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Photovoltaics Application in Benin City

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Abstract

This work examines the implementation of solar power systems in Southern Nigerian using Benin City as a case study. It designs solar power system for a 3-bedroom flat for Benin City for grid-tie, grid-tie with battery backup and off-grid design approaches and carried out cost and pollution analysis for the three approaches. Designing the systems involved electrical load estimate and solar system component sizing and costing. Analysis was carried out considering a 25-year operational period for the system. It was observed that though initial system cost was high, operational and maintenance costs were significantly minimal to deflate the initial cost of setting up the systems.

1.0 Introduction

Power generation and distribution in Nigeria has been so unreliable and unstable that a greater part of the country goes for as long as three or more months without having power for just one hour. Many of these places either live without electrical power or resort to the use of generators for solace. The total installed electrical power generation capacity is 6600MW [1] out of which the actual power generation at any material time fluctuates between 3500MW and 1700MW. [2, 3] This is grossly inadequate. The power utility company therefore resorts to load shedding which as consequence leaves some parts of a town, city or state in long wait for their turn leading them to long periods without power. Another factor responsible for long periods of darkness for some areas is the poor maintenance culture of the utility company which leads to long downtime occasioned by poor response to reported faults.[4]

For the economy of any place to develop, there must be sufficient power to meet demand plus reserved power for periods of peak demand [5]. This, the Nigerian nation does not have now as demand far exceeds generation. There is therefore need to explore alternative sources of power to boost power generation in a bid to meet the ever increasing power demand. Thus this paper presents the solar system design and cost and green house gas emission analysis for Nigeria using Benin City as a case study.

2.0 Design of a 2- and 3-bedroom flats solar systems for Benin City

The design of a photovoltaic system requires the sizing of solar panel requirement, battery bank (for off grid systems) and inverter. The sizes of these components are primarily a function of the daily sunshine hour for the locality where the design is to be implemented as well as the electrical load requirement. Thus the sunshine hour data for Benin City was used, Table 1. [6, 7] The electrical load estimate for a 3-bedroom flat is as shown in Table 2. [8]

2.1 Solar system design for the grid –tie system for the 3-bedroom flat.

The total wattHour estimate for 2-bedroom flat is 62,753. The WattHour power requirement per day for each device was obtained from:

Device Daily WattHour demand = Device power rating in Watts x Quantity x daily demand factor in hours . Thus, for Blender, Daily WattHour = 400W x 1 x 0.33hour = 132Watthour

2.1.1 Component Sizing for 3-bedroom flat solar design

Designing for the worst case scenario, i.e using the least monthly average of the average sunshine hour value, which is 2.44 sunshine hours,

Number of solar panels required is obtained from: [8]

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Table 1: Average of average monthly sunshine hour data for Benin City

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Sunshine Hours	**4.94**	**4.88**	**5.127**	**5.78**	**5.68**	**4.06**	**2.98**	**2.44**	**3.05**	**4.73**	**6.23**	**5.33**

Table 2: Daily Electrical load requirement for 3-bedroom flat

S/N	**Electrical device**	**Device Power (Watts)**	**Quantity**	**Total device power (Watts)**	**Hours of daily use**	**Average watt-hours per day**
1	Ceiling fans	50	5	250	12	3000
2	4ft Flourescents	36	6	216	12	2592
3	2ft Flourescents	19	9	171	2	342
4	Colour TV Flat screen	35	4	140	10	1400
5	Cable Decoder	30	1	30	10	300
6	CD Player	10	1	10	6	60
7	Laptop	75	1	75	4	300
8	Desktop	150	1	150	4	600
9	Printer	150	1	150	1	150
10	Satellite Dish	30	1	30	10	300
11	Incandescent bulbs	36	2	72	6	432
12	Toaster	1500	1	1500	0.33	495
13	Micro-wave	1500	1	1500	0.1	150
14	Pressing iron	1000	1	1000	0.5	500
15	Air conditioner	1000	4	4000	4	16000
16	Refrigerator	1500	1	1500	24	36000
17	Blender	400	1	400	0.33	132
	TOTAL			**11,194**	**TOTAL**	**62,753**

$$No\ of\ \ panels\ needed = \frac{LE}{W_p\ x\ H_s}\ x\,1.2 \qquad (1)$$

Where:LE = Electrical load estimate for intended application, W_p = Watt rating for the panel to be used, H_s = Daily sunshine Hours for the location where system is to implemented and 1.2 = Factor that gives additional 20% number of panels to cover for conversion losses and periods of prolonged cloud cover.
Therefore,

$$No\,of\ \ panels = \frac{62753}{2.44 \times 270} = 95.25 \approx 96 \quad 270 - Watts\,/\,24V\ \ Panels$$

