Designing a Green Power Delivery System for Base Transceiver Stations in Southwestern Nigeria

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Abstract— **In recent times, a green telecommunication system that is regarded as more environmental friendly is clamoring to adequately replace the usage of Diesel Generator only (DG-only) power sources. Alternatively, the diesel generator system can combine with other power supply systems to reduce the effect of greenhouse gases emitted to the environment and to improve power supply reliability. This paper aims at establishing an optimized configuration for typically powering base transceiver stations using remarkable hybrids of Renewable Energy Sources (RESs) with optimal performance in cost consideration, emission, space management and adequate reliability in base-transceiver station area. The optimization was tested on the diverse set of hybrids of RESs for powering BTSs in Southwestern part of Nigeria using Hybrid Optimization of Multiple Electric Renewables (HOMER) micro grid Analysis Tool 3.8.7. The simulated results show that hybrid H_2 made of Photovoltaic Cell (PV), Wind Turbine, Diesel Generator, Battery Storage and Converter has the lowest Total Net Present Cost (TNPC) in Lagos, Ogun and Oyo States while hybrid H_1 made of PV and DG emerged as the best in Ondo, Ekiti and Osun States. Hybrid H_2 with desired characteristics has an average TNPC reduction of 35.01 % over the present system of Diesel Generator-only. Further results revealed precisely that TNPC responds more to change in the global horizontal irradiation than any other uncontrollable variables. These notable findings will be extremely applicable for a cost-effective and environmentally friendly powering schemes that may be efficiently implemented on BTSs in different Southwestern regions of Nigeria.**

Index Terms— **Environmental friendly, Green telecommunication, HOMER-3, Optimal Performance, Renewable Energy.**

I. Introduction

THE economic expansion of the network coverage of the Global for Mobile Systems (GSM) networks over Nigeria has increased dramatically over the last two decades. Active voice subscriptions in Nigeria stood at 148.74 million and the considerable number of Base Transceiver Stations (BTSs) locations rose from about 20,000 at the end of first quarter of 2016 [1].

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In Nigeria, powering all these BTSs round the local clock is not an easy task, as energy supplies by national grid are either very low or not available. As stated in [2], Nigerian electricity experiences about 33 outages monthly with an average period of 8 hours per day [2]. Due to the reliability nature of the utility (national grid) supply, BTS infrastructure providers use Diesel Generators (DG) to power the majority of the BTSs in the country. A litre of diesel typically releases 41.9 g of considerable variety of dangerous gases into the atmosphere, which cause air pollution, acid rain, global warming and several other induced disasters. The largest proportion of these gases is carbon dioxide called Greenhouse Gas (GHG) which is one of the causes of global warming and results in a serious problem that adversely affect human and the environment.

The intergovernmental panel on likely climate change has reported that observed GHG emissions must be halved not later than the middle of this century [3]. As a possible result of this, telecommunication energy systems should be typically designed with an adequate consideration of GHG emission [4]. In view of this, the Nigeria Communication Commission (NCC) and the National Environmental Standard and Regulation Agency (NESREA) have to be adequately provided with necessary guidelines about the likely possibility of powering BTS without much emission havoc to the local environment.

There are different configurations of renewable energy sources being deployed for telecommunication use: DG + Battery (BAT); Photovoltaic cells (PV) + DG + BAT; PV + BAT; DG + BAT + (Wind Turbine) (WT); WT + DG + BAT; PV + WT +DG + BAT [5]. [8] estimated the reliability of an optimal hybrid model of PV + WT + BAT in Nepal based on the probability of reduction in the power supply. The optimal model obtained has a considerable size of the battery bank adequately reduced to 36 % with the overall 29 % reduction in the total cost of the system. [6] equally determined the optimal configuration model for a hybrid of PV + DG + BAT for BTS in Algeria. The work revealed that fuel consumption could be reduced by 97 %. In more recent work carried out by [7] in a local village in India, the cost analysis of optimal models of hybrid systems at different load classes of BTS was carefully studied. They reasonably concluded that Cost of Energy (COE) decreases with increasing load. All the previous studies however have considered only on possible configuration, cost, enhanced sensitivity and operational reliability of optimal renewable energy supply model for powering BTS. In order to replace the present DG energy supply system in Southwestern Nigeria, the land area occupied by the BTS needs to be taken into consideration especially in cities where the economic expansion of BTS area is considered costly or not possible.

