Potentials of Optimized Hybrid System in Powering Off-Grid Macro Base Transmitter Station Site

Ani Vincent Anayochukwu*‡, Nzeako Anthony Ndubueze**

*Department of Electronic Engineering, University of Nigeria, Nsukka

**Department of Computer Engineering, University of Ghana, Legon

(vincent_ani@yahoo.com, annzeako2005@yahoo.com)

‡ Corresponding Author; Ani Vincent Anayochukwu, Department of Electronic Engineering, University of Nigeria, Nsukka (UNN) Nigeria, +2348054024629, vincent_ani@yahoo.com

Received: 04.10.2013 Accepted: 08.11.2013

Abstract- This paper explores the possibility of hybridizing the diesel generator source system with renewable energy sources and demonstrates the potential of renewable energies to replace (partially) diesel as a source of power for mobile base station sites. The concept of hybridizing the diesel generator is to reduce both the operating cost and the quantity of different air pollutants. The patterns of load consumption by mobile base station are studied and suitably modeled for optimization using Hybrid Optimization Model for Electric Renewables (HOMER) software. The proposed Hybrid (Solar & Hydro) + DG system was simulated using the model which results in four different topologies. The solution with the highest optimization value is considered to be the best energy option (solution) for the Base Station Site. From the simulation results, the PV/Hydro-Diesel system solution has the highest optimization value. It saves $15,961,777 and 70.553 tonnes of CO_2 when compared with diesel only.

Keywords- Off-Grid Site, Base Transmitter Station (BTS), Power Generation, Hybrid System, Diesel generator, Renewable energy, HOMER, Optimization, Simulation, Nigeria.

1. Introduction

Operation of telecommunications networks requires electrical power. The expense on energy accounts for a significant share of the operational cost of these networks. This is particularly so in the rural areas where availability of power is uncertain. Network operators have become adept at generating their own off-grid power. This has typically been achieved by running diesel generators at each site, although increasing number of operators are installing renewable energy equipment, such as solar panels and hydro turbines, to power their base stations. The use of diesel generators to ensure continuous power supply has the disadvantage of increasing the greenhouse gas emission which has a negative impact on the environment. The use of renewable energy solutions consists in replacing (partially or totally) the diesel generator by solar panels or a wind turbine or a hydro as the main power supply of the BTS [1]. There are different configurations - combinations of renewable and convectional energy sources - been deployed for telecommunication purposes: Diesel-Battery; Solar-Diesel-Battery; Wind-Diesel-Battery; Solar-Wind-Diesel-Battery; Solar-Hydro-Diesel-Battery, etc. [2]. The choice of renewable power options is partly determined by the region in which the facility is located [3]. For instance, the performance of solar and wind energy systems (singly or in combination) is strongly dependent on the climatic conditions at the location, while the hydro resource depends from the location's topography and its rainfall patterns.

Study Area

Ikwerre is located in Rivers State of Nigeria and endowed with very abundant renewable energy resources that remained unexplored and unexploited for alternative energy solutions for telecommunications. Ikwerre lies along the Equator, with abundant sunshine all the year round. According to Bala et al [4], Nigeria is endowed with an annual average daily sunshine of 6.25 hours, ranging between about 3.5 hours in the coastal areas and 9.0 hours at the far northern boundary. Similarly, it has an annual average daily solar radiation of about 5.25 $KWh/m^2/day$, varying between about $3.5kWh/m^2/day$ in the coastal area and $7.0kWh/m^2/day$ at the northern boundary [5]. Ikwerre - Nigeria receives about 4.851 x 10^{12} kWh of energy per day from the sun. There are lots of canals, several minor streams and rivulets that crisscross the entire Ikwerre land mass, as well as tiny waterfalls having potentials for setting up mini/micro hydropower units that can power GSM Base Station Sites. Harnessing micro-hydro resources and setting up decentralized small-scale water power or micro-hydro schemes are a particularly attractive option in terrain areas without hampering the ecosystem.

Wind speed is relatively weak in the study area with an average of 2.1m/s throughout the year. This shows that the wind resource is extremely low at this site and therefore this research will not include a wind turbine option.

2. Hybrid Power System (HPS) Configuration

The configuration of a HPS depends on three factors: Resource (a renewable source), Load, and Cost (capital expenditure (CAPEX) and operating expenditure (OPEX)) [6]. The major problem faced by power generation using the hybrid system is the variation in load demand and renewable resources (solar radiation and water flow rate). Therefore, the major concern in the design of an electric power system that utilizes renewable energy sources is the accurate selection of system components that can economically satisfy the load demand. Based on the costs of components, fuel, labour, transportation and maintenance, it is desired to evaluate the most cost-effective sizing of all components to meet the predicated peak loads.

In the above optimization problem, hybrid system sizing is done with the aim of minimizing net present costs while meeting a given demand reliably and cost-effectively. One method of doing this is to incorporate computer simulation model for Hybrid power systems.

The purpose of this paper is to explore the possibility of hybridizing the diesel generator source system with renewable energy sources through design and optimization of PV/Hydro/Diesel Hybrid system using a computer based design optimization. To demonstrate the potential of renewable energies to replace (partially or totally) diesel as a source of power for mobile base station sites. This study will provide energy system solutions that can reduce GSM operator’s dependency on fossil fuel and thereby reduce the amount of greenhouse gas emission entering into the environment.

