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FEASIBILTY STUDIES OF A PROPOSED HYBRID POWER GENERATION SYSTEM FOR A COMPUTER CENTER IN A REMOTE STATION

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Abstract— **— This paper presents the feasibility study of a proposed Photovoltaic/Diesel power generation hybrid system for a remote computer centre in Nigeria. This design comprises the correct determination of station electrical daily load consumption and station solar radiation data. These data are used to determine the hybrid components sizes and its configuration via the use of HOMER software for design and simulation. The simulation results were used to carry out the optimization of this system based on twenty five years life expectances. Analyzing the hybrid power generation system (HPGS) helps in determining the cost effect, the level of emission and optimizes the size of the system. This analysis shows that the HPGS has lower cost, emit less harmful gaseous substances and give reasonable system sizes leading to reduction of energy wastage as compared to conventional stand alone Diesel generator. However, the final design perfectly meets the station energy requirement. Hence, (HPGS) is a recommended solution for this application.**

Index terms- **Hybrid power generation system, ICT electrical load consumption, Meteorology data, HOMER software.**

I. INTRODUCTION

This paper presents the preliminary evaluation of a Hybrid PV/Diesel power generating system. Renewable energy comes from natural sources that are constantly and sustainably replenished. The advantages of this Technology includes improved air quality, reduction in reliance of fossil fuel, curbing of global warming, provision of employment for the general masses and et cetera [1]. Hybrid renewable system present hope on increased reliability and energy security of power supply to the rural communities that are not connected to the National grid [2].Most of the off grid region depends on the use of standalone diesel fueled generator .This practice has been in existence for a long time but research shows that the cost of operation is unbearable for the people in the remote area necessitating the abandonment of the generator in most cases. A good example is the abandoned generating set of Epe fish market in Epe local government of Lagos, Nigeria. Asides the cost challenges, it also poses environmental hazard to both human and plants amongst other disadvantages. With the current world trend in renewable energy technology, these remote facilities are now redesigned to take the advantage of renewable energy Technology. This work discusses the design of a hybrid power generation system (HPGS) comprising of solar and diesel complimentary power plants taking into account the cost-effectiveness of the design system for a remote station. The computer centre facility is an incentive by the Federal Government of Nigeria to educate people on importance of information technology in this modern day. This facility has an installed stand alone generator set of 725kW. Section one of this paper discusses the introduction, section two discusses the hypothetical study of the computer centre, section three discusses the design and simulation of HPGS, section four discusses the results, while section five discusses the closing remarks.

II. HYPOTHETICAL STUDY OF THE REMOTE COMPUTER CENTRE

The petroleum trust fund computer center facility is considered and was used in the development of a feasibility study for the electrical daily load demand data. The energy consumption of 639.74kWh per day was required by the center and was used to develop the hypothetical study for electrical daily load profile of Tables 1 and 2 respectively as described in [3]. Figure 1 depicts the daily profile energy consumption of the remote computer center. The site of this facility has temperature of about 31oC, wind speed at 16km/h and 79 % humidity at location latitude of 6.60000N and longitude 3.50000E [4]. The wind speed is too low and therefore not suitable for wind power generation, hence wind power generation is discouraged in this work. Nigeria enjoys average daily sunshine of 6.25h ranging between 3.5h in coastal areas and 9.0h at far Northern boundary [5]. Solar energy is omnipresent, inexhaustible, freely available and environmental friendly. Therefore, solar radiation is considered very useful for this work. The renewable energy technology allows the integration of two energies sources (PV/Diesel) for high efficiency and power reliability. This paper will focus on feasibility study of the remote computer centre facility load data and the renewable solar radiation resources available for this work and evaluates the performance of the designed PV/Diesel hybrid power system.

Table 1: Remote computer center daily load demand.

