Mindanao Journal of Science and Technology Vol. 18 (1) (2020) 16-34

A Comparative Analysis of Techno-Economic Viability of Hybrid Renewable Systems as Sustainable Alternative for Energizing Selected Base Transceiver Station in Ogun State, Nigeria

Ignatius K. Okakwu[1*], Olakunle E. Olabode[2], Akintunde S. Alayande[3], Olanike O. Ade-Ikuesan[1] and Adedoyin M. Sulaiman[4]

[1]Department of Electrical and Electronics Engineering
[4]Department of Mechanical Engineering
Olabisi Onabanjo University
Ago-Iwoye, Nigeria
[*]*igokakwu@yahoo.com*

[2]Department of Electrical, Electronics and Computer Engineering
Bells University of Technology
Ota, Nigeria

[3]Department of Electrical and Electronics Engineering
University of Lagos
Akoka-Yaba, Nigeria

Date received: September 11, 2019
Revision accepted: October 22, 2019

Abstract

This paper presents a comparative analysis of techno-economic viability of four different system configurations (photovoltaic [PV]/diesel generator [DG], PV/battery [BAT], DG/BAT and DG-only) for energizing outdoor telecommunication sites located within the latitude 7.15˚N and longitude 3.35˚E of Abeokuta, Ogun State, Nigeria. The site used in this study has a maximum and average load of 1697 W and 39.6 kWh/day, respectively. Among all configurations examined, PV/BAT system configuration achieved the lowest life cycle cost (LCC) of ₦133,064,109 and cost of energy (COE) of ₦0.70 with a renewable fraction of 100%, adjured as the most cost-benefit configuration. However, the configuration with the least initial capital cost of ₦4,375,000 (DG-only) was the worst system configuration due to its high LCC (₦593,667,359) and COE (₦12.95). Suffice it to know that both high fuel consumption and exorbitant cost of maintenance account for this unfavorable scenario of DG-only system configuration. In line with the results obtained, it is unarguable that the system configuration with least initial capital cost might not be necessarily be the most suitable system configuration for any proposed telecommunication site. Conclusively, hybrid renewable system configuration showed superior performance relative to the long-used orthodox DG-only system.

Keywords: base transceiver station, cost of energy, hybrid renewable system, life cycle cost

1. Introduction

Prior to the advent of telecommunication industries in Nigeria, primitive systems of communication were employed. These systems include courier services, landline telephone, sending letters to exchange vital information through postal services, and personal travelling for message delivery. Most of the time, establishment of business contracts were more of face-to-face discussion. These communication systems, though suitable for their communication needs, are grossly inadequate for this present dispensation. Also, apart from the fact that the process of establishing contact between the senders and receivers is indeed time exhaustive, the information sent tends to suffer distortion either in magnitude or in content. In addition, there is high likelihood that the receivers might not be able to decipher the ideal meaning of the sent information.

The desire to shoulder communication processes appropriately and effectively has led to the advent of global system of telecommunication (GSM). Its real time espousal in Nigeria could be traced in the early days of the year 2000. This alone has demonstrated a distinct revolution not only on the global economy but also on the degree with which people dole out information and knowledge across the country (Aris and Shabani, 2015; Ogunjuyigbe and Ayodele, 2016). It has afforded both the common and cream of the society in Nigerian access to cheaper, efficient and reliable means of communication within a wink of an eye (Ogunjuyigbe and Ayodele, 2016). Business contacts can be initiated without facial contact; at a dial in mobile phones, information is disseminated without third parties. A means to establish efficient and reliable communication link between the GSM network provider and end users' mobile phone is the antennae which is being carried by the telecommunication mast housed at the base transceiver station (BTS). At the global perspective, there are more than four million BTS worldwide with which over six billion subscribers served (Faruk *et al*., 2012; Diamantoulakis and Karagiannidis, 2013; Aderemi *et al*., 2018). Nigeria has over 24,252 BTS sites across the country with 1,692 sites connected to the national grid while about 12,560 sites are entirely off-grid (Global System for Mobile Communications Association [GSMA], 2013a; Olatomiwa *et al*., 2014).

One of the major challenges impeding effective, reliable and sustainable operation of GSM base transceiver stations in Nigeria is traceable to erratic power supply across the country (Enwereuzor, 2016). The research reports of GSMA (2013b) and Olatomiwa *et al*. (2015b) confirmed that power available to many of these electrified communities within the country is approximately below 5 hours (h) on the average in a day. However, the energy requirement of BTS is far above what is obtainable from the national grid system. It is important to point out that BTS equipment alone consumed over 57% of total energy required for effective, reliable and sustainable GSM network operation (Alsharif *et al*., 2015). Yeshalem and Khan (2017) showed that the mobile BTS power consumption pattern is in direct proportion to traffic pattern of the mobile phone users. Report findings of GSMA (2013a) and Olatomiwa *et al*. (2015b) revealed that of the 1,692 sites that are grid connected, 9% experienced about 6 h loss of supply from the grid daily, 10% witnessed 6-12 h daily outage while the remaining 81% experienced daily cut away from supply for more than 12 h. To stay out of this lopsided and erratic power supply from the national grid, the diesel generator (DG) set was at start presumed to be an apposite standby to achieve steady, stable, reliable and sustainable power supply since its power supply is foreseeable and void of climate dependency (Ayodele and Ogunjuyigbe, 2016). However, high cost involvement in diesel procurement, prolonged downtime in the event of mechanical faults as well as its environmental negative impact in form of emission CO_2 and other dangerous greenhouse gases, proved DG to be capital intensive and difficult to rely on (Oyedepo and Adaramola, 2012). Renewable energies such as wind, solar, biomass and among others are thus proposed as sustainable, reliable, scalable and cost-effective alternative power supply for telecom BTS sites.

