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Environmental Impact Assessment of Power Generation Systems at GSM (Global Systems for Mobile Communication) Base Station Site

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ABSTRACT Hybrid power systems were used to minimize the environmental impact of power generation at GSM (global systems for mobile communication) base station sites. This paper presents the comparative environmental impact assessment of a diesel gas (DG) and hybrid (PV/wind/hydro/diesel) power system for the base station sites. The assessment was based on theoretical modeling of the power stations using Hybrid Optimization Model for Electric Renewables (HOMER) software. The model was designed to provide an optimal system configuration based on hour-by-hour data for energy availability and demands. Energy source, energy storage and their applicability in terms of performance are discussed. The proposed hybrid (solar, wind & hydro) + DG system was simulated using the model which results in eight different topologies: hybrid (solar, wind & hydro) + DG, hybrid (solar & hydro) + DG, hybrid (wind & hydro) + DG, hydro only + DG, hybrid (solar & wind) + DG, solar only + DG, wind only + DG, DG. From the simulation results, it is shown that a 69% renewable energy penetration in the designed hybrid PV/wind/hydro/diesel system reduces the quantity of different air pollutants relative to the case

of a diesel-only system. Details of the comparisons are presented.

KEYWORDS Hybrid optimization model for electric renewables, pollutants, diesel generator, hybrid power systems.

Introduction

GSM (global systems for mobile communication) technology is used by more than one in ten of the world's population. (www.gsmworld.com/news/press_2004/press04_Cannes_France_22_February_2004). Mobile or cellular phones are an integral part of modern society, and have revolutionized commerce and the personal lives of humans. GSM/Wireless telephony has become the Nigeria's leading and fastest-growing mobile standard, spanning the country. The progress has not stopped there. The GSM platform is growing and evolving, and offers an expansive and feature-rich family of services.

Fluctuating grid power delivery system within the system has caused that most of these base sta-

tion sites are not connected to the national grid but rather have diesel generator sets, that run 24 hours a day, throughout the entire year. These generators, however, are associated with many problems such as high operational cost, noise pollution, and environmental pollution. Diesel generator exhaust also contains harmful hydrocarbons, which are emitted in the atmosphere continuously. The emissions of carbon and other products that result from diesel generators which are used to operate the base station sites are a serious threat to health, the environment and sustainable economic growth.

The anticipated growth in the GSM industry creates potential risks in an environment where organizations are always seeking ways of improving efficiency (diverting to diesel generator due to unreliable grid). Elements of risk control, such as health and environmental management (emissions from the power generation) can therefore no longer be left out of the equation, particularly when organizations in the GSM industry are considering increasing their networks in Nigeria. It is contended that integrated health and environmental impact assessments should be a prerequisite before any further expansion of the GSM network in Nigeria is considered.

An Environmental Impact Assessment (EIA) is simply a study undertaken to understand the effect of a new development on the environment. An EIA is normally carried out when there is a perception of the possibility that the proposed development may harm the environment. An EIA may therefore be defined as a process of identifying, predicting, evaluating and mitigating the biophysical, social and other relevant effects of proposed projects and physical activities before major decisions and commitments are made (www.ea.gov.au/assessments 08 February 2002 p 3 of 23).

In the context of the GSM industry, the use of diesel generation systems to power a Base Transceiver Station (BTS) sites is a development that harms the environment. Little or no attention has been paid to the exploitation of all other available energy (renewable) resources in these rural areas and the latest technologies in the field. Renewable energy solutions

have positive environmental effects. From the view point of availability, using entirely renewable energy to power base station sites is still limited. However, hybridizing the diesel generator system with renewable energy sources like photovoltaic/or wind/or hydro system reduces environmental impact. The purpose of this paper is to theoretically quantify the environmental impact of using a hybrid power system in a base station site.

Hybrid power systems (HPS)

A hybrid powered system (HPS) can be described as an electricity production system which supply consists of a combination of two or more types of electricity generating sources (e.g. solar photovoltaic panels, wind turbine generators, pico-hydro plants, and/or fuel generators) in which at least one source is a renewable energy. Hybrid systems can include energy storage.

