



Techno-economic Analysis of Hybrid Diesel Generator/PV/Battery Power System for Telecommunication Application

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ABSTRACT

In this study, the techno-economic analysis of a hybrid diesel generator/PV/battery power system was carried out for telecommunication substation in Nigeria. A case study of a telecommunication substation located at Mabushi, Abuja was considered. Homer Pro software was used to carry out the technical, economic and environmental analysis of different configurations of power systems: DG only system, DG/Battery system, PV/Battery system and DG/PV/Battery system. The systems were compared with the DG/PV/Battery power system installed at Mabushi substation. Results show that the currently installed DG/PV/Battery system is oversized when compared with the optimized DG only system, DG/Battery system and DG/PV/Battery system. The installed DG/PV/Battery system has the least capacity factor of 6.42% when compared to other systems. The optimized DG/PV/Battery system has a capacity factor of 16.88%. The pure renewable system (PV/Battery system) has the highest NPC and COE. This is due to PV/Battery system high capital cost that contributed about 87.5% of total facility cost. The optimized PV/Battery/DG presented in this study gave the least NPC and COE of \$51,291 and \$0.453 respectively as compared to NPC and COE of \$63,600 and \$0.592 obtained in the currently installed power system. This implies that the optimized PV/Battery/DG system presented in this study is the most viable of all the systems considered and is therefore recommended for installation at the studied telecommunication substation. The sensitivity analysis of the diesel price on the COE in the recommended system shows that for 100% price increase in diesel fuel, the COE increases by about 30%. This is due to the fact that the integration of the PV/battery to the DG cushions the direct effect of the increased fuel price on the COE.

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INTRODUCTION

Telecommunication restructuring framework led to the introduction of GSM to Nigeria in 2001 (Nkordeh, Bob-Manuel, & Olowononi, n.d.). Recent statistics has

shown that the subscriber identity module (SIM) penetration in Nigeria is 82% and the number of lines connections is 151.8 million ("SMA Intell. Data," 2017). The growing number of subscribers has necessitated the



need to build more telecommunication infrastructure. Base stations (BSs) are among the key energy consumption elements of telecommunication infrastructure (M. H. Alsharif, Nordin, & Ismail, 2015)(Ahmed et al., n.d.).

A telecommunication transceiver operating with power outage can be a major source of communication failure. Therefore a continuous safe and cost-effective energy system is necessary to operate a telecommunication substations so as to curtail service disruption. There is a major challenge of insufficient power generation in Nigeria. Running industrial or business ventures entirely on electricity from the grid is not sustainable. Olatomiwa *et al.* (Olatomiwa, Mekhilef, Olatomiwa, Mekhilef, & Huda, 2014) reported that an approximately 12,560 mobile sites are not connected to the grid in Nigeria, while an estimated 11,692 sites are linked to the national grid. About 9% of the grid connected sites have an average of 6-hour grid outages per day, while, 10% have 6–12 hours grid outages per day and the remaining 81% have over 12 hours grid outages per day. Diesel generator are mostly used to power off-grid base stations and grid connected station during off-grid hours. . In off-grid systems, the primary component of plant-level energy costs is the expenditure on diesel fuel for generators, which accounts for almost 80% of the total energy costs(Feng, Jiang, Lim, Tutorials, & 2012, n.d.)(Mancuso, Vincenzo, 2011).

Alternatively, the required energy can be sourced from abundant solar energy using solar photovoltaic (PV) system or PV systems integrated to conventional electricity generating system (diesel generator) in a solar hybrid system. The hybrid system can lead to a reduction in electricity cost with a constant electricity supply. Several works (Agarwal, Nitin, 2013; Ahadi, Amir, Sang-Kyun Kang, 2016; Cristóbal-Monreal, Iván R., 2016; Dufo-

López, Rodolfo, Iván R. Cristóbal-Monreal, 2016; Kusakana, 2015; Maatallah, Taher, Nahed Ghodhbane, 2016) have been carried out in the area of solar hybrid systems. Dufo *et al.*,(Dufo-López, Rodolfo, Iván R. Cristóbal-Monreal, 2016) discussed the various ways of optimizing a PV-wind-diesel hybrid system. Ahadi *et al.*,(Ahadi, Amir, Sang-Kyun Kang, 2016) has done an extensive investigation on several hybrid renewable energy system combinations of solar, wind and diesel generators to supply energy to remote communities. Maatallah *et al.*, (Maatallah, Taher, Nahed Ghodhbane, 2016) performed a techno economic feasibility study of solar PV/wind/Diesel with storage batteries. They reported that the most economical system has an NPC and LCOE of \$57,320 and 0.26 \$/kW, respectively. Goel and Ali(Goel, Sonali, 2014) used the HOMER software to obtain the optimum net present cost (NPC and energy cost/kWh for telecom towers. Alsharif (M. Alsharif, 2017), compared solar-powered base stations with conventional energy sources, and obtained OPEX savings that ranges between 32% and 66%. He concluded that the solar-powered base stations would be a feasible long-term solution for the telecommunication industry. Summary of the findings of several researchers (Oviroh, Peter Ozaveshe, Tien-Chien Jen, Nosa Idusuyi, 2017; Shaahid, S. M., 2009; Vishnupriyan, J., 2018) showed that: (1) A 40-90% reduction in fuel consumption by the diesel generator (DG) with the solar hybrid system (2) a reduction in the operation and maintenance cost of up 50 % (3) Carbon footprint savings of 30-75% are also achieved as a result of the reduction in the burning of fossil fuel. (4) Reduction of diesel generator (DG) set run hour by about 50%. Most substations in Nigeria are run on contract basis. In order to ensure power availability on site most of the power equipment are over-sized leading to increased cost of electricity. Consequently, this study was carried out to design and