This present study addresses some of the aforementioned shortcomings associated with a renewable energy-based micro-grid system, traditional configurations and power management for telecommunication systems in Southwestern Nigeria. The optimization tool adopted for this work is termed "Hybrid Optimization of Multiple Energy Resources" (HOMER) software and is designed to handle complex renewable energy system configurations with maximum capacity of combination of RES. It also performs optimization and sensitivity analysis which makes it easier and faster to evaluate the performance of many possible RES system configurations [8-10].

The remaining part of the paper is arranged as follows; section 2 describes the methodology; section 3 discusses specific details of the possible results obtained while reasonable conclusions are carefully drawn and appropriate recommendation suggested in section 4.

II. METHODOLOGY

This section discusses the methodology adopted and employed in the present work. The optimization configuration for powering BTSs required some atmospheric parameters such as solar irradiation and wind speed of the areas under consideration, amongst others. The hybrid that meets the energy demands of the BTS will also be needed alongside with the optimization tool such as the HOMER.

A. *Site and Data Source*

Southwestern Nigeria (which comprises of Ekiti, Lagos, Ogun, Ondo, Osun and Oyo States) lies within 6.00° N to 9.00° N and 3.00° E to 6.00° E. Solar irradiation varies from North to South in the region. Wind speed in the region is relatively low compared to the far Northern part of the country. The site location lies within a humid forest with an average wind speed of 3.12 ms^{-1} and average Global Horizontal Irradiance (GHI) of 4.86 $kW/m^2/day$. Simulations were carried out based on two data sources: preprocessed data for 22 years (July 1983 to June 2005) of GHI and preprocessed data for 10 years (July 1983 to June 1993) of wind speed obtained from National Aeronautics and Space Administration (NASA), Surface Meteorology and Solar Energy (SSE) database. Tables 1 and 2, respectively present the GHI and wind speed for the study location. It must be stated here that Ondo and Ekiti States share equal renewable resources because they are close to each other. This is also applicable to Oyo and Lagos States. The GHI and the wind speed data were validated using measurement obtained from Nigerian Meteorological Agency as well as an on-site measurement from one of the study locations (Ondo).

For the purpose of this work, a combination of PV cells, WT, BAT and converter (CV) were considered. Four different feasible hybrid configurations can be identified based on the system combination. These hybrids have been categorized as: H_1 = PV + DG, H_2 = PV + WT + DG, H_3 = PV and H_4 = PV + DG. Diesel Generator (DG-only) is also included to provide the baseline or control system for comparison with the present energy system configurations used by BTS in the region.

TABLE I
AVERAGE MONTHLY GHI FOR THE STUDY LOCATIONS

Month	Solar Irradiation ($kW/m^2/d$)					
	Ondo	Oyo	Lagos	Osun	Ekiti	Ogun
Jan	5.670	5.280	5.280	5.570	5.670	5.500
Feb	5.770	5.490	5.490	5.720	5.770	5.700
Mar	5.630	5.460	5.460	5.660	5.630	5.640
Apr	5.350	5.210	5.210	5.340	5.350	5.350
May	5.030	4.760	4.760	5.020	5.030	5.090
Jun	4.560	4.040	4.040	4.510	4.560	4.570
Jul	3.980	3.950	3.950	3.890	3.980	4.000
Aug	3.780	3.980	3.980	3.730	3.780	3.790
Sep	4.090	4.090	4.090	4.060	4.090	4.170
Oct	4.650	4.550	4.550	4.620	4.650	4.700
Nov	5.260	4.550	4.550	5.180	5.260	5.110
Dec	5.500	5.170	5.170	5.370	5.500	5.350
Average	4.940	4.740	4.740	4.890	4.940	4.910