S/N	Power Consumption	Power (Watt)	Quantity	Load (Watt×Qty)	Load (kW)	Hours/Day	On-Time (Time in Use)
1	Air Conditioner	2000	20	40000	40	9	(08:00hr-17:00hr)
2	Fans	56	20	1120	1.12	9	(08:00hr-17:00hr)
3	Lightings	40	71	2840	2.84	9	(08:00hr-17:00hr)
4	Printers	720	2	1440	1.44	9	(08:00hr-17:00hr)
5	Desktop Computers	264	114	30096	30.096	7	(09:00hr-16:00hr)
6	Photocopy Machine	300	1	300	0.30	7	(09:00hr-16:00hr)
7	Water Dispenser	500	2	1000	1.00	7	(10:00hr-17:00hr)
8	Projector	210	2	420	0.42	7	(09:00hr-16:00hr)
9	Security Light	36	17	612	0.612	12	(18:00hr-06:00hr)
10	Routers	10	12	120	0.12	9	(08:00hr-17:00hr)

Table 2 The Electrical Load (Daily load demands) data

TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL (watt)	TOTAL (kwatt)
00:00 - 01:00									612																612	0.612
1:00 - 2:00									612																612	0.612
2:00 - 3:00									612																612	0.612
3:00 - 4:00									612																612	0.612
4:00 - 5:00									612																612	0.612
5:00 - 6:00									612																512	0.612
6:00 - 7:00																									0	0
7:00 - 8:00																									0	0
8:00 - 9:00	40000	1120	2840	1440						120															45520	45.520
9:00 - 10:00	40000	1120	2840	**1440**	30096	300		420		120															76336	76.336
10:00 - 11:00	40000	1120	2840	1440	30096	300	1000	420		120															77336	77.336
11:00 - 12:00	40000	1120	2840	1440	30096	300	1000	420		120															77336	77.336
12:00 - 13:00	40000	1120	2840	1440	30096	300	1000	420		120															77336	77.336
13:00 - 14:00	40000	1120	2840	1440	30096	300	1000	420		120															77336	77.336
14:00 - 15:00	40000	1120	2840	1440	30096	300	1000	420		120															77336	77.336
15:00 - 16:00	40000	1120	2840	1440	30096	300	1000	420		120															77336	77.336
16:00 - 17:00	40000	1120	2840	1440			1000			120															46520	46.520
17:00 - 18:00																									0	0
18:00 - 19:00									612																612	0.612
19:00 - 20:00									612																612	0.612
20:00 - 21:00									612																612	0.612
21:00 - 22:00									612																612	0.612
22:00 - 23:00									612																612	0.612
23:00 - 00:00									612																612	0.612
TOTAL																									639736	639.736

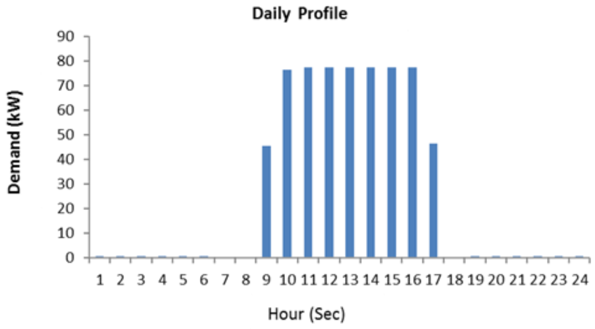

Figure 1 ; Daily profile energy consumption of computer center

A. Remote station load variation demand: As from 00:00hrs to 05:59hrs, load demand is 612W. The load demand increased at 08:00hrs to 45520W and at 9:00hrs demand increased to 76336W respectively. The load demand reached its peak of 77336W from 10:00hrs to 15:59hrs and reduces to 46520W at 16:00hrs.The load demand became minimal 612W from the hours of 18:00 to 23:59 in the night. These load demand data are taken directly at the cite.

B. Site meteorological data

a) Solar photovoltaic energy: The solar energy magnitude was determined by the climatic conditions of the computer center. The monthly average solar radiation data were obtained from national aeronautics and space administration (NASA). An annual average solar radiation for this location is 4.74 kW/m2/day as shown in Table 3 [6]. February has a peak solar energy resource of 5.49 kW/m2/day while July has lower solar energy resources of 3.95 kW/m2/day. Figure 2 shows the solar radiation profile graph of this location.