optimized different hybrid energy systems for a telecommunication substation in Mabushi, located in the capital of Nigeria (Abuja) using HOMER software. The proposed system was compared with the presently installed system at Mabushi substation.

SITE DESCRIPTION

The telecommunication substation in this study is located at kabir rabiu road,

Mabushi, Abuja, Nigeria ($9^{\circ}5.0'N$, $7^{\circ}26.9'E$). The substation is dedicated to serve the vehicle inspection office headquarters and adjoining subscribers. The substation was installed to enhance the transmission of telecommunication data. It has 3 RF radios, a microwave and 2 DC lights that comprises of the site load. Figure 1 shows the view of Mabushi telecommunication substation, located at ($9^{\circ}5.0'N$, $7^{\circ}26.9'E$). The ambient temperature varies between $18^{\circ}C$ to $30^{\circ}C$.



Fig.1: Mabushi telecommunication substation, Abuja Nigeria

Site Load

The Site loads are all DC loads, therefore the use of an AC to DC converter is

not required. The total rating of equipment on site is 988Watts that comprises of:



- Two DC security lamps: These lamps are necessary for illuminating of the site scene especially in the nights.
- Three RF antennas: the radio frequency antennas are the receivers of the radio waves or signals transmitted from a long distance of hundreds of meters or several kilometers away.
- One micro wave transmitter: A Microwave is a communications system that uses a beam of radio waves in the microwave frequency range to transmit audio, video and other information between locations, from a few feet or meters to several miles or kilometers apart.

Homer Pro software

Hybrid Optimization Model for Electric Renewable (HOMER) is a simulation software. HOMER can model both the grid-connected and off-grid micro-power systems comprising any combination of photovoltaic (PV) modules, wind turbines, small hydro, biomass power, generators, micro-turbines, fuel cells, batteries, and hydrogen storage etc. HOMER performs three major computations: simulation, optimization, and sensitivity analysis ("HOMER Pro User Manual," 2016). In the simulation process, HOMER models the performance of a given system configuration each hour of the year so as to determine its technical feasibility and life-cycle cost. In the optimization process, HOMER simulates many different system configurations in search of the one that satisfies the technical constraints at the lowest life-cycle cost. In the sensitivity analysis process, HOMER performs multiple

optimizations under a range of input assumptions to gauge the effects of different changes in the model inputs. In the present study, HOMER Software was used to simulate hybrid energy system for off-grid with different schedules and compared with a system that run with diesel generator only system. HOMER incorporates the entire cost of the system to calculate the economic viability of the systems. The metrics for comparing the viability of the system are the cost of electricity (COE) and the net present cost (NPC).

TECHNICAL AND ECONOMIC ANALYSIS OF THE SYSTEMS

Technical Analysis of the Systems

Base Case

The base case is the currently installed power system at the Mabuchi telecommunication substation. The system comprises of 17kWDC Diesel generator (DG), a 3.5kWh Photovoltaic (PV) solar panel and 24 batteries of 1KWh each, the schematic illustration of the system is shown on figure 2a. The system has no AC/DC converter because the generator has a DC output. The electrical load on the system is represented by the electrical incandescent lamp; this is the generic symbol HOMER uses to indicate loads on any system. The station combines a photovoltaic (PV) array, battery and the generator. The architecture is designed in such a way that the DC generator and the solar panels directly feed the required energy to the DC load of the base station. There is also provisions for both the diesel DC generator and the Photovoltaic solar panels to charge the batteries concurrently. Excess energy stored in the battery bank are used during night or when the PV cannot supply the required energy to the load.

