Simulation of Solar-Photovoltaic Hybrid Power Generation System with Energy Storage and Supervisory Control for Base Transceiver Station (BTS) Site Located in Rural Nigeria

Ani Vincent Anayochukwu*‡, Ani Emmanuel Onyeka**

*Department of Electronic Engineering, University of Nigeria, Nsukka (UNN), Nigeria
**Department of Accountancy, University of Nigeria, Enugu Campus (UNEC), Nigeria
(vincent_ani@yahoo.com; emmabek4real@yahoo.com)

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

Received: 23.11.2013 Accepted: 24.12.2013

Abstract – In this paper, we present the design of power generation (Photovoltaic (PV)/diesel hybrid power system) with energy storage for macro Base Transmitter Station (BTS) site located in Ogologo-Eji Ndiagu Akpugo in Nkanu-West Local Government Area of Enugu State – Nigeria. A supervisory control system for the hybrid energy system with battery storage was also developed to monitor and control the modes of power supply. The BTS site has a daily load of 254kwh/d. Solar resource for the design of the system was obtained from the National Aeronautics and Space Administration (NASA) Surface Meteorology and solar energy website at a location of 6°35'N latitude and 7°51'E Longitude, with an annual average solar radiation of 4.92kWh/m²/d. The Hybrid Optimization Model for Electric Renewables (HOMER) software was used for the design of the proposed stand-alone PV/diesel hybrid power system. The study assesses the savings associated with the conversion of the diesel powered system to a PV/diesel hybrid power system. The simulation results show that the PV/diesel hybrid system has a total NPC cost and the amount of CO_2 as ($19,451,848; 83.62 tons) and saves ($3,314,186; 14.88 tons) when compared with the diesel-only system ($22,766,034; 98.50 tons). The working principle of the developed control system coordinates when power should be supplied by PV panels only and when it should be supplied by PV panels together with the batteries, and only allocates the diesel generator when the demand cannot be met by the solar energy including battery bank.

Keywords: Ogologo-Eji Ndiagu Akpugo, HOMER, PV/Diesel Hybrid System, Diesel Generator, Energy Optimization, Simulation, Nigeria.

1. Introduction

The provision of reliable and cost effective power solutions for the global expansion of mobile telecommunications in the rural and remote areas-including towns and cities that lack the basic power infrastructure presents a very challenging problem. In the developed countries well-developed power infrastructure exists, whereas in the developing world the chances of having a constant power supply through the grids are not reliable and have limited coverage. From the above overview, it is evident that lack of grid power supply in rural Nigeria poses great challenges to all stakeholders in the telecommunications industry. In an attempt to provide solution to the aforementioned problem most network providers have resulted in the use of diesel generators [1]. Little or no attention has been paid to the exploitation of all other available energy (renewable) resources in the rural areas. Energy costs account for more than half of the mobile operators' operating expenses and about 65% of this is for the BTS equipment [2]. The operation and maintenance of diesel generators is relatively costly, which typically accounts for 35%

of the total cost of ownership (TCO) of the BTS [3]. Renewable energy is believed to contribute significantly to the reduction of this energy cost, if properly integrated into the BTS energy sources. Hybrid Power Systems (HPSs) have been described as among the popular cost-saving renewable energy applications in the telecommunications industry. But till date these systems (HPSs) have found little or no applications in Nigeria. This may be attributed to the lack of information on the necessary site and system parameters required to design suitable HPSs to meet given loads of BTS sites. The work reported in this paper has been designed to explore the HPS potentials for powering BTS site in rural area in Nigeria. The research is based on theoretical mathematical modeling and simulation using the hybrid optimization model for electric renewables (HOMER) software. Specifically, this study sought to: (i) demonstrate the potential of renewable energies to replace (partially or totally) diesel as a source of power for mobile base stations (ii) examine the effect of hybridizing diesel generator source system with renewable energy source on the operational hours of diesel generator and the reduction in greenhouse gas (GHG) emission, and (iii) the total net present cost (NPC) of generating energy.