Table 3: Daily averaged insulation incidents on a horizontal surface

Month	Clearness Index	Monthly average radiation ($kWh/m^2/day$)
January	0.525	5.28
February	0.529	5.49
March	0.520	5.46
April	0.511	5.21
May	0.493	4.76
June	0.434	4.04
July	0.419	3.95
August	0.401	3.98
September	0.396	4.09
October	0.439	4.55
November	0.490	4.95
December	0.522	5.17

Annual Average (kWh/m2/day): 4.74 [6]

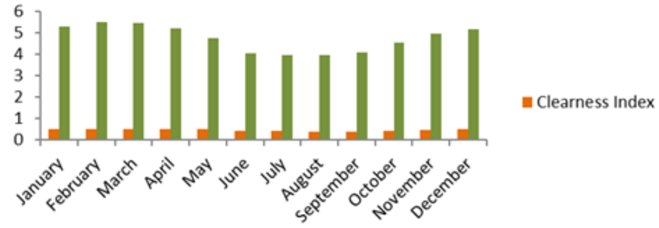

Figure 2 : Average monthly radiation curve with clearness index.

b) Solar radiation variation: There are increase in solar radiation from the months of august, september, october, november, december ,january and february from month to month as(0.03)(0.11)(0.46)(0.40)(0.22)(0.11)and(0.21) ,respectively whereas in the months of february ,march, april, may, june and july, the solar radiation decreases with differences from month to month as (0.21)(0.03)(0.25)(0.45)(0.72)and(0.09) respectively.

C. System configuration

The block diagram of Fig. 3 shows the system configuration layout.

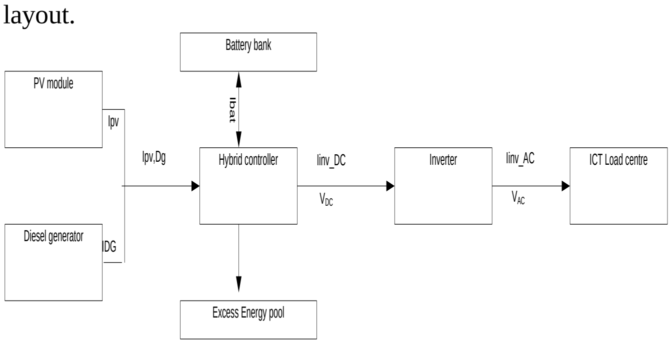

Figure 3: configuration of PV/Diesel Hybrid Power Supply

D. Modeling and simulation of HPGS components.

E.

Figure 4: Homer interface [7]

Hybrid optimization model for electrical renewable (HOMER) Version 3.3.1 Pro was used for the design, optimization and simulation of the hybrid power system as shown in Fig. 4. This software has provision for the following:

(i) Hourly load input.
(ii) Resources usage (Solar radiation data).
(iii) Component cost analysis .
(iv) Project design calculation for the best simulation results.

The hourly load demand data were obtained from the daily load energy consumption of the center. The monthly solar radiation values were gotten from NASA online data as at

June, 2015. The capital cost of each components used for this project were sorted from internet and PV system suppliers in Nigeria [8]. The calculation gives specific information about any cost which could occur during the stipulated project life time. These include the initial set-up costs, replacement cost, maintenance cost and fuel energy cost. Designing a hybrid system demands correct components selection and sizing with appropriate operational strategy [9]. The hybrid components include: Solar panels, Diesel generator, Battery and Converter as shown in Fig. 3. This project lifetime is estimated at 25 years and the annual interest rate is fixed at 5.88%.

a) Solar PV panels: The PV modules proposed for this project is rated 700kW, the initial cost, operation and maintenance cost are $116,480, $100,480 and $10 respe rating Table

Parameter	Value
Capital Cost	$116,480.00
Replacement Cost	$100,480.00
Operation and Maintenance Cost	$10.00
Lifetime	25 years
De-rating factor	80%

b)

*2.*Diesel generator*:* For Diesel generator capacity of 725kW, its initial cost is $362,500, replacement cost is $362,500 whiles the operation and maintenance cost is $10 for the system life time as shown in Table 5.

Table 5: Diesel generator cost analysis [7].

Parameter	Value
Size	725 kW
Capital cost	$362,500.00
Replacement	$362,500.00
Operation and Maintenance	$10
Life time	25
Minimum load ratio	30
Fuel curve intercept	0.0391
Fuel curve slope	0.2372
Fuel price	$0.750

c) Converter: The converter rated capacity of 800kW is used. It's initial and replacement cost are $360,000 and $360,000 respectively with efficiency of 100% as shown in Table 6.

