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Design of an Off Grid Photovoltaic System for a Three Bedroom Flat in Makurdi, Benue State, Nigeria

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Abstract: ***This is an off grid photovoltaic system designed for a three bedroom flat located in Makurdi Benue state, Nigeria. It is aimed at clearing doubts and fear engulfed by residential owners about photovoltaic systems in the country. The off grid photovoltaic system was design based on the electrical energy requirement of the flat. To achieve this, the power rating of common appliances which could be found in the flat were identified and multiplied by their time of operation to understand the energy demand of the house. The energy requirement of the flat was found to be 15.563kwh per day. The photovoltaic system was designed using Polysun application software. The result obtained from simulation shows that, the system will generate enough energy for operation of these appliances including in the night. The cost of the system was found to be ₦2862249 with a lifetime of at least 20 years. The cost was compared with the use of fuel generator within the same period. The payback period was found to be approximately 2.72years. This means that the cost of photovoltaic system for the flat is high but after 2.7 years, the installer of the PV system will be using energy virtually free for the remainder of the lifetime of the system.***

Keywords: Polysun, photovoltaic system, payback period, off grid

1. Introduction

The condition of energy generation and supply in Nigeria has deteriorated to the level that it is difficult to ascertain the time it will be available to consumers. Various administrations have come up with different ways of alleviating the situation but no meaningful result is achieved till date. Recently the country has privatized power sector but the expected result is still far reach [21]. Currently, the Nigeria electricity installed capacity is 8,876MW which is mostly from fossil fuels and still grossly inadequate to meet the energy needs of more than 160 million Nigerians [17].The availability is far below the installed capacity due to many factors. In fact, the recent vandalism of gas pipelines that supply gas to power plants has caused power generation to drop to 1,580.6 megawatts in March, 2016 [16]. This has brought untold hardship on the citizens and derailed economics activities [7].

The installed capacity is not enough even when the power plants are generating at peak capacity. Only 40% of Nigeria's population is connected to the grid and the situation is worst in the rural areas. The distribution companies out of no other alternatives resolve to the used of rationing technique and mostly supplies electricity at very low current, but still those that have access to the grid; only 30% of their needs are met [1].

The inability of energy supply to match demand has become unacceptable to many citizens. As a result, they resort to other means of energy such as burning of wood and grasses, fuel or gas used generators, for domestic and day to day running of their business without considering the effects their energy sources might caused to the environment [11]. The electricity generates by Nigeria is mostly from fossil fuels which is the reason the country was in 2012, ranked 46th in the world for CO_2 emissions with more than 73.69 metric tons emitted in 2011 [2].

The introduction of photovoltaic technologies is a relief to the situation faced by Nigeria today. After all, the use of fossil fuel for energy generation is outdated due to its effects on climate. Apart from that, it is costly and mostly a source of conflict [22].

Photovoltaic is a technology used to convert sunlight directly to electricity. Photovoltaics are also called solar cells. When sunlight strike the surface of the cell, the energy from the light is enough to eject one electron from the shell of its host atom with a constant amount of energy. The electron removal is proportional to the intensity of micro packets of light energy usually referred to as photons [22]. Very close to the surface of the cell is a membrane called pn-junction which allows only electrons with a specific amount of energy to cross. This makes the surface of the cell facing the sun to acquire negative voltage while the other side is positive voltage [6]. If electrical cables are connected to the negative and positive sides, forming an electrical circuit, the electrons can be collected in the form of electric current (electricity) which can be used to power electric appliances. Figure 1 is the summary of how photovoltaic works.

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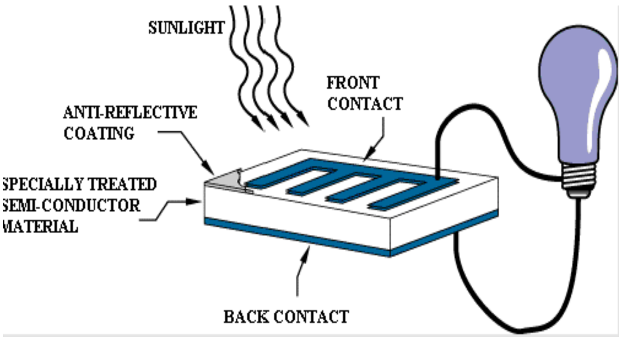
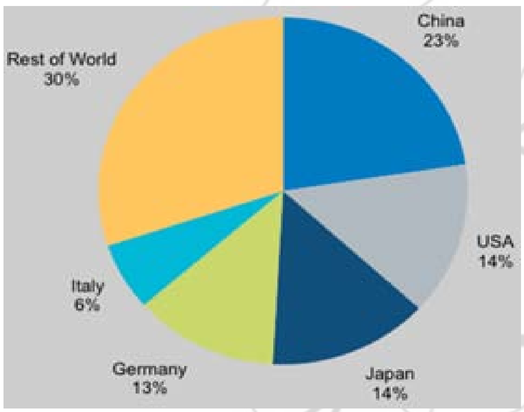