Several works on this concept have been reported over time. Reiniger *et al*. (1986) presented that the leading papers on hybrid power system came into being as early as mid-1980s. However, its widespread acceptance for different applications such as rural electrification project, powering of dam, and deep water well started in the early part of 1990s (Adebanji *et al*., 2017). Its successful application to power different GSM network base transceiver stations have been researched by many authors across the globe. In Bangladesh, Moury and Khandoker (2012) carried out the viability of using grid connected solar photovoltaic (PV) array only to power BTS. The results showed that the proposed approach provided cost-effective backup for the grid supply. The reliability and efficiency of solar PV array is limited considerably by the weather and climatic condition. In the Himalayas of south Asia, hybrid of PV/wind turbine (WT)/DG has been deployed to power BTS sites successfully. The estimated cost of the proposed hybrid system was found to be $81,512.04 Canadian dollars. The authors concluded that the proposed hybrid system guaranteed 24/7 reliably power supply for the targeted cellular mobile services at remote site of Nepal (Acharya and Dutta, 2013). In India, BTS sites located in southern India have been reported to have successfully powered with hybrid power systems using different configurations for the same load demand. Different configurations were analyzed to find the most suitable option based on the net present cost (NPC). The authors gave a list of suggested optimum configurations obtained with Hybrid Optimization Model for Electric Renewables (HOMER) software in the order of values obtained for the NPC of each configurations (Afzal *et al.*, 2010). Aderemi *et al.*, (2018) investigated techno-economic viability of using PV/battery (BATT) and PV/DG configurations of hybrid power systems (HPS) to power BTS sites situated in rural area of Soshanguve, South Africa. Both HOMER and MATLAB Simulink were employed as implementation tools. The authors concluded that PV/BATT was the most suitable configuration to meet the energy need of the proposed sites based on values obtained for NPC, levelized cost of energy (LCOE), operations and maintenance, and greenhouse gas emission. The sensitivity and reliability analyses of the said optimum configuration were not investigated. Yeshalem and Khan (2017) presented economic viability of PV/BATT and PV/WT/BATT compared to DG alone for power BTS sites in rural area of Ethiopia. HOMER software was used techno-economic analysis using NPC, LCOE, renewable fractions (RF), fuel consumption, capacity shortage, and excess electricity generation as the bases of comparison. PV/BATT configuration was found out as the most suitable configuration.

Also in Nigeria, the adoption of HPS for powering BTS sites is not a new thing, even its application has been extended to several other area of applications such as rural electrification (Akinbulire *et al.*, 2014; Adebanji *et al.*, 2017), household or domestic electrification (Modu *et al.*, 2018), primary health centers electrification (Adeyeye *et al.*, 2018), small-scale business ventures powering (Oti and Lewachi, 2017) and university communities electrification (Ikechukwu and Abam, 2018). Olatomiwa *et al.* (2015b) examined the techno-economic viability of hybrid PV/DG/BATT and PV/WT/DG/BATT for powering BTS sited in remote area in Nigeria. The cost effectiveness and environmental friendliness were used as the criteria to justify the most suitable configuration. HOMER software was employed for simulation, optimization and analysis. PV array (10 kW)/ DG (5.5 kW)/BATT (64 units Trojan L16P) was adjured as the most economically viable configuration based on NPC and CO_2 emission. Also, techno-economic viability of PV/DG/BATT, PV/WT/DG/BATT, PV/DG and DG/BATT hybrid system was analyzed using LCOE and CO_2 emission to power BTS sites located in Lagos, Nigeria (Olatomiwa *et al.*, 2014). HOMER software was explored for optimal sizing of different configurations examined. Overall, the PV/DG/BATT configuration system was identified as most economic viable and sustainable for the proposed site. Similarly, Ogunjuyigbe and Ayodele (2016) examined hybrid configurations of PV/DG/BATT, PV/BATT, DG/BATT, DG-only and PV-only to power BTS sites located in Ibadan, Oyo State. The HOMER software was used and the comparison assessment was done using NPC and lowest life cycle cost (LCC). In all cases considering 25 years project life cycle, PV/DG/BATT achieved the most economical viability. The said optimum configuration comprise PV (50 kW), DG (10 kW), Trojan LI6P (300 numbers) and converter (10 kW). This present work examined different system configurations of PV/DG, PV/BAT, DG/BAT and DG-only system in powering a BTS site in Ogun State, Nigeria.