2. Energy Consumption at a Macro Base Transmitter Station Site.

The energy consumption of the various components of a typical BTS site has been categorized by GSMA [4], Pierre [5], Roy [6], and Willson [7], and is implied by Ani, & Emetu [8], that a Macro Base Transmitter Station site consumes 10.7kWh of Electricity. The facilities at the BTS site are Radio Equipment, Power Conversion Equipment, Antenna Equipment, Transmission Equipment, climate equipment and Auxiliary Equipment. These facilities are all ON for 24hrs (12:00am – 11:00pm) per day except the Auxiliary equipment (security light) that comes ON only for 13hrs (06:00pm – 7:00am) per day. The power consumptions are assumed to be identical for every day of the year. The annual peak load of 10.67kW was observed between 06:00pm and 07:00am, with 254kWh/day energy consumption. The daily average load variation for the Radio Base station and Climate & Auxiliary Equipment are shown in table 1.

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

Hour	Radio Base Station Baseline Data Load (kW)	Climate & Auxiliary Equipment Baseline Data Load (kW)
12:00 am - 01:00 am	7.860	**2.790**
01:00 am - 02:00 am	7.860	**2.790**
02:00 am - 03:00 am	7.860	**2.790**
03:00 am - 04:00 am	7.860	**2.790**
04:00 am - 05:00 am	7.860	**2.790**
05:00 am - 06:00 am	7.860	**2.790**
06:00 am - 07:00 am	7.860	**2.790**
07:00 am - 08:00 am	7.860	**2.590**
08:00 am - 09:00 am	7.860	**2.590**
09:00 am - 10:00 am	7.860	**2.590**
10:00 am - 11:00 am	7.860	**2.590**
11:00 am - 12:00 pm	7.860	**2.590**
12:00 pm - 01:00 pm	7.860	**2.590**
01:00 pm - 02:00 pm	7.860	**2.590**
02:00 pm - 03:00 pm	7.860	**2.590**
03:00 pm - 04:00 pm	7.860	**2.590**
04:00 pm - 05:00 pm	7.860	**2.590**
05:00 pm - 06:00 pm	7.860	**2.790**
06:00 pm - 07:00 pm	7.860	**2.790**
07:00 pm - 08:00 pm	7.860	**2.790**
08:00 pm - 09:00 pm	7.860	**2.790**
09:00 pm - 10:00 pm	7.860	**2.790**
10:00 pm - 11:00 pm	7.860	**2.790**
11:00 pm - 12:00 am	7.860	**2.790**
Average (kWh/d)	**189**	**65.0**

Study area

The study is on the simulation of PV/diesel hybrid power generation system for BTS site located in Ogologo-Eji Ndiagu Akpugo. Ogologo-Eji Ndiagu Akpugo is in Nkanu-West L.G.A of Enugu State in South-Eastern Nigeria on Latitude 6°35'N and Longitude 7°51'E with annual average solar daily radiation of 4.92kWh/m²/d. The data for solar resource shown in Table 2 were obtained from the National Aeronautics and Space Administration (NASA) Surface Meteorology and Solar Energy web site [9].

Table 2. Solar Resources for Ogologo Eji Ndiagu Akpugo (Enugu State).

Month	Clearness Index	Average Daily Solar Radiation ($kWh/m^2/day$)
Jan	0.605	5.680
Feb	0.578	5.740
Mar	0.537	5.570
Apr	0.503	5.250
May	0.487	4.940
Jun	0.458	4.540
Jul	0.415	4.140
Aug	0.382	3.910
Sep	0.406	4.190
Oct	0.457	4.570
Nov	0.539	5.110
Dec	0.595	5.460
Scaled annual average		**4.950**

3. Methodology

The HOMER software was used to design an optimal hybrid power system based on comparative economic and environmental analysis. Reference to relevant literature provided the design guidelines. The capital costs of all the system components used for the study were gotten from PV system suppliers in Nigeria [10]. The project lifetime is estimated at 25 years and the annual interest rate is fixed at 6%. The hybrid system components, their attributes and the economic data of all the components of the hybrid system used in the simulation are shown in the appendix.

