COST BENEFIT ANALYSIS OF SOLAR INSTALLATION IN AN ACADEMIC ENVIRONMENT

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Abstract

Solar system's penetration is increasing globally as result of advancement in technology. In developing world such as Nigeria, the inadequate power supply has forced many to adopt standby generators as solution with its attendant noise pollution. Thus, there is a draw back in the delivery of services in many academic Institutions as a result of unstable power supply. The major barrier to wider acceptance of solar technology is initial cost. Recently, at the Department of Electrical Engineering, Federal Polytechnic Ilaro, the installation of 4kVA solar system was carried out to solve the perennial power problem. This paper assesses the impact of solar installation in such a typical academic environment. The cost benefits of both systems were compared. The cost benefit analysis (CBA) was carried out for a period of 20 years. The results show that the total expenditure on solar inverter system and generator will be 11.5 million naira and 32.7 million naira respectively. This shows that a sum of 21.2 million would be saved over the period of 20 years. Also, the incessant noise pollution and CO_2 have been effectively eliminated. The result shows that investment in solar is worthwhile both for economic and environmental factors. Efforts should therefore be geared towards replacing standby generators with alternative sources such as renewable energies like solar system.

Keywords: Solar system, Gasoline generator, power supply

Introduction

There is drawback in the delivery of services in many academic Institutions as a result of unstable power supply. Also, productivity and conduct of research are hampered due to lack of power supply. Therefore, the need for steady power supply for fair competitiveness among research institution globally is inevitable (Ogunyemi et al, 2021). Recently, an alternative energy source to solve the problem was implemented in the Department of Electrical Electronic Engineering, The Federal Polytechnic Ilaro. It involved design and installation of 4kVA solar inverter system. Inverters are the core component of grid-connected solar energy systems converting low (DC) voltage, high current signals from photovoltaic (PV) panels into a voltage that is compatible with the utility grid. Regular inspection and monitoring of inverter are very important since changes to voltage and frequency may occur that will affect the performance of the inverter (Adetona et al, 2020).

Renewable energy solutions are penetrating electric power system globally as they are widely deployed at cell sites with diesel generators as a backup. The solar cell works in several steps by converting the sunlight hitting the solar panel to electrical energy through semiconductor materials of the panel (James, 2009). Industrial cells are made of monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, copper indium selenide/sulfide or Gas-based multijunction (Conibeer & Willoughby, 2014).

The major environmental impact of diesel generators is constant CO2 emissions during service life. The CO2 emission from one litre of diesel fuel is 2.68kg which translate to many metric tons of CO2 emission annually. Complete replacement of these with renewable energy as a primary energy resource will lead to enormous carbon savings (Madden, 2011).

Another environmental effect of generator is noise. Noise is a human caused acoustic contaminant, aural litter or audible trash. It is an unusual pollutant unlike other types of pollutant because it is not visible; it is a pollutant impose directly on neighbouring environment. The recognition of noise as a serious health hazard as opposed to a nuisance is a recent development and the health effects of the hazardous noise exposure are now considered to be an increasingly important public health problem. According to the Centre of Disease Control in USA, about 22million workers are exposed to potentially damaging noise work at each year (ISHN, 2016). In Nigeria, more than half of the country's population has no access to electricity, and even those who do cannot guarantee having power every day (Akinbulire and Oluseyi, 2012). Hence, majority resulted in self-generation by using standby generators.

Generally, different levels of noise are obtained in different working environments. The variety of noise polluting devices and activities is large and seems to be growing on a daily basis, although there is no consensus about what items are useful and desirable or noise polluting and unnecessary (Muhammad et al, 2008). In most urban areas of the third or developing countries of the world, there are lots of noise pollutants which include noise from exhaust cars, industrial as well as home generating plants (Vijayalakshmi, 2003). The use of electricity generating plant with its attendant noise pollution on the environment and human health has been on the increase because of the poor power supply. The sound emanating from these generators constitutes noise and nuisance mostly at night hours when people have retired to rest after a hectic activity at workplaces. Table 1 shows the permissible noise levels specified by Tamil Nadu Pollution Control Board (TNPCB).