2.1. Component Sizing

In order to efficiently and economically utilize the renewable energy resources, an optimum sizing method is necessary. The optimum sizing method can help to guarantee the lowest investment with full use of the system component, so that the hybrid system can work at the optimum conditions in terms of investment and system power reliability requirement. Solar and hydro energy systems are among the most developed renewable energy systems (RES), with a diesel generator as hybrid system have been widely used in stand-alone applications. The sizing tool performs dimensioning of the system: given an energy requirement, it determines the optimal size of each of the different components of the system. In a hybrid system, 40% of the total energy loss are due to the non-optimal sizing of the system [7]. Simulation programs are the most common tools for evaluating performance of the hybrid systems. By using computer simulation, the optimum configuration can be found by comparing the performance and energy production cost of different system configurations. This requires that the user correctly identify the key variables and then repeatedly run the simulation, adjusting the variables manually to converge on an acceptable sizing. Some packages automate this process. A lot of research work has been carried out to optimize their size and evaluate their performance. In this study, HOMER simulation was used to obtain the optimum combination and sizing of components.

2.2. Optimization

Hybrid systems with energy storage in batteries have been studied by various authors. These systems have been installed for a number of decades, although their systems would be substantially improved if optimization methods were applied [8]. Numerous papers have been written about the optimum economic designs of PV and/or hydro and/or Diesel systems with energy storage in batteries. When working with stand-alone hybrid systems for the generation of electricity, various aspects must be taken into account [8]. Reliability and cost (economic and environmental) are two of these aspects [9 - 10].

Several studies have demonstrated the ability to optimize configurations of renewable energy systems in order to maximize performance while minimizing cost. The optimization of energy systems in the context of minimizing excess energy and cost of energy is addressed by Juhari et al [11]. The high upfront cost hybrid systems warrant the need to optimize unit sizing for reliable and cost-effective energy system [12]. The annualized cost of a component was used by Kamaruzzaman et al [13] and Lambert [14] to derive the calculation of the total Net Present Cost (NPC) of energy systems. Kamel et al [15] and Khan et al [16] used the HOMER software [17] to find optimum sizing and minimizing cost for hybrid power system with specific load demand in stand-alone applications. Ashok [18] developed a reliable system operation model based on HOMER [19] to find an optimal hybrid system among different renewable energy combinations while minimizing the total life cycle cost. HOMER has been used to conduct feasibility study of hybrid systems in many locations around the world [20 - 24]. The optimal system for providing electricity to a community of 200 families in Ethiopia were determined by Bekele et al [21]. They found that in the 2009 diesel price, the diesel generator/battery/converter set-up was the most cost-effective. A 51% RE-based system was 19% more expensive but with half the GHG emissions. With the ever increasing diesel price and continued decrease in solar PV module prices, RE-based systems are becoming more competitive. Al-Karaghouli et al [25] applied HOMER to study the life cycle cost of a hybrid system for a rural health clinic in Iraq. A system comprising PV/battery/inverter emerged as the most economic system. Shaahid et al [20] 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 cost of energy (COE), operational hours of diesel generators and reduction in GHG emissions. Van-Alphen et al [26] used HOMER to create optimal RE system designs in the Maldives. HOMER software contains a number of energy components and evaluates suitable options based on cost and availability of energy resources. HOMER is a sizing and optimization tool. The simulation approach is mainly economical model. The methods of dispatch and control strategies are determined by the software [27].

In this paper, computer software called HOMER was proposed to be used to optimize the unit sizing and cost analysis of PV/Hydro/Diesel Hybrid Power system in GSM base station sites located in a rural area of Ikwerre (Rivers State).

3. Methodology

Technological options explored were Solar-PV, Hydro turbine and diesel generator. Efforts were made to simulate and analyze a large number of alternative system configurations. Thereafter optimization analyses were carried out to make the best possible sizing configurations. For this task a tool called HOMER was used. The characteristics and capabilities of HOMER have been explained above and have previously been used [28 - 33].

3.1. Calibration of the Model

Without validating data coupled with optimization and modelling there is little reason to believe that the conclusions stated in any paper has applicability beyond the immediate circumstances stated in each specific paper. Before applying the measured data obtained from National Aeronautics and Space Administration (NASA) datasets in simulating the individual components of a PV/Hydro-Diesel Hybrid system, HOMER accuracy must be demonstrated. If the simulated data predicted by the software programs do not fall within the bounds of the measured data, then there is either a problem with how the models are formulated or a problem with the models that the programs use. If HOMER is proven sufficiently accurate, the software program will be used for the simulation and optimization of the hybrid PV/Hydro-Diesel system.

Using the solar radiation from the NASA datasets, and the measured stream flow, the bounds for the HOMER and measured parameter and the comparison between them are shown in figures 1.1 and 1.2. From these graphs, it was shown that the simulated data from HOMER fall within the bounds of the measured data (solar radiation and stream flow).

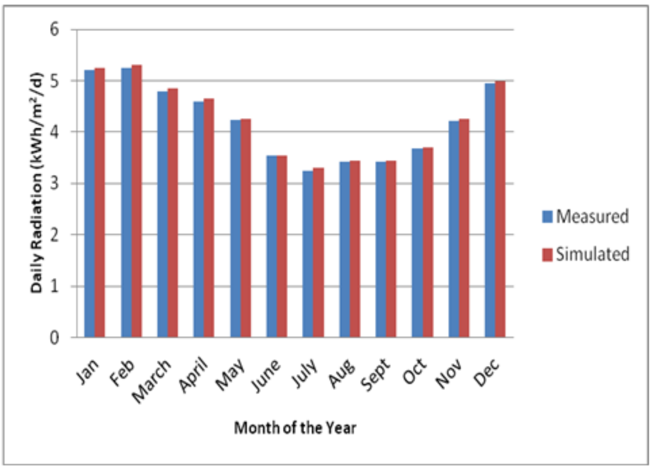

Fig. 1.1. Calibrated solar radiation.