Table6: Power converter parameters and cost [7]

Parameter	Value
Capital cost	$360,000
Replacement cost	$360,000
O and M cost	$0.30/year
Efficiency	100%
Lifetime	20 years

d) Battery: A unit capacity of 800kWh battery is used. The initial and replacement cost is fixed at $150,000 respectively. Operation and maintenance cost of $5 for the component life time period of 20 years is used as shown in Table 7.

Table 7: Battery Parameters and Cost [7]

Parameter	Value
Technology	CELLCUBE FB200-800
Capacity	800Kw
Nominal capacity	1142.86Ah
Voltage	700V
Minimum state of charge	0
Capital cost	$150,000.00
Replacement cost	$150,000.00
O and M cost	$5.00
Efficiency	80%
Lifetime	20 years

e) Selection of the HPGS generator:

The generator rated 725kW was chosen on the HOMER Software since the load requirement for the design is 639.74kW. The site specific inputs of the Diesel generator were analyzed as follows:

[a] Lifetime (Hours): This is the number of hours the generator is expected to provide service before replacement.

For the generator operating on minimum of 6hrs daily on weekdays, it lifetime hours can be calculated thus:

(i) Hours/Week $= 6 \times 5 = 30 hrs/week$

(ii) Hours/month $= 30 \times 4 = 120 hrs/month$

(iii) Hours/year $= 120 \times 12 = 1440 hrs/year$

(iv) Lifetime hrs (25 yrs.) $= 1440 \times 25 = 36000 hrs/25yrs$

For the generator working on weekly (7days) basis, it lifetime hours is calculated as follows:

(i) Hours/Week $= 6 \times 7 = 42 hrs/week$

(ii) Hours/month $= 42 \times 4 = 168 hrs/month$

(iii) Hours/year $= 168 \times 12 = 2016 hrs/year$

(iv) Lifetime hrs(25) $= 2016 \times 25 = 50400 hrs/lifetime$

[b] Minimum runtime (Minutes): This is when the dispatch starts the generator.

For the generator working on weekdays only, it Minimum Runtime (Minute) can be calculated as follows:

(i) Minutes/day $= 6 \times 60 = 360 \min/day$

(ii) Minutes/Week $= 360 \times 5 = 1800 \min/week$

(iii) Minutes/Month $= 1800 \times 4 = 7200 \min/Month$

(iv) Minutes/Year $= 7200 \times 12 = 86400 \min/month$

(v) Lifetime Min (25yrs) $= 86400 \times 25 = 2160000 \min/25yrs$

For the generator operating on minimum of 6hrs daily on weekly basis, it minimum runtime (minute) can be calculated as follow:

(i) Minutes/day $= 6 \times 60 = 360 \min/day$

(ii) Minutes/Week $= 360 \times 7 = 2520 \min s/week$

(iii) Minutes/month $= 2520 \times 4 = 10080 \min s/month$

(iv) Minutes/year $= 10080 \times 12 = 120960 \min/year$

(v) Lifetime Min (25yrs) $= 120960 \times 25 = 3024000 \min/25yrs$

[c] Minimum load ratio (%): This is the minimum allowable load on the generator expressed as a percentage of its capacity. For minimum capacity of 0.54kW, 82.724kW and 83.123kW,

the minimum load ratio can be calculated as follows:

(i) $0.612kW = \frac{0.612}{100} = 0.00612\%$

(ii) $45.5204kW = \frac{45.520}{100} = 0.4552\%$

(iii) $46.520kW = \frac{46.520}{100} = 0.4652\%$

[d]. Fuel curve: This provides assistance in calculating the two fuel curve inputs on the generator window.

Table 7a. Generator fuel consumption.

Fuel consumption (L/Hr)	Output (kW)
115	362.5
156	543.75
200	725.00

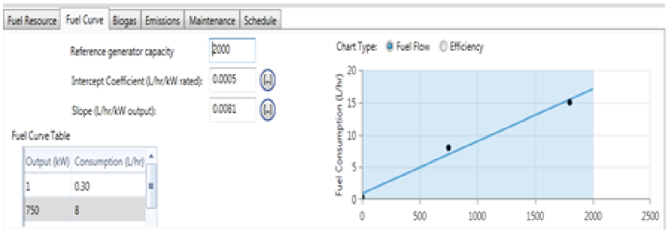

Figure 4: Generator fuel curve design [7]

[e]. Generator schedule: : Homer schedule decides each time step whether or not to operate the generator based on the electrical demand and the economics of the generator versus other power sources. The Generator Schedule Input helps to prevent HOMER from using the generator during some certain times, or force it to use the generator during other times.