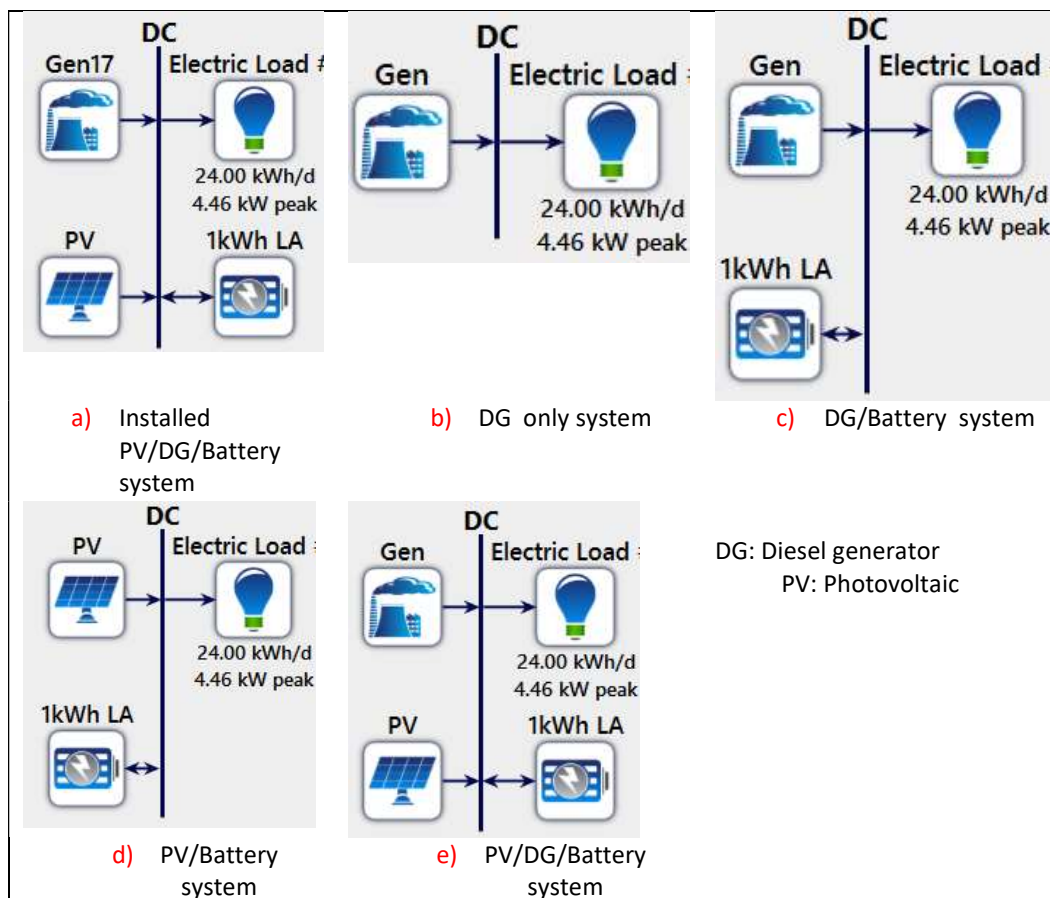


Fig.2: Various configurations of renewable energy hybrid power supply.

DIESEL GENERATOR (DG) CASE STUDY

In this case, a diesel generator (DG) is allowed to run the sites over the life span of the facility. The schematic representation of the generator alone running the site is shown in Figure 2b.

Diesel generator (DG) and battery case study

In this case study, the site is powered by the combination of a diesel generator and battery system (DG/Battery). In this system a DG is made to run the site and recharge the batteries until they their full capacity (100%). The DG is then off thereby allowing the batteries to power the site until the batteries capacity drops to 50%. The DG is then force-start to repeat the

cycle. Figure 2c is a schematic diagram that gives the physical representation of the system.

Photovoltaic (PV) array and battery case study

The fourth case study is a pure renewable energy system, where the PV and the Battery (PV/Battery) system are used to run the site continuously. The PV power the site and charges the batteries during the solar hour. The energy stored in the battery is used to power the site during non-solar hour. The schematic representation of this system is shown in figure 2d.

Diesel Generator (Dg), Photovoltaic (Pv) Array And Battery Case Study

The final case is the fifth case whereby the system employs the use of all the three components of the power system available on site; the PV, the Generator and the Batteries. The schematic representation of this system can be seen as shown in figure 2e.

TECHNICAL ANALYSIS OF SYSTEM COMPONENTS

PV model

The output of the PV is modeled in HOMER using the following equations (Akhtari, Mohammad Reza, 2019; Baneshi, Mehdi, 2016):

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{G_T}{G_{T,STC}} \right) [1 + \alpha_p (T_c - T_{c,STC})] \quad (1)$$

Y_{PV} is the PV rated capacity (kW) under standard test conditions, f_{PV} is the PV de-rating factor [%]. G_T is the instantaneous solar radiation incident on the PV array, while, $G_{T,STC}$ is the incident solar radiation at standard test conditions. α_p is the temperature coefficient of power [%/°C]. T_c and $T_{c,STC}$ are the PV cell temperature and PV cell temperature under standard test conditions [25 °C] respectively.