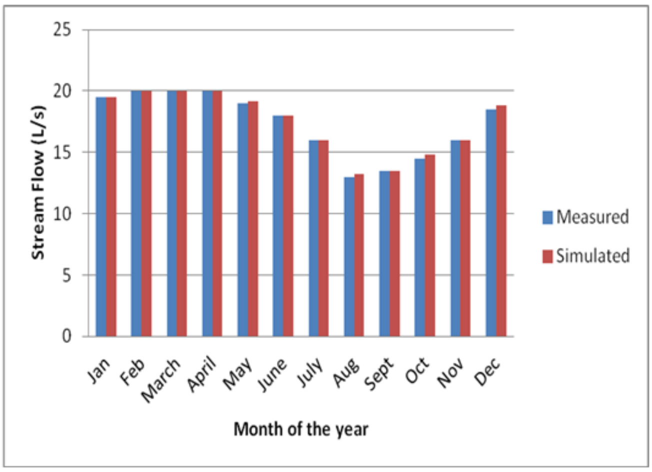

Fig. 1.2. Calibrated Stream flow.

3.2. Materials and Method

HOMER assists researchers in designing an optimal hybrid power system based on comparative economic analysis. The HOMER software determines optimal hybrid systems using combinations of photovoltaics, micro-hydro, diesel generation, battery storage, and inverter capacity. HOMER also takes into account both seasonal and hourly load variations as well as variations in resource availability such as flowrate and sunlight [34]. In addition, HOMER outputs multiple options ranked in order of least net present cost, which is based on a 20-yr lifecycle cost including interest.

Load

Hourly load demand (Macro Base Station Site perspective) has been given as an input in HOMER and then it generates daily and monthly load profile for a year. It has been found that this site consumes energy around 254kWh/day with a peak demand of nearly 10.67kW as shown in figure 3. The table below (table 1) shows the hourly load demand for radio base station and climate & auxiliary equipment.

Table 1. Load Inputs for Radio Base Station and Climate & Auxiliary Equipment [1].

Hour	Radio Base Station Baseline Data Load (kW)	Climate & Auxiliary Equipment Baseline Data Load (kW)
00:00 - 01:00	7.860	2.790
01:00 - 02:00	7.860	2.790
02:00 - 03:00	7.860	2.790
03:00 - 04:00	7.860	2.790
04:00 - 05:00	7.860	2.790
05:00 - 06:00	7.860	2.790
06:00 - 07:00	7.860	2.790
07:00 - 08:00	7.860	2.590
08:00 - 09:00	7.860	2.590
09:00 - 10:00	7.860	2.590
10:00 - 11:00	7.860	2.590
11:00 - 12:00	7.860	2.590
12:00 - 13:00	7.860	2.590
13:00 - 14:00	7.860	2.590
14:00 - 15:00	7.860	2.590
15:00 - 16:00	7.860	2.590
16:00 - 17:00	7.860	2.590
17:00 - 18:00	7.860	2.790
18:00 - 19:00	7.860	2.790
19:00 - 20:00	7.860	2.790
20:00 - 21:00	7.860	2.790
21:00 - 22:00	7.860	2.790
22:00 - 23:00	7.860	2.790
23:00 - 00:00	7.860	2.790

3.3. Renewable Resources

The data for solar resource was obtained from the National Aeronautics and Space Administration (NASA) Surface Meteorology and Solar Energy web site [35], while the hydro resource was measured at the site. The specific geographical location of Ikwerre (River State) is at a location of 4° 00' N latitude and 7° 00' E longitude with annual average solar (clearness index and daily radiation) of 4.21kWh/m²/d and annual average stream flow of 17.3L/s. Figures 2.1 and 2.2 show the solar and hydro resource profile of this area.

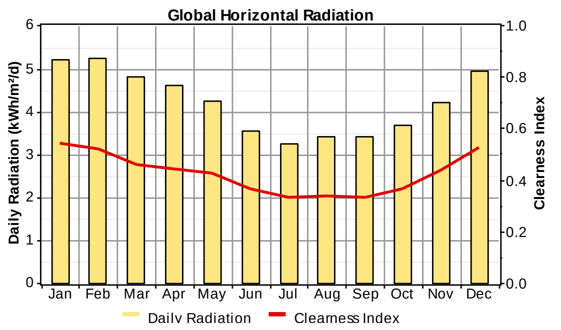

Fig. 2.1. HOMER output graphic for solar profile for Ikwerre (Rivers).

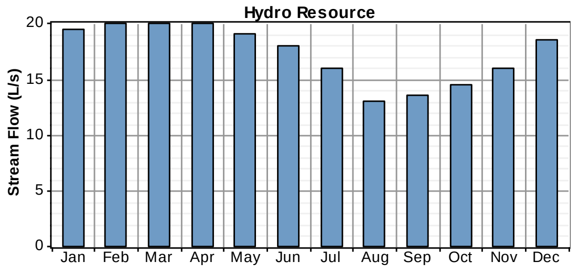

Fig. 2.2. HOMER output graphic for Stream flow profile for Ikwerre (Rivers)

3.4. Hybrid System Components

Photovoltaic Module

The PV modules used were Polycrystalline Photovoltaic Module with 140W Maximum Power. The PV module has a derating factor of 80% and a ground reflectance of 20%. The Photovoltaic system was considered to have no tracking system for the purpose of the study in order to determine the worst case resource. The details of solar properties are shown in table 2:

Table 2. Details of Solar Properties

Solar Module type: SolarWorld SW 140 poly R6A	
Module Size (kW)	0.140
Array Size (kW)	10.7
Lifetime	20 yr
PV Control	
Derating factor	80%
Tracking system	No Tracking
Azimuth	0 deg
Ground reflectance	20%

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 efficiency of the turbines. The life time of the micro hydro model in simulation is taken as 20 years. The details of micro hydro parameters have been given in table 3.

