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Solar Power System Source Versus Generator/PHCN Energy Supply Source for a 152-Unit Housing Estate in Warri, Nigeria.

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Abstract

This work focused on investigation of the efficacy of solar system source in comparison to the generator/PHCN source commonly employed in Nigeria. The investigation involved a 152-unit housing estate in Warri, Delta state.

The electrical load estimate for the estate was made, used to size and cost system components and then cost the solar system. The load estimate was also used to size and cost the generator for the Generator/PHCN option. The load estimate was further used to determine the cost of using power supplied from PHCN to the estate. It was assumed that the power supply to the estate from PHCN was an average of 14 Hours a day while the remaining 10 hours had power supplied from the generator.

The cost analysis for the two alternatives showed that the solar system required at least N 2,343,714,496:00 to supply power to the estate for a 25 year period while the generator/PHCN alternative required N 2,954,940,424.00. Thus, for long term power solutions in Nigeria where the generator/PHCN is almost always employed to solve power supply challenges, the solar power system option should be considered.

1.0 Introduction

The electricity industry in Nigeria is supposed to have come of age. However, the power generation capacity over the years has continued to be embarrassingly grossly inadequate with the total installed generation capacity standing at 6656.40MW as at the end of 2006. [1,2,3]

One of the major reasons for the poor power supply situation in Nigeria is the overall capacity and state of the power generation stations in Nigeria. In a bid to improve on the nation's electricity generating capacity, the Federal Government in May, 2007 approved the building of five power stations across the country located at Papalanto (Ogun State), Omotosho (Ondo State), Ughelli (Delta State), Ajaokuta (Kogi State), and Alaoji in Aba, Abia State, [4,5,6] aimed at increasing the nation's generation capacity to a target level of 10,000 megawatts by December, 2007.

Despite these efforts, the power generation and supply in Nigeria has remained epileptic due mainly to poor power generation capacity. The result of this state of affairs is that the utility company resorts to load shedding in a bid to service the above-generation power demand, thereby leaving most areas without electricity supply for most hours of the day.

Consequently, consumers resort to buying and employing generators as backup supply source for the periods of supply outages.

The goal of this work was to make a comparative cost analysis of this generator/PHCN hybrid supply alternative and an equivalent solar system to determine which alternative is more cost effective. This was necessitated by the skepticism and reluctance of most consumers to consider the solar system alternative because of its perceived exorbitant cost implication.

1.0 Methodology

The investigated used a one hundred and fifty two units(six 5-bedroom flats, twenty-four 4-bedroom flats, thirty-six 3-bedroom flats fifty-two 2-bedroom flats and thirty-six 1-bedroom apartments) housing estate in Warri as a case study. An electrical load estimate was made for the estate and used to design a solar system that could meet the electrical power needs of the estate and a cost analysis was made for a conservative 25-year life span of a solar system and the same load estimate was used to make a cost analysis for the generator/PHCN supply.

The electrical load estimate was obtained as shown in Tables 1(a) - (e) and the sunshine hour data for Warri is shown in Table 2 [7]. Table 1 was obtained from the adapted standard electrical load estimate for a 5-bedroom duplex [8, 9], 4-bedroom flat, 3-bedroom flat [8, 9], 2-bedroom flat [10] and 1-bedroom apartment. The electrical load estimate for each unit

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type was multiplied by the total number for the unit type in the estate to generate the total load estimate for the unit type. For instance, for 1-bedroom, the total load estimate was obtained from
Total load estimate for 1-bedroom = 30849 x 36 =1110564
Table 1: Electrical load estimate for 152-units (6 x5-bedroom flats, 24 x 4-bedroom flats, 36 x 3-bedroom flats, 52 x 2-bedroom flats and 36 x 1-bedroom apartments) housing estate adapted.

Table 1a : Daily Electrical load requirement for 5-bedroom Duplex with 2-Room Boy's Quarter

S/N	**Electrical device**	**Device watts**	**Quan tity**	**Total device power(Watts)**	**Hours of daily use (Hours)**	**Average watt-hours per day (WattsHours)**
1	Ceiling fans	50	9	450	12	5400
2	4ft Flourescents	36	10	360	12	4320
3	2f Flourescents	19	22	418	2	836
4	Colour TV Flat screen	35	7	245	7	1715
5	Cable Decoder	30	1	30	12	360
6	CD Player	10	7	70	6	420
7	Laptops	75	3	225	4	900
8	Iron	1000	2	2000	0.5	1000
9	Printer	150	1	150	1	150
10	Satellite Dish	30	1	30	12	360
11	Incandescent bulbs	36	4	144	10	1440
12	Toaster	1500	1	1500	0.33	495
13	Micro-wave	1500	1	1500	0.33	495
14	Air conditioner	1000	7	7000	10	70000
15	Refrigerators	1500	2	3000	24	72000
16	Blender	400	1	400	0.33	132
	TOTAL			17522		**160,023**