Table 7b: Generator operational schedule

Month	Force ON (Hours)	Force OFF (Hours)	Optimized (Hours)
January	4	9	11
February	4	9	11
March	4	9	11
April	4	9	11
May	4	9	11
June	4	9	11
July	4	9	11
August	4	9	11
September	4	9	11
October	4	9	11
November	4	9	11
December	4	9	11

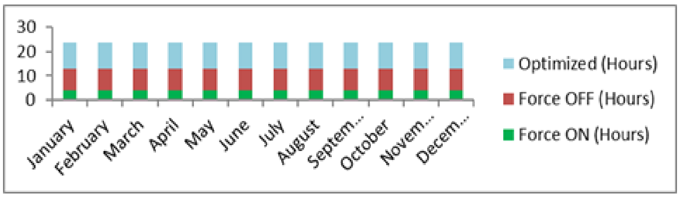

Figure 5: Diesel generator operation schedule chart

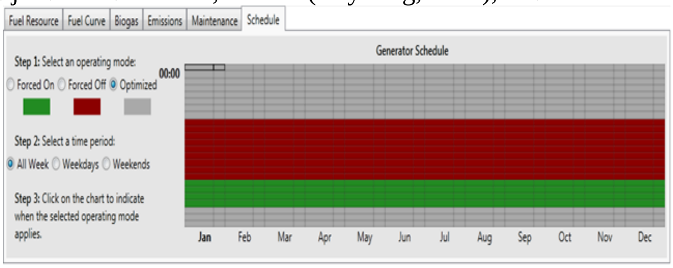

Figure 5: Diesel generator operation schedule chart [7].

[f]Solar photovoltaic panel

A generic flat plate of 350W rating was chosen for the design. PV capacity and cost are analyzed as follow: Total load of 716.22kWh per day divided by hours of sunlight per day (8hrs)

$$= , \frac{716.22}{8} = 89.5275kWh$$

For 0.35kW panel capacity, this will give $= \frac{89.5275}{0.35} = 256 panels$.

Also 0.35kW panels cost \$455. Therefore, 256 panels will cost $256 \times 455 = \$116480$ [11].

The price cost of 0.35kW panels in dollar is \$455.

For total load of 716.22kWh per day divided by hours of sunlight per day (8hrs)

We have, $\frac{716.22}{8} = 89.5275\,kWh$.

III. SIMULATION RESULTS AND DISCUSSION.

A. Simulation result: The simulation revealed information on the economic cost, electricity production and environmental characteristic of each system components of this proposed HPGS. The obtained results are presented in tables 8,9,10, and 11 respectively. The simulation results show that the hybrid system components of 725kW generator, 700kW PV array, a unit battery of 1142.86 Ah nominal capacity and 800kW AC/DC converter are good for the simulation best results. The solar power sub-system and the diesel generator have rated output energies of 969,355kWh/year and 636,405kWh/year respectively which adequately meet the ICT center energy demand of 639.74kWh/day. Analysis of Hybrid Power Generation System (HPGS) is carried out based on cost-benefit, reduction of pollutants and correction of energy wastage due to system oversize for twenty five years. The introduction of excess energy pool in Figure 3 provides electricity to the neighboring community around the facility. This caters for energy wastage. This analysis in Table 8,9,10and 11 respectively show that the HPGS has lower cost, emit less harmful gaseous substances and give best system sizes if compared with a conventional diesel generator.

Figure 6 displays the sensitivity case results while Fig. 7 displays the optimization case results respectively.

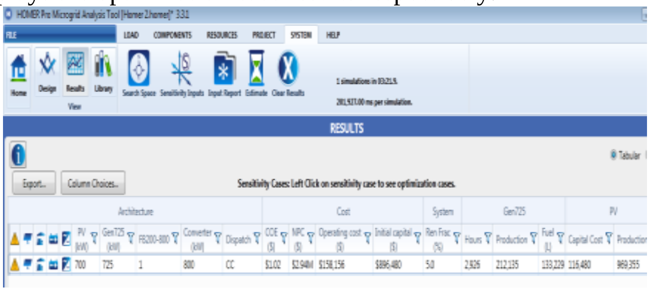

Figure 6: HOMER Simulation Result Showing Sensitivity Case Only [7].