Inverter size required is obtained by summing the power ratings of all appliances that can be used simultaneously and using the appliance combination with the highest power requirement. Therefore, the inverter size is

$$Invertersize = Freezerpwr + Ironpwr + ACpwr + Microwavepwr$$

$$= 1500 + 1000 + 2000 + 1500 \quad = 7000 Watts$$

Therefore, the inverter size is 7KVA. However, a 7.5KVA should be used.

$CostOfInverter = 1 \times 4356 \times 151 \quad = \quad 657,756.00$. Therefore the cost of inverter is ₦ 657,756.00

2.1.2 Cost estimate for 3-bedroom flat grid tie solar system

Table 3 shows the cost estimate for implementing a solar power system for a 3-bedroom flat using the sum of ₦ 700,000.00 for system accessories.

Table 3: Cost Estimate for implementing grid tie without battery backup solar system for a 3-bedroom flat

S/N	**Component**	**Units**	**Price/unit(N)**	**Total (N)**
1	270W SunTech solar Panels	96	101,472.00	9,741,312.00
2	7.5 KVA Frontius-IG-Plus purely grid-tie Pure Sinewave inverter	1	657,756.00	657,756.00
3	Others	Lot	700,000	700,000.00
			TOTAL	**11,099,068.00**

2.1.3 Cost Analysis Of The Grid Tie Systems

Cost analysis for this system covered annual cost analysis, net- metering and environmental cost benefits.

2.1.3.1 Annual Cost Analysis For The Grid Tie System

The annual cost analysis was carried out using equation: [9,10]

$$C_t = \frac{I + D + T}{100} C_c + (W + R + M) + C_f \quad (3)$$

Where I=interest in %, D=depreciation in %, T=Taxes and Insurance in %, Cc-Construction cost, W=Wages and Salaries, R=Repairs(Maintenance), M=Miscellaneous and Cf=Fuel Cost

Using I=T=W=M=C_f = 0 and D = 0.1% and R involving the basic maintenance of the panels and the battery bank, the annual cost tables for a 25 year period were obtained for the grid tie system for the 3-bedroom flat as shown in Tables 4 and the corresponding MATLAB Plots in Figures 1, 2 and 3.

Table 4: Annual Cost analysis for 3-bedroom flat grid tie solar system

YEAR	ANNUAL COST,CT (₦)	NET VALUE (₦)
1	14,099.07	11,087,969
2	14,087.97	11,076,881
3	14,076.88	11,065,804
4	14,065.80	11,054,738
5	14,054.74	11,043,683
6	14,043.68	11,032,639
7	14,032.64	11,021,606
8	14,021.61	11,010,584
9	14,010.58	10,999,573
10	13,999.57	10,988,573
11	13,988.57	10,977,584
12	13,977.58	10,966,606
13	13,966.61	10,955,639
14	13,955.64	10,944,683
15	13,944.68	10,933,738
16	13,933.74	10,922,804
17	13,922.80	10,911,881
18	13,911.88	10,900,969
19	13,900.97	10,890,068
20	13,890.07	10,879,178
21	13,879.18	10,868,299
22	13,868.30	10,857,431
23	13,857.43	10,846,574
24	13,846.57	10,835,727
25	13,835.73	10,824,891