Table 1b : Daily Electrical load requirement for 4-bedroom Flat

S/N	**Electrical device**	**Device watts**	**Quan tity**	**Total device power(Watts)**	**Hours of daily use (Hours)**	**Average watt-hours per day (WattsHours)**
1	Ceiling fans	50	5	250	12	3000
2	4ft Flourescents	36	8	288	12	3456
3	2f Flourescents	19	18	342	2	684
4	Colour TV Flat screen	35	5	175	7	1225
5	Cable Decoder	30	1	30	12	360
6	CD Player	10	5	50	6	300
7	Laptops	75	3	225	4	900
8	Iron	1000	2	2000	0.5	1000
9	Printer	150	1	150	1	150
10	Satellite Dish	30	1	30	12	360
11	Incandescent bulbs	36	4	144	10	1440
12	Toaster	1500	1	1500	0.33	495
13	Micro-wave	1500	1	1500	0.33	495
14	Air conditioner	1000	5	5000	10	50000
15	Refrigerators	1500	1	1500	24	36000
16	Blender	400	1	400	0.33	132
	TOTAL			13584		99997

Table 1c: 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**

Table 1d: Daily Electrical load requirement for 2-bedroom flat

S/N	Electrical device	Device watts	Quantity	Total device power(Watts)	Hours of daily use	Average watt-hours per day
1	Ceiling fans	50	4	20	12	2400
2	4ft Flourescents	36	6	216	12	2592
3	2ft Flourescents	19	7	133	2	266
4	Colour TV Flat screen	35	3	105	10	1050
5	Cable Decoder	30	1	30	10	300
6	CD Player	10	1	10	6	60
7	Laptop	75	1	75	4	300
8	Printer	150	1	150	1	150
9	Satellite Dish	30	1	30	10	300
10	Incandescent bulbs	36	2	72	6	432
11	Toaster	1500	1	1500	0.33	495
12	Micro-wave	1500	1	1500	0.5	750
13	Pressing iron	1000	1	1000	0.5	500
14	Air conditioner	1000	3	3000	4	12000
15	14 cubic feet fridge/freezer	1500	1	1500	12	18000
16	Blender	400	1	400	0.33	132
	TOTAL			**9,741**		**39,727**

Table 1e: Daily Electrical load requirement for 1-bedroom

S/N	Electrical device	Device watts	Quantity	Total device power(Watts)	Hours of daily use	Average watt-hours per day
1	Ceiling fans	50	2	100	12	1200
2	4ft Flourescents	36	4	144	12	1728
3	2ft Flourescents	19	4	76	2	152
4	Colour TV Flat screen	35	1	35	10	350

5	Cable Decoder	30	1	30	10	300
6	CD Player	10	1	10	6	60
7	Laptop	75	1	75	4	300
8	Printer	150	1	150	1	150
9	Satellite Dish	30	1	30	10	300
10	Incandescent bulbs	36	2	72	6	432
11	Toaster	1500	1	1500	0.33	495
12	Micro-wave	1500	1	1500	0.5	750
13	Pressing iron	1000	1	1000	0.5	500
14	Air conditioner	1000	1	1000	6	6000
15	14 cubic feet fridge/freezer	1500	1	1500	12	18000
16	Blender	400	1	400	0.33	132
	TOTAL			7,622		30849

$Total\ Electrical\ Load\ estimate\ for\ the\ Housing\ Estate = 160023\ \times 6 + 99997\ \times 24 + 62753\ \times 36 + 39727\ \times 52 + 30849\ \times 36 = 8795542$ WattsHour

Table 2: Average sunshine in Warri between 1996 and 2007

SUNSHINE HOURS FOR WARRI												
MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
AVG SUNSHINE (HOURS)	4.5	4.6	4.4	4.8	4.9	3.7	2.2	2.4	2.5	4.2	5.6	5.3

2.1 Solar Component Sizing

The design and implementation of a solar requires some well considered steps. These include:

1.1.1 Determining the amount of PV needed.

An electrical load estimate is made. This involves selecting a panel watt rating intended for use and using the sunshine hour data for the locality where the system is to be implemented, the number of panels required is obtained from: [10]

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

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
1.2 = Factor that gives additional 20% number of panels to cover for conversion losses and periods of prolonged cloud cover.
For worst case design, average sunshine was taken as 2.2Hours.

$$Number\ of\ Panels = \frac{8795542\ \times 1.2}{270\ \times 2.2} = \ 17768.8\ \ 270 - W\ panels$$

2.1.2 Sizing the battery bank: [10]

The size of the battery bank is evaluated from

$$No.\,of\ \ batteries = \frac{LE \times 2}{V_B \times AH_B} \qquad (2)$$

Where LE = Electrical load estimate for intended application, V_B = Battery Voltage (12V, 24V or 48V), AH_B = Battery Amp-Hour rating, 2 = Factor used to design for 50% depth-of –Discharge

$Battery\ Bank\ size\ in\ AH = \frac{2 \times 8795542}{48 \times 200} = \ 1832.4 \quad 200AH\ Batteries$

2.1.3 Selecting an inverter.

To determine the size of the inverter needed, add up the power requirements of all of the loads that are intended to run simultaneously. The total inverter size was obtained by taking inverter sizes [12] for 5-bedroom duplex, 4- 3- and 2- bedroom flats and 1-bedroom and multiplying them by their respective number of units in the estimate thus:

$$Total\ Inverter\ size = 15\ \times 6 + 12.5\ \times 24 + 7.5\ \times 36 + 5\ \times 52 + 5\ \times 36 = 90 + \ 300 + 270 + 260 + 180$$
$$= 1100\ KVA$$

IV) Selecting a Charge Controller.

A charge controller efficiently controls the battery charging voltage and current, and keeps the batteries from overcharging. Therefore the charge controller should be sized according to the current requirement of the system.

2.1.4 Capacity Of Charge Controller

ASSUMPTION: Each solar panel produces 8.7 Amps

$$Total\ Current\ generated = 17768.8\ \times 8.7\ Amps = \ 154588.56\ Amps\ \approx 1546\ \ 100 - Amps$$

2.1.5 Estimating The Cost Of The System

The estimated cost of the solar system over a 25-year period is shown in Table 3.

Table 3: Solar system Cost Estimate for the housing estate.

S/N	ITEM	UNIT COST (N)	QTY	TOTAL COST (N)
1	SOLAR PANELS	101,472.00	17768	1,802,954,496:00
2	BATTERIES	60,000:00	1832	109,920,000:00
3	CHARGE CONTROLLER	100,000:00	1546	154,600,000:00
4	INVERTER(100KVA)	4,400,000:00	11	48,400,000:00
5	REPLACEMENT(BATTERY EVERY 8 YEARS)	109,920,000:00	2	219,840,000:00
6	MISCELLANEOUS	LOT		8,000,000:00
	TOTAL			**2,343,714,496:00**

2.2 Generator/PHCN Combination Over A Period Of 25 Years

The cost of buying and running generator in conjunction with public utility supply over a 25 year period is carried out. It is assumed that the supply from the public utility company averaged over time is 14 hours daily with the generator supplying power for the other 10 hours of the day.

2.2.1 Cost For Diesel Generator

$$\boldsymbol{Load\ Estimate = 2101890\ Watts}$$

$$Generator\ Capacity = \left(\frac{Load\ Estimate}{1000\ \times Power\ Factor} KVA\right)$$
$$= \frac{1615056}{1000\ \times 0.9}\ = 1794.5\ KVA$$

NOTE: Most Load appliances on start demand an extra power supply. Therefore additional 205.5.6KVA was made to take care of this. Therefore,

$Generator\ Capacity = 2{,}000KVA$

1KVA of Diesel generator is \$100.

$2000KVA\ of\ Diesel\ Generator\ = \$100\ \times 2000 = \$200000$
$= 200000\ \times N151 = N30{,}200{,}000{:}\ 00$

For 10-Hour daily usage of the generator, it will most likely have to be scrapped every five (5) years for optimal power supply. Therefore for a twenty-five (25) year period, the generator will have to be scrapped four (4) times.