Table 1: Permissible noise levels

Zone	Daytime Permissible noise level (dB)	Night Permissible noise level (dB)
Industrial Zone	75	70
Commercial Zone	65	55
Residential Zone	55	45
Silent Zone	50	40

Source: (TNPCB)

1 METHODOLOGY

In this paper, the design of 4kVA solar installation was first presented and then followed by cost benefit analysis

1.1 Load calculation

The loads to be powered by the solar system were computed. Table 2 shows the various load and energy consumption of various appliances installed in the offices of the Department of Electrical and Electronics Engineering of the Federal Polytechnic Ilaro.

Table 2: Load audit of the area of study.

S/N	Load	Quantity	Wattage	Total Power (W)	Hours Used Daily (Hr/day)	Watt Hour (Whr/day)
1	Ceiling fan	11	75	825	8	6600
2	Lighting Point (LED)	18	25	450	8	3600
3	Desktop	3	100	300	5	1500
4	Plasma TV	1	95	95	5	475
5	Mini Fridge	1	110	110	5	550
6	Printer	1	50	50	4	200
7	Photocopier	1	550	550	5	2700
8	Laptop	9	90	810	6	4860
	TOTAL			3190		20485

2.1.1 Estimation of the solar inverter

Total power of the load = 3.190kW

Taking losses into consideration, inverter should be greater than 20-25% of the total load

Size of the inverter = $= (\frac{25}{100}\ X\ 3.190) + 3.190$ = 3.98W

Therefore, a solar inverter rating of 4KVA is used. The inverter has a voltage rating of 48V.

Fig 1: Pictorial view of 4KVA inverter

2.1.2 Calculation of required number of battery

Energy in Wh = 20485Wh; Power is 3190W and system voltage is 48V

With 1 day autonomy, Battery bank capacity $= \frac{\text{Energy in Wh}}{System\ Voltage}$

$$= \frac{20485}{48} = 427\text{AH}$$

Considering 200AH capacity battery at 48V

$=\frac{427\text{AH}}{200AH}$ = 2.1

Two (2) units of 200AH, 48V are used.

Fig 2: Pictorial view of 200AH (2units), 48V battery

2.1.3 PV panel calculation

Solar panel capacity = Battery bank capacity x $\frac{System\ Voltage}{Hours\ of\ sunlight}$

Battery bank capacity = 427Ah and assuming sunlight of 7hours;

$= \frac{427□□\ □\ 48□}{7□}$ = 2928W

The number of solar panel = $\frac{□□l□□\ □□□□□\ □□□□□□□□□}{□□□□□□□\ □□□□□\ □□□□□□}$

Selecting 250W solar panel; the number of solar panel = $\frac{2928}{250}$ = 11.7 units

Therefore, 12 units of 250W at 36V solar panel are needed to charge the required battery capacity.

Fig 3: Pictorial view of solar panels (12units at 250W, 36V)

2.1.4 Estimation of charge controller

Number of Solar panels = 12 each at 250W, 36V

Solar Panel Connection is a string of four in series and the four strings are connected in parallel.

Therefore, a Panel String = 4 * 36V = 144V @250W

Total Solar panel array Power in parallel = 4 * 250W = 1000W @ 144V

$$\text{Size of charge controller} = \frac{\text{Total Solar Panel Array Power in parallel}}{\text{System voltage}}$$

$$= \frac{1000}{48} = 20.8\text{Amps}$$

30A charge controller is used.

Fig 4: Pictorial view of 30A charge controller

2.1.5 Estimation of circuit breaker

Circuit current (total current from solar panel) = 30Amps

Circuit breaker size = 125% of the circuit current

= 1.25 X 30amps =37.5Amps

Since 37.5A circuit breaker is not available in the market, it is advisable to use 63Amps rating of circuit breaker in other to reduce over-current caused by surge which may yield to overheating of the circuit breaker.

2.1.6 Size of cable

$6mm^2$ cables are used to connect the PV panels to the charging controller in order to safely carry the PV's output current. The cable used is stranded because of its large diameter so that voltage drop is reduced. Lastly the charge controller is connected to the battery as close as possible. Here the length of the cable is reduced and as a result, voltage drop is minimum.

1.2 Cost Comparison of a Gasoline Generator and Solar system

1.2.1 Solar system

Table 3 shows the projected cost analysis of a 4KVA solar system.