Source: [12]

Figure 1: How photovoltaic work

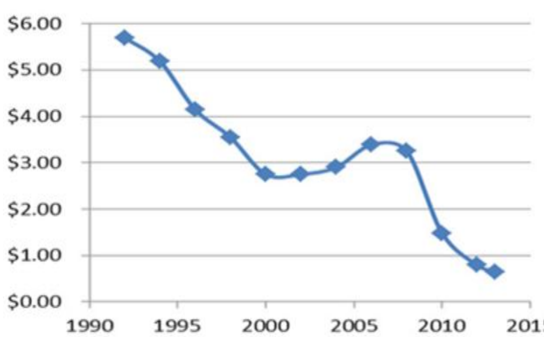
Different cells are connected together to form a solar module. A solar module supply electricity at a particular voltage just like conventional cells. Many different solar modules connected together forms an array. The solar module can have a life time of at least 20 years [12]. Photovoltaic is currently used in many countries for electricity generation. Figure 2 shows the global PV installation in 2016.



Source: [4]

Figure 2: Global PV installation

Many researchers have found out that PV systems are cheap and will even get cheaper as time passes. The cost of a PV system includes the capital cost, operation and maintenance cost and installation cost. The cost depends on factors such as the size, and whether it is mounted on a roof top or on the ground [9]. The roof top PV does not require an extra space but mounting on the ground requires a separate space for the system. Figure 3 shows the projected price of photovoltaic modules.



Source: [4]

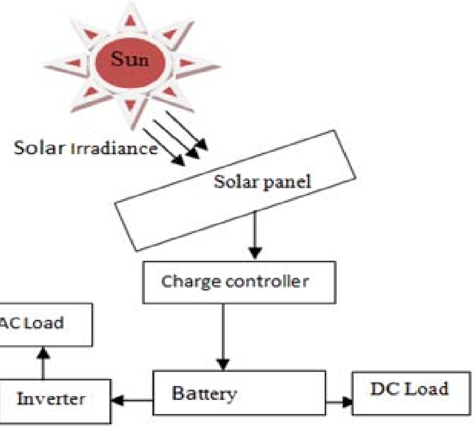
Figure 3: The decline in cost of PV modules

In a comparative study conducted by [10] at government secondary school Wudi, discovered that the cost of an off grid photovoltaic system is cheaper than the use of diesel for energy generation or when one embark on payment of electricity bills from the grid.

An off grid photovoltaic system generates electricity independently without grid connection. The components of the off grid photovoltaic system and their functions are seen in table 2 and the connection between the components is as seen in figure 4

Table 1: Components of PV system and their functions

Component	Function
Solar panel	Collect solar energy from the sun and convert it to electric current
Battery	Store electric power for later use when there is no sun light
Inverter	It converts DC to AC for appliances that uses AC
Charge controller	Protect the battery from overcharging
Electric meter	Measures the electric current produced by the solar panels
Circuit breaker	Prevent unwanted current from damaging connect appliances
Combiner box	An electrical enclosure which is used to connect different solar panels in parallel.
miscellaneous	This include wires, nuts, bolts, etc, for conventional connections



Source: [3]

Figure 4: Connection between PV components

1.1 The location of the project and metrological data

Makurdi is the capital of Benue state, Nigeria. It is located in the northern region of the country where solar energy is predominant. It is situated on latitude 7.719^0 and longitude 8.545^0. The solar irradiance incident on the location's site is as shown in figure 5.

Average outdoor temperature	26.9 °C
Global irradiation, annual sum	1,883.4 kWh/m²
Diffuse irradiation, annual sum	950.5 kWh/m²

Source: Polysun 1

Figure 5: Meteorological data of the Makurdi

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2. Methodology

The common electrical loads which could be found in any average house were identified in conjunction with their power ratings. The time of operation of the loads was estimated based on their use, type and frequency. This was done in order to have a broad knowledge of the energy requirement of the house per day. The information obtained was used to designed the off grid residential PV system using Polysun application software.

2.1 Estimated electricity consumption of the house

The electric power consumption of the house appliances is calculated and tabulated as seen in table 3. Each of the appliance's power consumption was calculated separately to arrive at the total power consumption for the house.

