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Energy Audit Assessment of Standalone PV System (A Case Study of Heartland Radio Broadcasting Station)

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Abstract

It is no longer news that the Nigerian Power sector is inundated with myriads of challenges to satisfy the energy needs of consumers. In this paper, an energy audit assessment of standalone PV system "a case study of heartland radio broadcasting station" is conducted which offered the most accurate estimate of energy savings, cost and provided uninterrupted power to the Broadcasting Station. The results obtained showed that the annual electricity bill of the broadcasting house dropped reasonably from ₦9,402,832.71 to ₦2,286,410.3 between the current and recommended load, while the total annual saving of electricity bill stands at ₦7,116,422.40. This is a clear indication that the energy audit carried out actually reduced the cost of energy consumption of the station.

Subject Areas

Engineering Management

Keywords

Energy Audit, PV System, Load Shedding, BlueSol, Payback Period

1. Introduction

The degree of development and civilization of a country is measured by the amount of the utilization of energy by human beings. The increase in energy demand is linearly proportional to the increase in population, urbanization and industrialization. Due to the depletion of fossil fuel globally, the increase in energy consumption exceeds the energy supply leading to an energy crisis [1]. Photovoltaic energy has been embraced as the most significant source of renewable energy used for electricity generation in recent times in view of its seeming unlimited abilities. In this paper, an energy audit is conducted in a broadcasting house to ascertain the actual energy consumption and identify ways to decrease energy usage and save cost. Energy audit is a careful examination of the electrical loads. This is crucial for stand-alone systems which are commonly seen in Nigeria. It helps to prevent oversizing of the system, safeguarding your electrical appliances from damaging from inappropriate power surges and it generally saves your cost. Secondly, information from energy audit is required in solar PV system design. Without an accurate energy audit, it's seemingly impossible to design a sustainable solar system. The first step to an Energy Audit is to evaluate how much energy is being used to enable an auditor to identify the improvements that need to be made in order to increase energy efficiency.

Heartland Radio Broadcasting Station Owerri was considered for the study. The city receives abundant solar energy with an average daily solar radiation of about 5.25 kW·h/m^2/day that can be usefully connected [2]. Standalone Solar PV system is an ultimate, convenient and self-sufficient alternative to provide electricity for people living far from the electric grid in remote locations facing long hours of load shedding due to where grid extension is practically unviable or for people living in metropolitan areas who want electric power without having a connection to utility grid [3].

2. Historical Review of Owerri Transmission Substation

Transmission Company of Nigeria (TCN) Owerri work Centre has installed capacity of 160 MW fed via 132 kV double circuit transmission line running from Alaoji in Aba Abia State to Owerri Imo State extending to Ahoada in Rivers State. An existing generation station at Gbarain is capable of supplying up 100 MW via Ahoada network, which means that Owerri can import or export from Ahoada on 132 kV level. The grid is stepped down to 33 kV via 2 × 60 MVA and 1 × 40 MVA Transformers into 8 × 33 kV feeders namely: Orlu, Mbaise, Alex, NewOguta, Oguta, Owerri 3, Owerri/Airport and Okigwe respectively. Upon all these facilities, the area is being under supplied with electricity. **Figure 1** shows line diagram representation of 132/33kV Owerri Transmission line. The total allocated supply from Alaoji GenCO to the work Centre ranges from 50 - 80 MW as against the installed capacity which shows that the demand is much higher than the supply. It has been estimated that about 86% of households in Imo depend on fuel wood as their source of energy. On that note, there is urgent need to adopt an alternative solar PV technology to augment the short fall in the industry which has poised serious threat to the power system security of the state and the nation at large.

