International Journal of Renewable Energy Resources 4 (2014) 1-12

FEASIBILITY STUDY OF STAND-ALONE HYBRID ENERGY SYSTEM FOR RURAL ELECTRIFICATION IN NIGERIA: THE CASE STUDY OF ALA-AJAGBUSI COMMUNITY

T.R. Ayodele
Electrical Engineering Department, Faculty of Technology, University of Ibadan, Nigeria
Email:tayodele2001@yahoo.com, tr.ayodele@ui.edu.ng

ABSTRACT

In this study, the energy demand of Ala-Ajagbusi community is met by simulation using hybrid energy system which consists of wind energy as primary energy source combined with diesel generator and researchable batteries. The community is situated in a remote area without electrical network access. The most suitable hybrid energy system based on the energy resources (wind and solar) available at the site is determined by simulation using HOMER while considering that energy continuity is maintained by using diesel generator and sufficient number of batteries. A life-cycle cost analysis is carried out over 20 year’s system lifetime. For each combination, the necessary number of batteries to continuously supply the community with energy is calculated and economic analysis of each system is performed. The simulation results demonstrate that wind/diesel/battery hybrid system is the most suitable option with optimal size of 300kW diesel generator, 3 numbers of Enercon-E33 wind turbines, 200 numbers of Trojan LI6P battery and 200kW converter. The option represents renewable energy fraction of 74% with total Net Present Cost (NPC) of $9,605,548 and Cost of Energy (COE) of $0.373/kWh. The result also show saving of 1,186,082kg/yr of carbon dioxide (CO_2) and 2,928kg/yr of carbon monoxide (CO) compared to non-renewable generation option (diesel generator only).

Keyword: Ala-Ajagbusi, Diesel Generator, Hybrid Energy System, Nigeria, Wind Energy

1. INTRODUCTION

The survey conducted by the United Nations Environment Program (UNEP) reveals that an approximately two billion people around the world have no access to grid based electricity services, the majority of which live in underdeveloped rural areas (Rehman *et al.* 2007, García-Valverde *et al.* 2009). Electricity has been identified as a vital tool to initiate a process of development and to maintain ongoing development (Barra and Coiante 1996, Dursun and Gokcol 2012). It is therefore used as a component of energy to measure the level of modernization and progress of a given country (Omer 2007). There are many factors contributing to the poor distribution of electrical resources, such as difficult terrains and the isolation of many rural villages (Dekker *et al.* 2010). However, the ultimate reason for the poor distribution comes down to economic investment. It is too expensive to install large grid connected power lines over long distances to supply electricity to a community consisting small number of people (Gabler 1998, Dekker *et al.* 2010). In this respect, Hybrid Energy System (HES) will provide visible alternative. HES is considered as the most promising and preferred technology for remotely located region where it seems impossible to connect to the grid due to harsh terrains (Al-Badi and Bourdoucen 2011, Shiroudi *et al.* 2012). It offers a cost effective solution in contrast to extending the utility grid in remote areas.

A Typical HES consist of a back-up diesel generator that supplements the PV/Wind power for peak loads and during poor resource periods (Givler and Lilienthal 2005). The interesting aspect of this technology is that it has complementary characteristic. This offers the advantage that the strengths of each type of sources can be used to complement one another (Al-Badi and Bourdoucen 2011). For example, the capital cost of wind turbine or PV generators is higher than that of diesel generator, but the operation and maintenance is lower and diesel is available all the time. Therefore, stand-alone HES usually incur lower costs and demonstrate higher reliability than photovoltaic (PV) or wind systems only (Jose´ *et al.* 2009). Hybrid Optimization Model for Electric Renewables (HOMER) developed by National Renewable Energy Laboratory USA, (NREL 2014) is the most-used optimization software for hybrid systems (Jose´ *et al.* 2009). It can evaluate a range of equipment options over varying constraints and sensitivities to optimize small hybrid power systems such as photovoltaic generator, batteries, wind turbines, hydraulic turbines, AC generators, fuel cells, electrolysers, hydrogen tanks, AC–DC bidirectional converters, and boilers. The loads can be AC, DC, and/or hydrogen loads, as well as thermal loads. The simulation is carried out using 1-hour intervals, during which all of the parameters (load, input and output power from the components, etc.) remain constant. HOMER’s flexibility makes it useful in the evaluation of design issues in the planning and early decision-making phase of rural electrification projects. The results could then serve as a starting point for the design of individual installations.