The PV cell temperature (Akhtari, Mohammad Reza, 2019) is computed from Eq. (2):

$$T_c = T_a + G_T \left(\frac{T_{c,NOCT} - T_{a,NOCT}}{G_{T,NOCT}} \right) \left(1 - \frac{\eta_c}{\tau\alpha} \right) \quad (2)$$

Where T_a is the ambient temperature, $T_{c,NOCT}$ is the nominal operating cell temperature [°C] and $T_{a,NOCT}$ is the ambient temperature at which the NOCT is defined [20°C], G_T and $G_{T,NOCT}$ are the instantaneous solar radiation and solar radiation at which the NOCT is defined [0.8 kW/m²] respectively. η_c is the PV array electrical efficiency, while PV transmittance – absorptance is expressed as $\tau\alpha$ and assumed as 0.9 in HOMER software.

Solar Resources

The solar radiation data for the telecommunication site (Abuja) was obtained from NASA surface meteorology and solar data base. The data was based on the global horizontal radiation, monthly averaged over 22 year period (July 1983 - June 2005) and presented in Figure 3. The monthly distribution of the clearness index was also given in figure 3. The months of May to August have relatively lower monthly average solar radiation and clearness index. This months are mostly characterized with high rainfall activity when compared to other months of the year. The month of December has the lowest solar radiation due to effect of winter. The annual daily average global solar radiation and clearness index of the telecommunication site was estimated as 5.579 kWh/m²/day and 0.566 respectively.

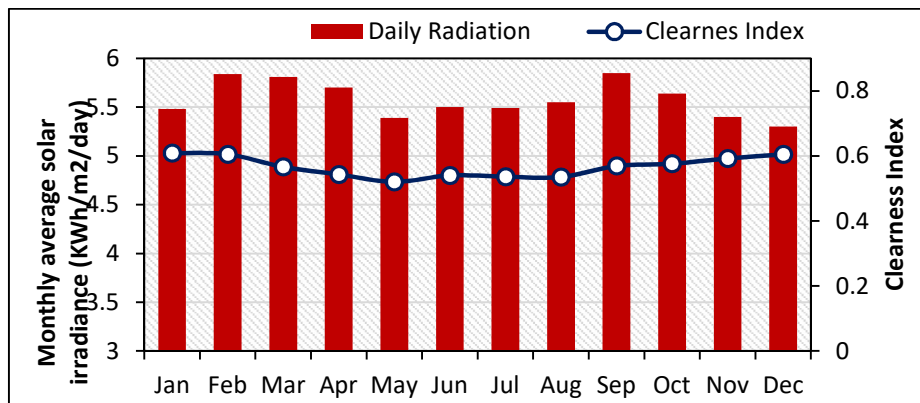


Figure 3: Monthly average solar irradiance and clearness index for Abuja

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Diesel Generator Model

The generator electrical efficiency is the ratio of the generator's electrical energy output and the chemical energy of the fuel ("HOMER Pro User Manual," 2016).

$$\eta_{gen} = \frac{3.6(P_{gen})}{\dot{m}_{fuel} LHV_{fuel}} \quad (3)$$

Where P_{gen} is the electrical output in kW, \dot{m}_{fuel} is the mass flow rate of the fuel in kg/hr and LHV_{fuel} is the lower heating value of the fuel in MJ/kg.

The amount of fuel the generator consumes (\dot{m}_{fuel}) is given as:

$$\dot{m}_{fuel} = \frac{\rho_{fuel} (F_0 Y_{gen} + F_1 P_{gen})}{1000} \quad (4)$$

Where F_0 is the fuel curve intercept coefficient in L/hr/kW, F_1 is the fuel curve slope in L/hr/kW, Y_{gen} is the rated capacity of the generator in kW, and P_{gen} is the electrical output of the generator in kW.

Battery Model

HOMER uses the Kinetic Battery Model (Azimoh, Chukwuma Leonard, Patrik Klintonberg, Fredrik Wallin, Björn Karlsson, 2016) to determine the amount of energy that can be absorbed by or withdrawn from the storage bank at each time step.

The maximum battery charge power is computed as:

$$P_{batt,cmax} = \eta_{batt,c} \cdot P_{batt,cmax,k} \quad (5)$$

$$P_{batt,cmax,k} = \frac{kQ_1 e^{-k\Delta t} + Qkc(1 - e^{-k\Delta t})}{1 - e^{-k\Delta t} + c(k\Delta t - 1 + e^{-k\Delta t})} \quad (6)$$

The maximum battery discharge power is computed as:

$$P_{batt,dmax,k} = \frac{-kcQ_{max} + kQ_1 e^{-k\Delta t} + Qkc(1 - e^{-k\Delta t})}{1 - e^{-k\Delta t} + c(k\Delta t - 1 + e^{-k\Delta t})} \quad (7)$$

$$P_{batt,dmax} = \eta_{batt,d} \cdot P_{batt,dmax,k} \quad (8)$$

$$\eta_{batt,c} = \eta_{batt,d} = (\eta_{batt,rt})^{1/2} \quad (9)$$

ECONOMIC ANALYSIS OF SYSTEM COMPONENTS

Cost of Electricity

The cost of electricity (COE) of different power systems considered is

computed as (Sanusi, Yinka S., Esmail MA Mokheimer, 2017):

$$COE = \frac{\text{Total annualized cost of the system} \left(\frac{\$}{\text{yr}}\right)}{\text{Total electricity supplied} \left(\frac{\text{kWh}}{\text{yr}}\right)} \quad (10)$$

The total annualized cost is computed from $C_{ann,tot} = C_{NPC} \cdot CRF$ (11)

Where C_{NPC} the net present cost (NPC) of a system and CRF is the capital recovery factor.