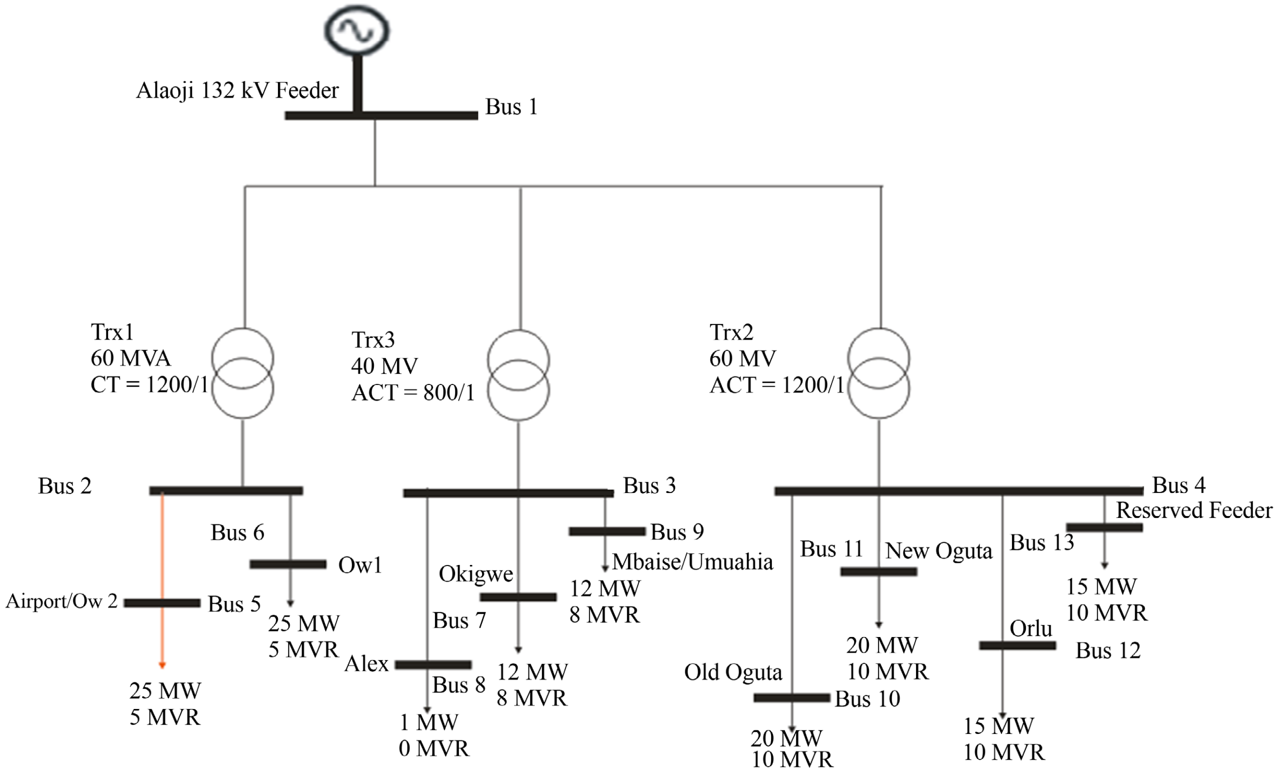

Figure 1. Line diagram representation of 132/33kV Owerri Transmission line.

3. Design Methodology

A systematic approach was adopted to carry out a detailed energy audit assessment of the broadcasting station, conduct PV system design. The method offered the most accurate estimate of energy savings and cost. The energy audit depends on the record of the actual energy consumption of the broadcasting house and calculations of energy use. Thereafter the actual energy consumption is calculated with recommended use is then compared to utility bill charges.

3.1. Load Calculation

A detailed load audit was carried out which offered the most accurate estimate of energy savings and cost. A load survey was conducted on the available load capacity of the Broadcasting house. The different types of electrical loads and their power rating were identified, as shown in Table 1. Note that this is the calculated building load, but practically, diversity factor will often come into play because all the loads may not be switched on at the same time. In Nigeria, official work hour for most companies is usually from 8 am to 5 pm. For the purpose of this paper, we are assuming that the office runs for an average of 10 h daily from Monday through Friday. This implies that a five-day work week is used. Using 261 work days per year and over the next 10 years, there are 2610 work days, taking into cognizance the average number of public holidays in a year [4].

From Table 2 comparing the yearly electricity bill between the current energy consumption to that recommended energy consumption after an energy audit

Table 1. Current energy consumption for the Broadcasting house.

S/N	Description	Ratings in (W)	Qty	Hrs in use	Estimated total load (W)	Daily energy
	Lightening points					
1	a) Internal	40	70	10	2800	28,000
	b) External 1	40	100	10	4000	40,000
2	Fans	80	15	10	1200	12,000
3	Refrigerators	10	20	10	200	2000
4	Aviation light	20	1	12	20	240
5	Air conditioners (1 Hp)	746	15	10	11,190	111,900
6	TV	60	10	10	600	6000
7	Photocopiers/Printers	1000	2	5	2000	10,000
8	Transmitter	20,000	1	24	2000	480,000
9	Laptop	80	10	10	800	8000
10	CCTV cameras	10	20	10	200	2000
11	Internet router	10	10	10	100	1000
12	Desktop computer	100	10	10	1000	10,000
15	Bore holes (1 Hp)	746	10	10	74,600	74,600
	Total energy in a day				**100,710**	**785,740**
	Total energy in a month (20 days)				2,014,200	**15,714,800**
	Total energy in a year (261 days)				26,285,310	**205,078,140**

Table 2. Electricity bill for the broadcasting house.