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
Minimum flow ratio	25 %
Maximum flow ratio	100 %
Turbine efficiency	75 %
Pipe head loss	10.5%

Diesel Generator Model

Diesel generator technology is widespread and the development of the power plant is relatively easy. The price of diesel fuel is N165 ($1.0/L) based on federal government approved pump price in Nigeria as of July, 2012. This price varies considerably based on region, transportation costs, and current market price. 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 hydro and solar systems fails to satisfy the load and when the battery storage is depleted.

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 hrs
Diesel Generator Control	
Minimum load ratio	30 %
Heat recovery ratio	0 %
Fuel used	Diesel
Fuel curve intercept	0.08 L/hr/kW
Fuel curve slope	0.25 L/hr/kW
Fuel: Diesel	
Price	N165 ($1.0/L)
Lower heating value	43.2 MJ/kg
Density	820 kg/m3
Carbon content	88.0%
Sulphur content	0.330%

Storage Battery

The variations of solar and hydro 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 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%. Batteries are considered as a major cost factor in small-scale stand-alone power systems. The details of storage battery model parameters have been given in table 5.

Table 5. Surrette 6CS25P Battery Properties [19]

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

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 instance, the size of the converter ranges from 0 to 50 kW for simulation purposes. The details of converter parameters have been given in table 6.

Table 6. Details of Converter Parameters

Converter	
Sizes to Consider (kW)	25, 50
Lifetime	20 yr
Converter Control	
Inverter efficiency	85%
Inverter can parallel with AC generator	Yes
Rectifier relative capacity	100%
Rectifier efficiency	85%

3.5. Hybrid System Control Parameters and Operating Strategies

Two types of dispatch strategies are available in HOMER. In the 'load following' strategy, the generators supply just enough power to service the loads whenever there is an insufficient renewable energy contribution. In the 'cycle charging' strategy, the generator (if present) runs at full power and surplus electricity is used for charging the batteries. In the present work, the dispatch strategy is 'cycle charging' and an 80% state of charge was set in this strategy.

When the renewable sources produce less energy than demanded (the water flow and the solar radiation are low), the deficit power should be supplied by the battery bank. When the state of charge of the battery bank reaches its minimal level (40%), the diesel generator functions. The surplus of energy produced by the diesel generator and the renewable energy sources (variation of the climatic data) is stored in the battery bank.

The storage batteries are a key factor in a hybrid system of renewable energy, it allows to minimize the number of starting/stopping cycle of the diesel generator which reduces the problem of its premature wear, and to satisfy the request of the Lord in spite of renewable sources fluctuations. The system control inputs used are shown in table 7.

Table 7. System control inputs

Simulation	
Simulation time step (minutes)	60
Dispatch Strategy	
Allow systems with multiple generators:	Yes
Allow multiple generators to operate simultaneously:	Yes
Allow systems with generator capacity less than peak load:	Yes
Generator control	
Check load following:	No
Check cycle charging:	Yes
Setpoint state of charge:	80%

3.6. Economics and Constraints

The project lifetime is estimated at 20 years. The annual interest rate is fixed at 6%. There is no capacity shortage for the system and operating reserve is 10% of hourly load. The operating reserve as a percentage of hourly load was 10%. Meanwhile, the operating reserve as a percentage of solar power output was 25%. Operating reserve is the safety margin that helps ensure reliability of the supply despite variability in electric load and solar power supply. The constraints inputs required by the software are given in table 8.

Table 8. Constraints inputs

Maximum annual capacity shortage:	**0%**
Minimum renewable fraction:	0%
Operating reserve as percentage of hourly load:	10%
Operating reserve as percentage of annual peak load:	0%
Operating reserve as percentage of solar power output:	25%

System Economics

The capital costs of all system components including PV module, hydro turbine, diesel generator, inverter, battery and balance of system prices are based on quotes from PV system suppliers in Nigeria [36]. These costs are estimates based on a limited number of internet enquiries and prices. They are likely to vary from the actual system quotes due to many market factors. The figures used in the analysis are therefore only indicative.

The replacement costs of equipment are estimated to be 20% - 30% lower than the initial costs, but because decommissioning and installation costs need to be added, it was assumed that they are the same as the initial costs.

The PV array, hydro turbine, diesel generator, Inverter and battery maintenance costs are estimates based on approximate time required and estimated wages for this sort of work in a remote area of Nigeria. All initial costs including installation and commissioning, replacement costs and operating & Maintenance costs of the site are summarized in Table (9). All costs presented are in US currencies Dollar ($).

Table 9. Summary of initial system costs, Replacement costs and operating & Maintenance costs

Item	**Initial System Costs**	**Replacement Costs**	**Operating & Maintenance Costs**
PV modules	N 324/W ($2)	N 291.6/W ($1.8)	N 16,200/kW/yr ($100)
Hydro turbine	N 8,100,000 ($50,000)	N 6,480,000 ($40,000)	N 162,000 ($1,000)
16kVA Diesel Generator	N 2,106,000 ($13,000)	N 2,106,000 ($13,000)	N 405/hr ($2.5)
Surrete 6CS25P battery	N 185,490 ($1,145)	N 162,000 ($1,000)	N 16,200 ($100)
Converter	N 324/W ($2)	N 324/W ($2)	N 16,200/kW/yr ($100)
Labour	N 6,480,000 ($40,000)	N/A	N/A

NA: Not Applicable

Inputs to the HOMER software in the simulation have been described (the technical and economic data of all the components of the hybrid system). The input parameters and system constraints, as described above, were used to simulate the hybrid system and perform optimization analysis. HOMER determines the optimal system by choosing suitable system components (system configuration) depending on parameters like solar radiation, water flowrate, diesel price and maximum annual capacity shortage. The feasibility of a configuration is based on the NPC and hourly performance.