2. Methodology

2.1 The Load Profile of the Case Study

The load profile was obtained from the power ratings of all available equipment in the BTS site with a special consideration given to the time interval of all power equipment. Generally, outdoor telecommunication sites are equipped with internal cooling mechanism supported with natural air-cooling system since these sites are not provided with air conditioning system. Presented in Table 1 is the load profile of the BTS Site of interest. The maximum demand is around 1.697 kW with an average load usage of 39.6 kWh/day.

Table 1. Load profile of the BTS site under investigation

Power Consumption of a 2G Outdoor Telecommunication Site in Nigeria						
Description of System Component	Vendor/Model	Power Ratings (W)	Quantity	Total Wattage (W)	Hours Usage per day	Total Wattage-hour (KWh/day)
Transmission Radio	Ceragon	100	3	300	24	7.2
RF Antenna	Huawei	100	3	300	24	7.2
(Sector)	Huawei	100	3	300	24	7.2
1800MHz RRU	Huawei	100	3	300	24	7.2
900MHz RRU	Huawei	100	3	300	24	7.2
Rectifier	Huawei	100	1	100	24	2.4
Lighting lambs	Ericsson	36	2	72	12	0.9
Aviation light	Ericsson	25	1	25	12	0.3
Total Average Energy Consumption				1697	168	39.6

2.2 Description of Site Location

BTS site used in this study is located in Abeokuta, Ogun State, South-Western, Nigeria (lat. 7.15°N and long. 3.35°E). The data obtained from Nigeria Meteorological Agency for monthly average daily solar irradiation for site are presented in Table 2.

Table 2. The average monthly solar radiation

Months of the year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
Average Solar ($kWh/m^2/day$)	5.50	5.70	5.64	5.35	5.09	4.57	4.00	3.79	4.11	4.70	5.11	5.35

2.3 System Configuration

In this study, four system scenarios were considered – PV/DG, PV/BAT, DG/BAT and DG-only systems. The configuration of each system is shown in Figure 1.

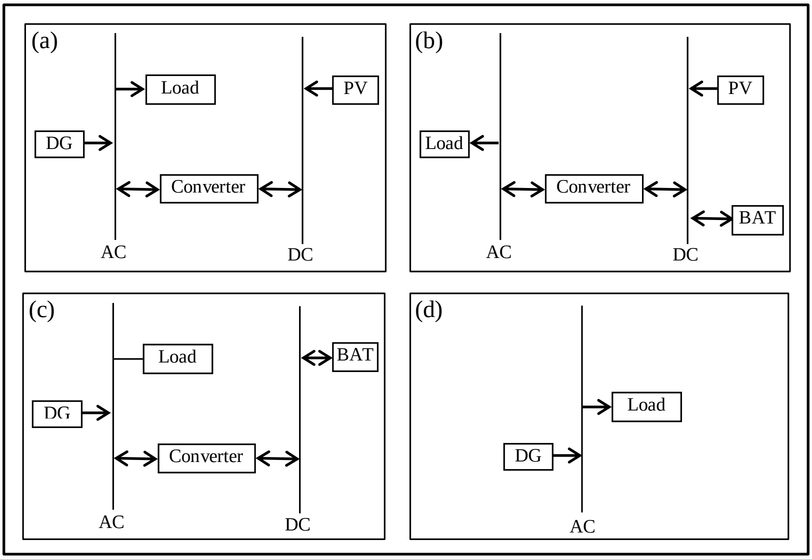

Figure 1. System configurations – PV/DG (a), PV/BAT (b), DG/BAT (c) and DG only (d)

2.4 Components of the Hybrid System

The hybrid system components comprised PV panels, DG, converter, batteries and charger controllers. The PV panels, batteries and DG were combined to provide the system output and unforeseen variation of renewable fraction (RF) sources. Increasing the RF of the hybrid system tends to lower both maintenance and replacement cost of the DG (Olatomiwa *et al*., 2015a). The detailed assumptions regarding components prices were as follows:

The capital cost of 250W, 24V polycrystalline module solar panel is taken as ₦55,000.00. The PV panel lifetime was taken as 25 years with a de-rating factor of 5% per year.

The 16 kW AC diesel generator initial capital cost was as ₦3,500,000.00 with a diesel consumption of 2.5 L per hour. The cost of sundry was ₦875,000.00. The operating lifetime of DG was 15,000 h and the DG was maintained at every 250 run hours. The diesel price was ₦240 per L.

The initial capital cost of a 2.5 kW, 48V/230AC, 50Hz bi-directional converter was ₦225,000.00 with a lifetime and efficiency of 10 years and 90%, respectively.

The initial capital cost of a unit 12V trojan deep cycle battery of 200Ah was taken to be ₦180,000.00 with a lifetime of five years.

The initial cost of a 100A, 24V solar charge controller was taken at ₦300,000.00.

The cost of cable installation materials, other accessories and civil work was ₦1,600,000.00.

Installation cost and cost of item delivery to site location were ₦750,000.00 and ₦265,000.00, respectively. One US dollars was equivalent to ₦360 as at the conduct of this study.