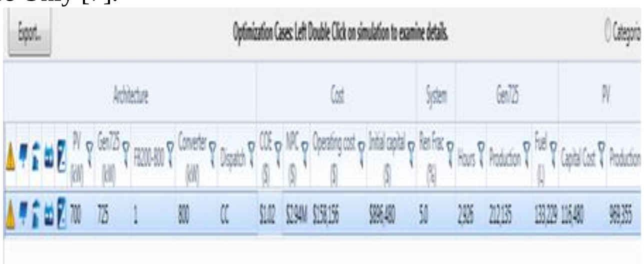

Figure 7: HOMER Simulation Result Showing Optimization Case Only [7]

B. Cost analysis of the HPGS .

The HPGS has operating cost of $454,299, initial cost of $896,480 and a total net present cost (NPC) of $1,350,779 for a lifetime period of 25 years compared to the existing diesel generator system that has operating cost of $1,358,022, initial cost of $780,000 and a total NPC of $2,138,022 for the same lifetime period. The results in Table 8, show that NPC of HPGS is cheaper compared to conventional generator, therefore HPGS is viable for this application.

C. Table 8. Simulation result of economic cost between the existing system and the hybrid system. [7].

Parameter	Existing diesel system only		Proposed hybrid (PV/Diesel) system	
Value	Dollar($)	Naira(#)	Dollar($)	Naira(#)
Initial cost	780,000	155,376,000	896,480	178,578,816
Operating cost	1,358,022	270,517,982.4	454,299	90,496,360.8
Total NPC	2,138,022	425,893,982.4	1,350,779	269,075,176.8

3.Environmental impact: Table 9, shows that the proposed HPGS emits 349,661kg of CO2, 1466kg of CO, 168kg of unburned hydrocarbons (UHC), 42kg of particulate matter (PM), 720kg of sulfur dioxide (SO2) and1466kg of nitrogen oxides (NO2) annually compared to the existing diesel generator system which emits 1,836,120kg of CO2, 7,696kg of CO, 882kg of unburned hydrocarbons (UHC), 220kg of particulate matter (PM), 3,780kg of sulfur dioxide (SO2) and 7,696kg of nitrogen oxides (NO2) annually. Comparatively, hybrid systems emission is reduced compared to diesel generator only. Therefore, HPGS fit its applicability in this remote station.

Table 9. Simulation results of emissions from the existing system and proposed system [7]

Pollutant	Emissions($Kgyr^{-1}$)				
	Existing diesel only		Proposed hybrid system		Difference
	($Kg\ yr^{-1}$)	($ton\ yr^{-1}$)	($Kg\ yr^{-1}$)	($ton\ yr^{-1}$)	($ton\ yr^{-1}$)
Carbon dioxide	**1,836,120**	1,836.12	349,661	349.661	1486.459
Carbon monoxide	7,696	7.696	1,466	1.466	6.230
Unburned hydro	882	0.882	168	0.168	0.714
Particular matter	220	0.220	42	0.042	0.178
Sulfur dioxide	3,780	3.780	720	0.720	3.060
Nitrogen Oxide	7,696	7.696	1,466	1.466	6.230

D. Electricity production: The proposed HPGS system produces 1,605,760kWh/yr with 60.37% fraction of solar PV and 39.63% fraction of diesel generator while the existing diesel generator produces 1,903,560kWh/yr at 100% fraction of diesel generator only. The load demand is 223,269kWh/yr at 100% fraction on each case, as shown in the Table 10. These results explain the energy wastage produced by a conventional generator set , due to system oversized. This has been corrected by HPGS design, thereby reduces energy wastage of a conventional generator.