Table 2: Daily energy demand of the flat

Appliance	Rated power(w)	Number	(KW)	Hours used/day	KWh/ day
bulbs	25	9	0.225	5	1.125
CD player	35	1	0.035	6	0.21
42'' plasma TV	250	1	0.25	6	1.50
Ceiling fan	100	4	0.4	8	3.20
Iron	1000	1	1.000	1	1.00
Satellite dish	30	1	0.03	8	0.24
Laptop	25	3	0.075	8	0.60
fridge	400	1	0.40	16	6.40
Cell phone	4	5	0.02	3	0.06
Electric cattle	150	1	0.15	1	0.15
Scanner	18	1	0.018	1	0.018
Inkjet printer	30	1	0.03	2	0.06
Washing machine	500	1	0.50	2	1.00
total		**30**	**3.133**		**15.563**

2.3 Selection of Photovoltaic Module

The photovoltaic modules for the house were selected based on the voltage rating of the modules so that the system will be able to produce the daily energy requirement of the house. This was done with aid of Polysun application software. Table 4 shows the features of the selected PV module. The house will contain 24 modules. The tilt angle of the PV modules is 9^0 closer to the latitude of the location.

Table 3: Features of the selected PV module

Name	STP200S-18/Ud
Manufacturer	Suntech power Co. Ltd
Data source	Photon
Number of modules	24
Number of modules layout	24
Total gross area	46.57m^2
Tilt angle	9^0
orientation	0
Total nominal generation field	6.72kw
Module type	monocrystalline
Efficiency STC	0.144
Nominal power STC	280w
Output voltage mpp-STC	35.2v
Output current mpp-STC	7.95A
Open circuit voltage	44.8v
Open circuit current	8.33A
Thickness	0.05m
Length	1.956m
Width	0.992m
Gross area	1.94m^2

2.4 selection of battery

The off grid PV system for the house is designed such that it will not take power from the grid. Therefore provision has been made such that the occupants will have access to power even when sun might have set. The number of batteries required for the system is six (6). The simulation from Polysun application shows that these batteries will be enough to supply electric power to the house throughout the night. Table 5 is the name and features of the battery for the project.

Table 4: Features of the selected storage battery

Name	Hoppecke 24 opzs3 3000
Nominal capacity	6kwh
Total nominal capacity	36kwh
Cumulative damage	12%
Lifetime	5years
Capacity ratio	0.316
Minimum manufacture SOC (state of charge)	0.3
Nominal voltage	2V
Battery rate constant	1.24
Charging efficiency	0.927
Discharging efficiency	0.927
Maximum charging power	1220w
Maximum discharging power	3200w
Daily safe discharge	0.1

2.5 Selection of Inverter

An inverter is an electronic device that converts dc current to ac current. The current produce by solar modules is dc current but most of the domestic appliances require ac current to power them. Therefore, an inverter is a necessity for an off grid PV system [5]. There are two types of inverters based on the form of wave they produced. They are called pure sine wave and modified sine wave. In this study, the pure sine wave inverter is preferred for its efficient performance and ability to operate any type of load. The selected inverter using Polysun application software is inverter 2900T with 98% efficiency and 1% cable losses. Two inverters are required for the system.

3. Energy Yield and Consumption

After the design of the system and simulation using Polysun application software, the system will generate monthly energy as can be seen in figure 6. The energy generation is found to be highest in March and November. This means that, the solar irradiation on the location is highest in these months. Energy consumption is found to be highest in January and December. Figure 7 is the monthly consumption summary of the system.

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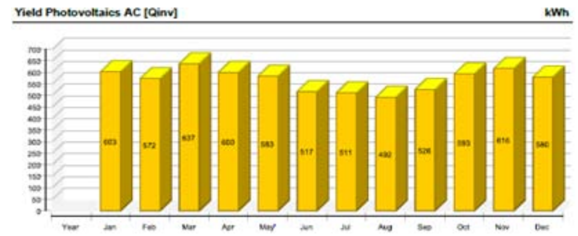
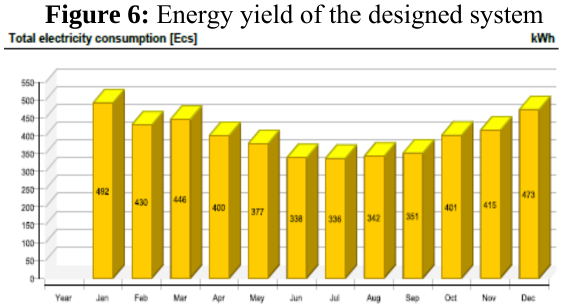


Source: Polysun 2

Figure 6: Energy yield of the designed system



Source: Polysun 3

Figure 7: Energy consumption of the flat

4. Cost estimation of the off grid PV system

The cost of the residential PV system includes the total capital cost, installation cost, replacement cost, cost of operating and maintenance throughout the entire life of the system [15]. Generally, the capital cost of a solar system is very high but it has no fuel cost, the replacement cost of inverter and battery is low. Therefore, maintenance cost is low [13]. The cost estimation of the system is as seen in table 6.