TABLE II
AVERAGE MONTHLY WIND SPEED OF THE STUDY LOCATIONS

Month	Wind Speed (ms^{-1})					
	Ondo	Oyo	Lagos	Osun	Ekiti	Ogun
Jan	2.980	4.150	4.150	3.120	2.980	3.370
Feb	3.110	4.300	4.300	3.230	3.110	3.350
Mar	3.230	4.010	4.010	3.350	3.230	3.480
Apr	3.060	3.490	3.490	3.130	3.060	3.170
May	2.590	3.000	3.000	2.650	2.590	2.900
Jun	2.630	3.120	3.120	2.680	2.630	2.820
Jul	3.360	3.700	3.700	2.810	2.740	3.360
Aug	2.810	3.870	3.870	2.870	2.810	3.490
Sep	2.650	3.500	3.500	2.700	2.650	3.320
Oct	2.350	2.830	2.830	2.410	2.350	2.620
Nov	2.690	3.050	3.050	2.740	2.690	3.160
Dec	2.660	3.65	3.65	2.79	2.66	2.990
Average	2.79	3.56	3.56	2.87	2.79	3.17

B. *Energy Consumption*

A station may be of outdoor type, room type or shelter type and the energy consumption in any of this type of station varies between 2 and 21 kW [11, 12].

It must be noted that the energy consumption of BTS is higher during operational hours of the week than weekend due to the significant number of electrical appliances used during the working hours. In addition, security and aviation lights increase energy consumption at night than in the day, despite the higher traffic in the daytime. The majority of BTSs in the studied locations were precisely the shelter type with an average rated power of 4.5 kW (a total energy consumption of approximately 108 kWh/day) as observed from the Diesel Generator output monitors of BTSs in the studied locations over a considerable period of two weeks.

C. Optimization Process

The optimizations are achieved by selecting all possible configurations of the hybrid that meets the energy demand of the BTS for a project lifetime of 25 years. The TNPC of each configuration may be evaluated by using the expression [11]:

$$TNPC\ (c_i) = N_i \times \left(CC_i + (RC_i \times M_i) + \frac{OMC_i}{CRF} \right) \quad (1)$$

where *TNPC* is the Total Net Present Cost, N_i is the total number of system component, *CCi* is the capital cost of a component, RC_i is the replacement cost of a component, M_i is the single payment present worth of a component, OMC_i is the operation and maintenance cost of a component while *CRF* is the Capital Recovery Factor. OMC_I is expressed as [11]:

$$OMC_i = C_{PV} + C_{WT} C_{DG} + C_{CONV} + C_{BAT} \quad (2)$$

where C_{PV}, C_{WT}, C_{DG} C_{CONV} and C_{BAT} are the cost of photovoltaic cell, wind turbine, diesel generator, converter and battery, respectively. The CFR can also be obtained using [11]:

$$CRF = \frac{r(r+1)^R}{(1+r)^R - 1} \quad (3)$$

subject to

$$P_{load} - P_{PV} - P_{WT} - P_{BAT} \leq 0 \quad (4)$$

where *R* and *r* are the project lifetime and the annual interest rate for the project life time, respectively. P_{load} is the BTS load while P_{PV}, P_{WT}, and P_{BAT} are energy available from output of PV, WT and BAT. The configuration with lowest TNPC is then selected based on (1) to (4).

D. Input Variables

In this work, HOMER simulation was used to obtain the economic costs of essential components based on the bulk price [13]. Table 3 summarizes all essential components used in the simulations and their economic costs. Existing BTS in the study locations covers an average land area of about 110 m^2. Due to broader land area requirement for installation of a considerable number of PV, expansion of BTS site may be required. The unnecessary cost will therefore be incurred in the course of possible expansion of the BTS site as well as extra rent. The spaces occupied by each module of the solar PV, self-support BTS mast and base area of WT turbine are 4.99 m^2, 6.93 m^2 and 3.0 m^2, respectively. It is reasonably assumed that PV can be installed above all other components except WT and BTS mast. These variables are used in the estimation of the possible increase in the site area and the unnecessary cost associated with it. The rent paid on BTS site depends on its location and to some extent on negotiation between BTS infrastructural service providers and landowners. The annualized cost of possible expansion of site area in each independent state was estimated from average rent paid to land owners on BTS sites for a period of 10 years as shown in Table 4.

