy potential and supply accessibility in Nigeria. A significant number focuses on solar energy while some attention on solar photovoltaic and offer techno-economic study. This is the gap this research proposes to fill; By utilizing the PV rather than diesel generator in their homes, by giving strategy support and motivation, by educating people on photovoltaic and utilization of energy. This will go far in working out gross-insufficient of the grid and epileptic power supply in the nation and in addition decreasing carbon emission.

It merits specifying, that there are some administrative bodies, especially a few schools that utilities photovoltaic system for power generation. Additionally, there are quantities of exclusive photovoltaic systems and numerous utilizations of solar PV in Nigeria for road lighting, water pumping. [8].

Ghafoorn and Munir [13] composed and performed economic analysis of an off-grid PV System for residential electrification in Faisalabad city, Pakistan. The author reasoned that unit cost of off-grid PV power is lower than the unit cost charged from the grid supply to local areas, in this manner making the system financially and actually feasible for residential electrification.

A. H. Mondal and S. Islam [15] analyzed potential and practicality of grid-connected PV system in Bangladesh, using a proposed 1MW grid-connected solar PV system in fourteen diverse places in the country. In their research, the authors utilize GeoSpatial toolbox, NASA SSE solar radiation information and a few simulation programmes like HOMER and RET Screen. Technically, the potential of grid-connected solar PV in the country was evaluated to be 50.17GW. They likewise found that energy yield from the diverse places shifts between 1653 MWh and 1854 MWh. The investigation presumed that all pointers favors sending of the proposed PV system and that unit cost of the system is lower than the grid connected fuel-oil based power generation.

Sudhakar and Baredar in 2016 [16] assessed the attainability of 110kWp grid-connected photovoltaic system for private lodge in India. The authors utilized four PV modules technologies of amorphous silicon (a-Si), crystalline silicon (c-Si), (CdTe) and (CIS). The technical analysis was done with Solargis PV Planner software. Their discoveries demonstrate that in that specific area, in spite of the fact that the four technologies perform attractively, a-Si performance is better than the other technologies, yielding energy of 181.1MWh out of a year.

R. Carbone in 2009 [17] tried different things with little scale model of grid-connected PV system with energy storage in battery. He discovered that energy storage by means for battery, worked in a dispersed way improve energy yield of grid-connected PV power plant by normally getting the most maximum power point (MPP)of the module, especially in mismatching condition.

All these and numerous other late studies appears to agree that solar photovoltaic is taken a toll aggressive with grid. The studies likewise settled a high initial cost and henceforth suggest great policy, government support and motivating force for mass usage of PV system.

3. METHODOLOGY AND LOAD REQUIREMENTS

Preliminary fieldwork on site selection is an essential measure in PV power system as it will affect the overall power output performance. The followings are the criteria in site selection: -

1. Avoid shading – Shadows of nearby buildings and trees that will cause partial shading on the PV modules, which in turn will decrease the overall voltage output of a PV string.
2. Sufficient compound – the site should be spacious enough to place all the components together, allowing easy maintenance and prevention of cable loss.

The following system sizing follows the steps and guidelines in the book Solar Photovoltaic Power: Designing Stand-Alone Systems, written by Shaari et. al. (2010), except for the inverter sizing. The values used in most of the equations are also from this book unless otherwise specified.

The author is aware that in the subsequent off-grid PV installation courses, there are some changes made to the course materials. As such, system sizing discussed is valid and correct as of system commissioned date 1st of February 2018 and solely for this project only.

3.1. ENERGY CALCULATION

The following table shows the daily energy consumption of a household in Benja Village, Ado-Ota, Ogun State, Nigeria.