The useful components of hybrid systems considered in this study are the solar photovoltaic panels, wind turbine and hydro turbine generator. A diesel generator can provide energy at any time, whereas energy from PV, wind and hydro is greatly dependent on the availability of solar radiation, wind speed and stream flow, respectively [Wichert, 1997; Yu et al., 2005]. This makes the system (generator) more reliable, and can be used to operate when PV and/or wind and/or hydro fail to satisfy the load and when the battery storage is depleted. Stand-alone hybrid power systems are used primarily for environmental concerns.

Based on current technologies, the deployment of renewable energies for telecommunication purposes (especially for base station sites) will require combining several sources of renewable energy, conventional generators (diesel generator, liquefied petroleum gas, LPG turbines etc.) and energy storage systems (battery bank) which is selected based on their comparative advantage while maintaining uninterrupted supply hence the HPS [Odadzic et al., 2011; Roskilde, 2000]. Different operation modes for the HPS is possible. A hybrid system uses advanced system control

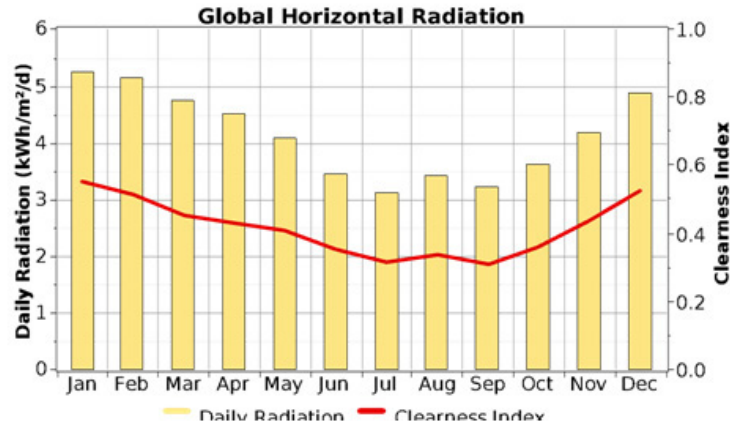


Figure 1a HOMER output graphic for solar radiation profile for Nembe.

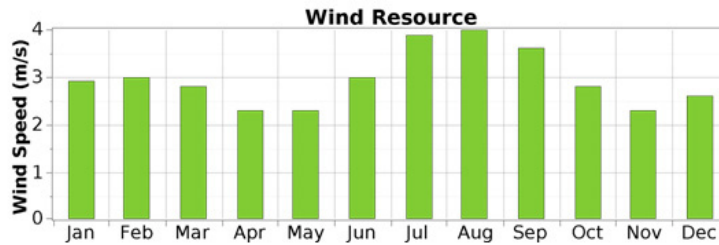


Figure 1b HOMER output graphic for Wind Speed profile for Nembe.

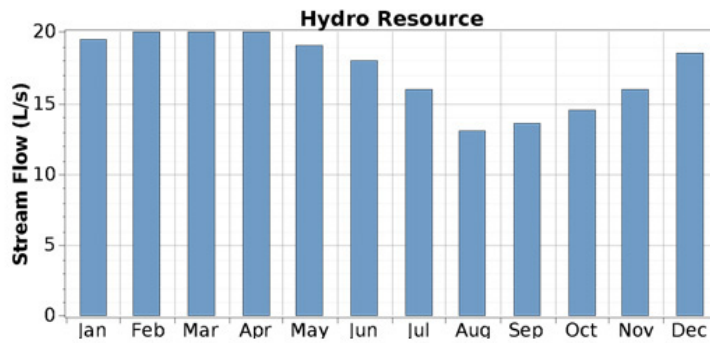


Figure 1c HOMER output graphic for stream flow profile for Nembe.

logic (also known as a *dispatch strategy*) to coordinate when power should be generated by renewable energy and when it should be generated by sources like diesel generators. It can also determine the percentage contribution of each component of HPS. Faruk et al. [2012] showed that HPS provide a realistic alternative for conventional energy sources in telecommunications in terms of reducing their carbon emission.