TABLE III
COMPONENTS USED IN THE SIMULATION AND THEIR COSTS (1$ = ₦364.50)

Component	Type of Cost	Value
PV	Capital Cost (₦/kW)	240,000
	Replacement Cost (₦/kW)	230,000
	O & M Cost	-
	Life Span (years)	25
Converter	Capital Cost ((₦/kW)	50,000
	Replacement Cost (₦/kW)	50,000
	O & M Cost	-
	Life Span (years)	15
Battery	Capital Cost (₦/kW)	110,000
	Replacement Cost (₦/kW)	100,000
	O & M Cost	-
	Life Span (years)	18
Wind Turbine (25 kW)	Capital Cost (₦)	13,000,000
	Replacement Cost (₦)	11,000,000
	O & M Cost (₦/year)	5,000
	Life Span (₦)	20
Generator (15 kW)	Capital Cost (₦)	1,400,000
	Replacement Cost (₦)	1,200,000
	O & M Cost (₦/hour)	30
	Diesel Price (₦/litre)	200
	Life Span (year)	15
Load	108 kWh/day	

TABLE IV
ESTIMATED ANNUALIZED COST OF BTS SITE EXPANSION AND RENT COSTS (1$ = ₦364.50)

State	Annualized Land Rent (₦/m^2/year)	Annualized Cost of BTS Site Expansion (₦/m^2/year)
Lagos	7,000.00	2000
Ekiti	3,636.36	1000
Ogun	6,000.00	1500
Ondo	3,636.36	1000
Osun	3,500.00	950
Oyo	5,000.00	1200

III. RESULTS AND DISCUSSION

HOMER has been used to model the parameters involved in each of the hybrid systems. Input parameters needed for the model are GHI, wind speed and load demand. Different possible configurations were arrived at and feasible configurations with desirable characteristics which involves low TNPC, space and emission are selected.

A. Optimal Hybrid

This section discusses the outcome of the simulation of the optimal hybrids H_1, H_2, H_3 and H_4. Hybrid H_2 was found to have the lowest TNPC especially in Lagos, Ogun and Oyo States as depicted in Table 5. H_1 has cost advantage over H_2 in

Ondo, Ekiti and Osun. The TNPC of H_2 is lower in Lagos State (Coastal part of Nigeria) due to higher wind resources in the state as shown in Fig. 1. Higher GHI in Ondo, Ekiti and Osun States gives hybrid H_1 its lower TNPC advantage in these states. All locations in the study area have TNPC lower than that of the base system of DG-only as presented in Table 5. The TNPC for H_2 in the study location varies from its lowest value of ₦36.0 million and ₦37.1 million in Oyo and Lagos, respectively and to its highest value of ₦42.5 million in Ondo and Ekiti States. This is due to the higher wind resources in Oyo and Lagos States which are located near the coastal region. Lower TNPC of H_1 in Ondo, Ekiti and Osun States is due to higher GHI and lower rent in these locations.

TABLE V
SIMULATION RESULT FOR BTS IN THE STUDY AREAS (1$ = ₦364.50)

Location	Hybrid	TNPC (10^6 ₦)	PV (kW)	Space (m^2)
Ondo State	H_1	35.4	36.3	178.03
	H_2	42.5	29.8	148.61
	H_3	53.7	57.0	284.25
	H_4	57.2	47.6	237.38
	DG	62.1	-	-
Lagos State	H_1	45.8	37.2	185.51
	H_2	37.1	22.3	111.21
	H_3	72.0	55.7	277.77
	H_4	55.4	36.6	182.52
Ekiti State	H_1	35.5	36.8	178.03
	H_2	42.5	30.0	148.61
	H_3	53.7	57.0	284.25
	H_4	42.5	47.6	237.38
Oyo State	H_1	39.8	37.2	185.51
	H_2	36.0	23.3	111.21
	H_3	59.6	55.7	277.77
	H_4	49.6	36.6	182.52
Ogun State	H_1	41.3	36.3	180.41
	H_2	40.8	26.3	194.79
	H_3	66.4	56.6	180.83
	H_4	50.8	35.3	202.77
Osun State	H_1	34.8	35.6	177.53
	H_2	41.8	29.3	148.61
	H_3	53.4	58.6	292.23
	H_4	52.9	41.3	205.96