Current energy bill	Recommended energy bill
1) Yearly $\frac{205078140}{1000}\times\frac{45.85}{1}=₦9402832.7$	1) Yearly $\frac{49867182}{1000}\times\frac{45.85}{1}=₦2286410.3$
2) Monthly $\frac{15714800}{1000}\times\frac{45.85}{1}=₦720523.5$	2) Monthly $\frac{3821240}{1000}\times\frac{45.85}{1}=₦175203.9$
3) Daily $\frac{785740}{1000}\times\frac{45.85}{1}=₦36026.2$	3) Daily $\frac{191062}{1000}\times\frac{45.85}{1}=₦8,760.2$

have been conducted showed a huge reduction in bill from ₦9,402,832.70 to ₦2,286,410.30 serving a sum of ₦7,116,422.40.

3.2. PV System Design

The power needed by the load in single day = 24,416 W.

From Table 3 below, daily energy consumption = 191,061 W·h/day:

$$\text{Total energy required} = 191061 \times 1.3 = 248379.3\ \text{W} \cdot \text{h/day} \quad (1)$$

where loss factor = 1.3, panel generation factor= 3.41 [5]:

$$\text{Total Energy needed from PV module to operate the appliance} = \frac{248379.3}{3.41} = 72839\ \text{W} \cdot \text{p} \quad (2)$$

PV power rating per module = 315 W·p [6]:

$$\text{The no of minimum of PV modules for the system} = \frac{72839}{315} = 231.2 \quad (3)$$

The number of panels required = 231.2 Panels.

Table 3. Recommended energy consumption for the broadcasting house.

S/N	Description	Ratings in (W)	Qty	Hrs in use	Estimated total load (W)	Daily energy
	Lightening points					
1	a) Internal	10	70	10	70	7000
	b) External 1	15	100	6	1500	9000
2	Fans	80	15	5	1200	6000
3	Refrigerators	10	20	5	200	10,000
4	Aviation light	10	1	12	10	120
5	Air conditioners (1 Hp)	746	15	5	11,190	55,950
6	TV	60	10	5	600	3000
7	Photocopiers/Printers	1000	2	2	2000	4000
8	Transmitter	5000	1	17	5000	85,000
9	Laptop	80	10	5	800	4000
10	CCTV cameras	10	10	5	50	250
11	Internet router	10	5	5	50	250
12	Desktop computer	100	10	5	1000	5000
15	Bore holes (1 Hp)	746	1	2	746	1492
	Total energy in a day				**24,416**	**191,062**
	Total energy in a month (20 days)				**488,320**	**3,821,240**
	Total energy in a Year (261 days)				**6,372,576**	**49,867,182**

The system will be powered with 232 panels of 315 W PV module.

$$N_{ms} = V_{\text{system}} / V_{\text{module}} = 1\ \text{module} \times 24\ \text{V}/6\ \text{V} = 4\ \text{PV modules} \quad [7] \tag{4}$$

$$N_{mt} = N_{ms} \times N_{mp}$$

$$N_{mp} = N_{mt} / N_{ms} = 1\ \text{module} \times 232/4 = 58\ \text{ panels are required in parallel}$$

$$P_{\text{array}} = N_{ms} \times N_{mp} \times P_{\text{module}} = 4 \times 58 \times 315 = 73080\ \text{W} \tag{5}$$

where

N_{ms} = Number of PV module in series;

N_{mp} = Number of PV module in parallel;

N_{mt} = Number of total PV modules.

3.2.1. Determination of Size of Inverter

Inverter is required to converter direct current to alternating current. If the power rating of inverter is less than the total power of electrical load our system will be overloaded so the inverter rating should be 25% - 30% greater than the power of appliances for safety margin [8].

From **Table 3**, total estimated load = 24,416 W;

Power factor = 0.85;

Loss factor = 1.3;

Inverter efficient 90% = 0.9.

$$\text{Total load in V} \cdot \text{A} = \frac{\text{total watt}}{\text{pf}} = \frac{24416}{0.85} = 28724\ \text{V} \cdot \text{A} \tag{6}$$

$$\begin{aligned} \text{Size of inverter}(\text{W}) &= \frac{\text{total watt} \times \text{loss factor}}{\text{efficiency}} \\ &= \frac{24416 \times 1.3}{0.9} = 35268\ \text{W or } 35\ \text{kW} \end{aligned} \tag{7}$$

$$\text{Size of inverter}(\text{V} \cdot \text{A}) = \frac{28724 \times 1.3}{0.9} = 41490\ \text{V} \cdot \text{A or } 42\ \text{kV} \cdot \text{A} \quad [9] \tag{8}$$

The inverter rating required for the design is ABB 3 Phase ABB 50 kW Solar on Grid System.