3.1. Simulation and Optimization of the Energy System

In this paper, it was proposed to use computer simulation and optimization software called HOMER to design the power generation (PV/diesel hybrid power system) for a BTS site located in Ogologo-Eji Ndiagu Akpugo. The description of HOMER can be found in Ani and Emetu [11]. Energy optimization of a BTS system looks into its sizing and the process of selecting the best components to provide efficient, reliable, environmentally friendly, and cost effective power supply. By “Energy Optimization” here it is meant the process of assessing the energy load of any BTS at a rural site and matching it with cost-effective and environmentally friendly power supply using the HOMER optimization software. This is pursued by selecting the best components and their sizing, and determining the best available energy option.

The energy system proposed for the BTS site consists of solar-PV and diesel generator. The system architecture employed in the hybrid system is DC coupled where the renewable (Solar-PV) and the conventional (diesel generator) systems all feed into the DC side of the network as represented in Fig. 1. The energy consumption at the BTS site used in this investigation is 254kWh/day with a 10.67kW peak demand load. The hybrid energy system components consist of a 16 kW diesel generator, 10.7 kW solar PV array, with 96 units Surrette 6CS25P Battery Cycle Charging and a 25 kW AC/ DC converter.

The economic and environmental evaluation of PV/diesel hybrid system was developed and simulated using the model (HOMER). From the outlined design below (fig. 1), the economic and environmental-effectiveness of adding renewable energy components (solar-PV) to the existing energy (diesel) were able to be compared.

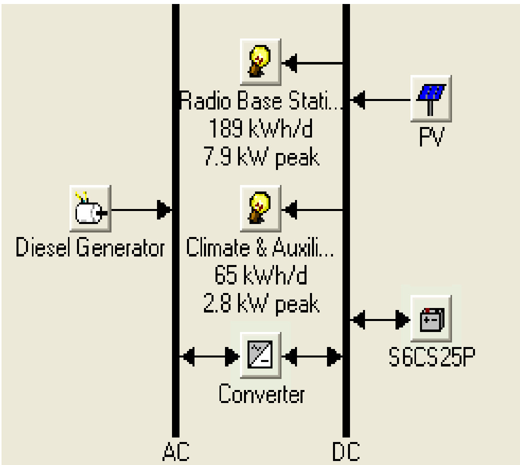

Fig. 1. The proposed energy system for BTS Site

4. Development of Supervisory Control for PV/Diesel Hybrid System

As is well-known, a good operation of energy systems can be achieved only by a suitable control of the interaction in the operation of the different devices. This is fundamental to optimize the use of the renewable source, thereby minimize the wear of batteries [1, 12 - 13].

In this study, the PV power (P_{PV}) generation is the primary source of energy, the battery ($P_{Bchar\_max,disch\_max}$) as the supplement and the diesel generator as the back-up source of energy. The flow between the different modes (4 modes) is outlined in Figure 2. The system uses only the energy generated by the PV panels to supply the load (P_L). When the PV panels produced more than what is needed by the load, the excess energy can be used to charge the battery (P_{Bchar_max}).