2.5 Solar PV Ray

The PV-array area is governed by Equation 1 (Bataineh and Dalalah, 2012).

$$PV_{area} = \frac{E_{LD}}{G_{in} \times \eta_{PV} \times TCF \times \eta_{out}} \tag{1}$$

where:

E_{LD} = average daily load (kWh/day)
G_{in} = case study average daily radiation (kWh/m^2/day)
η_{PV} = PV module efficiency
TCF = correction factor temperature
η_{out} = efficiency of the output

Also, output efficiency was modelled mathematical using Equation 2 (Bataineh and Dalalah, 2012).

$$\eta_{out} = \eta_{B} \times \eta_{inv} \tag{2}$$

where:

η_{B} = efficiency of the battery
η_{inv} = efficiency of the inverter

Similarly, the power output of a photovoltaic array was modelled using Equation 3 (Khaled and Doraid, 2012).

$$PV_{output} = PV_{area} \times PSI \times \eta_{PV} \times SF \tag{3}$$

where:

PSI = standard test conductions peak solar intensity (1000W/m^2)
SF = losses factor of safety

Also, number of PV-modules cascaded in series (NM_s) was expressed using Equation 4 (Jogunuri *et al*., 2017).

$$NM_S = \frac{System\ Voltage\ (V_{system})}{Module\ Voltage\ (V_{module})} \tag{4}$$

The number of modules in parallel (NM_p) was obtained with the aid of Equation 5 (Jogunuri *et al*., 2017).

$$NM_P = \frac{PV_{output}}{NM_s \times P_{module}} \tag{5}$$

where:

P_{module} = power output of the module

The total number of module (NM_{total}) required was attained using Equation 6 (Jogunuri *et al.*, 2017).

$$NM_{total} = NM_P \times NM_S \tag{6}$$

2.6 Battery Storage System

The capacity of the battery storage was modelled using Equation 7 as reported by Jogunuri *et al*. (2017).

$$B_{St} = \frac{E_{LD} \times A_d}{DOD \times \eta_g \times V_{system}} \tag{7}$$

where:

A_d = days of battery autonomy
DOD = depth of discharge

In this study, *DOD* of 80% was used for this research.

The number of batteries in parallel (NB_p) was expressed using Equation 8 of Jogunuri *et al*. (2017).

$$NB_p = \frac{B_{st}}{Unit\ battery\ rated\ capacity} \tag{8}$$

Also, number of batteries to be cascaded in series (NB_s) was obtained using Equation 9 (Jogunuri *et al.*, 2017).

$$NB_s = \frac{V_{system}}{B_v} \tag{9}$$

where:

B_v = battery unit voltage

Hence, the aggregate number of batteries (NB_r) needed was given using Equation 10 (Jogunuri *et al.*, 2017).

$$NB_r = NB_s \times NB_p \tag{10}$$

2.7 Inverter System

The essence of inverter in a hybrid configuration is for conversion DC voltage obtained from the batteries to AC voltage needed by the connected load (Esan and Egbune, 2017). Essentially, both the inverter and the battery must have the same nominal voltage and for safety purposes. The inverter should be 25.30% larger in rating relative to load. The rating of the inverter was given by Esan and Egbune (2017).

$$Inv_{rating} = Total\ load\ wattage + [0.3\ x\ total\ load\ wattage] \tag{11}$$

2.8 Solar Charge Controller

To match the voltage of the photovoltaic module and the batteries, solar charge controller is needed. The charge controllers are designed to effectively manage the maximum current generated by photovoltaic systems. Its voltage is comparatively compatible with voltage of the system. The solar charge controller rating (SCCR) was governed by Equation 12 (Guda and Aliyu, 2015) expressed as:

$$SCCR = I_{SC} \times NM_P \times SF \tag{12}$$

where:

I_{SC} = short-circuit current of the PV-array (8.74A)

In a nutshell, the number of controllers needed for parallel connection was obtained utilizing the Equation 13 of Guda and Aliyu (2015).

$$NCC_p = \frac{SCCR}{Ampere\ per\ controller} \tag{13}$$

2.9 System Economic Charger

The parameters for economic evaluation of a hybrid configuration consist of LCC and levelized cost of energy (LCE). The LCC comprises the aggregate investment cost are decommissioning, maintenance, operation and replacement. The LCC is designed to fish out the most cost-effective configuration among other available alternatives. The mathematical model for LCC was given by Oti and Lewachi (2017) as:

$$LCC = OC+OM+R+F \tag{14}$$

where:

OC = Investment capital cost
OM = cost of operation and maintenance
R = cost of replacement

F = cost of fuel
SV = salvage value

The OM was modeled using Equation 15 (Abaka *et al*., 2017) expressed as:

$$OM = F_I \times OC \times \left[\left(\frac{1+F_e}{d\text{-}F_e}\right) \times \left(1\text{-}\left(\frac{1+F_e}{1+d}\right)^N\right)\right] \tag{15}$$

where:

F_I = percentage (5%) of initial capital cost (Gupta, 2015)
F_e = escalation rate, assumed to be 20% (Otasowie and Ezomo, 2014)
d = discount rate, assumed to be 17.71% (Adeyeye *et al*., 2018)
N = number of years

The cost of replacement (R) was modeled as:

$$R = P \times (1+i)^N \tag{16}$$

where:
P = initial capital cost for replaced component
i = rate of interest, assumed to be 15.37% (Oti and Lewachi, 2017)

It is worthwhile to note that battery is usually the component to be replaced for solar system, while the generator is frequently replaced after 15,000 run hours for a diesel generator.