3.2.2. Determination of Battery Size

This step is also very important for reliability of our system because during night and cloud days' sufficient energy are required to operate the appliances. Solar battery is the one of the most important consideration when choosing the basic components of your solar electric system. The battery capacity should be large enough to store sufficient energy to operate the appliances at night and during the cloudy day.

$$\text{Size of Battery} = \frac{C \times n}{0.85 \times 0.6 \times V_{\text{system}}} \quad [10] \tag{9}$$

where:

0.85 = battery loss;

0.6 = depth of discharge;

V_{system} = 48 V;

C = Battery Bank capacity of energy per day in Wh;

n = number of autonomy.

Autonomy is the number of days that you need the system to operate when there is no power produced from PV panel.

$$\text{Battery size with 2 days autonomy} = \frac{C \times n}{0.85 \times 0.6 \times V_{\text{system}}} \quad [11] \tag{10}$$

$$\text{Size of Battery} = \frac{191062 \times 2\ \text{days/days}}{0.85 \times 0.6 \times 48} = 15609.6\ \text{A} \cdot \text{h} \tag{11}$$

The battery capacity adopted = Greensun Battery 2 V/1000 Ah:

$$N_{bt} = \frac{1\ \text{battery} \times \text{battery bank capacity}}{\text{capacity of the selected battery}} \tag{12}$$

$$\text{Number of batteries required} = \frac{1\ \text{battery} \times 15609.6\ \text{A} \cdot \text{h}}{1000\ \text{A} \cdot \text{h}} = 15.6 \tag{13}$$

Total number of batteries required = 16:

$$N_{bs} = \frac{V_{\text{system}}}{V_{\text{battery}}} = \frac{1\ \text{battery} \times 24}{2} = 12\ \text{batteries} \tag{14}$$

$$N_{bp} = \frac{1\ \text{battery} \times N_{bt}}{N_{bs}} = \frac{1\ \text{battery} \times 16}{2} = 8\ \text{Batteries} \tag{15}$$

N_{bt} = number of total batteries;

N_{bs} = number of batteries is series;

N_{bp} = number of batteries in parallel.

3.2.3. Determination of Size of Charge Controllers

In this step an appropriate charge controller to match the voltage of PV array and the battery. The function of the charge controller is to regulate the charge going into the batteries bank from the solar panel array and prevent overcharging and reverse current flow at the night. Most used charge controllers are pulse width modulation, Pulse Width Modulation (PWM) or Maximum Power Point tracking (MPPT). When MPPT solar charge controller notices a difference in voltage, it will automatically and efficiently convert the lower voltage so your panels, battery bank and PV charge can all be equal in voltage. PV module specifications, for the short circuit current = 10.10 A.

$$I_{\text{rated}} = \left(N_{bp} \times I_{sc}\right) \times 1.3 = 8 \times 10.10 \times 1.3 = 105.04\ \text{A} \quad [12] \tag{16}$$

where:

I_{rated}= solar controller rating;

I_{sc} short circuit current;

N_{bp} no of parallel battery;

1.3 = safety factor.

$$\text{Using a string of four PV modules per controller} \\ = (4 \times 10.10\ \text{A}) \times 1.3 = 52.52\ \text{A} \tag{17}$$

A Charge Controllers of 60 A is used (Pfanpusun Mppt Solar Charge controller 60 Ah, 48 V).

3.2.4. Determination of Cable Sizing

The purpose of this step is to match the type of wire you need to use with the current which will pass through it in order to maintain the reliability and the performance of our system. When the size and type of wire are well selected this improves reliability and performance of PV system that is why cable sizing is a very important step. In this we use copper wire. The cable cross sectional area is determined by the following equation:

$$A = \frac{P \times L \times I}{V_d} \tag{18}$$

where:

P = resistivity of wire;

For Copper $P = 1.724\text{E}-8\ \Omega \cdot \text{m}$;

L = length of wire;

A = cross sectional area of cable;

I = rated current of regulator;

V_d = voltage drop.

In both AC and DC wiring for grid tied PV system the voltage is taken not to exceed 4% value.

1) Determination of cables size between PV modules and batteries:

$$\text{Maximum voltage drop } V_d = \frac{4}{100} \times V_{\text{module}} \text{ [12]} \tag{19}$$

$$V_d = \frac{4}{100} \times 24 = 0.96$$

Let the length of the cable is 1 m:

$$\text{Now } A = \frac{P \times l \times I}{V_d} \times 2 = \frac{1.742 \times 10^{-8} \times 1 \times 4507.8}{0.96} \\ = 8.17977875 \times 10^{-5}\ \text{m}^2 = 8.1798\ \text{mm}^2 \tag{20}$$

This means that any copper cable of cross-sectional area 8.1715 mm^2 can be used for the wiring between PV module and batteries through the charge controller.

