Cost Implication of using a Petrol Generator and PV System in a Middle-Income Residential Apartment in Nigeria

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Abstract – In Nigeria, there is a yearning for an increase in the electricity supply to residential consumers. Hence, the need for an alternative source of electricity that would be sustainable and cost-effective. This study, therefore, carried out an energy audit for a middle-income residential three-bedroom apartment in Ilaro, Ogun State, Nigeria, to determine the load profile and power consumption in the apartment. The load data was collected by physical inspection. Two energy sources – solar PV and petrol generators- were considered based on the load demand and electricity consumption for a period of ten years. The result shows that the solar photovoltaic system, provides a sustainable electricity supply for this class of electricity users, despite the high initial cost of the facility.

Keywords - Energy audit, electricity consumption, load profile, petrol generator, power consumption, PV system, residential consumers

1 Introduction

Nigeria's electricity generation and supply are insufficient for domestic and commercial users, despite being among the largest Oil and Gas producing country in the world [1]. This affects the economic and infrastructural development of the nation and its citizenry, and otherwise, the standard of living. Generally, there are conventional means of electricity generation (Nuclear fission, Geothermal, Coal and Natural gas), which is continually replenished as quick as it is extracted and used up and the Non-conventional means (Wind, Thermal, Solar, Tidal, hydro), which are user friendly, pollution-free and has its source naturally replenished as they are being used [2]. At the moment, Nigeria depends largely on non-conventional sources for its electricity generation. The power plants in Nigeria have about 13,000 kW of installed plant capacity and out of which about 6,000 kW is in use due to gas constraints for over 200 million citizens [3]. This leaves a gap of about 46% between the installed capacity and the used capacity [4]. To compensate for this grid inefficiency, individuals, private businesses, corporate organizations, government agencies, and academic institutions make provision for an alternative means of electricity generation to serve either as a backup to the electricity from the national grid or for 100% power supply [5]. Consequently, this has led to an increased usage of fuel powered generators (diesel and petrol) to an extent that almost every household in Nigeria has a fuel generator, despite being a genuine source of variety of environmental problems ranging from Air pollution, noise pollution, high cost of maintenance, to safety hazards, security concern, psychological effects, amongst others [6] [7]. Sequel to this, Nigeria has earned the infamous title of being "The World's largest importer of generators" [8] [9]. Following the health and environmental impact of both diesel and petrol generators, a better alternative source of electricity generation that is environmentally friendly is necessary.

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From literatures, renewable energy sources have proven to be a better and sustainable source of electricity compared to conventional energy sources. In the work of [10], Nigeria has the capability of generating up to 190.55 TWh of energy for a year, if only 1% of its landmass is covered with solar modules. This amount of power is more than three hundred times the current Nigerian grid electricity capacity. Therefore, this potential needs to be tapped into for sustainability of electricity generation for household use as it accounts for the largest part amongst industrial, transport, commercial, and agricultural sectors with over 65% consumption capacity in Nigeria [11]. Moreover, the major domestic energy-consuming devices include those for cooking, lighting, and electrical appliances – Television, DVDs, DSTV, etc., [2]. This study hence investigates the cost implications of petrol generator and solar PV source which is the most deployed by the middle-income earners in Nigeria.

2 Solar Photovoltaic System

The Photovoltaic system otherwise referred to as the PV system are devices used to convert sunlight into electricity. A combination of solar cells in series and parallel connections for maximum output gives the solar panel. These systems are known to be safe, reliable and with low maintainability, their fuel (sunlight) is free and endless and more so, its life expectancy rate is about 25 years. At the moment, crystalline technology is the main technology commercially used to produce electricity based on this PV system. The efficiency of such cells is within 13-18% [12]. The PV system is usually split into two parts - the PV array (which includes the PV panel and support structures), and the balance-of-system (BOS) components (the batteries, Charge Controllers, Inverters, and wires). The block diagram of the solar PV system is shown in Figure 1.