The capital recovery factor can be given by eq.12 as (Sanusi, Yinka S., Esmail MA Mokheimer, 2017):

$$CRF(i, N) = \frac{i(i+1)^N}{(i+1)^N - 1} \quad (12)$$

Where; N is the project lifetime in years, i is the annual interest rate.

The net present cost (or life-cycle cost) of a component is the present value of all the costs of installing and operating that component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime.

RESULTS AND DISCUSSION

In this study, the techno-economic analysis of power facility installed at Mabushi telecommunication substation and those of DG only system, DG/Battery system, PV/Battery system and DG/PV/Battery system were simulated and optimized using HOMER software. The sensitivity analysis of the optimized system was thereafter carried out. Results of the optimized system for different power configuration is shown in Table1. The currently installed system has a DG of 17 kW and is allowed to run for 3 hrs. per day. Analysis shows that the required DG to power the site is 4.1 kW. This DG can also be used as a stand by energy supply during non- solar hour and when the battery is fully discharged. When the site is powered solely by DG (4.1 kW), the service life of the generator drop from 12.5 years in the installed system to about 1.91 years. This implies that, if two generators are used on a 12-hours basis, a total number of 14 (4.1kW-DG) generators will be required over a 25



years period. When the battery is installed with DG (i.e. DG/Battery system), the hour of operation of the generator will decrease by about 37% (when compared to DG only system) leading to the reduction of the number of 4.1 kW generator from 14 to 9 DGs. This will also lead to reduction the amount fuel used and generator maintenance cost. Five generators (4.1 kW each) will be required in the optimized DG/PV/Battery system, as compared to two DG (17 kW each) required in the installed

DG/PV/Battery system. In a pure renewable system (PV/Battery system), the size of the PV panel and battery required is significantly higher than those of the currently installed DG/PV/Battery system and optimized DG/PV/Battery system. It can further be seen from table 1 that the currently installed DG/PV/Battery system is oversized when compared to the optimized DG/PV/Battery system. This will lead to higher capital and operational cost.

Table 1: System configuration of the installed facility and optimized systems

	Installed facility	Optimized configurations			
		DG/PV/Battery	DG	DG/Battery	PV/Battery
Diesel Generator					
Capacity	17 kW	4.1	4.1	-	4.1
Hours of operation/yr	1196	7857	4941	-	2521
Number of starts/yr	1082	364	961	-	704
Operational life	12.5	1.91	3.04	-	5.95
PV panel	3.5 kW	-	-	14.3	3.19
Battery					
Total Number	24	-	8	80	12
String Size	4	-	4	4	4
Strings in parallel	6	-	2	20	3
Bus voltage	48	-	48	48	48

The electricity production from different power systems considered in this work is summarized in table 2. The least excess electricity is produced in DG/Battery system while the PV/Battery system produced the highest excess electricity of 13,622 kWh. This implies that electricity power wastages is minimal in DG/Battery system since excess electricity produced is not used by the telecommunication system. The installed DG/PV/Battery system has the least capacity factor of 6.42%. This implies that the installed system is highly under-utilized when compared to other systems

considered. The optimized DG/PV/Battery system that has similar configuration to the installed system has capacity factor of 16.88%. This is due to lower capacity of the power components such as the DG, PV and battery systems in the optimized system as compared to those in installed system. For instance, the number of battery suggested by the optimized configuration is half of the installed number on site. The reduced battery system capacity and DG capacity increases the utilization factor of the optimized DG/PV/Battery system.



Table 2: Electricity production of the installed facility and optimized systems

	Installed facility	Optimized configurations			
	DG/PV/Battery	DG	DG/Battery	PV/Battery	DG/PV/Battery
Electricity Production	10409	10386	9189	-	10785
Total electricity Produced	976	1,626	18.4	13622	551
Excess electricity Capacity factor (%)	6.42	28.9	25.6	18.8	16.88