Base station site power requirement

In identifying the energy consumption at GSM base station sites and assessing the impact of various operational strategies, a macro BTS was used as a model for this study. The description of energy consumption at a macro base transceiver station site can be found in [Ani and Emetu, 2013]. A BTS site load profile depends on multiple parameters including radio equip-

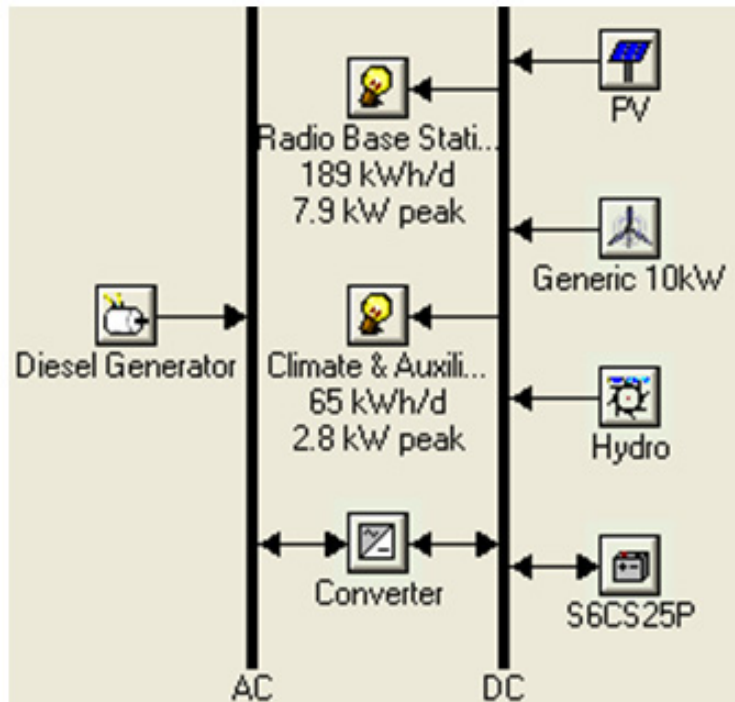


Figure 2 The network architecture for the HOMER simulator.

ment, antenna, power conversion equipment, transmission equipment, etc. The electric power needed for the base station site equipment in and the energy required to remove heat from the shelter (cabin) are stated below [Ani and Emetu, 2013].

- Base station site equipment power requirement = $8,060 \text{ W h}^{-1}$
- Climate equipment power requirement = $2,590 \text{ W h}^{-1}$

Hourly load demand (macro base station site perspective) was given as an input in HOMER a daily and monthly load profile was generated for a year. It was determined that the test site consumes 254 Wh d^{-1} of energy with a peak demand of 10.7 kW as shown in Fig. 2.

Methodology

Renewable resources

For this study, a base station site at Nembe in Bayelsa state, Nigeria was considered. The data for solar and wind resources were obtained from the NASA Sur-

face Meteorology and Solar Energy web site (NASA, 2010), while the hydro resource were measured at the site. The specific geographical location of Nembe (Bayelsa State) are of $4^{\circ} 17' \text{ N}$ latitude and $6^{\circ} 25' \text{ E}$ longitude with annual average solar daily radiation of $4.12 \text{ kWh m}^{-2} \text{ d}^{-1}$, annual average wind of 3.0 m s^{-1} and annual average stream flow of 17.3 L s^{-1} . Figs. 1a, 1b and 1c show the solar, wind and hydro resource profile of this area.

For the HPS, a diesel generator was used, hybridized with a PV/wind/hydro system. The details of the power generating set and the weather conditions of Nembe are used as input data in the simulation software used for this study.

Simulation and optimization

Hybrid Optimization Model for Electric Renewables (HOMER) software was used for this work. HOMER has been used to conduct several investigations of hybrid systems in many locations around the world [Shaahid and El-Amin, 2009; Bekele and Palm, 2010; Hassan et al., 2011; Nandi and Ghosh, 2010; Rehman

and Al-Hadhrami, 2010; Wies et al., 2005; HOMER, 2013; Muselli et al., 1999; Muselli et al., 2000]. Wies et al. [2005] presented a simulation work, using Simulink, of a real hybrid PV–diesel–battery system located in Alaska, comparing it with a system with only a diesel generator and another diesel–battery system to supply energy for the same load. Contaminating emissions were evaluated (CO₂, NO_x and particles) for the various cases, comparing the results with those obtained by means of HOMER software [HOMER, 2013]. Additionally, the global efficiency of the system was determined. The results obtained indicate that the system with only a diesel generator had less efficient and released more contaminating emissions than the PV–diesel–battery system. Shahid and El-Amin [2009] performed a techno-economic evaluation of PV/diesel/battery systems for rural electrification in Saudi Arabia. They examined the effect of the increase in PV/battery on the operational hours of diesel generators and reduction in GHG emissions.