Many authors in the literature have used HOMER in the study and design of hybrid system. The influence of energy efficiency in the process of sizing and optimizing the operation of off-grid hybrid PV/DG (photovoltaic/diesel generator) system was investigated for remote village of 30 households in South Africa (Dusabe *et al.* 2009). It was concluded that the use of efficient lamps and appliances, which consume less electrical energy reduces the time of operation of the diesel generator (DG) by approximately 20%. Anwaria *et al* analyzed the potential implementation of renewable hybrid wind/diesel energy system in Pemanggil Island, Malaysia. The authors demonstrated the impact of wind penetration and battery storage on energy production, cost of energy and number of operational hours of diesel generators for the given hybrid configurations (Anwari *et al.* 2012). Seyed and Mohammad proposed and analyses the suitability of hybrid power generation system for Remote island located in Alaska. The system consists of Hybrid Wind/Fuel Cell /Battery/Diesel Energy System. It was concluded that the proposed design will reduce the gas emission of the area by 37% compared to the existing system (Seyed and Mohammad 2011). The viability of solar/diesel/battery hybrid power system has been modeled by Nfah et-al (Nfaha *et al.* 2007) for the electrification of typical household and schools in rural area in northern region of Cameroon. Wind energy potentiality and techno- economic feasibility of offshore wind farms in Malaysia was investigated to assess the potential of wind energy along the South China Sea coastline (Mekhilef and Chandrasegaran 2011). In their work, the best sites to set up offshore wind farms was identified and economic visibility of two wind turbines (Vestas V-47 and V-80) were performed. Barsoum and Vicent were concerned with the development of hydrogen hybrid power system (Barsoum and Vacent 2007) to obtain a reliable autonomous system. The system is designed to provide electricity for a small and remote located community. A methodology is developed for calculating the correct size of the system and for optimizing the management. A biomass gasifier based hybrid energy system and optimal operating strategy was developed in (Ashok and Balamurugan 2007). The optimum hybrid system design is realized by satisfying the load demand, non-linear seasonal variations and equipment constraints. The potential of grid connected PV power generation in Zimbabwe was investigated using HOMER software tool (Rashayi and Chikuni 2012). The sensitivity analysis results show that an increase in electricity tariff to $ 0.15/kWh will make electricity from PV competitive for all regions in the country with minimum irradiation of 5.6kWh/m^2/day. Sekgoele *et-al* investigated the technical, economic and environmental assessment of both standalone and grid connected electricity generation from landfill gas in South Africa (Sekgoele *et al.* 2011). It was concluded that both are feasible, however, standalone is cheaper than grid connected scheme. Different hybrid configurations were analysed for Busher province of Iran (Nahari and Dashti 2011) with the aim of determining most suitable configuration in term of technical, economic and environment. It was found that PV is more suitable compared to other configurations in the province. Castañeda *et al* presents the comparative study of four different methods for sizing standalone hybrid generation system (Castañeda *et al.* 2012), these methods include: the use of basic equation, the use of Simulink model in MATLAB, HOMER software tool and HOGA. The results showed that all the four methods gives reasonable result, however, HOMER and HOGA present a more expensive system. Similarly, Akella *et al* (Akella *et al.* 2007) compared Lindo simulation tool to HOMER in modeling renewable energy system that meets the energy demand of Jaunpur block of Uttaranchal state of India. The result also showed that the range cost of energy is higher for HOMER simulation tool. However, it was revealed that the cost of converters, batteries and local grid cost were included in HOMER while Lindo software includes only renewable energy system cost. Wilmann and Sterling (Wilmann and Sterling 2005) show that HOMER software tool could be integrated with a specific agent based oriented software to increase the ease with which people may readily design and develop agent base system. Many authors have also reported on the environmental impact of hybrid system. The potential saving of primary energy and the reduction of greenhouse gas emission was studied in (Marco *et al.* 2007) for the city of Sicily. The study succeeded in estimating the specific cost per unit saved energy and the amount of carbon dioxide saved. Further information on hybrid energy system and renewable energy can be found in (Bin *et al.* 12, Kaundinya *et al.* 2009, Kılınc *et al.* 2009, Thompson and Duggirala 2009, Bentouba *et al.* 2012).

Although, the method of using HOMER in the simulation and optimization of hybrid system is far reaching from the aforementioned studies but the output solution depends on the local energy resources and the cost of components which differ from region to region. Therefore, the design and study of HES is site specific and needed to be carried out at every potential site and region of the world. Moreover, there is paucity of literature on hybrid system modelling for rural community in Nigeria. Rural communities in Nigeria are mainly characterized by poor access to electricity mostly due to the lack of grid connected power lines. It is therefore necessary to conduct studies on the economic feasibility of alternative energy source that is reliable and cost effective while taking into consideration the environmental impact for rural communities in the country.

In this study, different HES configurations are modeled using both the meteorological and surveyed load data collected from a typical remotely located village in the South West region of Nigeria with the aim of determining most suitable option that will optimally meet their energy demand economically while taken into consideration the environmental impact.

2. DESCRIPTION OF THE SITE

Ala-Ajagbusi is located on latitude 7.08^0N and longitude 5.36^0S. It has population of about 3500. The wind and solar resources for the simulation was obtained from Nigeria Metrological Agency (NMA) located in Akure. The data consist of daily average for a period of five years.

3. METHODOLOGY

The design of HES started with the collection of data about the existing condition of Ala-Ajagbusi such as load profile and energy resource potential. Oral interview was also conducted to determine the load requirement that will improve the social condition of the people living in the community such as computer bay, modern kitchen appliances i.e microwave oven, washing machine and pumping machine. The hybrid power system for community was designed as depicted in the flowchart in Figure 1.