Table 3: Cost Analysis of 4KVA solar inverter.

Component	**Initial Capital (#)**	**Annualised Capital (#/yr)**	**Annualised Replacement (#/yr)**	**Annual Maint.&Labour (#/yr)**	
PV array	468,000	___	___	___	
Inverter	220,000	___	___	19,200	
Charge controller	92,000	12,000	___	12,000	
Battery	520,000	___	___	___	
Battery rack	16,000	___	___	___	
Solar panel rack	68,000	___	___	___	
Accessories	115,500	50,000	40,000	___	
Total	1,495,500	62,000	40,000	31,200	1,628,700

PV panels have a lifespan of 20 – 25 years

Lifespan of tubular battery is 4-5 years. If well maintained, their service year can be more.

Assuming 5 years life span for batteries; for 20 years, batteries will be replaced 4 times.

Applying net present value (NPV) to calculate the total cost for a period of 20years;

$$FV = PV\,(1 + i\,)^n \qquad (1)$$

Where FV = future value

PV = present value

i = interest rate

n = number of compounding periods

Let assumed an interest rate of 80% since batteries will be replaced every five years.

Total cost of batteries for 20 years period at 80% interest;

$$= 520000\,(1 + 0.8)^4 = \#5{,}458{,}752 \qquad (2)$$

If the system is well maintained, all other initial costs remain constant for the period of 20 years.

Adding cost of batteries for 20 years period to initial capital as obtained from table 3,

Overall cost =#5,458,752 + 468,000 + 220,000 + 92,000 + 16000 + 68000 + 115500 = #6438252

Total cost of annualized capital, annualized replacement and annualized maintenance and labour = #62000 + #40000 + #31200 = #133200

Total cost for 20 years at 20% increment;

$$= 133200\ (1 + 0.2)^{20} = \#5106568.31 \qquad (3)$$

Overall cost for a period of 20 years = #5106568.31+ #6438252= #11,544,820.31

Overall total cost if a solar system were to be used to power the department for 20 years will be #11,544,820.31

1.2.2 Gasoline generator

Table 4 shows the projected cost analysis of a 3.5KVA gasoline generator.

Table 4: Cost Analysis of a 3.5KVA Gasoline Generator.

Component	Initial Capital (#)	Annualised Capital (#/yr)	Annualised Replacement (#/yr)	Annual Maintainance & Labour (#/yr)	Annual Fuel (#/yr)
Generator	168,999	___	___	28,000	367,200
Engine Oil	2,500	60,000	56,575	___	___
Spark plug	___	10,000	8,760	___	___
Total	171,499	70,000	65,335	28,000	367,200

In the above table, the initial cost referred to here is the cost of purchase. The cost of a 3.5KVA generator (copper) goes between #160,880 to #168,999 (konga.com) and also the largest capital is spent on fueling which accrual to the above sum (#367,200) on a 6 liters of fuel per 8 hours running each day on a 5 days week. The annual maintenance and labour cost is the cost for the workmanship for a period of one year.

A gasoline generator can work about 2000 hours to 3000 hours before replacement (americasgenerator.com, 2019).

If the gasoline generator is operated for 8hours daily on 5-days week;

Weekly working hour = 5 X 8 = 40 hrs

If the generator is shut down for maintenance during holidays and assuming a period of 3 months for maintenance throughout the year;

Number of weeks for maintenance and repairs = $\frac{3\ \text{months}}{12\ \text{months}}$ x 52weeks = 13weeks

Yearly operating week = 52 – 13 = 39 weeks

Hours of operation in a year = 39 X 40 = 1560 hrs.

If the gasoline generator last about 2500 hours;

Life span = $\frac{2500\ \text{hrs}}{1560\ \text{hrs}}$ = 1.6 years (1year 7 months) if properly maintained.

For 20 years period, number of generator that will be bought = $\frac{20\ \text{yrs}}{1.6\ \text{yrs}}$ = 12.5

That is 13 gasoline generators will be used for a period of 20 years.