Method

HOMER is an optimization program based on energy (cost and environmental) calculations. The system architecture employed in the hybrid system is DC coupled where the solar PV, wind turbine, hydro turbine and the diesel generator all feed into the DC side of the network as depicted in Fig. 2. This is the network arrangement used for this study.

Hybrid system components

Photovoltaic module

The PV modules used were polycrystalline photovoltaic module with 140 W maximum power connected in a series and parallel configuration. The PV module has a ground reflectance of 20%. The photovoltaic system has no tracking system. The details of the PV system are shown in Table 1.

Wind turbine model

The number of generic 10 kW wind turbines consid-

Table 1 Details of solar properties

Solar Module type: Solar World SW 140 W poly R6A	
Module Size (kW)	0.140
Array size (kW)	10.7
PV Control	
Tracking system	No Tracking
Slope	4°
Azimuth	0 deg
Ground reflectance	20%

Table 2 Details of the wind parameters

Wind turbine type: Generic 10kW	
Nominal power (kW)	10
Quantity considered	1
Lifetime	20 yr
Wind turbine control	
Weibull k	2.00
Autocorrelation factor	0.850
Anemometer height	10m
Altitude	0m
Wind shear profile	Logarithmic
Surface roughness length	0.01 m
Hub height	25 m

ered for simulation is one. The details of wind parameters have been given in Table 2.

Micro-hydro turbine model

The micro hydro model in HOMER software is not designed for a particular water resource. Certain assumptions are taken about available head, design flow rate, maximum and minimum flow ratio and efficien-

Table 3 Details of micro-hydro parameters

Hydro Turbine	
Nominal power (kW)	10.3
Quantity considered	1
Lifetime	20 yr
Hydro Turbine Control	
Available head	56 m
Design flow rate	25 L s ⁻¹
Minimum flow ratio	25 %
Maximum flow ratio	100 %
Turbine efficiency	75 %
Pipe head loss	10.5%

Table 4 The details of diesel generator model parameters

AC Generator type: 20kVA Diesel Generator	
Size considered (kW)	16
Quantity considered	1
Lifetime	20,000 h
Diesel Generator Control	
Minimum load ratio	30 %
Heat recovery ratio	0 %
Fuel used	Diesel
Fuel curve intercept	0.08 L h ⁻¹ kW ⁻¹
Fuel curve slope	0.25 L h ⁻¹ kW ⁻¹
Fuel: Diesel	
Lower heating value	43.2 MJ kg ⁻¹
Density	820 kg m ⁻³
Carbon content	88.0%
Sulphur content	0.330%

Table 5 Surrette 6CS25P Battery Properties

Battery type: Surrette 6CS25P	
Quantity considered	96
Lifetime throughput	9,645 kWh
Battery: Surrette 6CS25P Control	
Nominal capacity	1,156 Ah
Voltage	6 V

Table 6 Details of converter parameters

Converter	
Size considered (kW)	25
Lifetime	20 yr
Converter Control	
Inverter efficiency	85%
Inverter can parallel with AC generator	Yes
Rectifier relative capacity	100%
Rectifier efficiency	85%

cy to the turbines. The details of micro hydro parameters have been given in Table 3.

Diesel generator model

Diesel generator technology is widespread and the development of the power plant is relatively easy. The details of diesel generator model parameters have been given in Table 4. The diesel back-up system is operated at times when the output from wind, hydro and solar systems fails to satisfy the load and when the battery storage is depleted.