The cost breakdown of the installed facility and optimized systems are given in table 3. The PV/Battery system has the highest NPC and COE. The capital cost is the dominant cost of the PV/Battery system contributing about 87.5% of total facility cost. This implies that the installed DG/PV/Battery system is more viable than pure renewable energy source (i.e. PV/Battery). The installed system is also more cost effective than DG only system. Unlike in PV/Battery system in which capital cost is the dominant cost of the NPC. The fuel cost contributed about 60% of the NPC in the DG only system. The optimized PV/Battery/DG gave the least NPC and COE. This implies that this system is the most viable of all the system considered in the present study and is therefore recommended for installation at the studied telecommunication substation. The COE of

the recommended system is lower than the presently installed system by about 24%. Analysis of the presently installed DG/PV/Battery system and recommended system (i.e. optimized DG/PV/Battery system) shows that the two systems have similar capital expenditure (CAPEX). The installed system has higher number of batteries and PV panel capacity while it has lower number of replaceable diesel generators compared to the recommended system over the 25 years period considered in this work. The higher capacity of the presently installed system (Battery, DG and PV panel) when compared to the recommended system, is responsible for its higher operation and maintenance cost (OMEX) and Fuel cost. These costs are the major contributors to the higher NPC and cost of electricity in the installed system.

Table 3: Cost of the installed facility and optimized systems

	Installed facility	Optimized configurations			
	DG/PV/Battery	DG	DG/Battery	PV/Battery	DG/PV/Battery
Cost (\$)					
Net present cost	63600	68795	60815	97344	51291
CAPEX	27503	15082	19921	85156	27078
OMEX	10505	12493	8891	12188	5972
Fuel cost	25592	41220	32003	0.00	18241
COE	0.596	0.607	0.537	0.86	0.453

Figure 4 shows the cumulative cost of the optimized systems. The jump observed in the PV/Battery system is due to the replacement cost of one of the major components (batteries) of the system. It can be seen from the figure that the optimized DG/PV/Battery system with higher initial cost when compared to the DG only and DG/Battery systems has the lowest cumulative cost at the end of the 25 years period. This is due to the fact that DG only and DG/Battery systems has diesel fuel as their energy sources compared to optimized DG/PV/Battery system that has solar and diesel fuel as its energy sources. The break even cost of optimized DG/PV/Battery

system over the DG only and DG/Battery systems is observed at the end of the third year and seventh year respectively. This means that though the initial cost of optimized DG/PV/Battery system is seven (7) times more than that of the DG only system, the fuel cost incurred in running the DG only system would have been more than the cumulative cost for the optimized DG/PV/Battery system at the end of the third year of the site operation. Thus, the optimized DG/PV/Battery system became more profitable than DG only and DG/Battery systems at the end of the third year and seventh year respectively.

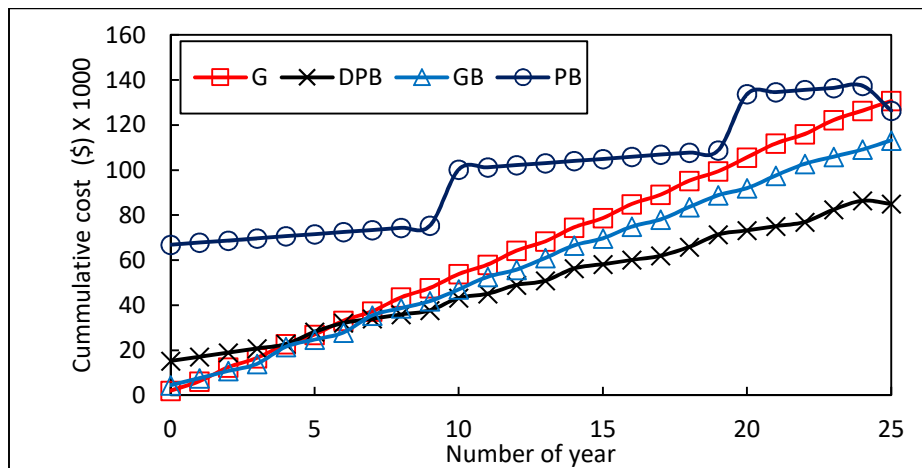


Figure 4: Cumulative cost of different optimized

Nigeria is signatory to Kyoto protocol on carbon emission (Ayoola, 2011), there is however no enforceable regulation on carbon emission especially in the power sector. Therefore, the carbon credit that supposed to accrue to the usage of renewable energy is not applicable in the financial analysis in this work. It is however important to note the emission for different

power configurations. As shown in Table 4, all the emission parameters are highest when running the site purely on DG. The least value are obtained in the recommended configuration (Optimized DG/PV/Battery system). It is important to note that no emission parameters are reported in PV/Battery configuration since no fossil fuel was used.

Table 4: Emissions of the installed facility and optimized systems

	Installed facility	Optimized configurations			
	DG/PV/Battery	DG	DG/Battery	PV/Battery	DG/PV/Battery
Emissions					
Carbon dioxide	5825	11128	8640	-	4925
Carbon monoxide	39.5	70.1	54.5	-	31
Unburned hydrocarbon	1.6	3.06	2.38	-	1.35
Particulate matter	2.39	0.425	0.33	-	0.188
Sulphur dioxide	14.3	27.3	21.2	-	12.1
Nitrogen oxide	44.9	65.9	51.2	-	29.2

RECOMMENDED DG/PV/BATTERY SYSTEM

The recommended configuration (Optimized DG/PV/Battery system) has the lowest COE and emissions. The technical

data of components in the recommended (optimized PV/Battery/DG) system is summarized in Table 5.