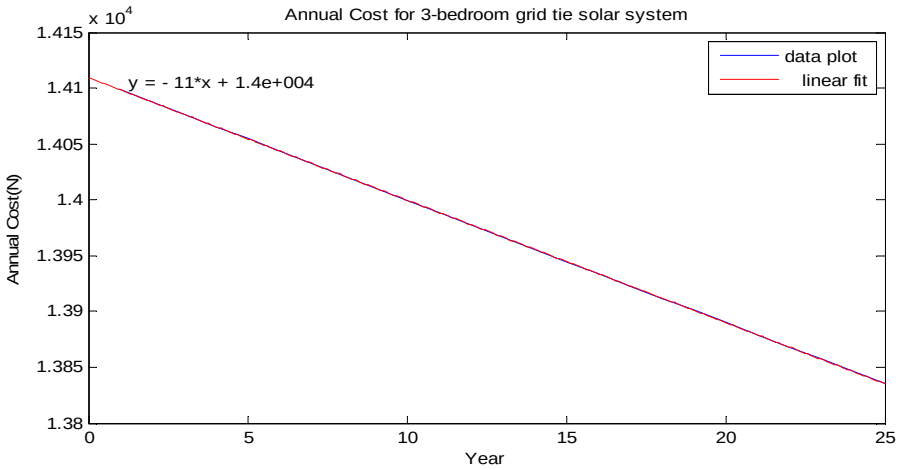

Figure 1: Annual Cost for 3-bedroom grid tie solar system

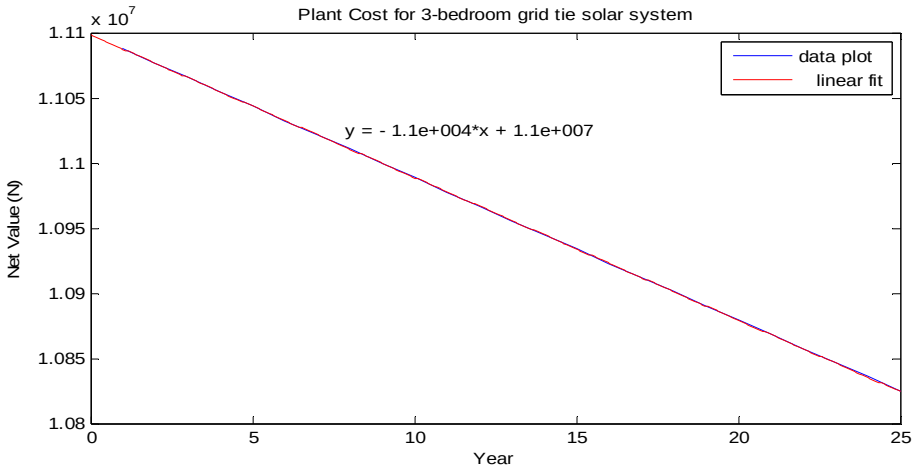

Figure 2: Plant cost for 3-bedroom grid tie solar system

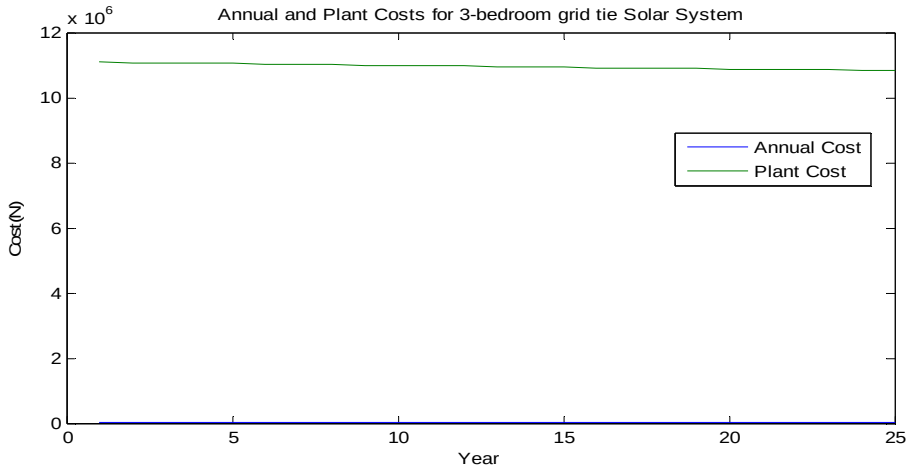

Figure3: Annual and Plant costs for 3-bedroom grid tie solar system

2.1.3.2 Pollution Cost Analysis

A combined cycle gas turbine (CCGT) emits 191.1 Kg/MWh of CO_2, 1.55 g/MWh of SO_2 and 31 g/MWh of NO_X.[11] Therefore generating power from solar energy for 3-bedroom flat would save the environment, in comparison to CCGT;
For 3-bedroom grid tie with load estimate of 62753 Wh = 0.062753MWh,