3.2.5. Determination of Cable between the Battery Bank and the Inverter

$$\text{Maximum voltage drop } V_d = \frac{4}{100} \times V_{\text{system}} \tag{21}$$

At full load, batteries maximum current $I_{\max}$ is given by:

$$I_{\max} = \frac{\text{Inverter kV}\cdot\text{A}}{\text{efficiency of inverter}\times V_{\text{system}}} \tag{22}$$

System voltage = 24 V.

Let length of the cable be 7 m:

$$I_{\max} = \frac{\text{Inverter kV}\cdot\text{A}}{\text{efficiency of inverter}\times V_{\text{system}}} = \frac{42\text{ kV}\cdot\text{A}}{0.96\times 24} = 2\text{ A} \tag{23}$$

$$\text{Maximum voltage drop}\quad V_d = \frac{4}{100}\times 24 = 0.96 \tag{24}$$

$$A = \frac{4}{100}\times 24 = 0.96$$

$$A = \frac{1.742\times 10^{-8}\times 7\times 2}{0.96}\times 2\text{ m}^2 = 59.1\text{ m}^2 = 6\text{ mm}^2 \tag{25}$$

3.2.6. Determination of Cable Sizes between the Inverter and Load

$$\text{Maximum voltage drop}\quad V_d = \frac{4}{100}\times V_{\text{system}} \tag{26}$$

Here the system voltage = 220 V:

$$I_{\text{phase}} = \frac{\text{Inverter kV}\cdot\text{A}}{V_{\text{out}}\times\sqrt{3}} = \frac{1374.2\text{ kV}\cdot\text{A}}{200\times\sqrt{3}} = 4\text{ A} \tag{27}$$

$$V_d = \frac{4}{100}\times 220\text{ V} = 8.8\text{ V} \tag{28}$$

where $V_{\text{out}} = 220$ V:

$$A = \frac{P\times l\times I}{V_d} \tag{29}$$

Let the maximum length of the cable be 20 m:

$$A = \frac{1.742\times 10^{-8}\times 20\times 4}{8.8}\times 2\text{ m}^2 = 3.17\text{ m}^2 \tag{30}$$

$$A = 3\text{ mm}^2$$

3.2.7. Determination of Land Area for PV Installation

The surface area of one 315-watts solar panel = Length × Breadth (31)

The dimension of the panel is 77.00 × 39.05 inches. Converting the dimension to sqm will yield 1.96 × 0.991.

The total land area required to mount the 232 PV panels will be 1.96 × 0.991 × 232 = 450.6 m^2.

3.2.8. Cost Estimation

Hence you have a project you need also to calculate the money required to run your project. In our PV system the cost estimation equal to the sum of cost of components, cost of balance of system component and the maintenance cost of the PV system per year.

3.2.9. Payback Period

The number of years required to return the initial investment through positive annual cash flow is called Payback Period. In 10 years, the profits together have paid back your original investment, and hence the payback period is 10 years. The payback period helps determine whether to go forward with a project or not. Most PV systems come with a warranty period of 25 years. So, while calculating the potential savings, we've to consider a span of 25 years.

Total expenditure = ₦69,583,950.00 (The total cost of investment from Table 4);

Total savings = ₦9,402,832.7 (The annual current electricity bill from Table 2);

-

₦2,286,410.3 (The annual recommended electricity bill from Table 2);

₦7,116,422.40.

$$\text{Payback period} = \frac{\text{Total Expenditure}(\text{N})}{\text{Total Savings}} = \frac{69583950.00}{7116422.40} = 9.778 \tag{32}$$

The number of years required to return the initial investment through positive annual cash flow is: 10 years.

4. Results and Discussion

The simulation was carried out using Bluesol software. The obtained simulation results are illustrated in the following tables and figures as discussed hereafter.

Table 5 shows the monthly average daily irradiation and the number of days which make up the twelve months of the year. It also determined the value of the annual global irradiation on a horizontal surface for the location of Owerri North (Imo). This value is equal to 1536.65 kWh/m^2. Figure 2 shows Bar chart of the energy produced monthly. The Bar chart recorded highest energy production of 59917.1 kWh in the month January followed by 57149.7 kWh in Dec respectively.

Figure 3 represents the P-V characteristics of the PV module, from the graph it can be deduced that maximum power is approximately 400 W and it occurs at a current of 6.6 A and voltage at 60 V. Figure 4 represents the I-V characteristics of the PV module. From the Figure it is realized that the short circuit current of PV module is approximately 9.0 A and open circuit voltage is approximately 64.0 V.

Figure 5 shows the effect of variation of solar irradiation on P-V characteristics. Variation in Solar irradiation effects mostly on current. In Figure 6, change in solar irradiation on I-V increases, short circuit current also increases. Variation in Solar irradiation effects mostly on current from 4.0 A to 10.1 A approximately but effect of variation of solar irradiation on voltage is very less.