The load profile, power supply and demand are shown below;

Table 3.1- Energy consumption of a household

APPLIANCE	NUMBER OF APPLIANCE	WATTAGE PER UNIT (W)	TOTAL WATTAGE (W)	HOURS USED PER DAY (HRS)	WHRS PER DAY
Refrigerator	1	119	119	8	952
Lighting System	15	5	75	8	600
Standing Fan	2	40	80	10	800
Phone Charging	3	5	15	6	90
			289		**2442**

Figure 3.2 show the daily load profile of the residential building

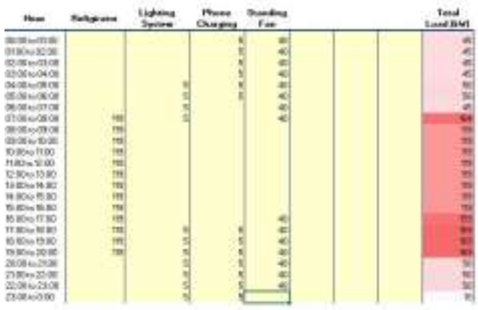
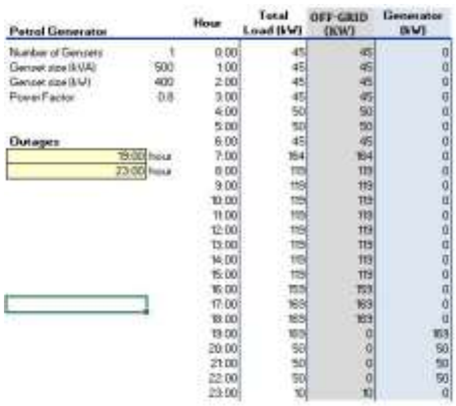


Figure 3.3 shows the daily load data for the residential building

Figure 3.3 shows the power supply and power demand for the residential building



Petrol Generator			Hour	Total Load (kW)	OFF-GRID (KW)	Generator (kW)
Number of Gensets	1		0.00	45	45	0
Genset size (kVA)	500		1.00	45	45	0
Genset size (kW)	400		2.00	45	45	0
Power Factor	0.8		3.00	45	45	0
			4.00	50	50	0
			5.00	50	50	0
Outages			6.00	45	45	0
19.00	hour		7.00	164	164	0
23.00	hour		8.00	119	119	0
			9.00	119	119	0
			10.00	119	119	0
			11.00	119	119	0
			12.00	119	119	0
			13.00	119	119	0
			14.00	119	119	0
			15.00	119	119	0
			16.00	153	153	0
			17.00	169	169	0
			18.00	169	169	0
			19.00	169	0	169
			20.00	50	0	50
			21.00	50	0	50
			22.00	50	0	50
			23.00	10	10	0

Figure 3.4 shows the power supply and power demand data for the residential building

The maximum load for the residential building in this case study is about 169 kW per day, whereas minimum load is 10-45 KW. From the load profile, between the hours 07:00am-

08:00pm, the refrigerator is on. This because at night the generator cannot power the refrigerator. While phone charging, Lighting system, and the standing fan are all used at night because during the day, the owner of the house leaves for work on week days and returns at night.

3.2. CAPACITY OF THE INVERTER

An inverter is a device that converts DC power into AC power. The input rating of the inverter ought to never be lower than the total watt of appliances. The inverter must have an equivalent nominal voltage as your battery. [2]

For stand-alone systems, the inverter must be sufficiently extensive to deal with the total amount of Watts you will use at one time [19]. The inverter size ought to be 25-30% greater than total watts of the appliances. Inverter size should be at least 3 times the capacity of those loads like motor, refrigerator or any load with high starting current. [1]

$$P_{I=} \sum Wattage + 25\%\ Extra\ power$$

Power rating of an inverter is related to the real power that is delivered by the output of the inverter and it is given by the expression “POWER FACTOR” [14].

$$PF = \frac{Deliverable\ real\ power}{power\ rating\ of\ the\ inverter}$$

Real power is the power that is consumed for work on load (P_I) and is calculated from the equation (Capacity of the Inverter). Value of power factor is generally taken as 0.8