(i) 0,062753 x 191Kg of CO_2 = 11.985823 Kg daily
Therefore, for using this system for 1 year, the environment would be saved:
11.985823Kg x 365 = 4374,8254Kg of CO_2 in comparison to a CCGT plant.
For a 25 year this system would save environmental pollution due to CO_2 produced by CCGT plant to the tune of: 4374.8254 x 25kg of CO_2 = 109,370.64 Kg of CO_2

(ii) 0.062753 x 1.55 g/MWh of SO_2 = 0.9726715g of SO_2 daily. Therefore for using the system for 1 year the environment is saved of: 0.9726715g x 365 = 355.0251g of SO_2.
For a 25 year period which is the conservative life span of a solar system, this system would save the environment of SO_2 pollution to the tune of: 25 x 355.0251 g of SO_2 = 8875.6275g or 8.88 Kg of SO_2 pollution in comparison to a CCGT plant.

(iii) 0.062753 x 31g of NOx daily = 19.45343g of NOx in comparison to a CCGT plant producing the same amount of power. This is equivalent to: 19.45343 g x 365 = 7100.502 g a year. For a 25year period the amount of NOx = 25 x 7100.502 g = 177512.55 g = 177.51 Kg

2.1.3.3 Net Metering

If at any time, the solar system's generated power is in excess of what the connected load is consuming then the excess could be sold to the public utility company (PHCN) according to the expression: [12,13]

$$₦/\text{kWh} = kW_{ac} \times sun = hours \times No.of\ days / month \times N / kWh \quad (4)$$

If the excess were, say, 22.5kWh for the 3-bedroom, then, Net Metering for the 3-bedroom flat system would be

₦/kWh $= 22.5 \times 30 \times 4 = 2,700$

For a year this would be $2700 \times 12 = 32,400$ and for the 25 year period, this would amount to $32,400 \times 25 = 810,000$. Therefore, there would a return of ₦810,000.00

2.2 Solar system design for the grid –tie with battery backup system for the 3-bedroom flat.

The total wattHour estimate for 2-bedroom flat is 62,753.

2.2.1 Component Sizing for 3-bedroom flat solar design

Designing for the worst case scenario, i.e using the least monthly average of the average sunshine hour value, which is 2.44 sunshine hours,Number of solar panels required is, from eqn 1

$$No\ of\ \ panels = \frac{62753}{2.44 \times 270} = 95.25 \approx 96 \quad 270 - Watts\ /\ 24V\ \ Panels$$

Number of batteries required is obtained from as:

$$No of\ batteries = \frac{62753 \times 2}{24 \times 200} = 26.147 \approx 27 \quad 200 - AH\ /\ 24V\ \ Batteries$$

The inverter size is:

$$Invertersize = Freezerpwr + Ironpwr + ACpwr + Microwavepwr$$

$$= 1500 + 1000 + 2000 + 1500 \quad = 7000\, Watts$$

Therefore, the inverter size is 7KVA. However, a 7.5KVA should be used.

2.2.2 Cost estimate for 3-bedroom flat

Table 5 shows the cost estimate for implementing a solar power system for a 3-bedroom flat using the sum of ₦ 800,000.00 for system accessories.

Table5: Cost Estimate for implementing grid tie with battery backup solar system for a 3-bedroom flat

S/N	Component	Units	Price/unit(N)	Total (N)
1	270W SunTech solar Panels	96	101,472.00	9,741,312.00
2	4 KVA Xantrex inverter 3.5KVA OutBack inverter	1 1	440,769.00 286,749.00	440,769.00 286,749.00
3	200AH,24V AGM Battery	27	85,000.00	2,295,000.00
4	Others	Lot	800,000	800,000.00
			TOTAL	**13,563,830.00**

2.2.3 Cost Analysis Of The Grid Tie Systems With Battery Back Up

Cost analysis for this system covered annual cost analysis, net- metering and environmental cost benefits.

2.2.3.1 Annual Cost Analysis For The Grid Tie System

The annual cost analysis was carried out using equation 4 to obtain Table 6 and MATLAB plots of Figures 4, 5 and 6 were made.