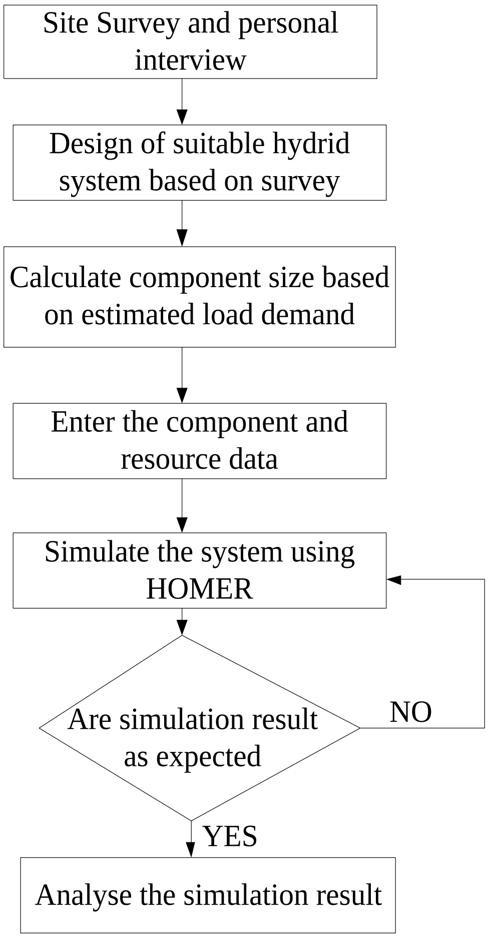

Figure 1 Design of hybrid power system

4. ASSESSMENT CRITERIA

The criteria for selecting the most suitable HES for the community is based on Net Present Cost, C_{NPC}, Levilised Cost of Energy (COE) and Carbon Emission Intensity (CEI).

4.1 Net Present Cost (NPC)

The Net Present Cost (C_{NPC}) which represents the life cycle cost of the system can be calculated as (1). An energy project for example will have a total net present cost comprising of the following costs: capital investment, non-fuel operation and maintenance costs, replacement costs, energy costs (fuel cost plus any options are being considered then the option with the lowest net present cost will be the most favorable financial option (Dalton *et al.* 2009). The total annualized cost can be determined as (2) (Lambert and Lilienthal 2004) associated costs, and any other costs. If a number of

$$C_{NPC} = C_O + C_{rep} + \sum_{t=1}^{N} \frac{C_t}{(1+i)^t} - SV \quad (1)$$

$$CA = C_{NPC} * CRF \quad (2)$$

where C_O is the cost of initial investment, C_{rep} is the replacement cost (at $t = 0$), C_t is the expenses in year t, SV is the salvage value (at $t = 0$), and CRF is the Capital Recovery Factor.
In the present study, C_t can be calculated as (3)

$$C_t = C_{OM,t} + C_{f,t} \quad (3)$$

where $C_{OM,t}$ and $C_{f,t}$ are the operation and maintenance cost and the fuel cost, respectively, in year t. The analysis is based on zero inflation rate, therefore, the expenses does not change from year to year. Hence, equation (1) can be re-written as (4)

$$C_{NPC} = C_O + C_{rep} + C_{OM} + C_f - SV \quad (4)$$

Operational and maintenance cost (C_{OM}) and the cost of fuel (C_f) are given by (5) and (6), respectively.

$$C_{OM} = C_{OM,1} \sum_{t=1}^{N} \frac{1}{(1+i)^t} = C_{OM,1} * PWF \quad (5)$$

$$C_f = C_{f,1} \sum_{t=1}^{N} \frac{1}{(1+i)^t} = C_{f,1} * PWF \quad (6)$$

where

$$PWF = \sum_{t=1}^{N} \frac{1}{(1+i)^t} = \frac{(1+i)^N - 1}{i(1+i)^N} = \frac{1}{CRF}$$

N is the number of year of the project also known as project lifetime and i is the annual interest rate for the project lifetime.

4.2 Cost of Energy (COE)

Cost of Energy (COE) can be calculated as given by (7). It gives an idea of the cost of electrical energy produced by the system (Sunderan *et al.* 2011) and can be defined as the average cost/kWh of useful electrical energy produced by the system. To calculate the COE, the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) is divided by the total useful electric energy production (Demiroren and Yilmaz 2009).

$$COE = \frac{CA}{EAC} \quad (7)$$

where EAC is the annualized AC load served by the system.

4.3 Carbon Emission Intensity

Carbon Emission Intensity (CEI) can be calculated as (8)

$$CEI = \sum_{1}^{5} (E_i * P_i) \quad (8)$$

where E_i is carbon intensity of each kind of power source (gCO_2-e/kWh), P_i is the weight of each kind of power source (%).