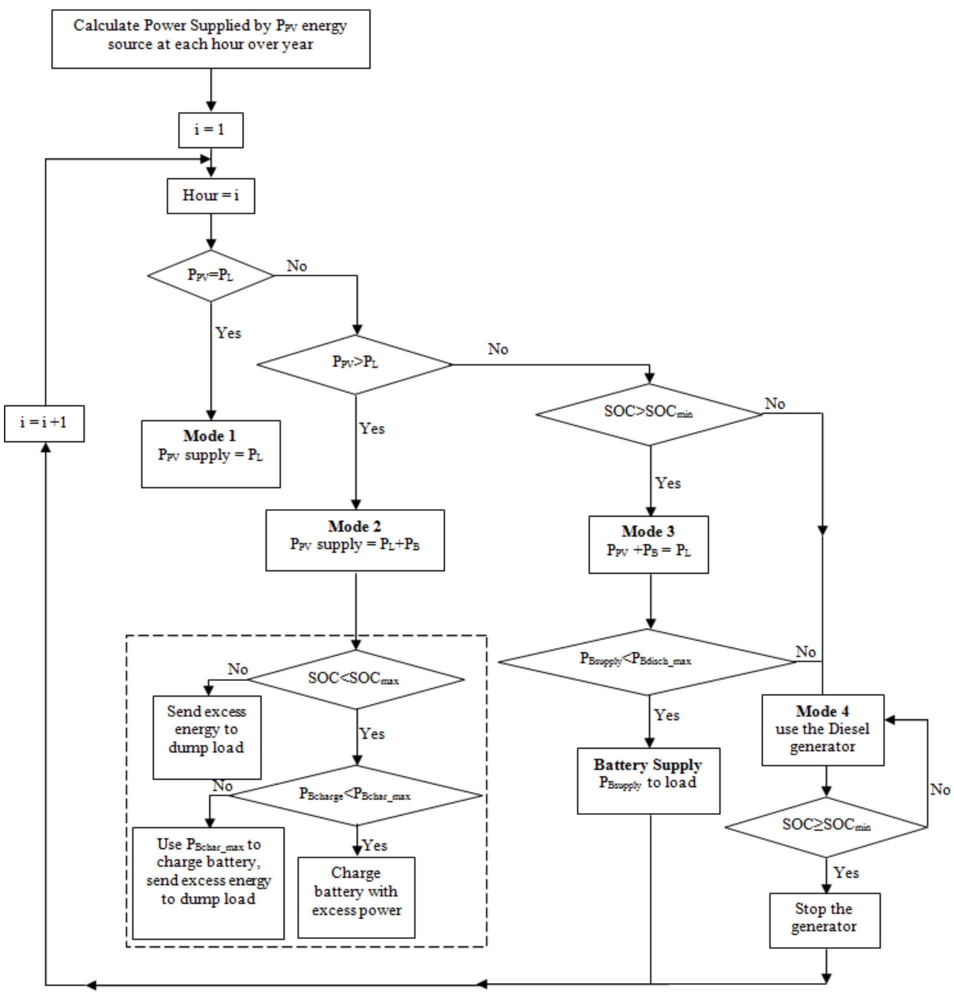

Fig. 2. Flowchart of modes of control for PV/diesel - Battery Energy System.

During the charging of the battery, if the SOC of the battery is at its maximum possible SOC value, the excess power is sent to a dump load [**Dump load** is a device to which power flows when the system batteries are too full to accept more power], which can be defined according to the base station's need, charging of phones, etc. The flowchart inside the dotted line shown in figure 2 is the charging control circuit. If the SOC of the battery is less than the maximum SOC, the amount of excess power is checked. Battery-Experts [14] advise not using a charging current of more than 60A. The power is then checked to make sure that the current used to charge the battery will be less than 60A. If the excess power is less than this maximum charging power, the battery is charged with the full excess power. If the power is above that of maximum charging of the battery, the maximum battery charge power is used to charge the battery and the excess is used for the dump load.

On the other hand, when the solar radiation is low and the PV panels produces less energy than demanded, the deficit power should be supplied by the battery bank. At night when there is no solar power, the diesel generator supplies to the load.

The operations which start (ON) and stop (OFF) the diesel generator; activate or deactivate the charging or discharging of the battery, are being managed and done by a hybrid controller unit. The controller unit monitors and manages the load demand and energy supplied as shown in figure 3.