Table 6: Annual Cost analysis for 3-bedroom flat grid tie with battery backup solar system

YEAR	ANNUAL COST,CT (₦)	NET VALUE (₦)
1	15,326.94	9,317,608.10
2	15,317.61	9,308,290.50
3	15,308.29	9,298,982.20
4	15,298.98	9,289,683.20
5	15,289.68	9,280,393.50
6	15,280.39	9,271,113.10
7	15,271.11	9,261,842.00
8	15,261.84	9,252,580.20
9	15,252.58	9,243,327.60
10	15,243.33	9,234,084.30
11	15,234.08	9,224,850.20
12	15,224.85	9,215,625.40
13	15,215.63	9,206,409.80
14	15,206.41	9,197,203.40
15	15,197.20	9,188,006.20
16	15,188.01	9,178,818.20
17	15,178.82	9,169,639.40

18	15,169.64	9,160,469.80
19	15,160.47	9,151,309.30
20	15,151.31	9,142,158.00
21	15,142.16	9,133,015.80
YEAR	**ANNUAL COST,CT (₦)**	**NET VALUE (₦)**
22	15,133.02	9,123,882.80
23	15,123.88	9,114,758.90
24	15,114.76	9,105,644.10
25	15,105.64	9,096,538.50

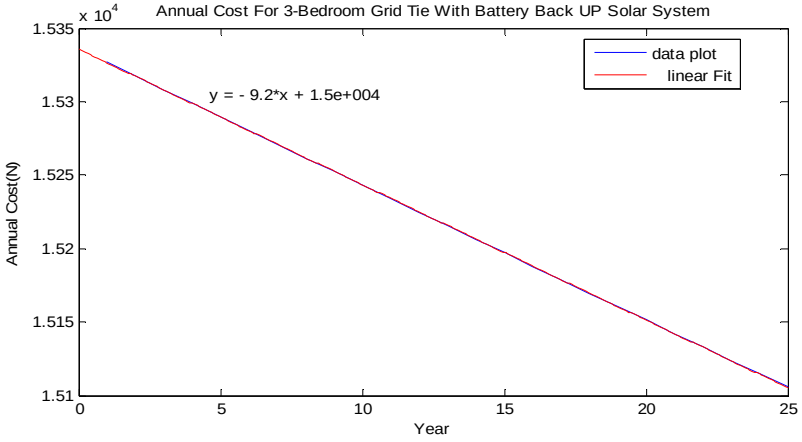

Figure 4: Annual cost for 3-bedroom grid tie with battery back up solar system

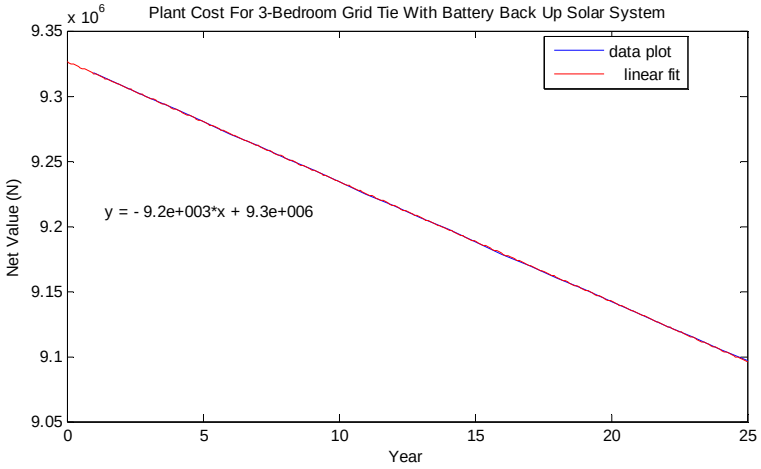

Figure 5: Plant cost for 3-bedroom grid tie with battery back up solar system

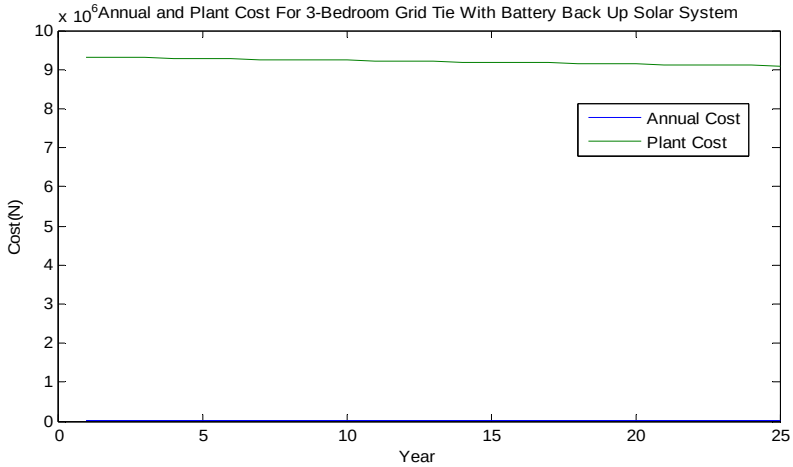

Figure6: Annual and plant cost for 3-bedroom grid tie with battery backup solar system