The life time of the system is 20 years. The life time of storage batteries is 5 years so it is expected that within the 20 year's life time, three extra sets of 6 batteries each will be bought. That is after five years, ten years and fifteen years. An extra inverter will be purchased after 12 years. All prices in table 5 are from [20].

Table 5: Capital cost estimation

			Years of specific p	
Component	Quantity	Price (N)	1	5
PV module	24	80000	1920000	
Battery	6	15000	90000	90900
Inverter	2	75000	150000	
Others componenets		10%of pv co	192000	
			Total cost of componenets	

The total cost per component = quantity of the component x the unit price of the component. The cost of other components like fuses, meter, cables, etc is estimated to be 10% of PV cost.

PV systems require minimal maintenance because it has no fuel cost, no movable parts that may be damaged in the process [12]. Thus, maintenance cost of the system per year is estimated to be 0.1% of the system's capital cost.

Therefore Maintenance cost of the system per

Year = 0.1% x 2778900

= ₦2779

The off grid PV system will last for at least 20 years. Therefore, the maintenance cost for 20 years is the product of maintenance cost per year and years of its life time

Maintenance cost for 20 years = ₦2779 x 20

= ₦55560

The cost of the system has been estimated based on economic realities but there is a need of contingency cost [22]. Contingency cost here means the cost that has not been accounted for in the course of cost estimation. Therefore the contingency cost is assumed to be 1% of the capital cost. That is:

Contingency cost = 1% x 2778900

= ₦27789

The overall cost of the PV system for 20 years is the sum of capital cost, maintenance cost and contingency cost. That is:

Overall cost = 2778900 + 55560 + 27789

= ₦2862249

4.1 Cost Estimation of Fuel Generator

Diesel generator will be used especially if there is no access to the grid. In this study, it is assumed that there is no grid connection and the user exclusively depends on the generator for energy generation for 20 years. All the cost stated in the study is obtained from [23].The cost calculation for the fuel generator is as follows:

Sumec Firman ECO10990ES Petrol Generator 8.4KVA (Key starter) = ₦195000

Hours of use per day = 8

Liters of fuel consumed per hour = 2Liters

Liters of fuel consumed per day = 2 x 8

= 16Liters

The total number of liters consumed per year

= 16 x 365

= 5840 liters

The current price of fuel = N140 per liter [18]

The cost of fuel per year = 140 x 5840

= ₦817600

If the Maintenance cost of the generator per year is 10% of its cost price, then

Maintenance cost = 0.1 x 195000

= ₦19500

Cost of stabilizer 2000VA = ₦16000

Cost of installation includes cost of wires, clips, etc. In this study, the installation cost is estimated to be 10% of the generator cost. That is:

Installation cost = 0.1 x 195000

= ₦19500

The total cost of using the fuel generator is the sum of generator cost, fuel cost, stabilizer cost and cost of installation. That is:

Total cost of using fuel generator per year

= 195000 + 817600 + 19500 + 19500

= ₦1051600

The payback period from [19] can be calculated using this formula as

$$payback\ period\ (Pb) = \frac{overall\ cost\ of\ pv\ system for\ 20\ years}{total\ cost\ of\ using\ fuel\ generator\ for\ the\ first\ year} \quad (1)$$

$$= \frac{2862249}{1051600}$$

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= 2.72 years

This means that the user of the fuel generator will spend the same cost of off grid PV system after 2 years and seven months.

5. Conclusion

The study is the design of an off grid photovoltaic system for a three bedroom flat located in Makurdi, Benue state, Nigeria. This has become necessary because of inadequate electricity supply from the grid, the increase in militants' vandalism of pipelines that supply gas to electricity generating plants resulting to total black out or power shielding, arbitral charges from electricity distribution companies and the effects of co_2 emission from fossil fuels. In the mist of these problems, photovoltaic system can use the abundant solar energy in Makurdi to generate electrical energy needed for daily use. This source is very cheap compare to the use of fuel generators as alternative energy source. Apart from that it is environmentally friendly; it brings about independent energy generation and economy stability.

The daily electrical need of the house was estimated using power rating of common domestic appliances and found to be 15.563kw. The information was used to design a photovoltaic system for the house using Polysun application software. The system is made up of 24 PV modules, 6 storage batteries, two inverters, charge controller and other electrical connecting devices. The simulation obtained shows that, the system will generate 6.72kw/h which is enough to satisfy the energy requirement of the house. The PV system has a life time of 20 years. The estimated cost of the system is ₦2862249 which is very high but when it is compared with the use of fuel generator, the payback period was found to be approximately 2.72 years. This means that, after two years and seven months, the user of the PV system will be using energy from the system virtually free for the remainder of the system's life time.

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