Method

Based on the energy consumption of mobile base station and the availability of renewable energy sources, it was decided to implement an innovative stand alone Hybrid Energy System [37 - 38] combining solar photo-voltaic panels, pico-hydro turbine-generator, diesel generator, battery storage, and bi-directional converter. The system architecture employed in the hybrid system is DC coupled where the renewable energy sources and the conventional diesel generators all feed into the DC side of the network as depicted in Fig. 3.

To obtain this optimal system, a few assumptions and restrictions have been made. Firstly, willing to keep all the different components within the system, the minimum power of each component is limited to 10kW.

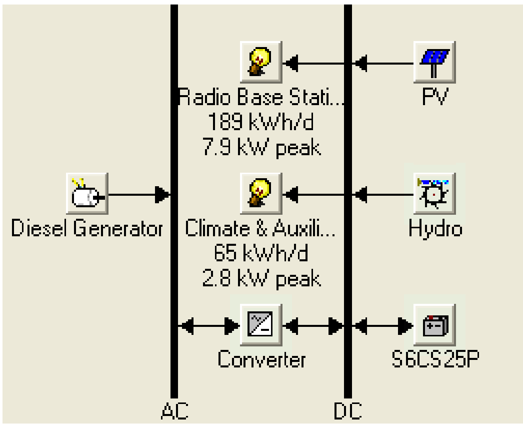

Fig 3. The network architecture for the HOMER simulator

Finally, in order to favour the use of renewables over the use of the Diesel Generator, the Generator size has been limited to 16kW to match its energy production. This optimal sizing has been obtained step by step by modifying gradually the size of the different elements with the objectives to minimize their size for cost interests and to reduce as far as possible the use of the diesel generators for environmental interests.

It is also important to note that this optimal system has been obtained with particular capital, replacement, operation and maintenance costs for each component. HOMER basing its optimization process on costs calculations, it is obvious that changes in these costs would generate different results and therefore a different optimal system. However, these costs seem quite logical and in accordance with the prices of the market.

The total Net Present Cost (NPC) for economic and environmental evaluation of Hybrid (Solar & Hydro) + DG, Hydro only + DG, Solar only + DG, DG system have been developed and simulated using the model which results in four different topologies:

- Diesel system
- Solar-diesel system
- Hydro-diesel system
- PV/hydro-diesel system

From the outlined design above, there is the possibility of comparing the cost-effectiveness of adding renewable energy components to the existing energy (Diesel):

1. The standard diesel generator configuration with pure hydro and/or pure solar models.
2. The standard diesel generator configuration with renewable hybrids (solar & hydro).

In the optimization process, the proposed system was simulated with many different system configurations in search of the one that satisfies the technical constraints at the lowest life-cycle cost.

4. Results and Discussion

4.1. Simulation and Optimization Results

The different types of possible single-source systems and hybrid system combinations were simulated with their costing and sizing compared with a PV/hydro/diesel/battery system. It can be seen from the simulation results in Table 10 that no renewable only system, PV/battery or hydro/battery, can meet the demand requirements cost effectively. For the high demand level of 254kWh/day, a diesel generator only system is more reasonable in cost than a renewable only system. However, the life cycle costing of a diesel generator only system can be improved by adding one renewable with a battery, and can be further improved by also adding other renewable sources, as in Diesel/PV/hydro/battery system. From the optimization results the best optimal combination of energy system components are 10.7kW PV-Array, 10.3kW Hydro, 16 kW Diesel Generator, Surrette 6CS25P and 25kW Rectifier.

In order to achieve a realistic result, different energy component configurations were considered.

The categorized list displays four different configurations, in ascending order by the most effective NPC as follows:

1. Hybrid (Solar & Hydro) + DG + Batteries + Converter
2. Hydro only + DG + Batteries + Converter
3. Solar only + DG + Batteries + Converter
4. DG + Converter

Results of the Analysis

This is to carry out four energy component configurations for power supply to GSM Base Station Sites located in rural area of Ikwerre (Rivers) for the project lifetime of 20 years. The results of the analysis of four possible system configuration scenarios considered in this study are shown in Tables 10, 11, and 12. This enables comparisons between options based on economic performance and environmental factors. These scenarios are also compared with the existing diesel only option.

Economic Analysis

Economic indices determine the life cycle economics of the system. Of particular interest is the total net present cost (NPC). This information, in turn, enables the optimum renewable energy component sizes that would be required to meet the specified fraction of the load at the least cost. As HOMER calculates in US Dollar ($), all costs have been converted from Naira (N) into USD ($) as shown in table 9 using the equivalent as 1US Dollar ($) equal to N162 of Nigerian currency. Afterwards the calculations have been performed, the costs in USD was given by HOMER's output windows.

Table 10. Initial Cost, Operating Cost, and Total NPC of single and hybrid Energy System

Parameter	Diesel	PV-Diesel	Hydro-Diesel	PV/Hydro-Diesel
Initial Cost	$310,360	$380,220	$360,360	$435,260
Operating Cost	$1,756,634	$1,532,202	$759,911	$493,226
Total NPC	$22,766,034	$19,966,900	$10,074,569	$6,804,257

The Contribution to the Total Electricity Generated by Individual System Components

Table 11 shows the contribution to the total electricity generated by individual system components.