5. SYSTEM DESIGN

Four different hybrid schemes were designed as illustrated in Table 1. The schemes were compared in term of NPC, COE and CEI to determine the best option of HES for the community. Figure 2 represent one of the typical designs (Scheme B) for Ala Ajagbusi community.

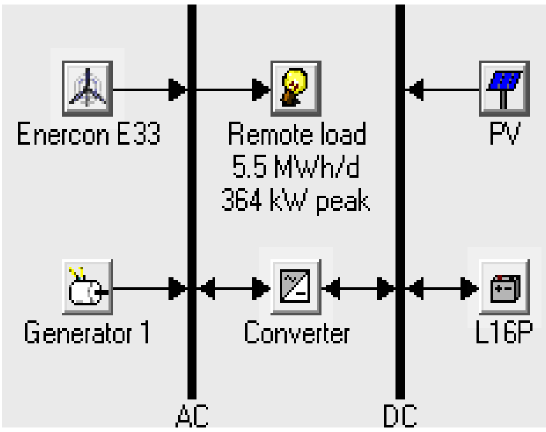

Figure 2 Scheme B, Wind/PV/Battery/Diesel Hybrid Energy System

6. DATA INPUT

The knowledge of energy resources of a given location is important to design hybrid system for such location. This section presents the energy resource (wind and solar) for Ala-Ajagbusi community.

6.1 Wind Resource

The data used for the simulation are daily average wind speed sampled at 0.5Hz for a period of five year. The data was observed at the anemometer height of 10m. Critical analysis of this data shows that the gross data recovery percentage (the actual percentage of expected data received) was 93% and the net data recovery percentage (the percentage of expected data which passed all quality assurance tests) was 88%. The two percentages are high indicating that both the sensors and the data loggers performed well. The annual average wind speed is 4.6m/s, the highest wind speed occur in December with the average wind speed of 5.5m/s while the lowest wind speed occur in March with average wind speed of 3.8m/s. The wind speed can be modeled using Weibull distribution as depicted in Figure 3 with scale parameter (c) of 5.15m/s and shape parameter (k) of 2.21. The autocorrelation factor and diurnal pattern strength was determined as 0.893 and of 0.283 respectively.

Table 1 Hybrid Energy System Design for Ala-Ajagbusi

Scheme	Wind	PV	Batt-ery	Die-sel	Combination
A	X	-	X	X	Wind/Diesel/Batter
B	X	X	X	X	Wind/PV/Diesel/Battery
C	-	X	X	X	PV/Diesel/battery
D	-	-	-	X	Diesel Only

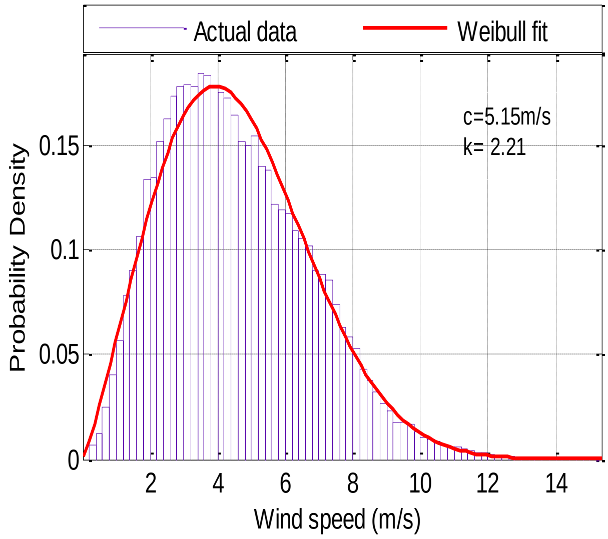

Figure 3 Weibull fit for the wind speed of Ala-Ajagbusi

Most wind speeds are observed at the height that does not match the hub height of most commercially available wind turbines. It is therefore necessary to redefine the wind speed from the observed height to the hub height of the wind turbines. This can be achieved using power law equation (9) (Di Piazza *et al.* 2010)

$$v_2 = v_1 \left(\frac{H_2}{H_1} \right)^m \tag{9}$$

where v_2 is the wind speed at the height, H_2 and v_1 is the wind speed at the height, H_1. The shear exponent (m) is the factor that depends on surface roughness and atmospheric stability. It is site specific and it is usually in the range of 0.00001–3m. Ala-Ajagbusi is located in rainforest vegetation zone; it is surrounded by trees and crops. Therefore, surface roughness of 0.1m was selected for the simulation. This information was used to calculate the wind speed at the hub height of the wind turbine.

6.2 Solar Resource

Nigeria is a tropical country blessed with sunlight round the year. Based on the data collected from Nigerian Metrological Agency (NMA), the yearly average daily solar irradiation of Ala-Ajagbusi community is 4.8 kWh/m^2/day. The highest global solar irradiation is approximately 6.1 kWh/m^2/day and it occurs in February whereas the lowest radiation occurs in June with approximately 3.96 kWh/m^2/day. Once the average daily solar irradiation is entered into HOMER, it automatically calculates the clearness index. The plot of global solar rradiation and the clearness index of Ala-Ajagbusi are depicted in Figure 4.