Figure 7 shows the Bar chart of average monthly irradiance both (Direct and Diffuse) of Owerri North the location of the station.

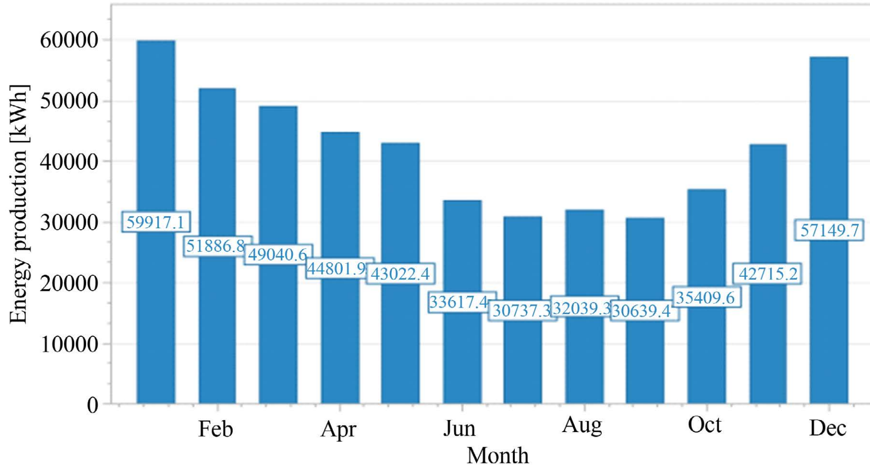

Figure 2. Monthly energy production.

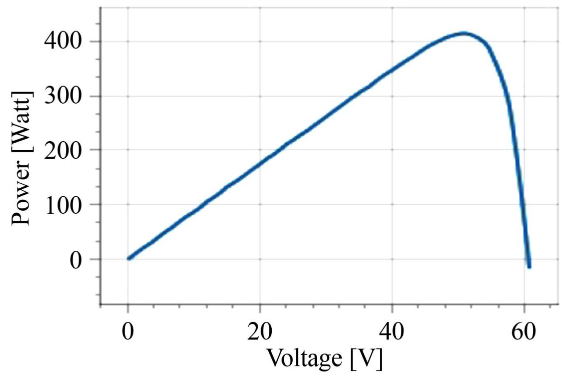

Figure 3. P-V chart characteristics.

Table 4. Cost estimate for setting up solar PV system.

S/n	Device	Model	Qty	Unit price (₦)	Total amt (₦)
1	Batteries	2 V, 1000 Ah	16	70,000	1,120,000.00
2	PV panels	315 sun power	232	207,000	48,024,000.00
3	Charge controller	60 A, 48 V	1	239,950	239,950.00
4	Inverter	3 phase ABB 50 kW	1	1,000,000	1,000,000.00
5	Combiner boxes		232	50,000	11,600,000.00
6	Panel rack		42	100,000	4,200,000.00
7	Battery rack		8	100,000	800,000.00
8	AC breaker		2	200,000	400,000.00
9	Isolator switch		1	200,000	200,000.00
10	Bus bar unit		1	2,000,000	2,000,000.00
		Total cost			69,583,950.00

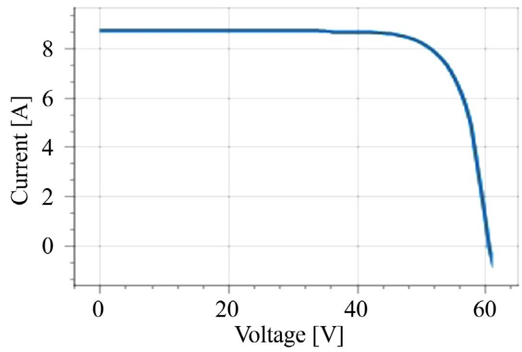

Figure 4. I-V chart characteristics.