2.2.4 Pollution Cost Analysis

A combined cycle gas turbine (CCGT) emits 191.1 Kg/MWh of CO_2, 1.55 g/MWh of SO_2 and 31 g/MWh of NO_X. Therefore generating power from solar energy for 3-bedroom flat would save the environment, in comparison to CCGT;
For 3-bedroom grid tie with battery backup with load estimate of 62753 Wh = 0.062753MWh,

(i) 0,062753 x 191Kg of CO_2 = 11.985823 Kg daily . Therefore, for using this system for 1 year, the environment would be saved:
11.985823Kg x 365 = 4374,8254Kg of CO_2 in comparison to a CCGT plant.
For a 25 year this system would save environmental pollution due to CO_2 produced by CCGT plant to the tune of : 4374.8254 x 25kg of CO_2 = 109,370.64 Kg of CO_2

(ii) 0.062753 x 1.55 g/MWh of SO_2 = 0.9726715g of SO_2 daily
Therefore for using the system for 1 year the environment is saved of:
0.9726715g x 365 = 355.0251g of SO_2
For a 25 year period which is the conservative life span of a solar system, this system would save the environment of SO_2 pollution to the tune of:
25 x 355.0251 g of SO_2 = 8875.6275g or 8.88 Kg of SO_2 pollution in comparison to a CCGT plant.
(iii) 0.062753 x 31g of NOx daily = 19.45343g of NOx in comparison to a CCGT plant producing the same amount of power. This is equivalent to: 19.45343 g x 365 = 7100.502 g a year. For a 25year period the amount of NOx = 25 x 7100.502 g = 177512.55 g = 177.51 Kg

2.2.5 Net Metering

From eqn 4, if the excess were, say, 15kWh for the 2-bedroom, 22.5kWh for the 3-bedroom and 55 kWh for the 5-bedroom duplex, then,

Net Metering for the 3-bedroom flat system would be: ₦/kWh $= 22.5 \times 30 \times 4 = 2,700$

For a year this would be $2700 \times 12 = 32,400$ and for the 25 year period, this would amount to $32,400 \times 25 = 810,000$. Therefore, there would a return of ₦810,000.00

2.3 Solar system design for the Off-grid with battery backup system for the 3-bedroom flat.

The total wattHour estimate for 2-bedroom flat is 62,753.

2.3.1 Component Sizing for 3-bedroom flat solar design

Designing for the worst case scenario, i.e using the least monthly average of the average sunshine hour value, which is 2.44 sunshine hours,
Number of solar panels required is, from eqn 1:

$$No\ of\ panels = \frac{62753}{2.44 \times 270} = 95.25 \approx 96 \quad 270 - Watts/24V\ Panels$$

Number of batteries required is from eqn 2:

$$No\ of\ batteries = \frac{62753 \times 2}{24 \times 200} = 26.147 \approx 27 \quad 200 - AH/24V\ Batteries$$

Inverter size required is obtained by summing the power ratings of all appliances that can be used simultaneously and using the appliance combination with the highest power requirement that can be connected simultaneously. Therefore, the inverter size is

$$Invertersize = Freezerpwr + Ironpwr + ACpwr + Microwavepwr$$
$$= 1500 + 1000 + 2000 + 1500 = 7000 Watts$$

Therefore, the inverter size is 7KVA. However, a 7.5KVA should be used.

2.3.2 Cost estimate for 3-bedroom flat

Table 7 shows the cost estimate for implementing an Off-grid solar power system for a 3-bedroom flat using the sum of ₦ 800,000.00 for system accessories.

Table 7: Cost Estimate for off-grid solar system for a 3-bedroom flat

S/N	Component	Units	Price/unit(N)	Total (N)
1	270W SunTech solar Panels	96	101,472.00	9,741,312.00
2	5 KVA Genus inverter 2.5KVA Genus inverter	1 1	220,000.00 120,000.00	220,000.00 120,000.00
3	200AH,24V AGM Battery	27	85,000.00	2,295,000.00

4	Others	Lot	800,000	800,000.00
			TOTAL	**13,176,312.00**

2.3.3 Cost Analysis Of The Off Grid Systems With Battery Back Up

Cost analysis for this system covered annual cost analysis, net- metering and environmental cost benefits.