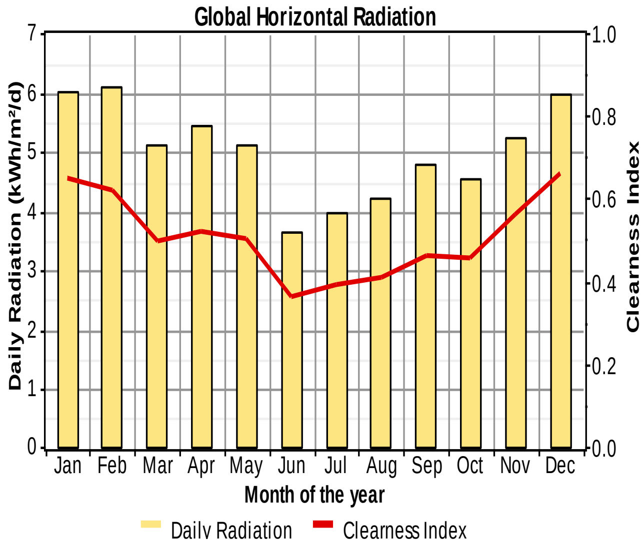

Figure 4 The plot of daily irradiation and the clearness index for Ala-Ajagbusi

6.3 Estimating and Profiling of Hourly Load for Ala-Ajagbusi Community

The load profile of the community was estimated after conducting oral interview with the people living in the community and personal site seeing. The community consists of about 200 buildings. To determine the load demand of the community, it is assumed that load requirement of every building is the same. Estimation was made for one building based on the anticipated requirement of the people living in the community and then integrated over the total buildings in the community.

The load scheduling is based on the projected appliances that becomes necessary to be used at a particular period during the 24 hours cycle. The loads are divided into two, the uncontrollable and the controllable loads. The uncontrollable loads (L1 and L2) demands instantaneous power and are therefore scheduled to run all through the daily cycle. The controllable loads (L3-L8) operate at deferrable periods and do not demand instantaneous power. The controllable loads are spread over the 24 hours cycle of operation by allowing each of them to be operated only at the time they will be most needed in such a way that the peak load at any point in time is reduced. The uncontrollable loads are scheduled to receive instantaneous power through the 24 hours cycle while the remaining load categories L3 to L4 are distributed. The estimated load requirement for a building in the community is furnished in Table 2. The overall load profile of the community is estimated as depicted in Table 3. A diversity factor of 0.6 is used as load profile of the community is shown in Figure 5. From the figure, it can be observed that the peak period is in the morning (6:00 -7:00) and is estimated as 364kW. The estimated average power demand is 240kW with load factor of 63.1%.

Table 2 Estimated Load Schedule for a single Building in Ala-Ajagbusi

LOAD	Electrical Appliances		No in use	Wattage (W)	Total Wattage (W)	Daily Duty cycle (h)	Daily Energy Consumed kWh/day
UNCONTROLLABLE LOADS							
L1	Lights	Indoor Lights	14	15	210	24	5.04
		Passage Way light	3	15	45	24	1.08
	Television Set		1	150	150	24	3.60
	DVD Player		1	35	35	24	0.84
	Satellite Decoder		1	30	30	24	0.72
	Antenna Module		1	25	25	24	0.6
	Ceiling Fan		4	100	400	24	9.60
	L1 Total				**895**		**21.48**
L2	Computer Systems	Desktop PC	1	150	150	24	3.60
		Accessories	2	100	200	24	4.80
		Mobile Phones	5	15	75	24	1.80
		Laptop PC	1	65	65	24	1.56
	L2 Total				**490**		**11.76**
CONTROLLABLE LOADS							
L3	Refrigerator unit		1	400	400	9	0.360
L4	Security Light		8	25	200	10	1.2
L5	Washing Machine		1	500	500	2	1.000
L6	Water Pump		1	750	750	1	0.750
L7	Kitchen Appliance	Blender	1	300	300	1	0.30
		Electric Stove	1	850	850	1	0.85
	Total				**1150**		**0.500**
L8	Water Heater		1	800	800	1	0.8

Table 3 Proposed Load Profiling for Ala-Ajagbusi

Hours of the day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
L1	895	895	895	895	895	895	895	895	895	895	895	895	895	895	895	895	895	895	895	895	895	895	895
L2	490	490	490	490	490	490	490	490	490	490	490	490	490	490	490	490	490	490	490	490	490	490	490
L3										400	400	400	400	400	400	400	400	400					
L4	200	200	200	200	200	200															200	200	200
L5							500	500															
L6									750														
L7							1150	1150											1150	1150			
L8						800																	
Total Load/building (W)	1585	1585	1585	1585	1585	2385	3035	3035	2135	1785	1785	1785	1785	1785	1785	1785	1785	1785	2535	2535	1585	1585	1585
x Diversity Factor	951	951	951	951	951	1431	1821	1821	1281	1071	1071	1071	1071	1071	1071	1071	1071	1071	1521	1521	951	951	951
Village Load Profile (k W)	190.2	190.2	190	190	190.2	286	364.2	364.2	256	214.2	214.2	214.2	214	214	214.2	214.2	214.2	214.2	304	304	190	190	190