Diesel consumption for every 5hrs of 500KVA = 200 litres but 4 pieces of 500KVA sums up to 2000KVA.Therefore,

$Total\ Diesel\ Consumption\ per\ day = 200\ \times 4\ \times 2 = 1600$

Assuming a fixed diesel price of N110 per litre,

$Cost\ per\ day\ for\ diesel\ consumption = N110\ \times 1600 = N176{,}000$

$Cost\ per\ per\ year\ for\ diesel\ consumption = N176{,}000\ \times 365 = N64{,}240{,}000$

Assuming that the scrap value for each 500KVA generator is N2,000,000, the total scrap value every five years would be:

$Generator\ Scrap\ Value = N2{,}000{,}000\ \times 4 = N8{,}000{,}000$

Assuming that the price of diesel will remain stable over the 25 year period, the net annual cost for running the generator over a 25-year period is given in Table 4.

Table 4: Cost Analysis for running generator supply for the housing estate for 25 years

YR	GENERATOR UNIT COST (N) (2500KVA)	DIESEL COST (N)	TOTAL YEARLY COST (N)	SCRAP VALUE (N)	NET YEARLY CUMULATIVE COST (N)
1	30,200,000:00	64,240,000:00	94,440,000:00	0	94,440,000:00
2		64,240,000:00	64,240,000:00	0	158,680,000:00
3		64,240,000:00	64,240,000:00	0	222,920,000:00
4		64,240,000:00	64,240,000:00	0	287,160,000:00
5		64,240,000:00	64,240,000:00	8,000,000:00	343,400,000:00
6	30,200,000:00	64,240,000:00	94,440,000:00	0	437,840,000:00
7		64,240,000:00	64,240,000:00	0	502,080,000:00
8		64,240,000:00	64,240,000:00	0	566,320,000:00
9		64,240,000:00	64,240,000:00	0	630,560,000:00
10		64,240,000:00	64,240,000:00	8,000,000:00	686,800,000:00
11	30,200,000:00	64,240,000:00	94,440,000:00	0	781,240,000:00
12		64,240,000:00	64,240,000:00	0	845,480,000:00
13		64,240,000:00	64,240,000:00	0	909,720,000:00
14		64,240,000:00	64,240,000:00	0	973,960,000:00
15		64,240,000:00	64,240,000:00	8,000,000:00	1,030,200,000:00
16	30,200,000:00	64,240,000:00	94,440,000:00	0	1,124,640,000:00
17		64,240,000:00	64,240,000:00	0	1,188,880,000:00
18		64,240,000:00	64,240,000:00	0	1,253,120,000:00
19		64,240,000:00	64,240,000:00	0	1,317,360,000:00
20		64,240,000:00	64,240,000:00	8,000,000:00	1,373,600,000:00
21	30,200,000:00	64,240,000:00	94,440,000:00	0	1,468,040,000:00
22		64,240,000:00	64,240,000:00	0	1532,280,000:00
23		64,240,000:00	64,240,000:00	0	1,596,520,000:00
24		64,240,000:00	64,240,000:00	0	1,660,760,000:00
25		64,240,000:00	64,240,000:00	8,000,000:00	1,717,000,000:00

2.2.2 Billing cost of PHCN for the estate assuming PHCN supplies power 14 Hours a day while the remaining 10 Hours come from generators.

Table 5 gives PHCN billing currently in use.This rate was used for estimated electricity cost for the estate for 25 years.

Table 5: PHCN billing rates

S/N	CONNECTION TYPE	BILLING RATE (N)
1	Single phase Residential	**4.00**
2	Single phase Commercial	**6.50**
3	Three phase Residential	**6.00**
4	Three phase Commercial	**8.50**
5	Single phase for welder and the like	**6.50**
6	Three phase for welder and the like	**8.50**

Assuming that each housing unit in the estate is supplied from a three phase PHCN source, the three phase residential billing rate was used.

$$Bill\ for\ a\ \ year\ period =$$
$$((Total\ Daily\ Watts)/1000)KWh \times 14\ Hours\ \times 365\ days\ \times 3 - phase\ residential\ billing\ rate$$
$$Bill\ for\ a\ year\ period = 1615.056 \times 14\ \times 365\ \times 6\ = N49{,}517{,}616.96$$

Using this bill and assuming that the billing would remain constant over the 25 year period would produce the yearly cumulative bill shown in Table 6.

Table 6.