The cost of fuel (F) was obtained with the aid of Equation 17 (Oti and Lewachi, 2017) expressed as:

$$F = C_A \times A_D \times \left[\left(\frac{1+F_e}{d\text{-}F_e}\right) \times \left(1\text{-}\left(\frac{1+F_e}{1+d}\right)^N\right)\right] \tag{17}$$

where:
C_A = cost per liter of diesel (₦240)
A_D = yearly diesel consumption

$$A_D = \textit{average consumption per day} \times 365 \tag{18}$$

The existing 20 kVA generator consumes 60 L of diesel per day as indicated in the BTS logbook. The Cost of energy (COE) represents the net present value of the unit cost of electricity over the lifetime of each electricity generating asset (Oti and Lewachi, 2017). It was modelled mathematical using Equation 19.

$$COE = \frac{\sum_{i=1}^{n} \frac{OC + OM + R + F}{(1+d)^t}}{\sum_{i=1}^{n} \frac{E_t}{(1+\mathrm{d})^t}} \tag{19}$$

where:

E_t = electrical energy produced in (t) year

Renewable energy fraction (REF) stands for aggregate power produced by the renewable energy sources relative to the power generated from the entire hybrid configuration (Al-Shamma'a and Addoweesh, 2012). This was obtained using Equation 20 expressed as:

$$REF = \left(1 - \frac{E_{L,DG}}{E_{L,served}}\right) \times 100\% \tag{20}$$

The REF of 100% means pure renewable system and 0% implies pure diesel system.

3. Results and Discussion

The simulation was done by juxtaposing the four different system configurations (PV/DG, PV/BAT, DG/BAT and DG-only). The optimal results obtained for the hybrid system are presented in Table 3. A vivid analysis of Table 3 shows that the least initial capital cost of approximately ₦4,375,000 was achieved with DG-only configuration which amounts to the following: about 15.28% of the initial capital cost of PV/BAT configuration; 20.13% of initial capital cost of PV/DG and 51.50% of initial cost of DG/BAT configuration. Also, Table 3 shows that the PV/BAT configuration has the highest initial capital cost which brands the DG-only configuration to be easily accessible to the telecom operators when special consideration is given to the initial cost.

Table 3. Comparison of various System Configurations

System configuration	PV/DG	PV/BAT	DG/BAT	DG-only
COE (₦/kWh)	5.11	0.70	5.59	12.95
LCC (₦)	478,969,756	133,064,109	256,327,586	593,667,359
Initial capital cost (₦)	21,735,000	28,640,000	7,255,000	4,375,000
O & M cost (₦)	103,182,637	46,435,428	28,373,604	85,120,813
Fuel cost (₦)	113,624,120	0.00	56,812,060	170,436,180
Replacement cost (₦)	240,427,999	57,988,681	163,886,921	333,735,366
RF (%)	33.33	100.00	0.00	0.00

The result of the analysis (Table 3) also reveals that the PV/BAT system configuration has the least LCC of ₦133,064,109 and COE of ₦0.70, followed by DG/BAT (LCC = ₦256,327,586; COE = ₦5.59), PV/DG (LCC = ₦548,238,438; COE = ₦5.85), and DG-only (LCC = ₦593,667,359; COE = ₦12.95). This places the PV/BAT system configuration as the best system configuration with the lowest LCC and COE. On the other hand, DG-only is the worst system configuration with the highest LCC and COE for providing power sources for a telecommunication site.

Figures 2 and 3 show the LCC and COE for all system configurations for a lifetime of 25 years. Figure 2 shows how the LCC of the system configuration increases exponentially. Figure 2 portrays a breakeven point of 10 years between two configurations, PV/DG and DG-only, and between DG/BAT and PV/BAT. This implies that the DG-only is more economical than PV/DG and DG/BAT is more economical than PV/BAT in the first 10 years. Figure 3 shows the COE for all the four system configurations. PV/BAT has the lowest COE while DG-only has the highest COE. Therefore, the DG-only system configuration shows to be the worst one, despite its least initial capital cost, due to its high maintenance and fuel cost. It can be deduced from the obtained result that configuration with the least initial capital cost may not necessarily be the configuration that will guarantee lowest COE. Hence, addition of renewable source like PV system and batteries to the long-used diesel system configuration is regarded as an excellent investment cost, relative to maintenance and fuel consumption.