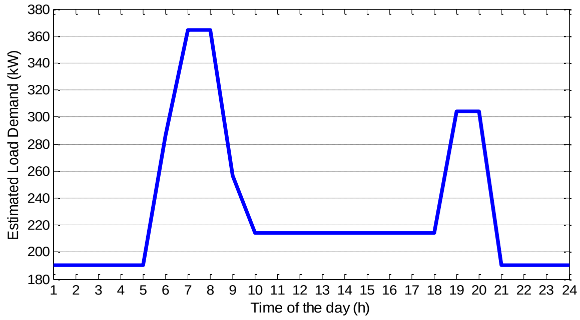

Figure 5 Estimated Load Demand for Ala-Ajagbusi

7. COMPONENT SIZING

The energy requirement for the village is 518MWh/day which cumulates to about 2GWh per annum. For every scheme designed, energy is shared between the diesel generator, wind generator and or PV system. The components are sized based on the village Peak Load (PL), Error Margin (EM) and Capacity Factor CF and is given as (10).

$$P = \frac{PL\ (kW) + EM\ (kW)}{CF} \qquad (10)$$

7.1 PV sizing

PV sizing was based on the peak load of 364kW. However, the system component sizing can be refined after seeing the result. The PV sizing can therefore be adjusted to increase or reduce according to the simulation result. For a 1kW system, the cost of solar module is given as US$300

(Rashayi and Chikuni 2012). The initial cost of installation is estimated at US$6500 with replacement cost of US$500 and efficiency of 13% (Moury *et al.*)

7.2 Battery Sizing

The battery size (C_b) can be estimated using the excess energy as follows (11) (Hajiah and Sebzali 2013)

$$C_b = \frac{\sum_{i=0}^{8760} Ee(t) * \eta_b}{Vb} \qquad (11)$$

where Ee is the excess energy, η_b is the charging efficiency and Vb is the battery voltage
The excess energy can be written as (12)

$$Ee(t) = \sum_{i=0}^{8760} (E_T(t) - E_L(t)) \qquad (12)$$

where $E_T(t)$ is the total energy generated by the generators (wind, PV) per hour and $E_L(t)$ is the total energy demand per hour. When $E_T > E_L$, then there are excess energy and the battery will have to store this excess energy. However when $E_T < E_L$, then there is energy deficit, the load will have to be supplied from the battery.

The required size of battery is determined in HOMER by adjusting the initial selected size so as to reduce the excess energy as much as possible. The excess energy can be known from the result obtained after simulation. The initial cost of battery is estimated at US$300 per unit with replacement cost of US$300 and efficiency of 80% (Moury *et al.*)

7.3 Power Converter

Ala-Ajagbusi has a peak load of 364kW. If we add error margin of 10% and capacity factor of 0.9. The minimum size of inverter required is

$$P_{inv} = \frac{364 * 1.1}{0.9} = 444.8kW \qquad (13)$$

Therefore, for the initial simulation a 450kW inverter is selected based on availability in the market. The size can then be reduced or increased according to the result of the simulation. The cost of 1.0kW inverter is estimated to be US$700.00 (2013). It may need to be replaced after 20 years,
the replacement cost is also estimated as US$600.00 with efficiency of 90% (2013).

7.4 Diesel Generator sizing

The diesel generators are used to meet the peak loads and to charge the batteries in time of low resources (i.e low wind speed and/ solar irradiation). The selection is based on the village peak load of 364kW

$$P_{dg} = \frac{364 * 1.1}{0.9} = 444.8kW \qquad (14)$$

Hence, diesel generator with rated power of 450kW is selected. The diesel price in Nigeria is at present US$0.96/L with the current conversion ratio of 1US$ to 162 Nigerian Naira. The fuel has a lower heating value of 43.2MJ/kg and density of 820kg/m^3, the carbon content is 88% and sulfur content of 0.33%. The initial cost of generator is estimated asUS$350/kW with replacement cost of US$250/kW and efficiency of 85% (Moury *et al.*)

7.5 Wind Generator sizing

For any given site, the wind turbine choice is made on the basis of the wind profile of the site. Once the most probable and the maximum wind speeds are known, the wind turbine operating range can be estimated and is given by (15) (Nigim and Parker 2007).

$$2v_{max} \le v_{co} \le 3v_{max}$$

$$1.8v_{mp} \le v_{rated} \le 3v_{mp} \quad (15)$$

$$0.5v_{mp} \le v_{ci} \le 0.8v_{mp}$$

where v_{co} is the wind speed at which the wind turbine shuts down (cut–out wind speed), v_{ci} is the wind speed at which the wind turbine starts to produce power known as cut–in wind speed and v_{rated} is the wind speed at which the wind turbine operates at full rating. The most probable wind speed , v_{mp} (m/s), and the wind speed carrying the maximum energy , v_{max} (m/s), can be determined using the Weibull parameters k and c (Akpinar and S.Akpinar 2005) and they are given as (16) and (17) respectively.

$$v_{mp} = c\left(\frac{k-1}{k}\right)^{\frac{1}{k}} \quad (16)$$

$$v_{max} = c\left(\frac{k+2}{k}\right)^{\frac{1}{k}} \quad (17)$$

The wind speed was extrapolated to 50m height using (5), the result given in Table 4.