Table 10. Simulation results of electricity production (kWh yr-1)

Quantity	Diesel only		Hybrid system(Solar PV/diesel)	
	$kWh\ yr^{-1}$%	**%**	**$kWh\ yr^{-1}$ %**	**%**
Load consumption				
AC Primary load	223,269	100	223,269	100
Production				
PV array	None	None	969,355	60.37
Diesel Generator	1,903,560	100	636,405	39.63
Total energy	1,903,560	100	1,605,760	100
Excess electricity	1,670,059	87.7	1,382,490	86.1

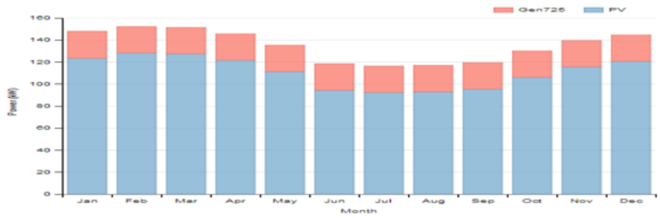

Figure 8 Simulation result of the electricity production of the hybrid system [7]

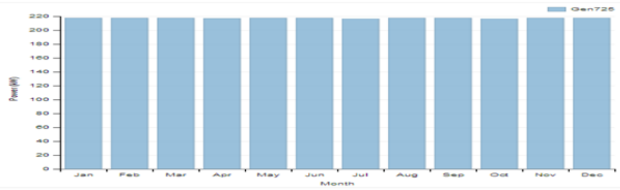

Figure 9 Simulation result of the electricity production from the existing diesel system [7]

E. Fuel consumption: The hybrid system with 7,306 hours of operation per year consumed 133,229 liters of diesel per year compared to the existing diesel generator system with 8,752 hrs/yr that will consume 699,603 liters of diesel fuel per year as shown in Table 11.

Table 11. Simulation result of fuel consumption between the existing system (diesel only) and proposed hybrid system

Quantity	Diesel only		Diesel in Hybrid system	
	Value	Units	Value	Units
Operational life	2.74	yr	6.0	yr
Capacitor factor	29.97	%	15.81	%
Hour of operation	8,752	hyr^{-1}	7306	hyr^{-1}
Fuel consumption	699,603	$L\,yr^{-1}$	133,229	$L\,yr^{-1}$

F. System optimization

a) System economic

The capital cost and replacement cost are likely to vary from the actual system quotes due to many market factors. The replacement costs of equipments are estimated to be 10% - 20% lower than the initial costs, but because the decommissioning and installation costs needed to be added, it was assumed that they are the same as the initial cost. All initial costs including installation and commissioning, replacement costs, operating and maintenance costs of the ICT center are summarized in Table 8. HOMER software calculates in US Dollar ($). All costs have been converted from USD ($) into Naira (N) as shown in Table 8 using the equivalent of N199.20 Nigerian currency to 1 US Dollar ($) [10].

b) System constraints

The project lifetime is fixed to be 25 years at annual interest rate of 5.88 %. The safety margin of the operating reserve ensures the reliability of the power supply irrespective of the load variation. No capacity shortage was noted. The operating reserve as percentage of solar power output is fixed at 25% [11].The system constraints are summarized in Table 12.

Table 12: System constraints [7]

Parameter	Value
Maximum unreserved energy	0%
Maximum renewable fraction	0 to 100 %
Maximum battery life	N/A
Maximum annual capacity shortage	8%

IV. CONCLUSIONS

This paper presents the feasibility studies and analysis of a proposed hybrid power generation system (HGPS) for Petroleum Trust Fund (PTF) ICT center in a remote station, using Photovoltaic/Diesel power generation hybrid system in a remote station shows that optimal hybrid system is economically profitable for use in a remote areas compared to using standalone diesel only power generating set. The HPGS also help to reduce global warming as less harmful gaseous substances is emitted if compared with stand alone diesel generating set as discussed earlier in this literature. The simulation results also revealed that when battery is used with an hybrid system, very high reduction in NPC and emission is possible. Conclusively, this design meets the annual load demand of the remote ICT centre at a reasonable reduced cost . It is highly reliable and environmentally friendly, therefore recommended for its application. 4.1 Recommendation. The excess energy generated should be used to plan for future load expansion of any other station this type of model is to be applied. The power generated in excess here could be used to power the neighboring community. If no one lives around, multiple generators connected in parallel are used instead of one generator with higher capacity to reduce the amount of excess electricity generated on order to minimize energy wastage[12].The emission in both system is too high and this cause global warming, equipment like carbon capture could be deployed to reduce the emission. During the design, each component must be stated accurately with respect to the load demand. These component sizes must be at least 10% greater than the load demand. The converter and battery input voltage must be the same. Many sensitivity variables required a lot of time to run , therefore too many sensitivity variables should be avoided.

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