Year	Yearly Bill (N)	Yearly Cumulative Bill (N)
1	49,517,616.96	49,517,616.96
2	49,517,616.96	99,035,233.92
3	49,517,616.96	148,552,850.90
4	49,517,616.96	198,070,467.80
5	49,517,616.96	247,588,084.80
6	49,517,616.96	297,105,701.80
7	49,517,616.96	346,623,318.70
8	49,517,616.96	396,140,935.70
9	49,517,616.96	445,658,552.60
10	49,517,616.96	495,176,169.60
11	49,517,616.96	544,693,786.60
12	49,517,616.96	594,211,403.50
13	49,517,616.96	643,729,020.50
14	49,517,616.96	693,246,637.40
15	49,517,616.96	742,764,254.40
16	49,517,616.96	792,281,871.40
17	49,517,616.96	841,799,488.30
18	49,517,616.96	891,317,105.30
19	49,517,616.96	940,834,722.20
20	49,517,616.96	990,352,339.20
21	49,517,616.96	1,039,869,956:00
22	49,517,616.96	1,089,387,573:00
23	49,517,616.96	1,138,905,190:00
24	49,517,616.96	1,188,422,807:00
25	49,517,616.96	1,237,940,424:00

The total annual cost of running the PHCN/Generator hybrid source is given in Table 7.

Table 7: Total Annual cost for the PHCN/Generator Hybrid source

Year	GENERATOR COST (N)	Yearly Cumulative Bill (N)	NET PHCN/GEN CUMULATIVE COST
1	94,440,000:00	49,517,616.96	143,957,616.96
2	158,680,000:00	99,035,233.92	257,715,233.92
3	222,920,000:00	148,552,850.90	371,472,850.90
4	287,160,000:00	198,070,467.80	485,230,467.80
5	343,400,000:00	247,588,084.80	590,988,084.80

6	437,840,000:00	297,105,701.80	734,945,701.80
7	502,080,000:00	346,623,318.70	848,703,318.70
8	566,320,000:00	396,140,935.70	962,460,935.70
9	630,560,000:00	445,658,552.60	1,076,218,552.60
10	686,800,000:00	495,176,169.60	1,181,976,169.60
11	781,240,000:00	544,693,786.60	1,325,933,786.60
12	845,480,000:00	594,211,403.50	1,439,691,403.50
13	909,720,000:00	643,729,020.50	1,553,449,020.50
14	973,960,000:00	693,246,637.40	1,667,206,637.40
15	1,030,200,000:00	742,764,254.40	1,772,964,254.40
16	1,124,640,000:00	792,281,871.40	1,916,921,871.40
17	1,188,880,000:00	841,799,488.30	2,030,679,488.30
18	1,253,120,000:00	891,317,105.30	2,144,437,105.30
19	1,317,360,000:00	940,834,722.20	2,258,194,722.20
20	1,373,600,000:00	990,352,339.20	2,363,952,339.20
21	1,468,040,000:00	1,039,869,956:00	2,507,909,956.00
22	1532,280,000:00	1,089,387,573:00	2,621,667,573.00
23	1,596,520,000:00	1,138,905,190:00	2,735,425,190.00
24	1,660,760,000:00	1,188,422,807:00	2,849,182,807.00
25	1,717,000,000:00	1,237,940,424:00	2,954,940,424.00

The assumption that the billing system would remain constant over the period is obviously not likely. This means that this figure is the minimum.
Table 8 therefore gives the summary of the solar system source versus the PHCN/Generator system source.
The total cost of running the PHCN/Generator hybrid system for 25 years is obtained as follows.

$$TOTAL\ PHCN - GEN\ COST = Total\ Cost\ for\ PHCN + Generator\ source$$
$$= N1{,}717{,}000{,}000{:}\,00 + N1{,}237{,}940{,}424{:}\,00$$
$$= \text{N}2{,}954{,}940{,}424.00$$

Table 8: Comparative Cost for solar system vs generator/PHCN system

Components	**Solar System (N)**	**PHCN/Generator (N)**
System Cost	**2,343,714,496:00**	**2,954,940,424.00**
Maintenance	Minimal	Often and expensive

The Excel plot of solar system versus PHCN/Generator annual cumulative costs is shown in Figure 1.