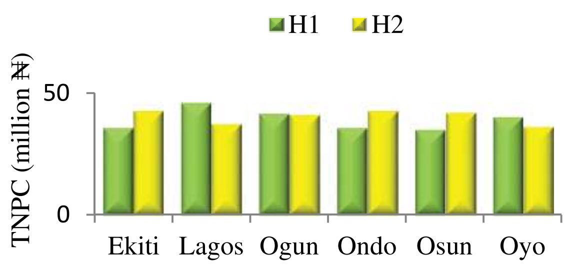


Fig 1. Variation in the levelized cost for Hybrids H_1 and H_2

B. *Hybrid Configurations*

This section describes the properties and architecture of the optimal hybrids in a typical location-Ondo State. The state was selected among the studied areas for the purpose of sensitivity analysis. Performance parameters of H_1 and H_2 are presented in Table 6.

TABLE VI
SIMULATION RESULT FOR OPTIMAL HYBRIDS

Content	Quantity	H_1	H_2
	Rated Capacity (kW)	35.70	29.84
	Total Production (kWh/year)	54,147.00	45,256.97
	Mean Output (kW)	6.18	5.17
	Penetration (%)	137.00	137.00
	Fraction (%)	96.13	77.04
Battery	Energy In (kWh/year)	25,369.85	21,824.35
	Energy Out (kWh/year)	2,1642.61	18,642.91
	Losses (kWh/year)	3,812.10	3,281.46
DG	Rated Capacity (kW)	15.00	15.00
	Total Production (kWh/year)	2,177	1,677.00
	Mean Output (kW)	0.25	0.19
	Fuel Consumption (L/year)	1,047.55	809.00
	Fraction (%)	3.87	2.87
WT	Rated Capacity (kW)	-	25.00
	Total Production (kWh/yr)	-	11,809
	Mean Output (kW)	-	1.35
	Penetration (%)	-	29.96
	Fraction (%)	-	20.10

Hybrid H_1 required about 35.7 kW to achieve its optimal configuration. 108 Sunpower X-21-335LK (SPR-X21) PV with rated power of 335 W each is considered. 54 strings are to be connected in parallel, each consists of two PV in series tied to a 96 V bus. The Diesel Generator is 15 kW Generac protector (Gener 15) with fuel curve intercept of 0.635 L/hr and fuel curve slope of 0.327 L/hr/kW. A battery bank of 72 Discover 12VRE 3000TF-L batteries each of 12 V 245 Ah, 2.94 kWh in parallel connection of 9 strings of 8 batteries in series per string is estimated. H_1 has TNPC of ₦35.4 million (against ₦62.1 million of the base system of DG only) with 43% cost reduction as earlier pointed out in Table 5.

The annual emission of Hybrid H_1 is 2,798.46 kg/yr of pollutants against 50,151.27 kg/yr of DG with 94.42 % reduction in observed annual emission as presented in Table 7.