2.3.3.1 Annual Cost Analysis For The Grid Tie System

Using eqn 3, Table 8 was obtained and the MATLAB plots of Figures 7, 8 and 9 were made.

Table 8: Annual Cost analysis for 3-bedroom flat off grid with battery backup solar system

YEAR	ANNUAL COST,CT (₦)	NET VALUE (₦)
1	31,176.31	13,163,136
2	31,163.14	13,149,973
3	31,149.97	13,136,823
4	31,136.82	13,123,686
5	31,123.69	13,110,562
6	31,110.56	13,097,451
7	31,097.45	13,084,354
8	31,084.35	13,071,270
9	31,071.27	13,058,199
10	31,058.20	13,045,141
11	31,045.14	13,032,096
12	31,032.10	13,019,064
13	31,019.06	13,006,045
14	31,006.05	12,993,039
15	30,993.04	12,980,046
16	30,980.05	12,967,066
17	30,967.07	12,954,099
18	30,954.10	12,941,145
19	30,941.15	12,928,204
20	30,928.20	12,915,276
21	30,915.28	12,902,361
22	30,902.36	12,889,459
23	30,889.46	12,876,570
YEAR	**ANNUAL COST,CT (₦)**	**NET VALUE (₦)**
24	30,876.57	12,863,693
25	30,863.69	12,850,829