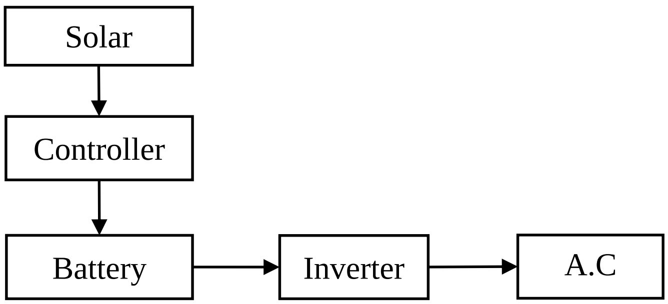

Figure 1: Block Diagram of a Solar System.

3 Materials and Method

3.1 Data Collection

The relevant data for this study were collected from the case study using primary method of data collection. By this, the authors physically inspected the electrical appliances in the concerned apartments and collected the relevant data (voltage, current and power rating) of each of the appliances, and thereafter carried out the energy audit of the apartment [13] [14]. This method used is to ensure that the correct data regarding each electrical appliance is well captured.

3.2 Load Analysis and System Sizing

Electrical Load Analysis is used in estimating the electrical system capacity needed to supply electrical loads [15]. For the case study, it was done to identify different electrical loads and their corresponding power ratings. Also, a time average of 5 hours was adopted since the study group runs a generator at an average of 5 hours/day. This implies 365 days/year and for the next 10 years, 3650 days ignoring the extra day in a leap year.

3.3 Load Audit

After collecting and processing the data, the load energy demand calculation was done and estimation of the solar PV system and petrol generator was carried out. Table 1 is the average load audit for three-bedroom middle-income residential apartment in Ilaro.

3.4 Sizing of Petrol Generator

The load demand of the apartment from Table 1 is 3176 W or 3.176 kW. Thus, the load in kVA assuming 0.8 power factor is calculated using the equation:

$$KVA = \frac{Kw}{pf} = \frac{3.176}{0.8} = 3.97\ kVA$$

Hence, A 4.5 kVA, 220, 50 Hz, fireman petrol generator, is selected. The fuel (petrol) consumption rate is 1.5 L/h. Therefore, the cost of electricity using a petrol generator is performed on a day and extrapolated for a 10-years period. Following this, the cost of using Petrol Generator to power the case study for 5 hours is:

Table 1: Typical three-bedroom middle-income residential apartment in Ilaro

S/N	Description	Quantity	Unit Wattage (W)	Total Wattage (W)	H/Day (hrs)	Needed Watt-hour Energy (Wh)
	Sitting Room					
1	Bulbs	4	12	48	5	240
2	Television	1	41	41	5	205
3	Sound system	1	50	50	5	250
4	DSTV Decoder	1	15	15	5	75
5	Standing Fan	2	75	150	5	750
6	Refrigerator	1	250	250	2.5	625
7	Visitor's toilet	1	12	12	0.5	6
	Dinning					
8	Bulbs	3	12	36	1.5	54
9	Ceiling fan	1	50	50	1.5	75
	Room 1 (Master's Room)					
10	Bulbs	3	12	36	2	72
11	Ceiling fan	1	50	50	3	150
12	Television	1	41	41	2	82
	Room 2 (children's room)					
13	Bulbs	2	12	24	2	48
14	Ceiling fan	1	50	50	2	100
	Room 3					
15	Bulbs	2	12	24	2	48
16	Ceiling fan	1	50	50	3	150
	Visitor's room					
17	Bulbs	2	12	24	3	72
18	Ceiling fan	1	50	50	4	200
	Kitchen and lobby					
19	Bulbs	1	12	12	2	24
	Store					
20	Bulbs	1	12	12	0.5	6
	Security light					
21	Bulbs	5	10	50	5	250
	Other additional loads					
22	Pumping machine	1	560	560	1.5	840
23	Washing machine	1	1500	1500	1	1500
	TOTAL			3176		6027

Cost of purchase and installation of the said petrol generator = ₦ 100,000.00
Average Cost of petrol with yearly inflation = 175 ₦/L
Petrol consumption per Day (5 hours period) = 1.5 × 5 = 7.5 litres
Cost of petrol per Day (5 hours period) = 7.5 × 175 = ₦ 1,300
Cost of Annual maintenance and repair = ₦ 30,000
Cost of using petrol generator considering 10 years period = 100,000 + (1300 × 3650) + (30,000 ×10) = ₦ 5,145,000

Hence, cost of using the petrol generator/day =

$$\frac{10\ year\ cost}{working\ period} = \frac{5145000}{3650} = ₦\ 1{,}409.59$$