Applying net present value (NPV) to calculate the total cost for a period of 20years

$$FV = PV\ (1 + i\ )^n$$

Assuming an interest value of 25%; total cost of 13 gasoline generators and Engine oil for 19.2years (1.6X12) period will be

$$FV = 171499\ (1 + 0.25)^{19.2} = \#12443250.43 \qquad (4)$$

From the table, total annual cost = Annualised Capital + Annualised Replacement + Annual Maintainance & Labour + Annual Fuel = #70000 + #65335 + #28000 + #367200

Total annual cost = #530535 and for a period of 20 years;

$$\text{Total cost} = 530535\ (1 + 0.2)^{20} = \#20339438.58 \qquad (5)$$

Overall total cost if a gasoline were to be used to power the department for 20 years will be:

#12443250.43 + #20339438.58 = #32782689.01

RESULTS

Table 5 shows the PV output voltage, charging current and battery voltage for six day duration.

Table 5: Solar output results for the six days.

Time		7:00	9:00	11:00	13:00	15:00	17:00	19:00
PV voltage (V)	Day 1	14.9	*28.0*	57.8	71.3	70.0	53.5	12.5
	Day 2	14.1	24.8	52.7	71.3	70.2	52.7	12.8
	Day 3	13.9	28.0	58.9	70.8	69.3	50.4	13.4
	Day 4	11.9	28.0	57.4	71.5	69.0	51.2	12.9
	Day 5	12.2	28.0	57.8	71.3	70.0	53.2	13.1
	Day 6	14.9	28.0	57.8	71.3	70.0	53.2	12.1
Charging current (A)	Day 1	3.6	7.1	12.4	13.6	0.0	10.4	3.0
	Day 2	3.3	6.1	12.4	12.6	0.1	9.8	2.0
	Day 3	2.8	5.1	11.4	16.6	0.2	4.4	1.9
	Day 4	1.6	6.9	17.4	16.6	0.1	8.4	2.2
	Day 5	1.4	7.1	13.8	15.6	0.8	7.4	2.3
	Day 6	2.6	8.1	12.4	17.8	0.2	8.7	1.9
Battery voltage (V)	Day 1	48.2	48.8	49.7	53.5	55.6	53.1	54.5
	Day 2	50.23	50.6	52.7	53.3	55.6	53.6	54.6
	Day 3	49.5	49.8	50.2	16.6	55.6	54.7	51.1
	Day 4	49.2	50.7	52.1	54.6	55.5	52.8	50.5
	Day 5	48.7	49.2	50.1	52.6	56.7	50.1	52.4
	Day 6	48.9	50.2	52.1	52.6	56.8	53.2	55.5

The solar outputs for each day obtained in table 5 are plotted in a bar chart as shown in figure 5 to 10.