Table 11. The contribution to the total electricity generated by individual system components

Parameter	Diesel	PV-Diesel	Hydro-Diesel	PV/Hydro-Diesel
Diesel	(113,349) 100%	(98,869) 88%	(49,072) 47%	(32,160) 32%
PV	0%	(13,527) 12%	0%	(13,527) 13%
Hydro	0%	0%	(55,885) 53%	(55,885) 55%
Total	(113,349) 100%	(112,396) 100%	(104,957) 100%	(101,572) 100%

Emission Estimation Analysis from the use of Diesel Fuel (Diesel Generator)

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 sources [39 - 40]. In the present work, the amount of possible pollutants arising from the use of diesel fuel in powering the GSM Base Station Site was simulated with HOMER software. The simulated results are shown in Table 12.

Table 12. Comparison of Simulation results of Environmental pollution

Parameter	Diesel	PV-Diesel	Hydro-Diesel	PV/Hydro-Diesel
Carbon dioxide (kg/yr)	98,500	85,914	42,644	27,947
Carbon monoxide (kg/yr)	243	212	105	69
Unburned hydrocarbon (kg/yr)	26.9	23.5	11.7	7.64
Particulate matter (kg/yr)	18.3	16	7.94	5.2
Sulphur dioxide (kg/yr)	198	173	85.6	56.1
Nitrogen oxides (kg/yr)	2,170	1,892	939	616

4.2. Discussion

Hybrid (PV & Hydro) + Diesel Generator

Economic Cost

PV/hydro-diesel has total NPC of $6,804,257, operating cost of $493,226, and initial cost of $435,260 as shown in Table 10. This system saves $15,961,777 to the network operator when compared with the diesel only.

Electricity Production

In hybrid PV/hydro-diesel system, the PV system has a capacity factor of 14.4% and supplies 13% of the annual electricity production, while the hydro turbine contributes 55% with a capacity factor of 61.9%. Diesel generator contributes 32% of the annual electricity production, has an overall efficiency of 30.8%, and has a capacity factor of 22.9%. PV/hydro-diesel system has the ability for reducing the proportion of energy supplied by diesel generator to 32% of the total electricity as shown in Table 11.

Environmental Impact

In the hybrid PV/hydro-diesel system, Diesel generator operates for 2,010h/annum with fuel consumption of 10,613L/annum. This system emits 27.947 tonnes of CO_2, 0.069 tonnes of CO, 0.00764 tonnes of UHC, 0.0052 tonnes of PM, 0.0561 tonnes of SO_2, and 0.616 tonnes of NOx annually into the atmosphere of the location under consideration as shown in Table 12. 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: 70.553 tonnes of CO_2, 0.174 tonnes of CO, 0.01926 tonnes of UHC, 0.0131 tonnes of PM, 0.1419 tonnes of SO_2, and 1.554 tonnes of NOx.

Hydro only + Diesel Generator

Economic Cost

Hydro-diesel has total NPC of $10,074,569, operating cost of $759,911, and initial cost of $360,360 as shown in Table 10. This system saves $12,691,465 to the network operator when compared with the diesel only.

Electricity Production

In hybrid Hydro-diesel system, the Hydro system has a capacity factor of 61.9% and supplies 53% of the annual electricity production. Diesel generator contributes 47% of the total electricity with a capacity factor of 35.0%. The hydro - diesel system gives an opportunity for renewable energy to supply 53% of the total electricity as shown in Table 11.

Environmental Impact

In the hybrid Hydro-diesel system, Diesel generator operates for 3,067h/annum has a fuel consumption of 16,194L/annum. This system emits 42.644 tonnes of CO_2, 0.105 tonnes of CO, 0.0117 tonnes of UHC, 0.00794 tonnes of PM, 0.0856 tonnes of SO_2, and 0.939 tonnes of NOx annually into the atmosphere of the location under consideration as shown in Table 12. Nearly 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: 55.856 tonnes of CO_2, 0.138 tonnes of CO, 0.0152 tonnes of UHC, 0.01036 tonnes of PM, 0.1124 tonnes of SO_2, and 1.231 tonnes of NOx.

PV only + Diesel Generator

Economic Cost

PV-diesel has total NPC of $19,966,900, operating cost of $1,532,202, and initial cost of $380,220 as shown in Table 10. This system saves $2,799,134 to the network operator when compared with the diesel only.

Electricity Production

In hybrid PV-diesel system, the PV system has a capacity factor of 14.4% and supplies 12% of the annual electricity production. Diesel generator contributes 88% of the total electricity with a capacity factor of 70.5%. The PV - diesel system gives an opportunity for renewable energy to supply 12% of the total electricity as shown in Table 11.

Environmental Impact

In the hybrid PV-diesel system, Diesel generator operates for 6,180h/annum has a fuel consumption of 32,626L/annum. This system emits 85.914 tonnes of CO_2, 0.212 tonnes of CO, 0.0235 tonnes of UHC, 0.016 tonnes of PM, 0.173 tonnes of SO_2, and 1.892 tonnes of NOx annually into the atmosphere of the location under consideration as shown in Table 12. 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: 12.586 tonnes of CO_2, 0.031 tonnes of CO, 0.0034 tonnes of UHC, 0.0023 tonnes of PM, 0.025 tonnes of SO_2, and 0.278 tonnes of NOx.

Diesel Generator

Economic Cost

Diesel only has total NPC of $22,766,034, operating cost of $1,756,634 and initial cost of $310,360 as shown in Table 10.

Electricity Production

There is no change in the conventional system due to optimization. Thus power is drawn from the generator continuously. The diesel only system contributes 100% of the total electricity with a capacity factor of 81.1%.

Environmental Impact

Diesel only generates 98.5 tonnes of CO_2, 0.243 tonnes of CO, 0.0269 tonnes of UHC, 0.0183 tonnes of PM, 0.198 tonnes of SO_2, and 2.17 tonnes of NOx as shown in Table 12. Carbon emission for this system is very high as a result of burning a lot of fossil fuel.