Unit cost =

$$\frac{\text{Daily cost of using the petrol generator}}{total\ kWh\ consumption} = \frac{1{,}409.59}{6.027} = 233.88\ ₦/\text{kWh}$$

3.5 Sizing of Solar PV System

Inverter Sizing

In an off-grid solar system, an inverter is required where AC output is needed. Also, one of the design specifications for inverters is that it must have same nominal voltage rating as the battery it is to be connected to and the total wattage of the appliances the inverter is to supply should be lower than the rating of the inverter. Hence, the inverter is rated 25% - 30% bigger than the total wattage of the appliances it is meant to supply. For this study,

Inverter rating = $total\ appliance\ wattage * 1.25$

$$= 3.176 * 1.25 = 3.97\ kW \cong 4.0\ kW\ or\ 5\ kVA$$

Therefore, for this study 4.0 kW (5 kVA), 48 V pure sinewave Inverter is used

PV Module Sizing

The data of the solar panels used in this study are shown in table

TABLE 2: DATA OF SOLAR PANEL USED

MODEL: 270M-60	
MAXIMUM POWER	270 ± 3%
MAXIMUM POWER VOLTAGE	30 V
MAXIMUM POWER CURRENT	9 A
OPEN-CIRCUIT VOLTAGE	36 V
SHORT-CIRCUIT CURRENT	9.81 A
MAXIMUM SYSTEM VOLTAGE	IEC1000V
MAXIMUM FUSE CURRENT	15 A
ELECTRICAL DATA AT STANDARD TEST CONDITIONS: AM 1.5, IRRADIANCE 10000W/M, CELL TEMPERATURE 250C	

2.

But, the Watt-hour (Wh) consumption of the case study from table 1 is 6027 Wh.

Therefore, the Wh needed from the PV module =

$$total\ appliance\ Wh * 1.3\ (system\ loss\ factor)$$

= 6027 * 1.3 = 7835.1 Wh/day

Total Watt-peak (Wp) needed for PV modules

$$= \frac{total\ Watt-hours/day}{Panel\ generation\ factor} = \frac{7835.1}{3.41} = 2297.68\ Wp$$

Minimum number of PV Panels =

$$\frac{Total\ Watt-peak\ rating\ needed\ for\ PV\ Modules}{rated\ output\ Watt-peak\ of\ the\ avalible\ PV\ Modules}$$

$$= \frac{2297.68}{270} = 8.5 \cong 8\ panels$$

Deep Cycle Battery Sizing

The most commonly used battery type in solar PV system design is deep cycle battery. This is because it is specially designed to be discharged to a low energy level and cycled charged after discharge day-by-day for the period of its lifespan. For durability, batteries should not be discharged below 50% capacity. From table 1, the total Watt-hours = **6027 Wh.**
Therefore,

$$Battery\ rating\ (AH) = \frac{Total\ watt-hour/day * DOA}{BLF * DOD * NBV}$$

Where,
DOA = Days of autonomy, BLF = Battery loss factor, DOD = Depth of Discharge, NBV = Nominal Battery Voltage

$$Battery\ capacity\ (AH) = \frac{6027 * 1}{0.85 * 0.5 * 48} = 295.44\ Ah$$

$$Battery\ capacity\ (AH) \cong 300\ Ah$$

$$\text{Number of battery} = \frac{300}{100} = 3\ batteries\ of\ 48\ V$$

Thus, since batteries do not come in 48 V, the study would need twelve (12) 12 V, 100 Ah batteries.

Solar charge controller

The control of the rate of charging and discharging of a battery is done by solar charge controller. They are rated against voltage and current capacities; hence, their voltage has to be the same as the voltage of the battery and that of the solar panel. The sizing of the controller depends on the panel input current, and the PV panel arrangement (series or parallel connection). Following the standard practice, the solar charge controller rating is expressed mathematically as:

Solar charge controller rating = Number of Panel parallel paths * short circuit current * 1.3 = $3 * 9.81 * 1.3 = 38.26\ A \cong 40\ A$

Calculation of the Cost of using solar system to power the case study for 5 hours

The cost requirement of a solar system that will handle the case study, considering the solar panel lifespan (25 years), the battery warranty (5 -15 years for non-grid systems), and the inverter warranty (5 -10 years) is shown in Table 3.