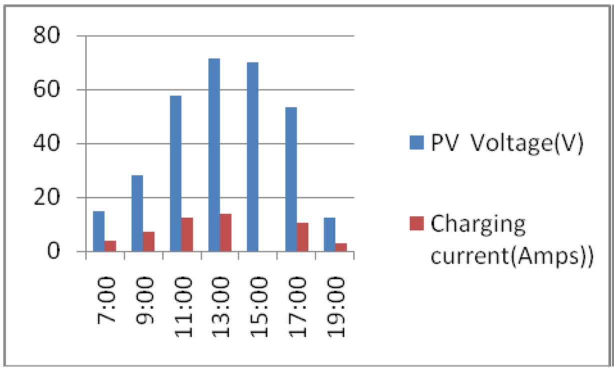

Fig 5: Day 1 solar outputs

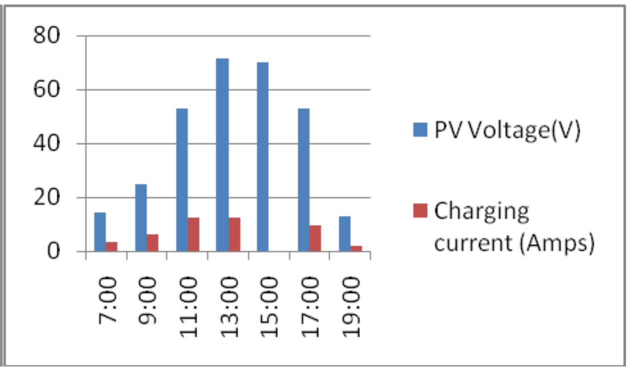

Fig 6: Day 2 solar outputs

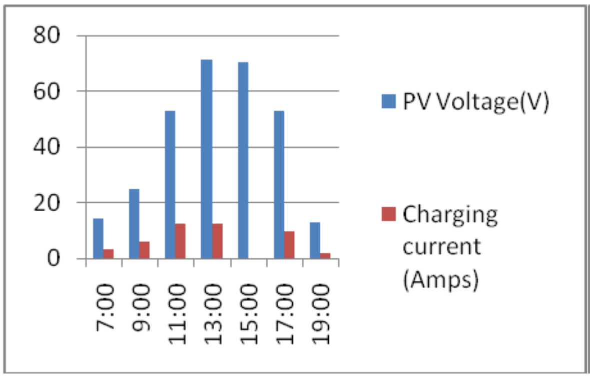

Fig 7: Day 3 solar outputs

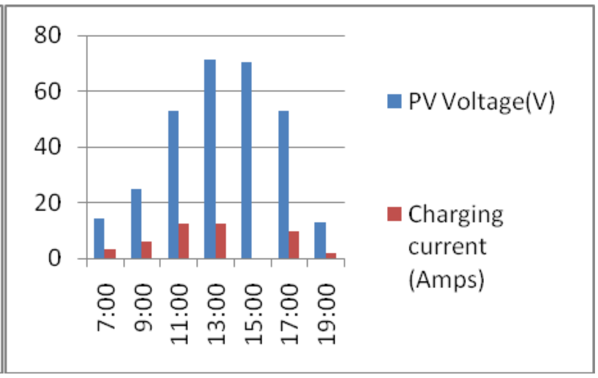

Fig 8: Day 4 solar outputs

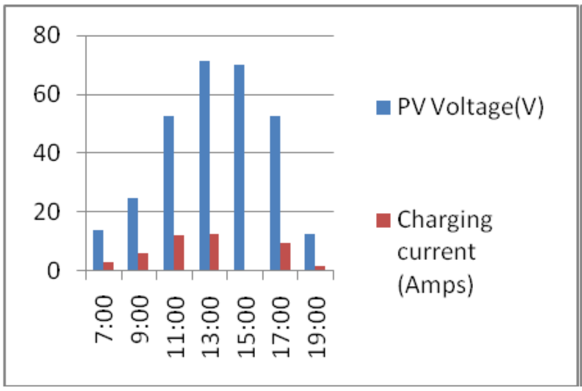

Fig 9: Day 5 solar outputs

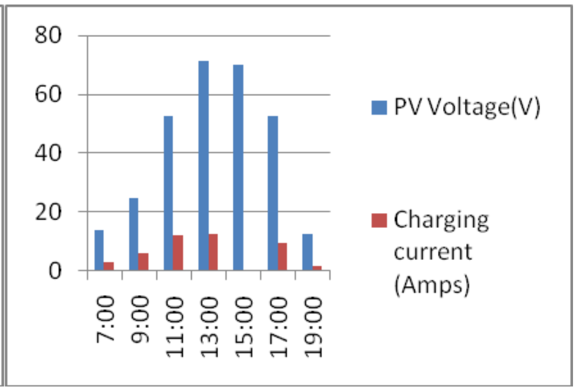

Fig 10: Day 6 solar outputs

Table 6 shows the cost analysis for the solar installation involved in the study. It contains initial cost of purchase for all components installed in millions and how these costs accrue for a period of 20years. Costs are analyzed using equations 1, 2 and 3.

Table 6: Cost estimation of 4KVA solar inverter for 20years period

Yr	I.C	1	2	3	4	5	6	7	8	9	10	11
Battery (#M)	0.52	_	_	_	_	0.94	_	_	_	_	1.68	_
Total Maint. (#M)	0.13	0.16	0.19	0.23	0.28	0.33	0.40	0.48	0.57	0.69	0.82	0.99
PV, inverter and others (#M)	0.98	–	–	–	–	–	–	–	–	–	–	–

Yr	12	I.3	14	15	16	17	18	19	20
Battery (#M)	_	_	_	3.03	_	_	_	_	5.46
Total Maint. (#M)	1.19	1.43	1.71	2.05	2.46	2.96	3.55	4.26	5.11
PV, inverter and others (#M)	_	_	_	_	_	_	_	_	_

Table 7 shows the cost analysis for the gasoline generator involved in the study. It contains initial cost of purchase of the generator, oil and cost of maintenance in millions and how these costs accrue for a period of 20years. Costs on table 7 are analyzed using equations 1, 4 and 5.