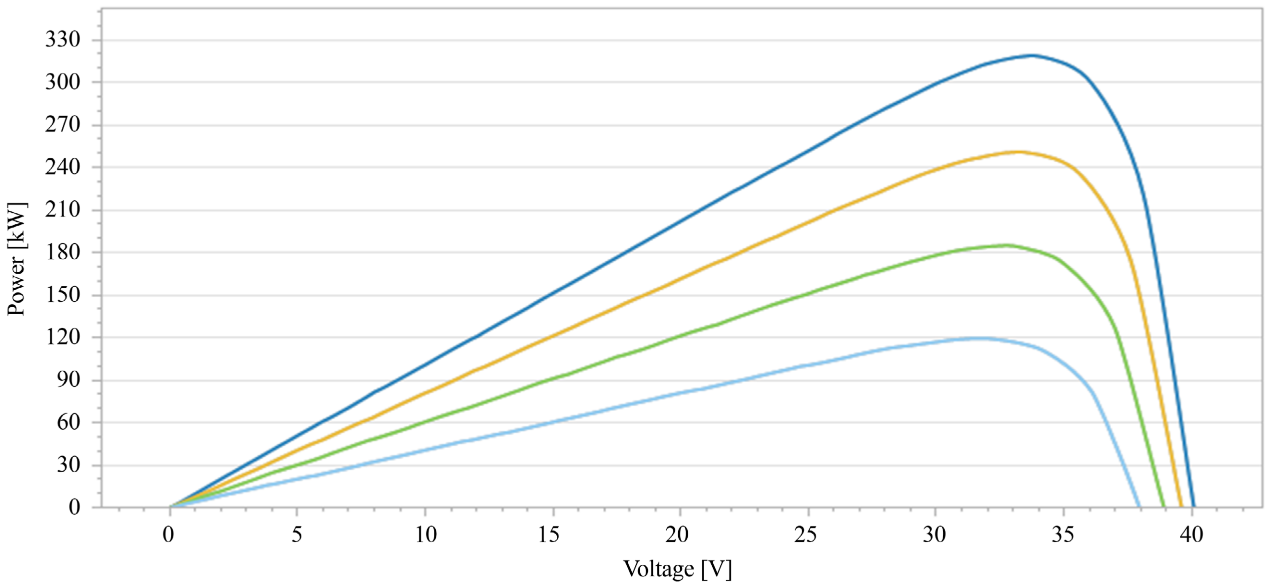

Figure 5. Effect of variation on irradiation on P-V characteristics.

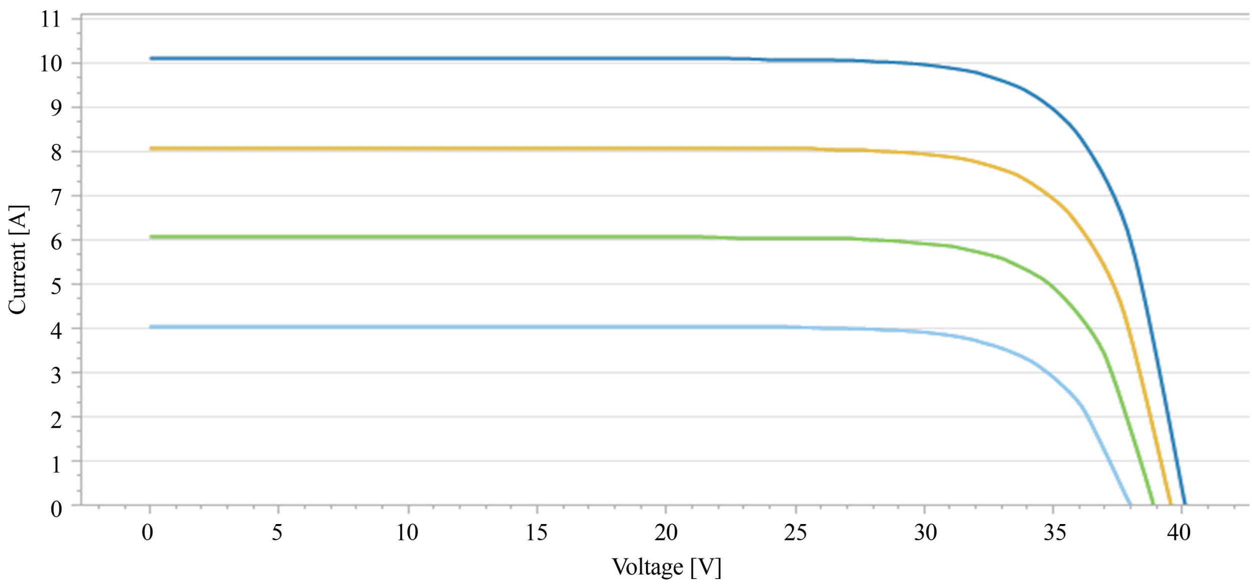

Figure 6. Effect of variation on irradiation on I-V characteristics.