Storage battery

The variations of solar and wind energy generation do not match the time distribution of the demand. The storage battery chosen was Surrette 6CS25P. These batteries were configured such that each string consisted of two batteries, with a total of forty-eight

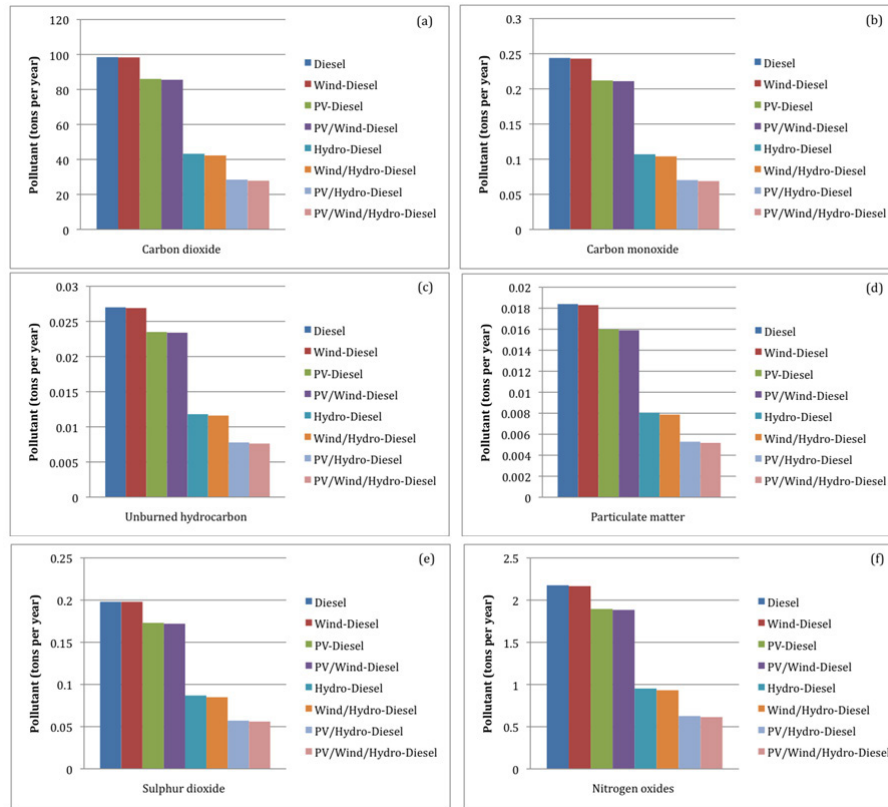


Figure 3 (a) Carbon dioxide (b) carbon monoxide (c) unburned hydrocarbon (d) particulate matter (e) sulphur dioxide and (f) nitrogen oxides emitted by diesel only and diesel in hybrid energy System.

strings. This means the total batteries used were 96 units. From the datasheet given by HOMER software, the minimum state of charge of the battery is 40%. Its round trip efficiency is 80%. The details of storage battery model parameters have been given in Table 5.

Converter

Here converter is used which can work both as an inverter and rectifier depending on the direction of flow of power. In the present case, the size of the converter used is 50 kW for simulation purposes. The details of converter parameters have been given in Table 6.

Results and discussion

Simulation Results

Eight energy component configurations were carried out for power supply to GSM base station sites located Nembe (Bayelsa State) for the project lifetime of

one year. The results of the analysis of eight possible system configuration scenarios considered in this study are shown in Figs. 3(a-f). This enabled comparisons between options based on environmental factors. These scenarios were also compared with the existing diesel only option.

Discussion

The most important environmental indices are fuel consumption and pollutant emissions. It is well known that the hazards of diesel exhaust and fumes from the use of diesel generators can cause both serious health and environmental problems according to numerous resources [OSHA, 2009; DOSH, 2004]. In the present work, the amount of possible pollutants arising from the use of diesel fuel in powering the GSM base station sites was simulated with HOMER software. The simulated results are discussed and shown in Figs. 3(a-f).

Hybrid (PV, wind & hydro) + diesel generator

PV/wind/hydro-diesel system - diesel generator operates for 2,004 h annum⁻¹ with fuel consumption of 10,581 L annum⁻¹. This system emits 27.864 tonnes of CO₂, 0.0688 tonnes of CO, 0.00762 tonnes of UHC, 0.00518 tonnes of PM, 0.056 tonnes of SO₂, and 0.614 tonnes of NO_x annually into the atmosphere of the location under consideration as shown in Figs. 3(a), 3(b), 3(c), 3(d), 3(e), and 3(f), respectively.