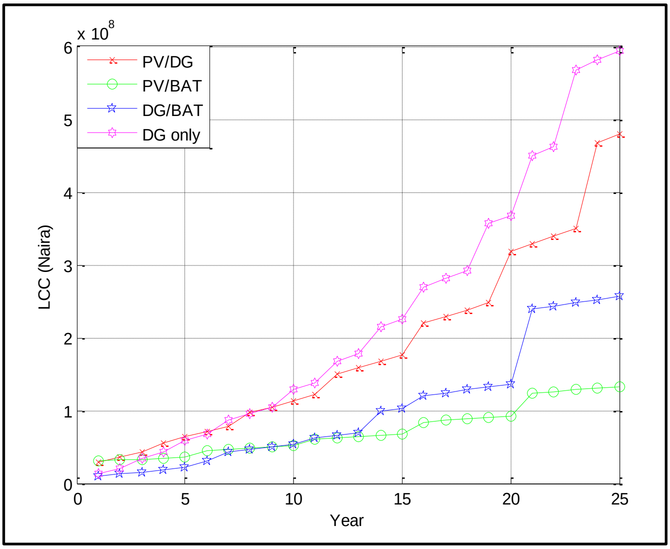

Figure 2. LCC of different system configurations

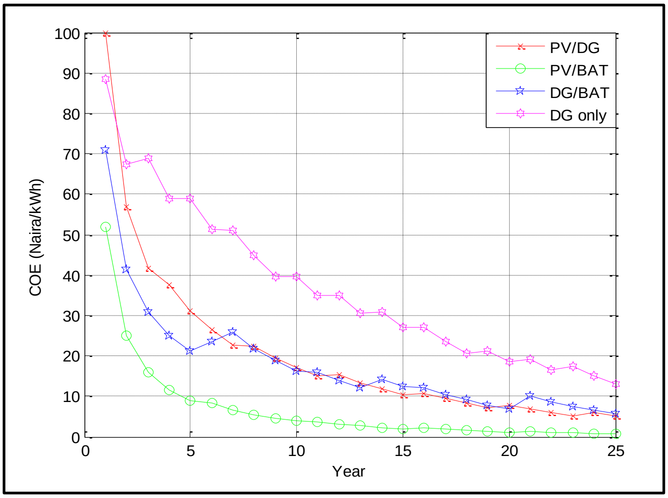

Figure 3. COE of different system configurations

Sensitivity analysis showcases how changes in some variables will affect economic value. Figures 4 to 6 show the effect of interest and discount rates and diesel price on COE of the different configurations. Figure 4 shows that COE is directly proportional to interest rate while Figure 5 shows that COE is inversely proportional to discount rate. The COE increases as the interest rate increases; the COE decreases as the discount rate increases. Figures 6 depicts that COE increases as diesel price increases. From the said figures, it can be observed that the best configuration is the hybrid PV/BAT, followed by PV/DG and DG/BAT, while DG-only is the system with the worst case scenario. The worst case configuration result is in agreement with the findings of Olatomiwa *et al*. (2014).