In summary, Diesel only system has the least initial capital cost but in the end has the highest total net present cost for the whole project. While the hybrid system topologies need higher initial capital cost, but in the end they have less total net present cost as a result of less fuel consumption.

In this study, the overall cost (NPC) of the system is found to be linearly decreasing with increase in renewable fraction. Also, by increasing the renewable fraction, the amount of CO_2 emitted by the system as a whole would be considerably reduced. From the simulation results it was observed that the use of PV panels and hydro turbine with diesel as a backup were viable power supply options for BTS site considered here.

Finally, among the four energy configurations studied (PV/Hydro-Diesel, Hydro-Diesel, PV-Diesel and Diesel), the best option is PV/Hydro-Diesel system. It has the least NPC and the power drawn from the diesel is minimal, thus is a considerable reduction in the amount of CO_2 emitted from the system.

This study proves that using renewable sources to power GSM base station sites is far better than the conventional diesel system especially in rural areas where there is no utility power. The proposed system reduces both the cost and the amount of CO_2 emitted from the entire setup.

5. Conclusion

The possibility of utilizing renewable power to reduce the dependence on fossil fuel for power generation to meet the energy requirement of a GSM base station site located in Ikwerre (Rivers State) was explored. HOMER software was used to determine the possible combination of renewable energy systems and set the optimum hybrid configuration for telecoms station based in Ikwerre (Rivers State) - Nigeria. The availability of different renewable energy sources is highly variable and the comparison suggests that there is a need of integrated renewable energy systems which will reduce the dependencies on diesel generating units and other conventional energy sources. These combinations show the economic analysis of adopting each energy resource over a period of 20 years.

The PV/Hydro-Diesel system has the highest renewable energy penetration by supplying 72% of the energy demand. It has total NPC of $6,804,257 and saves $15,961,777 to the network operator; emits 558.94 tonnes of CO_2 and saves 1411.06 tonnes of CO_2 from entering into the atmosphere when compared with the diesel only. This system has the ability for reducing the proportion of energy supplied by diesel generator to 32%. The reduction in total GHG with increasing renewable penetration of 68% show visible positive impact on GHG reduction.

In summary, the hybrid power system offers a better performance to provide power supply than the diesel only system. The simulation results demonstrate that utilizing renewable generators such as a hybrid (PV and/or hydro and/or Diesel systems) generator reduces the operating costs and the greenhouse gases (CO_2 and NOx) and particulate matter emitted to the environment, as an impact of improving diesel efficiency operation and also less fuel consumption. The results also demonstrate that renewable energy technologies, including solar PV and micro hydro systems, have the potential of supplying electricity to base station sites in a cost effective manner.

A major contribution of this study is the evaluation of cost savings and the reduction in the quantity of different air pollutants engendered by converting the existing diesel-only system at GSM base station sites in rural areas into a hybrid power system.

References

[1] Ani, V. (2013). Energy Optimization at Telecommunication Base Station Sites. Unpublished doctoral dissertation, University of Nigeria, Nsukka. Nigeria

[2] CAT, Caterpillar, (2011) "Power Your Telecom Site With Cat ® Hybrid Power For Telecom Applications.

[3] SOLUTIONS PAPER: Alternative Power for Mobile Telephony Base Stations. (2007). Source: www.motorola.com

[4] Bala, E.J., Ojosu, J.O. & Umar, I. H. (2000). Government Policies and Programmes on the Development of Solar-PV Sub-sector in Nigeria. Nigerian Journal of Renewable Energy, 8 (1&2), 1-6.

[5] Chendo, M. A. C. (2002). Factors Militating Against the Growth of the Solars-PV Industry in Nigeria and their Removal. Nigerian Journal of Renewable Energy 10 (1&2), 151-158

[6] Taylor R., Hybrid power systems. Retrieved from http://files.harc.edu/Documents/EBS/CEDP/HybridPowerSystems.pdf on 16 December, 2011.

[7] Peterson A. J, Perez R, Bailey B and Elsholz K. (1999), Operational experience of a residential photovoltaic hybrid system. Solar Energy 65, 1999, 227-235

[8] Jose´ L. Bernal-Agustı´n and Rodolfo Dufo-Lo´ pez, (2009) Simulation and optimization of stand-alone hybrid renewable energy systems. Renewable and Sustainable Energy Reviews 13 (2009) 2111-2118

[9] Muselli M, Notton G, Louche A. (1999), Design of hybrid-photovoltaic power generator, with optimization of energy management. Solar Energy 1999; 65(3): 143-57.

[10] Bagen, Billinton R. (2005), Evaluation of different operating strategies in small standalone power systems. IEEE Trans Energy Convers 2005;20(3):654-60.

[11] Juhari Ab. Razak, Kamaruzzaman Sopian & Yusoff Ali, (2007), Optimization of Renewable Energy Hybrid System by Minimizing Excess Capacity. International Journal of Energy, Issue 3, Vol. 1, 2007, pp. 77 - 81.

[12] Kellog, W., Nehrir, M.H., Venkataramanan, G. & Gerez, V. (1996) Optimal Unit Sizing for a Hybrid Wind/Photovotaic Generating System. Electric Power Systems Research, Vol 39, 1996, pp. 35-38.

[13] Kamaruzzaman Sopian, Azami Zaharim, Yusoff Ali, Zulkifli Mohd Nopiah, Juhari Ab. Razak, Nor Salim Muhammad, (2008) Optimal Operational Strategy for Hybrid Renewable Energy System Using Genetic Algorithms WSEAS TRANSACTIONS on MATHEMATICS Issue 4, Volume 7, April 2008, pp130-140.