3.2.1. Inverter Design; P_I

The inverter rating should be greater than 25% of the total load;

$$P_{I=} \sum Wattage + 25\%\ Extra\ power$$

$$P_I = 289 + 72.25$$

$$P_I = 361.25$$

$$P_{KVA} = \frac{P_I}{PF\ (Power\ factor)}$$

$$P_{KVA} = \frac{361.25}{0.8} = 451.56W \approx 500W$$

From the inverter catalogue,

Therefore, an inverter of 500W and above would be needed for this design but considering the presence or a refrigerator with its high desire for energy, we use the formula below to get the actual rating of the inverter needed for this design and a common refrigerator has a starting current of 8A;

$$P_s = P_w - P_k + 230V * I_A$$

Where;

$P_w = Total\ wattage\ of\ the\ system$

$P_k = Nominal\ Power\ of\ the\ refridge$

$I_A = Start\ current\ of\ the\ Fridge$

$P_s = 289W - 100W + 230V * 8A$

$P_s = 2029W$

Therefore, an inverter of 2500W and above would be needed for this design

3.3. CAPACITY OF THE BATTERY

The battery type suggested for utilizing a solar system is a deep cycle battery. Deep cycle battery is particularly intended for to be released to low energy level and quick energized or cycle charged and released for quite a while for years [3]. The battery ought to be sufficiently huge to store adequate energy to work the machines at night and cloudy days. To find out the size of battery, calculate as follows:

3.3.1. Required No of Batteries

Now the required Back up Time of batteries in Hours = 6 Hours

Suppose we are going to install 200Ah, 12 V batteries,

$$12V * 200Ah = 2400Wh$$

Now for One Battery (i.e. the Backup time of one battery)

$$\frac{2400Wh}{289W} = 8.034Hours$$

But our required Backup time is 6 Hours.

Therefore, $\frac{8.034}{6} = 1.38 \approx 2 \rightarrow$ i.e. we will have to connect two (2) batteries each of 200Ah, 12V.

3.3.2. Backup Hours of Batteries

If the number of batteries is given, and you want to know the Backup Time for these given batteries, then use this formula to calculate the backup hours of batteries.

$$2400Wh * 2\ Batteries = 4800Wh$$

$$\frac{4800Wh}{289W} = 16.6\ Hours$$

In the first scenario, we will use 12V inverter system, therefore, we will have to connect two (2) batteries (each of 12V, 100 Ah) in Parallel. But a question raised below:

Battery Charging Time??

Series or Parallel Connection for Batteries

Why Batteries in Parallel, not in Series?

Because this is a 12V inverter System, so if we connect these batteries in series instead of parallel, then the rating of batteries become $V_1 + V_2$ = 12V + 12V = 24V while the current rating would be same i.e.200Ah.

In Series Circuits, Current is same in each wire while voltage is different i.e. Voltage are summed. For example, $V1 + V2 + V3 \ldots .Vn$. Batteries are connected in parallel, because the voltage of batteries (12 V) remains same, while its Ah (Ampere Hour) rating will be increased. i.e. the system would become = $12V\ and\ 200Ah + 200Ah = 400Ah$. In parallel Connection, voltage will be same in each wire, while current will be different i.e current is summed. For example, $I1 + I2 + I3 \ldots + In$

We will now connect 2 batteries in parallel (each of 100Ah, 12V) i.e. 2 12V, 200Ah batteries will be connected in Parallel

$= 12V, 200Ah + 200Ah = 12V, 400Ah\ (Parallel)$

3.3.3. Charging Current for Batteries

Now the Required Charging Current for these two batteries.

$$Charging\ current = \frac{1}{10}\ of\ batteries\ Ah$$

$$400Ah * \frac{1}{10} = 40A$$

Charging Time required for Battery

Here is the formula of Charging Time of a Deep-Cycle battery.