Almost 69% decrease in each pollutant is noticed for a 69% renewable penetration into the existing diesel only power system. The reduction in the quantity of different air pollutants for 69% renewable penetration compared to that diesel only are thus: 70.636 tonnes of CO₂, 0.1752 tonnes of CO, 0.01938 tonnes of UHC, 0.01322 tonnes of PM, 0.142 tonnes of SO₂, and 1.562 tonnes of NO_x.

Hybrid (PV & hydro) + diesel generator

PV/hydro-diesel system - diesel generator operates for 2,046 h annum⁻¹ with fuel consumption of 10,803 L annum⁻¹. This system emits 28.448 tonnes of CO₂, 0.0702 tonnes of CO, 0.00778 tonnes of UHC, 0.00529 tonnes of PM, 0.0571 tonnes of SO₂, and 0.627 tonnes of NO_x annually into the atmosphere of the location under consideration as shown in Figs. 3(a), 3(b), 3(c), 3(d), 3(e), and 3(f), respectively.

Almost 68% decrease in each pollutant is noticed for a 68% renewable penetration into the existing diesel only power system. The reduction in the quantity of different air pollutants for 68% renewable penetration compared to that diesel only are thus: 70.052 tonnes of CO₂, 0.1738 tonnes of CO, 0.01922 tonnes of UHC, 0.01311 tonnes of PM, 0.1409 tonnes of SO₂, and 1.549 tonnes of NO_x.

Hybrid (wind & hydro) + diesel generator

Wind/hydro-diesel system - diesel generator operates for 3,042 h annum⁻¹ with fuel consumption of 16,062 L annum⁻¹. This system emits 42.297 tonnes of CO₂, 0.104 tonnes of CO, 0.0116 tonnes of UHC, 0.00787 tonnes of PM, 0.0849 tonnes of SO₂, and 0.932 tonnes of NO_x annually into the atmosphere of the location

under consideration as shown in Figs. 3(a), 3(b), 3(c), 3(d), 3(e), and 3(f), respectively.

Almost 54% decrease in each pollutant is noticed for a 54% renewable penetration into the existing diesel only power system. The reduction in the quantity of different air pollutants for 54% renewable penetration compared to that diesel only are thus: 56.203 tonnes of CO₂, 0.14 tonnes of CO, 0.0154 tonnes of UHC, 0.01053 tonnes of PM, 0.1131 tonnes of SO₂, and 1.244 tonnes of NO_x.

Hydro only + diesel generator

Hydro-diesel system - diesel generator operates for 3,111 h annum⁻¹ has a fuel consumption of 16,426 L annum⁻¹. This system emits 43.256 tonnes of CO₂, 0.107 tonnes of CO, 0.0118 tonnes of UHC, 0.00805 tonnes of PM, 0.0869 tonnes of SO₂, and 0.953 tonnes of NO_x annually into the atmosphere of the location under consideration as shown in Figs. 3(a), 3(b), 3(c), 3(d), 3(e), and 3(f), respectively.

Almost 53% decrease in each pollutant is noticed for a 53% renewable penetration into the existing diesel only power system. The reduction in the quantity of different air pollutants for 53% renewable penetration compared to that diesel only are thus: 55.244 tonnes of CO₂, 0.137 tonnes of CO, 0.0152 tonnes of UHC, 0.01035 tonnes of PM, 0.1111 tonnes of SO₂, and 1.223 tonnes of NO_x.

Hybrid (PV & wind) + diesel generator

PV/wind-diesel system - diesel generator operates for 6,154 h annum⁻¹ with fuel consumption of 32,488 L annum⁻¹. This system emits 85.553 tonnes of CO₂, 0.211 tonnes of CO, 0.0234 tonnes of UHC, 0.0159 tonnes of PM, 0.172 tonnes of SO₂, and 1.884 tonnes of NO_x annually into the atmosphere of the location under consideration as shown in Figs. 3(a), 3(b), 3(c), 3(d), 3(e), and 3(f), respectively.