TABLE VII
ANNUAL EMISSION OF THE OPTIMAL HYBRIDS

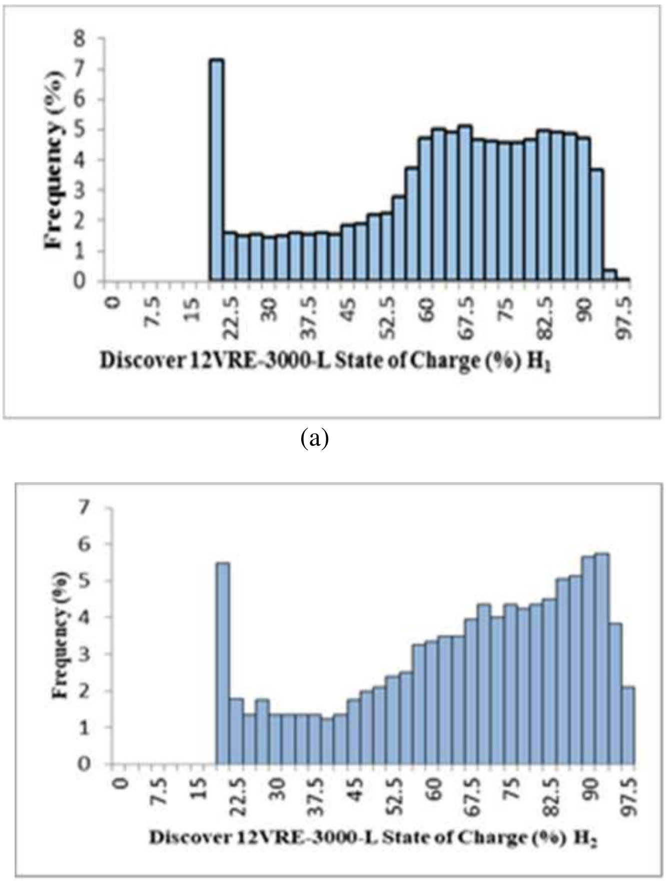
Quantity	Emission (kg/yr)		
	H_1	H_2	DG
Carbon dioxide	2,742.12	2,117.68	49,282.47
Carbon Monoxide	18.60	14.36	334.28
Unburned Hydrocarbons	0.75	0.58	13.57
Particulate Matter	1.13	0.87	20.26
Sulphur Dioxide	6.27	4.84	120.77
Nitrogen Oxides	21.14	16.33	379.86
Annual Total	2,789.40	2,154.70	50,151.20

The emission of Hybrid H_1 is low enough and next to a green environment. Hybrid H_2 typically has TNPC of ₦42.5 million with 32 % cost reduction over the base system of DG-only as earlier indicated in Table 5. The results from Table 7 also show that about 2,154.70 kg of potential pollutants will be released by this hybrid annually, a 95.69 % reduction in emission when compared with DG. 29.84 kW PV is needed in the optimal hybrid. A total of 90 Sun power X-21-335LK PV with 45 strings connected in parallel, each consisting of two PVs in series tied to a 96 V bus. At bus voltage of 48 V, a BTS site of power 4.5 kW will draw a current of 93.75 A. This excessive high current will require unnecessarily heavy cable. Hence, the bus voltage for this proposed hybrid is also optimized. The Diesel Generator is estimated at 15 kW Generac protector and a battery bank of 64 Discover 12VRE 3000TF-L in parallel connection of 8 strings of 8 batteries in series per string.

C. Hybrid Storage

The relative State of Charge (SOC) is the ratio of the current absolute state of energy charge to the maximum capacity of the storage bank. It must be noted that when the battery is fully charged, the relative SOC is 100 %.

The battery minimum charge is set as 20% to intentionally allow ample room for occasional discharge of the battery storage. This will ensure that the electrolyte in it does not form crystal. Figs 2a and 2b show that the battery SOC is always above 20 % with desired frequency of about 7.2 % and 5.5 % for hybrid H_1 and H_2 battery storage, respectively.



(b)
Fig. 2. Battery storage SOC histogram for (a) H_1 and (b) H_2

D. Sensitivity Analysis

The considerable variation in TNPC of a Hybrid system with some contributing factors like wind speed, GHI and diesel price which cannot be properly controlled is presented in this section.

Figure 3 presents the sensitivity of TNPC to diesel price and wind speed at GHI of 4.5 kWh/m^2/day. The result demonstrates the sensitivity of TNPC to change appreciably in GHI and diesel price at the average wind speed of 2.6 ms^{-1}. The TNPC reduces with increasing GHI and consequently leads to an increase with a rise in diesel price. Sensitivity analysis of GHI and wind speed on TNPC which represent the effect of change in GHI and wind speed on TNPC of the hybrid is also presented in Fig. 4. TNPC reduces with increase in GHI and wind speed but the respond of TNPC to change in GHI is far greater than that of the wind speed.

Sensitivity analysis of the diesel price and wind speed on TNPC which is the effect of change in diesel price and wind speed on TNPC of the hybrid is also presented in Fig. 5.