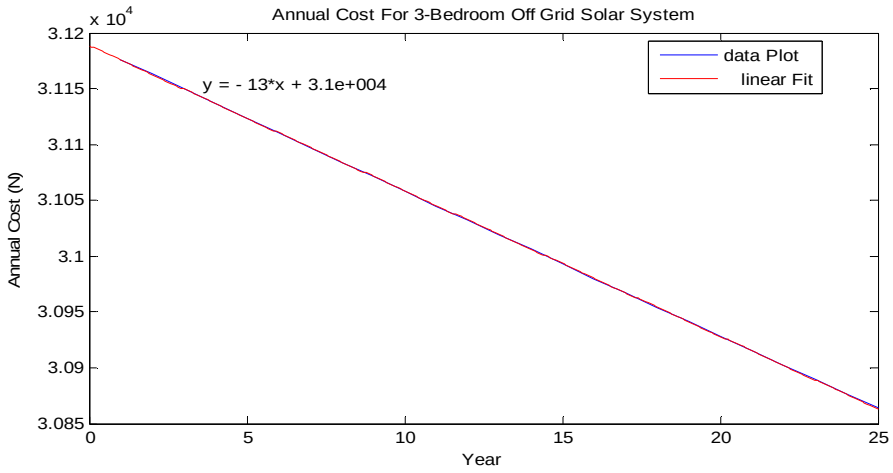

Figure7: Annual cost for 3-bedroom off grid solar system

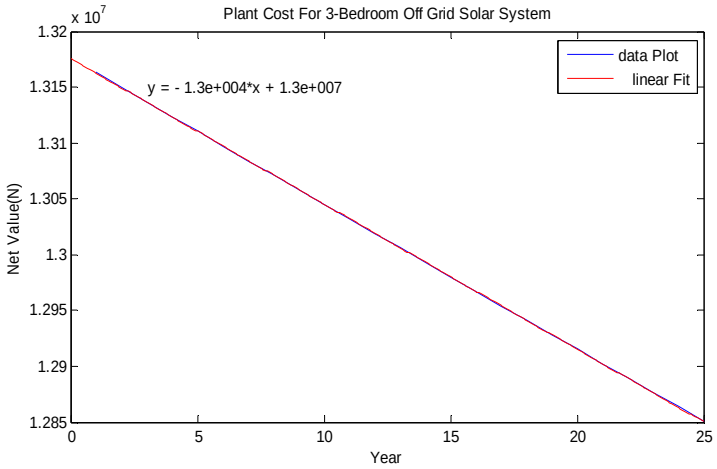

Figure 8: Plant cost for 3-bedroom off grid solar system

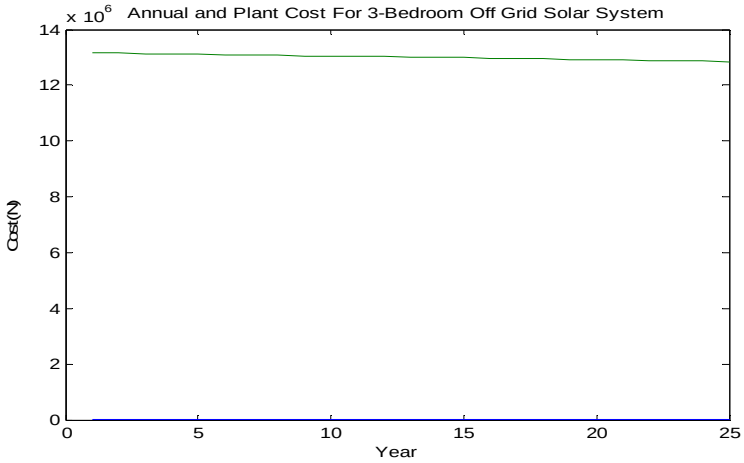

Figure 9: Annual and plant costs for 3-bedroom off grid solar system

2.3.3.2 Pollution Cost Analysis For The 3-Bedroom Flat

A combined cycle gas turbine (CCGT) emits 191.1 Kg/MWh of CO_2, 1.55 g/MWh of SO_2 and 31 g/MWh of NO_X. Therefore generating power from solar energy 3-bedroom flat would save the environment, in comparison to CCGT:
For 3-bedroom grid tie with load estimate of 62753 Wh = 0.062753MWh,

(i) 0,062753 x 191Kg of CO_2 = 11.985823 Kg daily
Therefore, for using this system for 1 year, the environment would be saved:
11.985823Kg x 365 = 4374,8254Kg of CO_2 in comparison to a CCGT plant.
For a 25 year this system would save environmental pollution due to CO_2 produced by CCGT plant to the tune of : 4374.8254 x 25kg of CO_2 = 109,370.64 Kg of CO_2

(ii) 0.062753 x 1.55 g/MWh of SO_2 = 0.9726715g of SO_2 daily
Therefore for using the system for 1 year the environment is saved of:
0.9726715g x 365 = 355.0251g of SO_2.
For a 25 year period which is the conservative life span of a solar system, this system would save the environment of SO_2 pollution to the tune of 25 x 355.0251 g of SO_2 = 8875.6275g or 8.88 Kg of SO_2 pollution in comparison to a CCGT plant.

(iii) 0.062753 x 31g of NOx daily = 19.45343g of NOx in comparison to a CCGT plant producing the same amount of power. This is equivalent to:
19.45343 g x 365 = 7100.502 g a year.
For a 25year period the amount of NOx = 25 x 7100.502 g = 177512.55 g = 177.51 Kg

3.0 Discussion

The solar system estimate for Benin City for a 3-bedroom flat for grid tie system, grid tie with battery backup and off-grid were respectively **₦11,099,068.00**, **₦13,563,830.00** and **₦13,176,312.00.** For a 3-bedroom flat implementation the environment would be saved gree house gas (GHG) emissions equivalent to 4374,8254Kg of CO_2, 355.0251g of SO_2 and 7100.502 g of NOx a year for grid tie, 4374,8254Kg of CO_2, 355.0251g of SO_2 and 7100.502 g of NOx a year for grid tie with battery backup, and 4374,8254Kg of CO_2 , 355.0251g of SO_2 and 7100.502 g of NOx a year, in comparison to a CCGT plant respectively.

Using Net Metering for the gird tie and grid tie with battery backup, for 3-bedroom flat implementation, ₦2.700 per month would be earned for 22.5kWh excess power for ₦4/kWh power pricing. There is no Net Metering for off grid system implementations. The plots of Figures 1– 9 give the pictorial representation for cost implication for implementing and running a solar system for a 3-bedroom off grid solar system in Benin City for a 25-year period. It is obvious from the plots that though the initial system cost is high, once implemented the running cost would be significantly minimal.

4.0 Conclusion

Solar system design using photovoltaic was carried out for a 3-bedrroom flat for Benin City environment for the three implementation platforms and the cost analysis was carried out. The analysis showed minimal running cost for solar systems as well as huge environmental benefit. The only seeming drawback was the high initial cost. However this seeming drawback becomes deflated when it is understood that solar system implementations using photovoltaic can be carried out in phases.

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