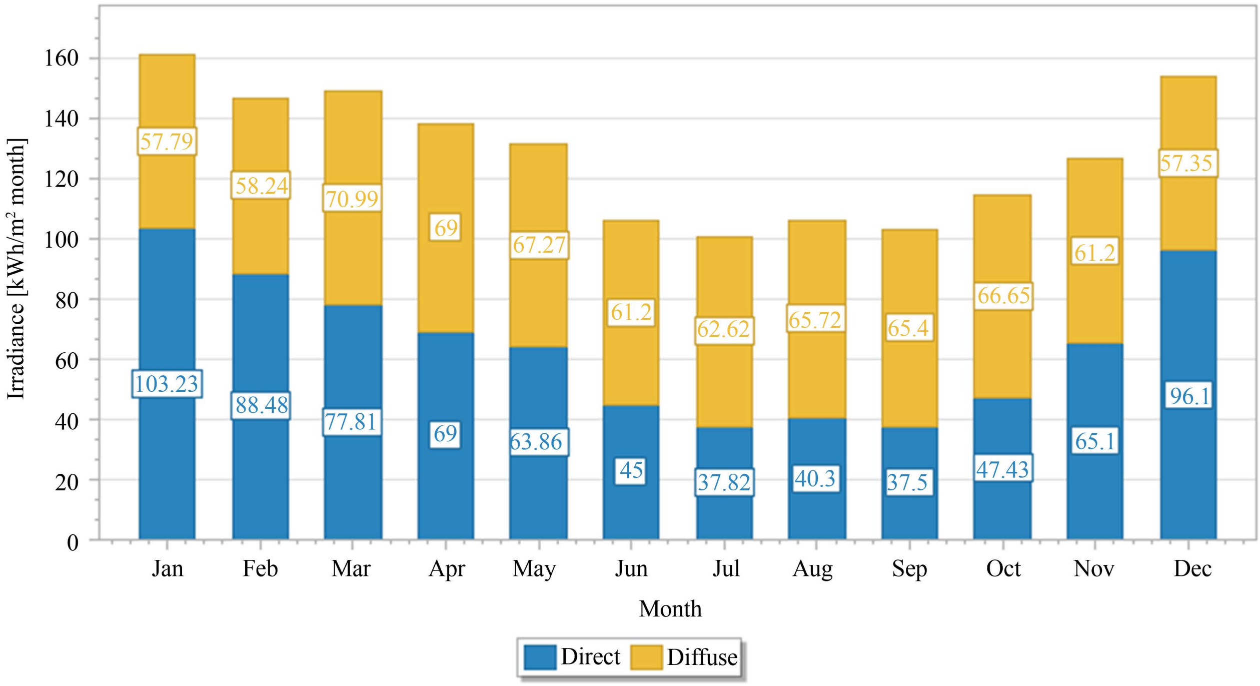

Figure 7. Annual producibility.

Table 5. Daily irradiation on horizontal surface.

Month	Diffuse daily (kWh/m²)	Direct daily (kWh/m²)	Global daily (kWh/m²)
January	1.87	3.33	5.20
February	2.08	3.16	5.24
March	2.29	2.51	4.80
April	2.30	2.30	4.60
May	2.17	2.06	4.23
June	2.04	1.50	3.54
July	2.02	1.22	3.24
August	2.12	1.30	3.42
September	2.18	1.25	3.43
October	2.15	1.53	3.68
November	2.04	2.17	4.21
December	1.85	3.10	4.95
Yearly	**762.85**	**773.80**	**1536.65**

5. Conclusion

Energy audit and performance evaluation of standalone PV system “a case study of heartland FM station” was successfully conducted. The calculation of the required components needed to meet the energy demand was obtained. The results yielded an annual energy production of 510,976.79 kWh and with total annual global irradiance of 1536.65 kWh/m^2. The annual electricity bill dropped reasonably from ₦9,402,832.71 to ₦2,286,410.3 between the current and recommended load, saving a total sum of ₦7,116,422.40 annually, which is a clear indication that energy audit actually reduced the cost of electricity consumption. The estimated costs of the realization of plant amounted to ₦69,583,950.00. It means that with a payback period of 10 years, the total amount spent on the realization of the project must have been recovered.

6. Recommendations

The paper strongly recommends the following:

- Replacement of the obsolete equipment likes transmitter and air-conditioners that account for a big chunk of the broadcasting house monthly utility bill. Due to recent technological advancement most appliances don't consume energy the way older models do because they meet minimum federal energy efficiency standards. These standards have been tightened over the years, so any new appliance purchased these days, consume less energy than the model purchased 10 years ago. For instance, if you buy one of today's most energy-efficient air conditioner (Inverter AC or Digital Transmitter, it will use less than half the energy of a model that is 10 years older;
- Lighting: The use of Light emitting diodes bulbs (LED bulbs) other than filament bulbs it highly recommended;
- Changing our attitude of switching electrical equipment off at the mains rather than leaving it on standby, turning off lights when they're not being used;
- Turn off the monitor; this device alone uses more than half the system's energy;
- Screen savers save computer screens, not energy;
- Laser printers use more electricity than inkjet printers;
- Adequate sensitization of everyone in the home, including children and domestic helpers on the importance of saving energy and how best they can behave to save it;
- Employ the use of automated systems such as light and motion sensors to save energy;
- Refrigerator: avoid running the refrigerators when its empty. Avoid frequent opening of refrigerator doors when on load.

Conflicts of Interest

The authors declare no conflicts of interest.

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