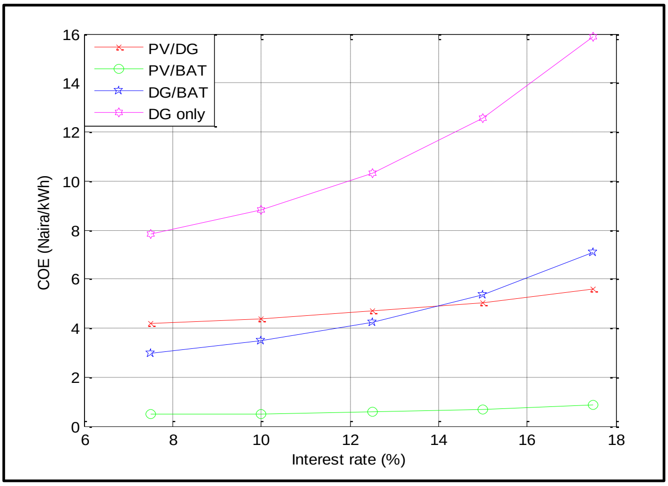

Figure 4. Sensitivity analysis of interest rate against COE

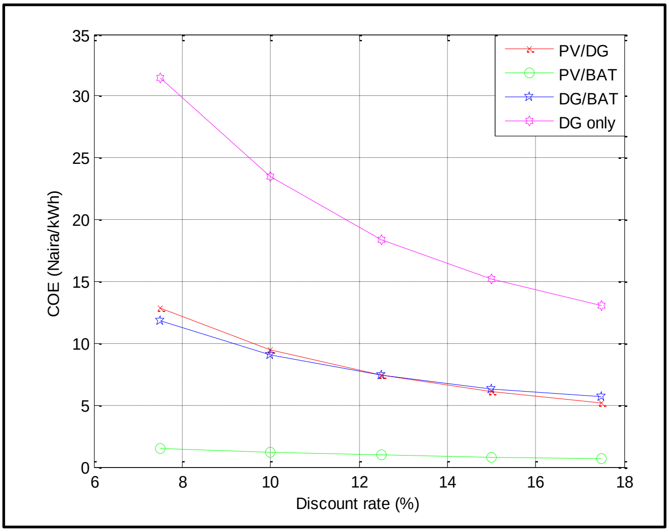

Figure 5. Sensitivity analysis of discount rate against COE

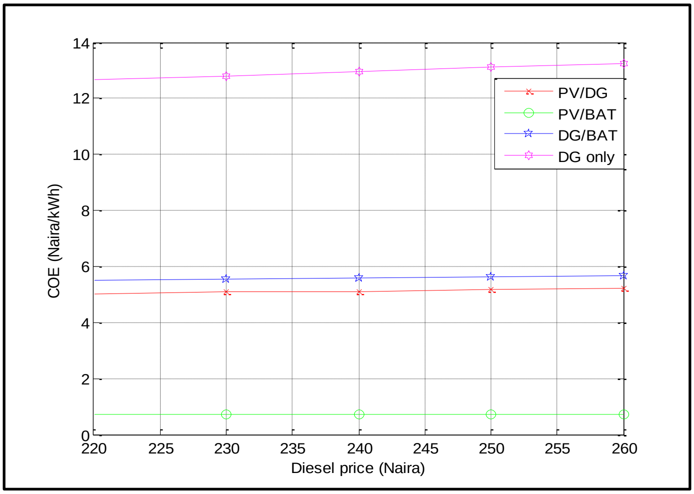

Figure 6. Sensitivity analysis of diesel price against COE

The above sensitivity results reveals that policy makers should encourage decrease in interest rate, increase in discount rate and decrease in fuel price for renewable energy technology investors.

4. Conclusion

This study compared four different (PV/DG, PV/BAT, DG/BAT and DG-only) system configurations for energizing an outdoor BTS station in Nigeria. In concomitant with the results of the analysis, appropriately sized PV/BAT configuration was adjured the best optimal system configuration since it obtained the lowest LCC and COE as compared to other investigated configurations. The PV/BAT configuration has LCC of ₦133,064,109 and COE of ₦0.70 with the highest initial capital cost of ₦28,640,000. Although, the DG-only system configuration recorded the least initial capital cost (₦4,375,000), it can be considered as the worst system configuration due to its high LCC (₦593,667,359) and COE (₦12.95). High fuel consumption and maintenance cost are major potential factors responsible for this undeserved scenario. This shows that the configuration with the least initial capital cost may not necessarily result in lower cost of energy. Therefore, it is safe to advise telecommunication operators to invest more on renewable sources of energy in powering the BTS site instead of the usual DG-only system.

5. References

Abaka, J.U., Iortyer, H.A., & Ibrahim, T.B. (2017). Sizing and economic assessment of PV and diesel generator for rural Nigeria. The International Journal of Engineering and Science, 6, 10-17. doi: 10.9790/1813-0610021017

Acharya, D., & Dutta, A. (2013). Solar and wind hybrid power for an extremely remote mobile base station. Guelph Engineering Journal, 5, 1-10.

Adebanji, B., Adepoju, G.A., Oni, J.O., & Olulope, P.K. (2017). Optimal sizing of an off-grid small hydrophotovoltaic-diesel generator hybrid power system for a distant village. International Journal of Scientific and Technology Research, 6(8), 208-213.

Aderemi, B.A., Chowdhury, S.P.D., Olwal, T.O., & Abu-Mahfouz, A.M. (2018). Techno-economic feasibility of hybrid solar photovoltaic and battery energy storage power system for a mobile cellular base station in Soshanguve, South Africa. Energies 11(6), 1572-1572. https://doi.org/10.3390/en11061572

Adeyeye, A., Tsado, J., & Olatomiwa, L. (2018). Techno-economic analysis of pv/diesel/battery hybrid renewable system for remote primary healthcare center. Proceedings of the International Conference of Mechanical Engineering, Energy Technology and Management, Ibadan, Nigeria, 173-179.

Afzal, A., Mohibullah, M., & Sharma, V.K. (2010). Optimal hybrid renewable energy systems for energy security: A comparative study. International Journal of Sustainable Energy, 29(1), 48-58. https://doi.org/10.1080/14786460903337241

Akinbulire, T.O., Oluseyi, P.O., & Babatunde, O.M. (2014). Techno-economic and environmental evaluation of demand side management techniques for rural electrification in Ibadan, Nigeria. International Journal of Energy and Environmental Engineering, 5, 132-137. https://doi.org/10.1007/s40095-014-0132-2

Alsharif, M. H., Nordin, R., & Ismail, M. (2015). Green wireless network optimization strategies within smart grid environments for long term evolution (LTE) cellular networks in Malaysia. Renewable Energy, 85, 157-170. https://doi.org/10.10 16/j.renene.2015.06.044

Al-Shamma'a, A.A., & Addoweesh, K.E. (2012). Optimum sizing of hybrid PV/wind/battery/diesel system considering wind turbine parameters using genetic algorithm. Proceedings of 2012 IEEE International Conference on Power and Energy (PECon), Kota Kinabalu, Malaysia, 121-126.

Aris, A.M., & Shabani, B. (2015). Sustainable power supply solutions for off-grid base stations. Energies, 8(10), 10905-10941. https://doi.org/10.3390/en81010904

Ayodele, T.R., & Ogunjuyigbe, A.S.O. (2016). Wind energy potential of vesleskarvet and the feasibility of meeting the South African's SANAE IV energy demand. Renewable and Sustainable Energy Reviews, 56, 226-234. https://doi.org/10. 1016/j.rser.2015.11.053

Bataineh, K., & Dalalah, D. (2012). Optimal configuration for design of stand-alone PV system. Smart Grid and Renewable Energy, 3, 139-147. http://dx.doi.org/10. 4236/sgre.2012.32020

Diamantoulakis, P.D., & Karagiannidis, G.K. (2013). On the design of an optimal hybrid energy system for base transceiver stations. Journal of Green Engineering, 3, 1-19.