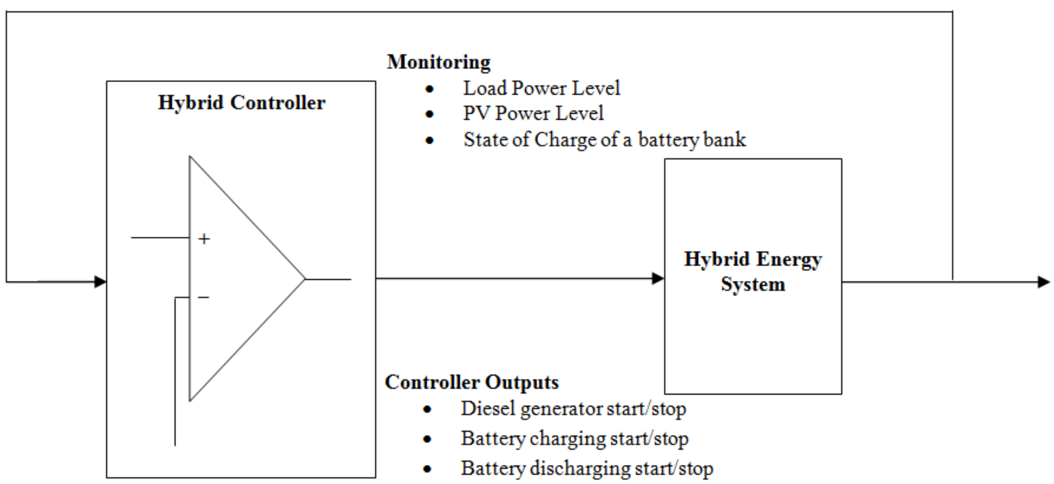

Fig. 3. Hybrid Energy System Controller [10].

5. Results and Discussion

5.1. Simulation Results

The detailed result analyses obtained at the end of the simulations are presented in tables 3, 4, 5, and 6. These are described below:

Diesel-only system:

The diesel generator system has the least initial capital cost, high operating cost, high annualized cost and high total NPC for the whole project as shown in table 3. Furthermore, this system emits more CO_2, and other pollutant emissions as a result of lot of fossil fuel consumptions as shown in tables 4 and 6.

PV/Diesel Hybrid System:

PV/diesel hybrid system gives an opportunity for PV panels to supply 14% of the energy demand in the BTS site. This is shown in table 5. The hybrid system has less annualized and total NPC as a result of less fuel consumption as shown in table 6. Fuel consumptions reduction means reducing pollutant emissions. This is shown by the solar-PV/diesel hybrid system which has the lowest emission of CO_2, and other pollutant emissions as shown in table 4.

Table 3. Comparison of Simulation results of Economic cost of diesel-only and PV/diesel hybrid system

Parameter	Diesel-only System	PV/ diesel hybrid system
	Dollars($)	Dollars($)
Initial Cost	310,360	385,260
Operating Cost	1,756,634	1,491,517
Annualized Cost	1,780,913	1,521,655
Total NPC	22,766,034	19,451,848

Table 4. Comparison of simulation results of emissions

Pollutant	Emissions (tons/yr)		Differences in the Emission (tons/yr)
	Diesel-only	PV/diesel hybrid system	
Carbon dioxide	98.50	83.62	14.88
Carbon monoxide	0.24	0.21	0.03
Unburned hydrocarbons	0.03	0.02	0.01
Particulate matter	0.02	0.02	0.00
Sulfur dioxide	0.20	0.17	0.03
Nitrogen oxides	2.17	1.84	0.33

Electricity production

The diesel-only system generates 113,349kWh/yr (100%), whereas the proposed hybrid system produces 16,024kWh/yr (14%) from PV array and 96,229kWh/yr (86%) from diesel generator thus making a total of 112,253kWh/yr (100%) as shown in table 5. The load demand is 92,715kWh/yr, while the excess electricity from the diesel-only system is 725kWh/yr and the proposed project has excess electricity of 743kWh/yr as shown in table 5.

5.2. Discussions

Economic Cost

The economic cost used in comparing the energy systems were annualized cost and total NPC. In the annualized cost, the PV/diesel hybrid system has $ 1,521,655, while the diesel only system has $ 1,780,913, as shown in table 3. In comparison, the PV/diesel hybrid system saves $ 259,258 to the network operator.