Table 4 Extrapolated wind characteristics at 50m hub height

Parameters	Value	Parameters	Value
Hub height	50m	v_{max}	8.5m/s
Mean wind speed	5.3m/s	k	2.2
v_{mp}	4.2m/s	c	6.1m/s

Based on the wind characteristic in Table 4 and equation (15), the estimated turbine parameter range: v_{ci} , v_{rated} and v_{co} are calculated to be approximately 2-3m/s, 8-13m/s and 17-26m/s respectively. Based on this, Enercon E330 was selected for the simulation because the operating parameters fall within the calculated range and it has rated wind power close to the peak load demand of Ala-Ajagbusi. Moreover, it is in-built in HOMER (Lambert and Lilienthal 2004). The operating parameters of the wind turbine are furnished in Table 5 while the turbine power curve is shown in Figure 6. The installation cost of the turbine as obtained from the manufacturer website (ENERCON-E33 2013) is estimated as US$2800/kW and replacement cost is taken usually in the range of 20% of initial capital cost while the cost of maintenance is 2% (Srivastava *et al.* 2012).

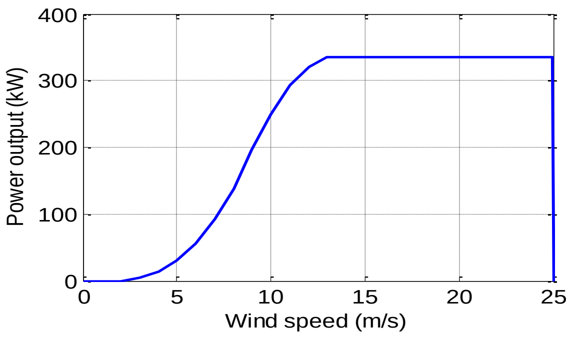

Figure 6: Enercon E33 wind turbine power curve

8. SIMULATION RESULTS AND DISCUSSION

Based on the design in Table 1, overall simulation options of 3840 were obtained. The best option in each designed scheme was categorized and the result is furnished in Table 6. The table clearly revealed that scheme A (Wind/Diesel/Battery) is the most suitable for the community technically and economically with the lowest total NPC of $9,605,548 and COE of $0.373/kWh. The cost summary for scheme A is presented in Table 7. Due to the abundance of wind resources at the site, the fraction of renewable energy in the scheme is 74% and this translates to limiting the usage of diesel generator to 4,797 hours in a year (55% reduction). This helps in improving the environment while meeting the electricity demand of the community. To appreciate the environmental impact of the scheme, the emissions for the four schemes are compared in Table 8. It can be observed from the table that CO_2 and CO emission can be reduced by about 50% by using scheme A or B compared to scheme D and E. However scheme A is preferred compared to B because of its lower NPC and COE. The monthly average electric production of scheme A for the community is depicted in Figure 7. The Figure shows that more wind energy is produced in December. This corresponds to the high wind speed that is observed in December. The annual energy production and consumption by both diesel generator and wind turbine is depicted in Table 9. The table reveals that the wind turbines generate a total of 2.4MWh/yr while the diesel generator produced 0.87MWh/yr. This can be inferred that the diesel generator was only used at the time of low wind resources and during peak hours to meet the peak loads. The result showing output of diesel generator complimenting the wind power generator at the time of low wind resources to meet the community load demand in some selected days in June and July is depicted in Figure 8.

Table 5 Enercon E33 Wind turbine parameters

Parameters	Values	Parameters	Values
Rated Power	330kW	Cut in wind speed	3m/s
Rotor diameter	33.4m	Rated wind speed	12m/s
Hub height	50m	Cut-out wind speed	25m/s

Table 6 Categorized simulation result of the designed scheme for Ala-Ajagbusi community

	PV (kW)	E33	Gen (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen (hrs)
A		3	300	200	200	$ 3,077,000	510,707	$ 9,605,548	0.373	0.74	333,417	4,797
B	5	3	300	200	200	$ 3,109,500	510,557	$ 9,636,133	0.374	0.74	332,379	4,794
C	5		300	170	100	$ 258,500	893,002	$ 11,674,063	0.453	0.00	718,214	8,760
D			400			$ 140,000	983,059	$ 12,706,799	0.494	0.00	783,829	8,760

Table 7 Cost Summary for Scheme A (most suitable option)