Almost 13% decrease in each pollutant is noticed for a 13% renewable penetration into the existing diesel only power system. The reduction in the quantity of different air pollutants for 13% renewable penetration compared to that diesel only are thus: 12.947 tonnes of CO₂, 0.033 tonnes of CO, 0.0036 tonnes of

UHC, 0.0025 tonnes of PM, 0.026 tonnes of SO₂, and 0.292 tonnes of NO_x.

PV only + diesel generator

PV-diesel system - diesel generator operates for 6,190 h annum⁻¹ has a fuel consumption of 32,679 L annum⁻¹. This system emits 86.053 tonnes of CO₂, 0.212 tonnes of CO, 0.0235 tonnes of UHC, 0.016 tonnes of PM, 0.173 tonnes of SO₂, and 1.895 tonnes of NO_x annually into the atmosphere of the location under consideration as shown in Figs. 3(a), 3(b), 3(c), 3(d), 3(e), and 3(f), respectively.

Almost 12% decrease in each pollutant is noticed for a 12% renewable penetration into the existing diesel only power system. The reduction in the quantity of different air pollutants for 12% renewable penetration compared to that diesel only are thus: 12.447 tonnes of CO₂, 0.032 tonnes of CO, 0.0035 tonnes of UHC, 0.0024 tonnes of PM, 0.025 tonnes of SO₂, and 0.281 tonnes of NO_x.

Wind only + diesel generator

Wind-diesel system - diesel generator operates for 7,075 h annum⁻¹ has a fuel consumption of 37,352 L annum⁻¹. This system emits 98.361 tonnes of CO₂, 0.243 tonnes of CO, 0.0269 tonnes of UHC, 0.0183 tonnes of PM, 0.198 tonnes of SO₂, and 2.166 tonnes of NO_x annually into the atmosphere of the location under consideration as shown in Figs. 3(a), 3(b), 3(c), 3(d), 3(e), and 3(f), respectively.

Almost 1% decrease in each pollutant is noticed for a 1% renewable penetration into the existing diesel only power system. The reduction in the quantity of different air pollutants for 1% renewable penetration compared to that diesel only are thus: 0.139 tonnes of CO₂, 0.001 tonnes of CO, 0.0001 tonnes of UHC, 0.0001 tonnes of PM, 0 tonnes of SO₂, and 0.01 tonnes of NO_x.

Diesel generator

Diesel only generates 98.5 tonnes of CO₂, 0.244 tonnes of CO, 0.027 tonnes of UHC, 0.0184 tonnes of PM, 0.198 tonnes of SO₂, and 2.176 tonnes of NO_x

as shown in Figs. 3(a), 3(b), 3(c), 3(d), 3(e), and 3(f), respectively.

In this study, increasing the renewable fraction would considerably reduce the amount of CO₂ emitted by the system as a whole. From the simulation results it was observed that the proposed system reduces the amount of CO₂ emitted from the entire setup.

Conclusions

HOMER software was used to find the possible combination of renewable energy schemes and determine the optimum hybrid configuration for telecoms stations based in Nembe. These combinations show the environmental analysis of adopting each energy resource over a period of one year. The PV/wind/hydro-diesel system has the highest renewable energy penetration by supplying 69% of the energy demand and emits 557.28 tonnes of CO₂ and saves 1412.72 tonnes of CO₂ from entering into the atmosphere when compared with the diesel only. The reduction in total GHG with increasing renewable penetration of 69% shows visible positive impact on GHG reduction.

Diesel only emits 1970 tonnes of CO₂. There is no change in the conventional system due to optimization. Thus power is drawn from the generator continuously. The carbon emission is very high as a result of burning a lot of fossil fuel.

Finally, among the eight energy configurations studied (PV/wind/hydro-diesel, PV/hydro-diesel, wind/hydro-diesel, hydro-diesel, PV/wind-diesel, PV-diesel, wind-diesel and diesel), the best option in terms of environmental friendly is PV/wind/hydro-diesel system. The power drawn from the diesel is minimal, thus is a considerable reduction in the amount of CO₂ emitted from the system in the studied location.

In conclusion, this study shows that developing a stand-alone hybrid power system is more environmentally friendly and suitable for GSM base station sites in rural areas, while renewable energies are available, than running diesel generators. The result of this study encourages private investors especially in Nigeria, to take advantage of renewable energy and

be convinced that there is sustainability in investing in stand-alone hybrid power systems.

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