Table 5. Comparison of simulation results of the electricity production (kWh/yr), Battery and converter losses, and excess energy of the energy system configuration (PV/diesel and diesel-only)

System Operation	PV/diesel		Diesel-only	
Consumption	kWh/yr	%	kWh/yr	%
DC primary load	92,715	100	92,715	100
The total load to be supplied	92,715	100	92,715	100
Production	**kWh/yr**	**%**	**kWh/yr**	**%**
PV array	16,024	14		
Generator	96,229	86	113,349	100
Total energy generated	112,253	100	113,349	100
Losses	kWh/yr		kWh/yr	
Battery	4,366		2,913	
Inverter	0		0	
Rectifier	14,429		16,996	
Total losses	18,795		19,909	
Excess energy	743		725	
Energy Supplied	kWh/yr	%	kWh/yr	%
Total energy supplied to the load	92,715	100	92,715	100

Table 6. Comparison of simulation of Diesel-only System and Diesel in Hybrid System (PV/diesel)

Quantity/Unit	Diesel-only	Diesel in Hybrid System (PV/diesel)
	Value	Value
Operational life (yr)	2.82	3.33
Capacity factor (%)	80.9	68.7
Hours of operation (hr/yr)	7,085	6,015
Fuel consumption (L/yr)	37,405	31,755
Fuel energy input (kWh/yr)	368,067	312,467

In the total NPC, the PV/diesel hybrid system has $19,451,848, operating cost of $ 1,491,517, and initial cost of $ 385,260, while the diesel-only system has total NPC of $ 22,766,034, operating cost of $ 1,756,634, and initial cost of $ 310,360,as shown in table 3. In comparison, the

PV/diesel hybrid system saves $ 3,314,186 to the network operator.

Finally, in the annualized and total NPC of power generation for the BTS site, the hybrid system is the best in the perspective of economic analysis.

Electricity Production

In the PV/diesel hybrid system, the PV array has a capacity factor of 17.1% and supplies 14% of the annual electricity production, and the diesel generator contribute 86% of the total electricity with a capacity factor of 68.7%; while the diesel-only system generates 100% of the total electricity with a capacity factor of 80.9% as shown in table 5.

Environmental Impact

Diesel-only system operates for 7,085h/annum has a fuel consumption of 37,405L/annum. It generates 98.50 tons of CO_2, 0.24 tons of CO, 0.03 tons of UHC, 0.02 tons of PM, 0.20 tons of SO_2, and 2.17 tons of NO_X as shown in table 4; while in the PV/diesel hybrid system, diesel generator operates for 6,015h/annum and has a fuel consumption of 31,755L/annum. This system emits 83.62 tons of CO_2, 0.21 tons of CO, 0.02 tons of UHC, 0.02 tons of PM, 0.17 tons of SO_2, and 1.84 tons of NO_x annually into the atmosphere of the location of the BTS station site as shown in table 4. A 14% decrease was noticed in each pollutant. This was due to the 14% renewable penetration into the diesel-only power system. The reduction in the quantity of different air pollutants for the 14% renewable penetration compared to that of diesel-only are thus: 14.88 tons of CO_2, 0.03 tons of CO, 0.01 tons of UHC, 0.00 tons of PM, 0.03 tons of SO_2, and 0.33 tons of NO_x. In terms of fuel consumption, this hybrid system when compared with the diesel-only system saves about 5,650 litres of fuel per annum to the network operator.

In summary, the PV/diesel hybrid system needs high initial capital cost, but in the end they have less total NPC for the whole project; while diesel-only system has the least initial capital cost, but in the end has the highest total NPC as a result of fuel consumption. On the environmental impact perspective, an increase in the operational hours of diesel generator brings about an increase in the fuel consumption and as well an increase in GHG emission, whereas a reduction in the operational hours of diesel generator brings about a reduction in the fuel consumption thereby a reduction in GHG emission. This is in line with the review of [1].