$$\boldsymbol{Charging\ Time\ of\ Battery} = \frac{\boldsymbol{Battery\ (Ah)}}{\boldsymbol{Charging\ Current(A)}} T = \frac{Ah}{A}$$

For example, for a single 12V, 200Ah battery, the charging time would be:

$$T = \frac{Ah}{A} = \frac{400Ah}{40A} = \boldsymbol{10Hrs\ (Ideal\ Case)}$$

due to some losses, (it has been noted that 40% of losses occurred during the battery charging), this way, we take 10-12A charging current instead of 10 A, this way, the charging time required for a 12V, 400Ah battery would be:

$$400 * \left(\frac{40}{100}\right) / 40 * \left(\frac{40}{100}\right) = \frac{400Ah}{80A} = \boldsymbol{5hours}$$

Now the required charging current for the battery would be:

160Ah / 16A = 10 Hours.

3.4. PHOTOVOLTAIC SYSTEM SPECIFICATION

The initial step towards measuring the PV array is to find out the daily energy requirements from the array. The required energy is then divided by the normal sun-hours every day for Ogun state to get the peak-power. The peak power is then divided by the selected system dc voltage to obtain the total dc current. Finally, the number of series and parallel modules can then be determined to give the array size. From the cost of an individual module the total cost of the PV array can then be determined. [9]

Required daily energy demand; $\boldsymbol{E_{dd}}$

$$E_{dd} = \frac{E_d}{\eta_b \eta_I \eta_c}$$

$$E_{dd} = \frac{2442}{0.85 * 0.9 * 0.9} = 3.562KWh/Day$$

$Where\ E_d = Daily\ Average\ Demand\ from\ the\ load\ audit$

3.4.1. Average peak-power; P_{pp}

$$P_{pp} = \frac{E_{dd}}{T_{Ash}}$$

$Where;\ T_{Ash} = Average\ sun - hour\ for\ Ogun\ State$

$$P_{pp} = \frac{3562.4}{8} = 445.3W$$

3.4.2. Total DC Current; I_{dc}

$$I_{dc} = \frac{P_{pp}}{V_{dc}}$$

$Where;\ V_{dc} = System\ Voltage$

$$I_{dc} = \frac{445.3}{22.1} = 20.149A$$

3.4.3. Number of Modules

$$N_p = \frac{Average\ peak\ power}{module\ power} = \frac{445.3}{100} = 4.453$$

From the PV catalogue, 5 modules would be used for this design.

3.5. CHARGE CONTROLLER SPECIFICATION

Charge controllers limit the rate at which electric current is added or drawn from batteries. It prevents overcharging and may also prevent completely draining (deep discharging) a battery to protect battery life. Estimating an appropriate charge controller begins by calculating the required total current that the controller ought to withstand. From the outcome of the required current, the total number of charge controllers would then be able to be figured and once the cost of a single charge controller is known, the total cost of the controllers would then be able to be resolved. [9]

3.5.1. Required charge controller current; I_{rcc}

$$I_{rcc} = I_{sc} * N_p * F_{safe}$$

$Where;\ I_{sc} = Short\ circut\ current\ and$

$F_{safe} = Saftey\ factor\ of\ the\ charge\ controller$

$I_{rcc} = 8.12 * 5 * 1.25 = 50.75A$

3.5.2. Number of charge controller(s); N_{cc}

$$N_{cc} = \frac{I_{rcc}}{I_{cc}}$$

$Where;\ I_{cc} = DC\ current\ of\ the\ charge\ controller$

$$N_{cc} = \frac{50.75}{60} = 0.84 \approx 1$$

From the Charge controller catalogue, this project work needs 1 charge controller.

3.6. CABLE SIZING

The design of a solar system is partial until the point when the right size and type of cable is chosen for wiring the components together. The follow cable interfaces in the PV system must be suitably chosen:

- The dc cable from the PV array to the battery bank through the charge controller.
- The ac cable from the inverter to the distribution board (DB) of the residence.