Table 5: Technical Data for the recommended DG/PV/Battery system.

PV	
Panel type	Flat plate
Rated capacity	1 kw
Temperature coefficient	-0.5%/°C
Nominal operating cell temperature	47°C
Efficiency at standard test	13 %
Battery	
Battery type	Lead acid
Nominal voltage	12 V
Nominal capacity	1 kWh
Maximum capacity	80A
Depth of discharge	40 %
Diesel generator	
Capacity	4.1 kW
Fuel curve slope	0.1 L/kWh
Life time	15,000 h

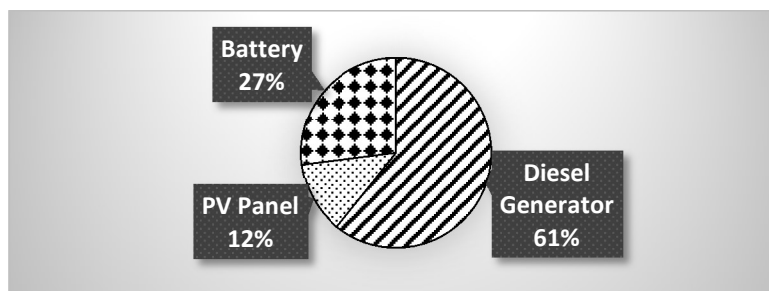


Figure 5: Cost break down of optimized PV/DG/Battery system.

The net present cost and cost of electricity production for the recommended DG/PV/Battery system are obtained as \$51,291 and \$0.453 respectively. The cost breakdown of the system shows that the cost of operating the Diesel generator (i.e. its Capital cost, maintenance cost and fuel cost) dominated the NPC of electricity generation

as shown in Fig. 5. The cost of the fuel (diesel) is the major part of the annualized Diesel generator cost. This implies that any change in the Diesel price will affect the COE for the recommended system. In section 4.2, the sensitivity analysis of the NPC and COE were reported.

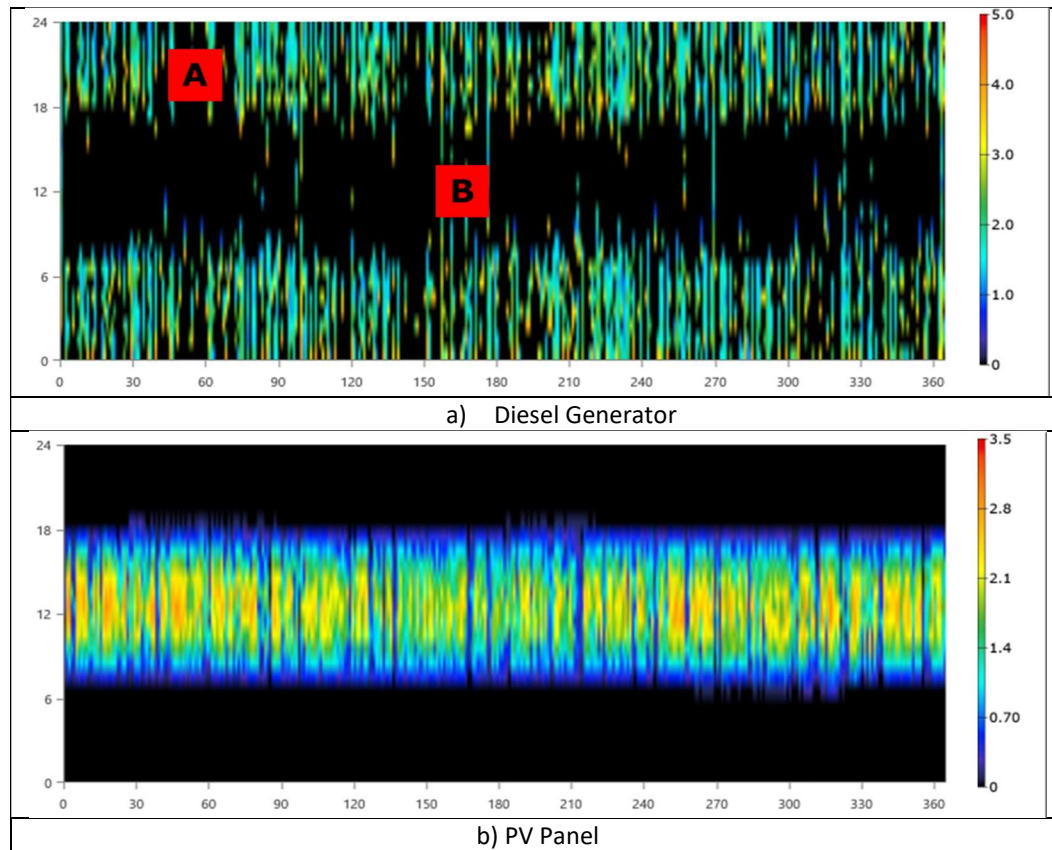


Figure 6: Hourly power output from primary energy sources (kW) over a period of 360 days