6. Conclusion

The hybrid approach involves reliance upon solar, in combination with efficient, optimized energy switching to diesel fuel based system. This offers BTS site the "best of both worlds" – combining reductions in CO_2 emissions and fuel costs, with greater power reliability than any single system could provide on its own. The supervisory control system designed maximizes the use of renewable system when it is available and minimizes the use of diesel generator thereby reduces the pollution. Simulation results shown that the PV/diesel hybrid system has a total NPC cost and the amount of CO_2 as ($19,451,848; 83.62 tons) and saves ($3,314,186; 14.88 tons) when compared with the diesel-only system ($22,766,034; 98.50 tons). The study has illustrated that, although the cost of PV/diesel hybrid system is very high during installation (initial cost), yet at the end has the least cost. From the environmental analysis of pollutant emission, one will prefer PV/diesel hybrid system for diesel-only system. As a conclusion, this paper has verified the predictions that the PV/diesel hybrid system is superior to the diesel-only system for power generation at BTS sites in Nigeria in the perspective of economic and environmental analyses.

References

[1]. Ani, Vincent Anayochukwu, and Emetu Alice Nnene. "Simulation and optimization of hybrid diesel power generation system for GSM

base station site in Nigeria." Electronic Journal of Energy & Environment 1.1 (2013).

[2]. Ericsson Press Release. "Energy-saving solutions helping mobile operators meet commercial and sustainability goals worldwide". (June 2008).

[3]. Tamm Oliver, Christian Hermsmeyer, and Allen M. Rush. "Eco- sustainable system and network architectures for future transport networks." Bell Labs Technical Journal 14.4 (2010): 311-327.

[4]. Environmental Impact of Mobile Communications Networks. GSM Association, 2009

[5]. Pierre Gildert, Power System Efficiency in Wireless Communication, Ericsson, 2006.

[6]. Roy Steve, Energy Logic for Telecommunications. Emerson Network Power Energy Systems, North America, 2008

[7]. Willson John, Energy & Emissions at Cellular Base Stations. WireIE Holdings International Inc, 2009

[8]. Ani Vincent Anayochukwu, and Emetu Alice Nnene. "Measuring the Environmental Impact of Power Generation at GSM Base Station Sites." Electronic Journal of Energy & Environment 1.1 (2013).

[9]. NASA, 2012 http://eosweb.larc.nasa.gov/

[10]. Renewable energy shop in Nigeria

http://www.solarshopnigeria.com/ [Accessed on 12/01/2013]

[11]. Ani Vincent Anayochukwu, and Emetu Alice Nnene. "Simulation and Optimization of Photovoltaic/Diesel Hybrid Power Generation Systems for Health Service Facilities in Rural Environments." Electronic Journal of Energy & Environment 1.1 (2013).

[12]. Ani, Vincent Anayochukwu. "Optimal Control of PV/Wind/Hydro-Diesel Hybrid Power Generation System for Off-grid Macro Base Transmitter Station Site."Electronic Journal of Energy & Environment (2013).

[13]. Seeling-Hochmuth, G. "A Combined Optimization Concept for the Design and Operation Strategy of Hybrid PV Energy Systems", Solar Energy, Vol. 61, No. 2, (1997) 77-87, Elsevier Science Ltd.

[14]. Battery Experts (2012) [Online].

http://www.batteryexperts.co.za/batteries_sealed.html

Appendix

Table A1. Details of Solar Properties

Solar Module type: SolarWorld SW 140 poly R6A	
Size (kW)	0.140
Size Considered (kW)	10.7
PV Control	
Derating factor	90%
Tracking system	No Tracking
Azimuth	0 deg
Ground reflectance	20%

Table A2. The details of Diesel Generator Model Parameters.

AC Generator type: 20kVA diesel generator	
Size Considered (kW)	16
Quantity	1
Fuel used	Diesel
Price of fuel	$1 per litre

Table A3. Surrette 6CS25P Battery Properties

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

Table A4. Details of Converter Parameters

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

Table A5. Economic data of all the components of the hybrid system used in the Simulation

Item	Initial System Costs	Replacement Costs	Operating & Maintenance Costs
PV modules	$2,000/kW	$1,800/kW	$1/yr
16kW diesel generator	$13,950/kW	$13,750/kW	$0.1/hr
Surrete 6CS25P battery	$1,145	$1,000	$200/yr
Converter	$200/kW	$200/kW	$4/yr