[14] Lambert T., HOMER: The Hybrid Optimization Model for Electrical Renewables. http://www.nrel.gov/international/tools/HOMER/homer.html

[15] Kamel, S. & Dahl, C., (2005), The Economics of Hybrid Power Systems for Sustainable Desert Agriculture in Egypt, Energy, Vol. 30, 2005, pp 1271-1281.

[16] Khan, M.J., & Iqbal, M.T., (2005), Pre-Feasibility Study of Stand-Alone Hybrid Energy Systems for Applications in Newfoundland, Renewable Energy, Vol. 30, 2005, pp. 835-854.

[17] National Renewable Energy Laboratory, HOMER Getting Started Guide Version 2.1, NREL, 2005.

[18] Ashok, S. (2007), Optimised Model for Community-Based Hybrid Energy System. Renewable Energy, Vol. 32, No. 7, 2007, pp. 1155-1164.

[19] HOMER (The Hybrid Optimization Model for Electric Renewables). Available from: http://www.nrel/gov/HOMER.

[20] Shaahid SM, El-Amin I. (2009), Techno-economic evaluation of off-grid hybrid photovoltaic-diesel-battery power systems for rural electrification in Saudi Arabia-a way forward for sustainable development. Renew Sustain Energy Rev 2009. doi: 10.1016/j.rser.2007.11.017.

[21] Bekele, G., Palm, B. (2010), Feasibility study for a standalone solar-wind-based hybrid energy system for application in Ethiopia. Applied Energy 87, 487-495 (2010).

[22] Hassan, K., Faitma, K., Mahmood, H.S. (2011), Feasibility of hybrid power generation over wind and solar standalone system. In: 5th Power Engineering and Optimization Conference (PEOCO), Selangor, 6-7 June 2011.

[23] Nandi, S.K., Ghosh, H.R. (2010), Prospect of wind-PV-battery hybrid power system as an alternative to grid extension in Bangladesh. Energy 35, 3040-3047 (2010).

[24] Rehman, S., Al-Hadhrami, M.L. (2010), Study of a solar PV-diesel-battery hybrid power system for a remotely located population near Rafha Saudi Arabia. Energy 36, 4986-4995 (2010).

[25] Al-Karaghouli, A., Kazmerski, L. (2010), Optimization and life-cycle cost of health clinic PV system for a rural area in southern Iraq using HOMER software. Solar Energy 84, 710-714 (2010).

[26] Van-Alphen, K., Wilfried, G.J.H.M., Hekkert, M.P. (2007), Renewable energy technologies in the Maldives-determining the potential. Renew. Sustain. Energy Rev. 11, 1650-1674 (2007).

[27] Givler T. and Lilienthal P. (2005) Using HOMER® Software, NREL's Micropower Optimization Model, to Explore the Role of Gen-sets in Small Solar Power Systems Case Study: Sri Lanka. Technical Report NREL/TP-710-36774 May 2005. http://www.nrel.gov/docs/fy05osti/36774.pdf

[28] Khan MJ, Iqbal MT (2005), Pre-feasibility study of stand-alone hybrid energy systems for applications in Newfoundland. Renew Energy 2005; 30(6):835-54.

[29] Nfah, E.M., Ngundam, J.M., Vandenbergh, M., Schmid, J., (2008). Simulation of off-grid generation options for remote villages in Cameroon. Renewable Energy. 33 1064-1072

[30] Rehman, S., El-Amin, I.M., Ahmad, F., Shaahid, S.M., Al-Shehri, A.M., Bakhashwain, J.M., Shash, A., (2007), Feasibility study of hybrid retrofits to an isolated off-grid diesel power plant. Renewable and Sustainable Energy Reviews, Volume 11, Issue 4, 635-653

[31] Georgilakis, P.S., (2005), State-of-the-art of decision support systems for the choice of renewable energy sources for energy supply in isolated regions, International Journal of Distributed Energy Resources, 2 (2), 129-150

[32] Shaahid, S.M., El-Amin, I., Rehman, S., Al-Shehri, A., Bakashwain, J., Ahmad, F., (2004), Potential of autonomous/off-grid hybrid wind-diesel power system for electrification of a remote settlement in Saudi Arabia, Wind Engineering, 28 (5), 621-628

[33] Lilienthal, P., Lambert, T., Gilman, P., (2004), Computer modeling of renewable power systems. In (Ed.) Cleveland, C.J., Encyclopedia of Energy, Elsevier Inc., Volume 1, pp. 633-647

[34] Lambert, T., & Lilienthal, P. (2001). HOMER Interactive Training Manual. Golden, CO: National Renewable Energy Lab.

[35] National Aeronautics and Space Administration (NASA, 2013) Atmospheric Science Data Center http://eosweb.larc.nasa.gov/sse/2010.

[36] http://www.solarshopnigeria.com/index.php/solar-pv-modules/solarworld-modules/sunmodule-sw-140-poly-r6a.html.

[37] Celik A.N. (2002). The system performance of autonomous photovoltaic-wind hybrid energy systems using synthetically generated weather data. Renewable Energy 27, 107-121

[38] Nema Pragya, Nema R.K., Rangnekar Saroj (2010) PV-solar / wind hybrid energy system for GSM/CDMA type mobile telephony base station. International Journal of Energy and Environment Volume 1, Issue 2, 2010 pp.359-366 Available at: www.ijee.ieefoundation.org/vol1/issue2/IJEE_14_v1n2.pdf

[39] OSHA. Safety and health topic: Diesel emission, Occupational Safety & Health Administration (OSHA), U.S. Department of Labor, US. See also, http://www.osha.gov/SLTC/dieselexhaust/; 2009 [accessed 29.04.08].

[40] DOSH. Guidelines on occupational safety and health. Malaysia: Department of Occupational, Safety and Health (DOSH); 2004.