The hourly power production from the diesel generator and PV system in the recommended system for a whole year is shown in Fig. 6. The power production from the PV Panel occurs during the day (sunrise to sunset) due to the availability of solar radiation during this period and depicted by the colourful zone between the hour of 6 and 18. There are however some black strips during the day time indicating there is lack of

solar radiation due to non-favorable weather conditions. During the non favourable weather conditions, power is produced by diesel generator as seen in zone B in Fig. 3b. Zone A is dominated by non-diesel power generation. This zone also falls into non-solar period. This implies that electricity is supplied to the telecommunication system by stored energy in the battery.

Sensitivity Analysis

The price of diesel is subject to review by the federal government of Nigeria. The sensitivity analysis of the diesel price on the NPC and COE was carried out and shown in Figure 7. As expected, an increased diesel fuel cost increases the NPC and COE. For 100% price increase in diesel fuel the COE however increases by about 30%. This is due

to the fact that the integration of the PV/battery to the DG cushions the direct effect of the increased fuel price on the COE. For 100% increase in the price of diesel fuel in the recommended system (i.e. \$1.5/Litre), its COE is still lower than COE obtainable in PV/Battery and DG only systems (at \$ 0.75/Litre).

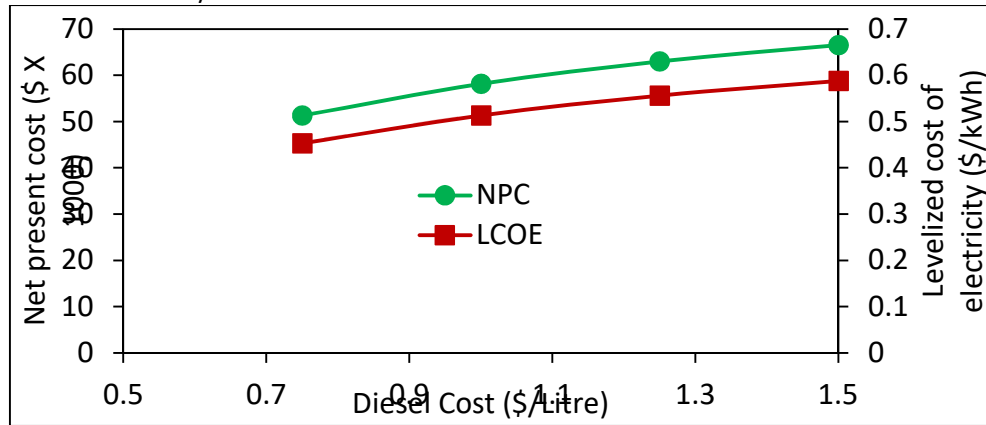


Figure 7: Hourly power output from primary energy sources (kW) over a period of 360 days

CONCLUSIONS

Different hybrid system of diesel generator/PV/battery power system were designed, analyzed and compared with that of a hybrid diesel generator/PV/battery power system installed at a telecommunication substation located in Mabushi, Abuja, Nigeria. The following conclusions were drawn from the study.

1. The installed DG/PV/Battery system is oversized when compared to the optimized DG only system, DG/ Battery system and DG/PV/Battery system. Analysis shows that the required DG to power the site is 4.1 kW as compared to 17 kW installed at the substation.
2. The installed DG/PV/Battery system has the least capacity factor of 6.42% as compared to the optimized DG/PV/Battery system (capacity factor of 16.88 %)

presented in this study. This implies that the installed system is highly under-utilized when compared to other systems considered.

3. The optimized PV/Battery system has the highest NPC and COE of \$97344 and \$0.86 respectively. The capital cost is the dominant cost of the PV/Battery system contributing about 87.5% to the NPC.
4. The optimized PV/Battery/DG gave the least NPC and COE of \$97344 and \$0.86 respectively as compared to the NPC and COE of \$97344 and \$0.86 respectively for the presently installed PV/Battery/DG power system. This implies that the optimized PV/Battery/DG system is the most viable of all the systems considered in the present study and is therefore recommended for installation at the studied telecommunication substation.



5. The sensitivity analysis of the diesel price on the COE in the recommended system shows that for 100 % price increase in diesel fuel, the COE increases by about 30%. This is due to the fact that the integration of the PV/battery to the DG cushions the direct effect of the increased fuel price on the COE.
6. The recommended configuration (Optimized DG/PV/Battery system) also has the lowest emissions beside the pure renewable system (optimized PV/Battery system).

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