TABLE 3: THE BILL OF ENGINEERING MEASUREMENT AND EVALUATION FOR THE DESIGNED SOLAR SYSTEM.

S/N	Description	Requirement	Quantity	Estimated Rate	Amount (N)
1	Batteries	100Ah, 12 V Deep cycle	12	40,000	480,000
2	Solar PV panels	270 W, 24 V	8	40,000	320,000
3	Charge controller	MPPT 40 A, 48 V	1	65,000	65,000
4	Inverter	4 kW or 5 kVA	1	170,000	170,000
5	Battery rack		1	10,000	10,000
6	Panel rack		1	10,000	10,000
7	Change over switch		1	5,000	5,000
8	Cables and accessories		Assorted	20,000	20,000
9	Cost of installation			50,000	50,000
	TOTAL COST				1,125,000

For the design, these three major things are to be considered namely - the maintenance cost of the solar panel over 10 years, inverter maintenance cost, and cleaning of the solar panel after every 6 months. To this end, the unit cost of electricity from solar PV based on the cost estimation in Table 3 is:

Cost of acquisition and installation = ₦ 1,125,000
Cost of maintenance (Annual) = ₦10,000
Considering a-10-year cost = 1,125,000+ (10,000 ×10)
= ₦1,225,000

Cost of using the solar PV system/day =

$$\frac{Cost\ over\ 10\ yrs}{number\ of\ days} = \frac{1{,}225{,}000}{3650} = ₦\,335.62$$

Per unit cost

$$= \frac{Daily\ Cost\ of\ energy}{Total\ daily\ kWh} = \frac{335.62}{6.027} = 55.69\ Naira/kWh$$

4.0 RESULT AND DISCUSSION

Figure 2 is the summary of the cost implication of using a Petrol generator and Solar PV system to provide five hours of electrical power for a three-bedroom residential middle-income apartment in Nigeria.

From Figure 2, the cost of purchase and installation of solar PV system is higher than that of petrol generator. But after the first year, the cost of operating the petrol generator keeps increasing and for a period of ten years it had 98.1% increase in cost of acquisition and installation while the solar had only 8.2% increase. Therefore, it is evident that the solar PV system over a while is more profitable when compared to a petrol generator in providing electricity for three bedroom middle-income apartment, considering the annual maintenance cost, the daily cost of using the source, and per-unit cost.

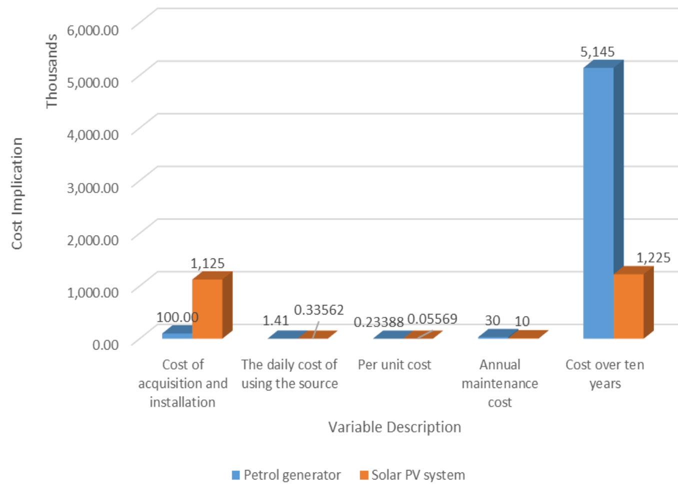

Figure 2: Summary of cost implication of using petrol generator and solar PV system

5.0 CONCLUSION

The Nigeria national grid suffers from an insufficient supply of electricity despite the vast potential resources for electricity generation in the country. This necessitates an alternative source of electricity of which generators and solar PV are the ones predominately in use. This paper, therefore, contains a cost analysis of using a petrol generator and PV system to power a three-bedroom middle-income residential apartment in Ilaro, Nigeria for five hours of the day, which can also be used for an individual with a similar load audit. The cost analysis shows that the unit cost of using petrol generator and solar PV system is N 233.88 and N 55.69 respectively. From the result, the supply of electricity from the solar PV system is the most cost-effective means of energy usage among the two sources considered regardless of its high cost of acquisition and installation, over a long time.

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