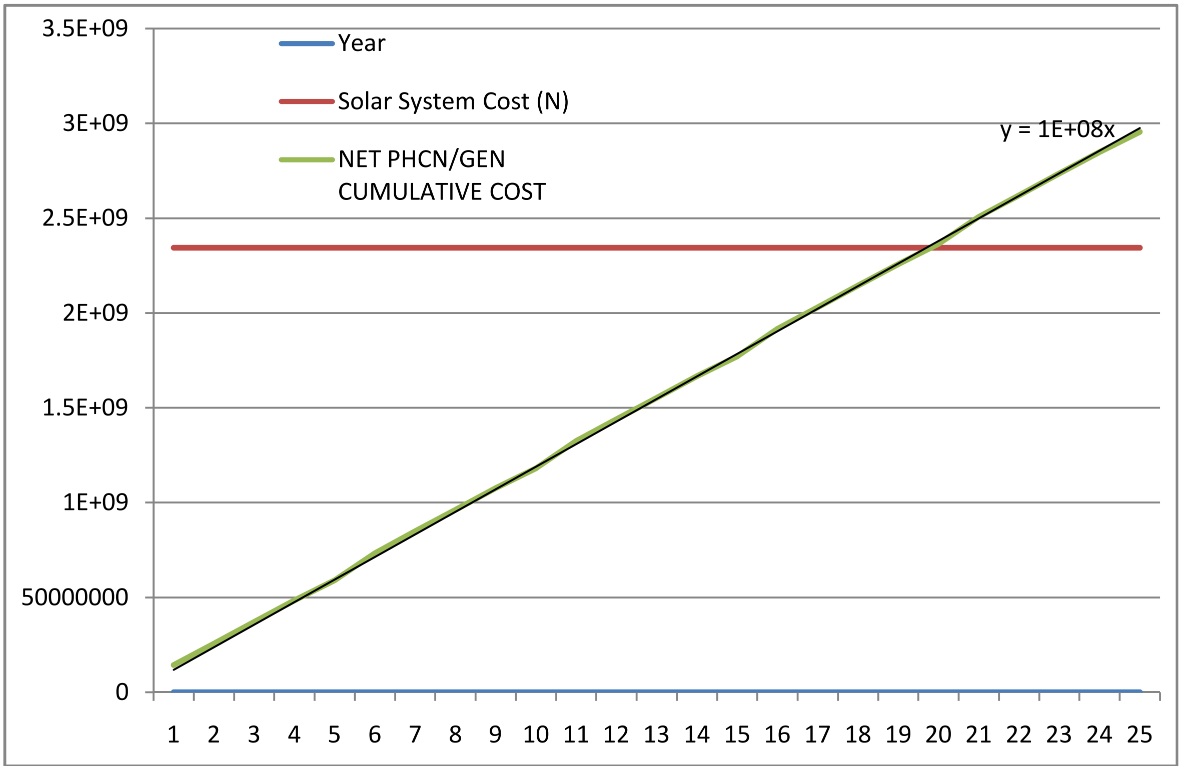

Figure 1: Solar system versus PHCN/Generator hybrid system annual cumulative costs

2.0 Discussion

Table 3 shows the breakdown in cost of setting up a solar system for the housing estate while tables 4 shows the annual cost and net annual cost of running generator for a 25 year period while Table 6 shows the annual billing cost and net annual billing cost for PHCN supply. Table 7 shows the cumulative annual cost of running the PHCN/Generator hybrid system for period under consideration. Table 8 shows the summary of the cost estimate of building and maintaining a solar power system for the 152 housing estate in comparison to the cost incurred by using generator/PHCN supply source.

Figure 1 shows the plot of the solar system cost versus net annual cost for the PHCN/Generator source. The breakdown of the costs would reveal that though the initial cost of the solar system is far more than that for acquiring a generating set and pairing its use with the supply from the public power utility supply as can be seen on Figure 1, over a long period of time the cost of deploying the generator/PHCN system far outweighs that of the solar system. In the case under consideration, the cost of the PHCN/Generator source levels up with that for the solar system towards the end of the 19^{th} year and by the end of the 20^{th} year exceeds it. By the end of the 25 year period cost of the PHCN/Generator source far outweighs that for the solar system

It is noteworthy here that though the initial cost of implementing a solar system is quite high (which could actually be a disincentive), the maintenance cost is very minimal while maintenance and fuel costs for the generator make the generator/PHCN option unattractive for long term application.

4.0 Conclusion

This work showed that for the 152 unit housing estate, it was cheaper to implement a solar system power solution than the combination of a 10-hour generator/14-hour PHCN power supply alternative. It proved that though the initial installation cost for the solar system was quite high compared to the initial cost of the Generator/PHCN alternative, the long term (exceeding 20 years in the case and circumstances considered in this work), the cost analysis would prove the solar system option to be considerably cheaper.

When this long term cost effectiveness of solar systems is added to the no-pollution and health (no noise) advantage of solar systems, the solar system option far outweighs the generator/PHCN option in cost-effectiveness. A solar system/PHCN option could however be implemented to harness the benefits of both approaches.

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