TNPC increases with the increase in the cost of the diesel price and reduces with the increase in the magnitude of the wind speed. The response of TNPC to change in diesel price is significantly greater than that of the wind speed. The result implies that hybrid RES (wind and PV) will significantly reduce the operational cost in specific locations with a high GHI and enhance the energy availability at the affordability cost with the optimum harnessing of energy solar energy using embedded solar tracking devices.

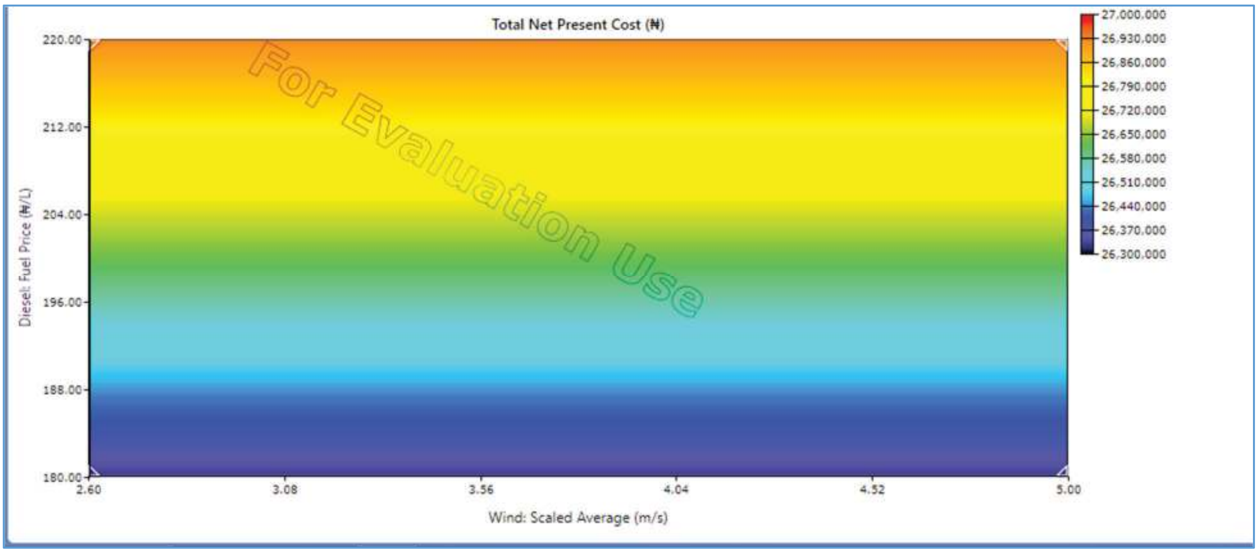


Fig. 3. Sensitivity of TNPC to diesel price and wind speed at GHI of 4.5 kWh/m^2/day