Enwereuzor, O. (2016). Techno-economic modelling and simulation of cost-effective and reliable off-grid hybrid energy system for GSM transceiver station in Nigeria. Proceedings of the 2nd African International Conference/Workshop on Application of Nanotechnology for Energy, Environment and Health: African Scenario, Nsukka, Nigeria, 73-83.

Esan, A.B., & Egbune, D. (2017). Estimating the solar home system sizing for rural residential apartments using a panel tilt angle of 82 degrees: Ilorin, Kwara State as case study. American Journal of Electrical and Computer Engineering, 2(1), 90-96. doi: 10.11648/j.ajece.20170102.15

Faruk, N., Ayeni, A.A., Muhammad, M.Y., Abdulkarim, A., & Moses, O. (2012). Hybrid power systems for cell sites in mobile cellular networks. Journal of Selected Areas in Renewable and Sustainable Energy, 8-12.

Global System for Mobile Communications Association (GSMA). (2013a). Market Research and Analysis. Bi-annual Report July 2013. GSMA: London, UK: GSMA.

Global System for Mobile Communications Association (GSMA). (2013b). Powering Telecoms: West Africa Market Analysis. London, UK: GSMA.

Guda, H.A., & Aliyu, U.O. (2015). Design of a stand-alone PV-system for a resident in Bauchi. International Journal of Engineering and Technology, 3, 36-44.

Gupta, M. (2015). Economic analysis of renewable energy-based power generation system using LCC analysis techniques. International Journal of Scientific Research and Education, 3, 4545-4554.

Ikechukwu, I.F., & Abam F.I. (2018). Evaluation of photovoltaic-hydro-diesel hybrid system for electricity generation. Umudike Journal of Engineering and Technology, 4(1), 45-51.

Jogunuri, S., Kumar, R., & Kumar, D. (2017). Sizing an off-grid PV-system. Proceedings of the IEEE International Conference on Energy, Communication, Data Analytics and Soft Computing, Chennai, Tamil Nadu, India, 2618-2622.

Modu, B., Aliyu, A.K., Bukar, A.L., Abdulkadir, M., Gwoma1, Z.M., & Mustapha, M. (2018). Techno-economic analysis of off-grid hybrid PV-diesel-battery system in Katsina state, Nigeria. Arid Zone Journal of Engineering, Technology and Environment, 14(2), 317-324.

Moury, S., & Khandoker, M.N. (2012). Feasibility study of solar PV arrays in grid connected cellular BTS sites. Proceedings of the 2012 International Conference on

Advances in Power Conversion and Energy Technologies (APCET), Mylavaram, Andhra Pradesh, 1-5.

Ogunjuyigbe, A.S.O., & Ayodele, T.R. (2016). Techno-economic analysis of stand-alone hybrid energy system for Nigerian telecom industry. International Journal of Renewable Energy Technology, 7(2), 148-162. https://dx.doi.org/10.1504/IJRET.2016.076089

Olatomiwa, L.J., Mekhilef, S., & Huda, A.S.N. (2014). Optimal sizing of hybrid energy system for a remote telecom tower: A case study in Nigeria. Proceedings of the IEEE Conference on Energy Conversion (CENCON), Johor Bahru, Malaysia, 243-247.

Olatomiwa, L.J., Mekhilef, S., Huda, A.S.N., & Ohunakin, O. (2015a). Economic evaluation of hybrid energy systems for rural electrification in six geo-political zones of Nigeria. Renewable Energy, 83, 435-446. https://doi.org/10.1016/j.renene.2015.04.057

Olatomiwa, L., Mekhilef, S., Huda, A.S.N., & Sanusi, K. (2015b). Techno-economic analysis of hybrid PV–diesel–battery and PV–wind–diesel–battery power systems for mobile BTS: The way forward for rural development. Energy Science and Engineering, 3(4), 271-285. https://doi.org/10.1002/ese3.71

Otasowie, P.O., & Ezomo, P.I. (2014). Life cycle cost analysis of diesel generator set and national grid in Nigeria. Journal of Emerging Trends in Engineering and Applied Science, 5(5), 363-367.

Oti, O.F., & Lewachi, A.A. (2017). Analysis of economic viability of solar photovoltaic systems for small off-grid electricity generation in Nigeria. Umidike Journal of Engineering and Technology, 3, 36-44.

Oyedepo, S.O., & Adaramola, M.S. (2012). Analysis of wind speed data and wind energy potential in three selected locations in South East Nigeria. International Journal of Energy and Environmental Engineering, 3, 1-8. https://doi.org/10.1186/2251-6832-3-7

Reiniger, K., Schott, T., & Zeidler, A. (1986). Optimization of hybrid stand-alone systems. Proceedings of European Wind Energy Association Conference and Exhibition, Rome, Italy, 196-210.

Yeshalem, M.T., & Khan, B. (2017). Design of an off-grid hybrid PV/wind power system for remote mobile base station: A case study. AIMS Energy, 5(1), 96-112.