Table 7: Cost estimation of 3.5KVA gasoline generator for 20years period

Yr	I.C	1	2	3	4	5	6	7	8	9	10	11
Gen + Engine Oil (#M)	0.17		0.25		0.35	0.50		0.72	1.02		1.46	
Total Maint. (#M)	0.53	0.64	0.76	0.92	1.10	1.32	1.58	1.90	2.28	2.74	3.28	3.94

Yr	12	I.3	14	15	16	17	18	19	20
Gen + Engine Oil (#M)	2.09	2.98		4.26	6.09		8.71		12.44
Total Maint. (#M)	4.73	5.68	6.81	8.17	9.81	11.77	14.12	16.95	20.34

DISCUSSION

The PV voltage characteristic for each day follows a normal distribution model. It rises from early morning values (7:00am) steadily to peak values in the afternoon (1:00pm) before gradually decline to minimum values in the evening (19:00pm). The minimum and maximum voltages observed in the morning are 11.9V (Thursday) and 14.9V (Monday and Saturday) respectively. For peak period, we have 70.8V (Wednesday) and 71.5V (Thursday) as minimum and maximum values respectively too. It can also be seen that the peak voltage in the afternoon are relatively constant. In the evening, we have 12.1V (Saturday) and 13.4V (Wednesday).

Similarly for the charging current; the values are 1.4A (Friday) and 3.6A (Monday); 12.6A (Tuesday) and 17.8A (Saturday); 1.9A (Wednesday and Saturday) and 3.0A (Monday) as morning, peak time and evening periods respectively for minimum and maximum values.

For the battery voltage monitored during the six day period; the values are 48.2V (Monday) and 50.23V (Tuesday); 16.6V (Wednesday) and 54.6V (Thursday); 50.5V (Thursday) and 55.5V (Saturday) for morning, peak time and evening periods respectively for minimum and maximum values. The minimum peak battery voltage (16.6V) of Wednesday was abnormally low compared to others.

It is seen that when the sun is at peak, the battery voltage goes as high as 56.8V which is just the voltage while the sun is at peak and it is expected to come back to the normal battery full charge voltage of 51V. When the sun is at peak i.e (1:00pm), the PV voltage rises as high as 71.5V the charging current is at maximum in other to charge the battery faster. The charging current is regulated to as low as 0.1A at around 3:00pm as the sun is still shinning but the battery is fully charged in other to prevent the battery from bursting from the excess current from the charge controller.

For the comparative analysis, the total cost estimation for the solar installation for the 20years period is 11.5million naira. That of 3.5kVA generator is 32.7million naira for the same period. The cost could have been higher if 4kVA generator or higher one had been installed. Thus additional cost of 21.2million naira or more would have been incurred if generator is continuously used. In the study area, there are other three departments in the building with each having similar challenges. The cost of running generators for each department could be further saved if replaced by solar system especially if the whole building could be integrated.

Also, the noise level in the department and various adjacent offices to the noise source has been eliminated. Though the noise distortion reduces as the distance increases from the noise source yet the impact of the noise is enough to affect assimilation during serious study at nearby offices. The typical noise level indicated on such generator is 93dB. This is far above the specified limit and capable of causing hearing problem in addition to distraction and lack of concentration befitting an academic environment where serenity is expected to be the norm.

CONCLUSION

This paper has discussed the implementation of 4kVA solar system for application in academic environment to replace a standby generator. The design and performance analysis were enumerated. The variations in measured parameters follow a normal distribution. The cost benefit analysis revealed reduction from 32.7 million naira to 11.5 million naira for the twenty years duration which amounts to 21.2 million naira saving. This is aside the noise pollution and CO_2 emission which will be relatively difficult to quantify over the same period. The result shows that investment in solar is worthwhile both for economic and environmental factors. Efforts should therefore be geared towards replacing standby generators with alternative sources such as renewable energies like solar system.

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