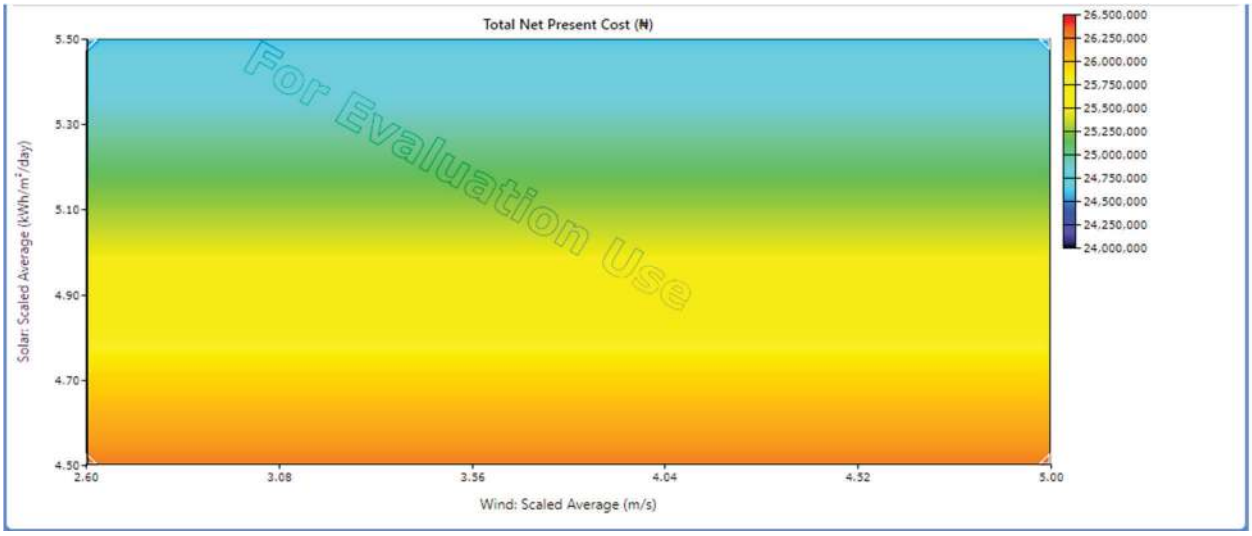


Fig. 4. Sensitivity of TNPC to GHI and wind speed at fixed diesel price of ₦180

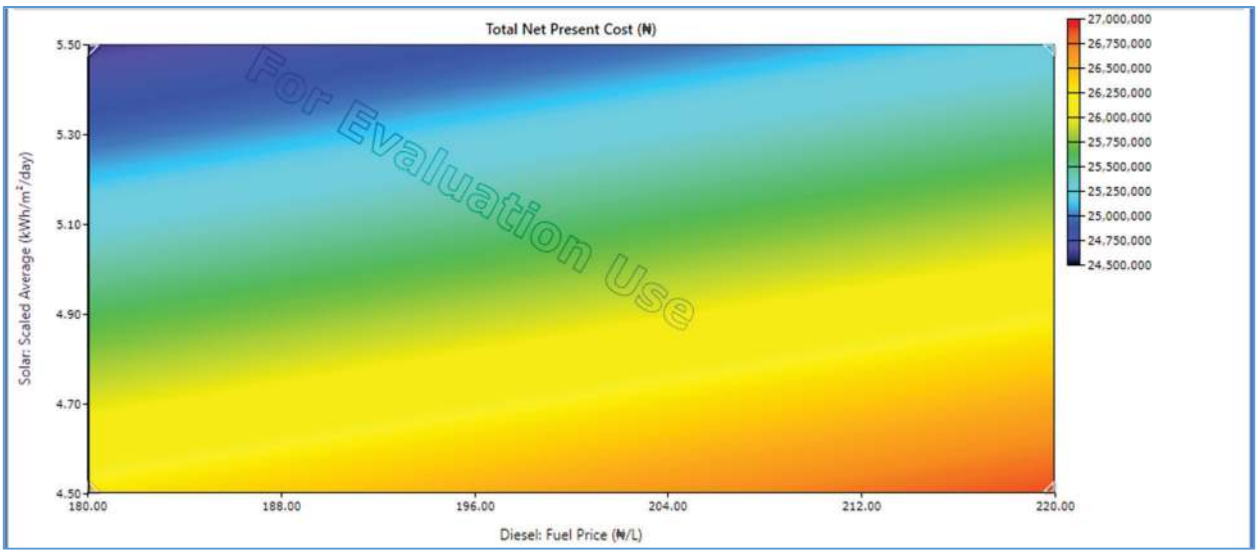


Fig. 5. Sensitivity of TNPC to GHI and diesel price at average wind speed of 2.6 ms^{-1}

IV. CONCLUSION

This paper established the essential fact that despite low wind resources in Southwestern Nigeria, it is nevertheless possible to efficiently generate sufficient renewable energy economically for powering BTS in the specific region with manifold advantages over the expensive DG system being used. BTS can be powered with the hybrid H_1 in Ondo, Ekiti and Osun States at lowest cost while H_2 is the best for Lagos, Ogun and Oyo States at lowest cost and added advantage of further emission and space reduction while H_1 made of PV and DG emerged the best in Ondo, Ekiti and Osun States. The overall results will adequately provide more environmentally pleasant medium, cost efficient and a robust platform for powering BTSs in the studied locations. The obtained results will also be resourceful for policy makers, telecommunication regulators, the telecommunication service providers and base station systems designers in planning and deploying an eco-friendly green communication in Nigeria as a whole.

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