3.6.1. PV array to battery bank through charge controller; I_{cab}

$$I_{cab} = I_{rcc} = I_{sc} * N_p * F_{safe}$$

$$I_{rcc} = 8.12 * 5 * 1.25 = 50.75A$$

There the selected cable size and type = 3X35mm^2 insulated flexible copper cable

3.6.2. Inverter to distribution board of residence; I_{oi}

$$I_{oi} = \frac{P_I}{V_{oi} * P_F}$$

$$Where;\ V_{oi} = Output\ voltage\ of\ the\ inverter$$

$$I_{oi} = \frac{361.25}{220 * 0.8} = 2.05A$$

From the design it can be the following can be deduced, the system would need;

5 PV modules, 8 deep cycle batteries, 1 charge controller, 1 stand-alone inverter 12V/220V, 28m string cable 2.5mm^2

The block diagram, schematic diagram and wiring diagram are shown in fig 3.1, fig 3.2 and fig 3.3 respectively.

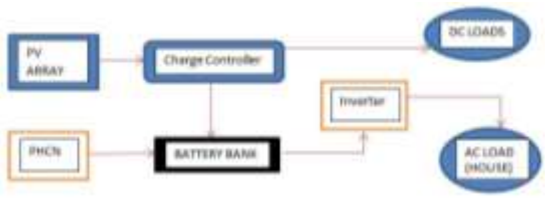


Figure 3.1 Block diagram of the system

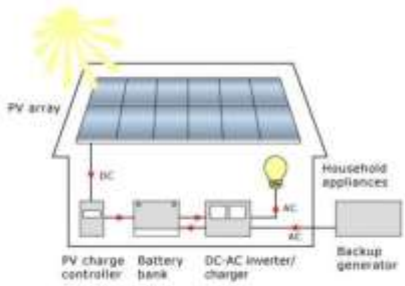


Figure 3.2 Schematic diagram of the system

Figure 3.3 Wiring diagram of the system

4. CONCLUSION

The geographical location of Benja Village, Ado-Ota, Ota, Ogun state, Nigeria has an annual solar irradiance of more than 1650KWh/m^2, making it a good region for solar electrification. Due to the vast energy coming from the sun, the use of stand-alone photovoltaic system in remote areas would play a great role in electrification. This system needs to be made known to the people living in remote areas. In this paper, the components of a stand-alone photovoltaic system are based on the load requirements or demand. As a case study, a residence in Benja Village, Ado-Ota, Ota, Ogun state, Nigeria with medium energy consumption is selected.

Economically, the stand-alone solar system is cost effective than the energy from the grid. Solar systems are not equipped for guaranteeing a continuous electric power supply unless they are connected to a storage system. This became a challenge during the rainy season making it impossible for the PV panels to supply the needed electric power. Batteries have been related with solar home system, remote system and some solar based technology. This makes the use of solar systems for electricity supply as the best solution for remote areas that have no access to the grid.

Finally, this paper provides a basis and framework for the evaluation of this solution not only in Benja village, but also in other parts of the country where the sun shine is relatively intensive and based on the results from simulation; an additional step of an off-grid connection during the rainy season can also be embraced. The option for an off-grid connection will depend on the increase of load demand and climate change and this will enable the solar system to sell power to the grid in case of excess production of PV modules and to buy power from the grid during the rainy season.

The availability and sustainability of power supply requires the introduction of solar photovoltaic systems into the country's energy mix. In this design, solar photovoltaic system with 2 batteries of 12v, 200Ah and 5 modules are required to meet the power demand of 289W of the appliances of the residential building considered. Although the solar system has high initial cost, its toughness, consistency, ease of maintenance, and environmental friendliness, make the system good for residential and other applications. Therefore, the government should look into supplying solar energy to remote houses that have little or no access to the grid.

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