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Enercon E33	2,772,000	172,116	708,710	0	-96,462	3,556,365
Diesel Gen	105,000	270,449	919,827	4,091,707	-87	5,386,895
Trojan L16P	60,000	118,196	51,133	0	-3,456	225,874
Converter	140,000	50,072	255,667	0	-9,320	436,419
System	3,077,000	610,833	1,935,337	4,091,707	-109,325	9,605,553

Table 8 Emission comparison of the four Schemes

Emission (kg/yr)	Scheme			
	A	B	C	D
Carbon dioxide (CO_2)	877,997	875,264	1,891,294	2,064,079
Carbon monoxide (CO)	2,167	2,160	4,668	5,095
Unburned hydrocarbons	240	239	517	564
Particulate matter	163	163	352	384
Sulfur dioxide (SO_2)	1,763	1758	3,798	4,145
Nitrogen oxides	19,338	19,278	41,656	45,462

This complimentary characteristic enhances both the reliability and availability of electricity supply to the community.Figure 9 reveals that the diesel generator operates at full load (300kW) between the hour of 6.00-7.00 and 18:00-20:00. This corresponds to the two peak periods (morning and evening) in a day shown in Figure 5. There is annual excess generated electricity of about 1.3MWh/yr. This can be used to boost the economic activities of other nearby community that is also excluded from the grid. The monthly excess electricity generated is depicted in Figure 10.

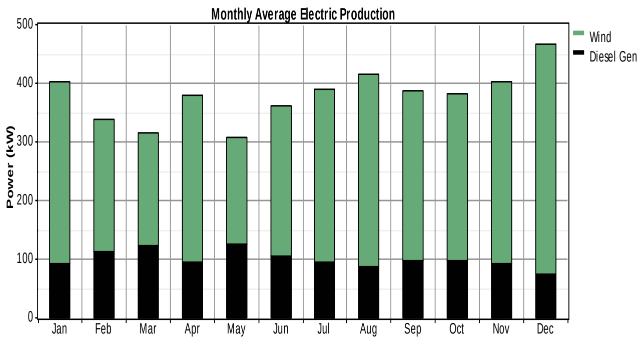

Figure 7 Monthly Average Electric Production of Scheme A for Ala-Ajagbusi Community

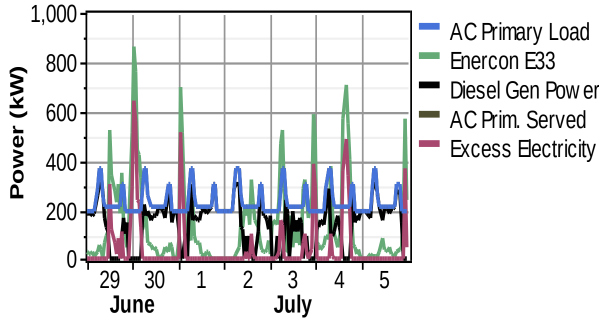

Figure 8 Selected Days with low wind resources

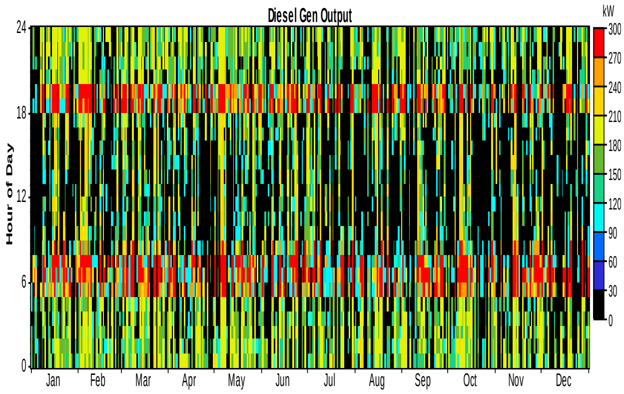

Figure 9 Diesel generator output per hour of the day

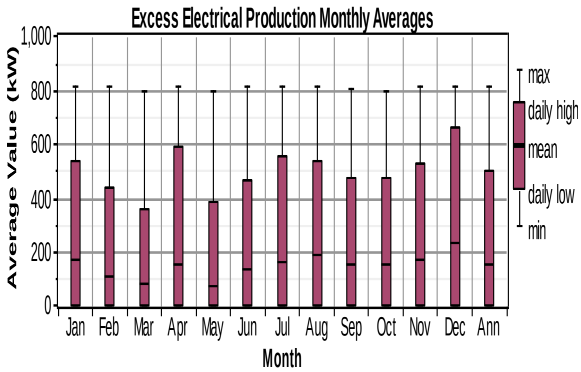

Figure 10 Average monthly excess electricity

9. CONCLUSION

The Hybrid Energy System (HES) that meets the energy demand of Ala-Ajagbusi community has been simulated using HOMER simulation tool. Four different schemes of HES are tested in order to determine the optimal design option that covers the estimated load of the community reliably and economically. The result of the simulation shows that wind/diesel/battery hybrid system is the most suitable option with optimal size of 300kW diesel generator, 3 numbers of Enercon-E33 wind turbines, 200 numbers of Trojan LI6P battery and 200kW converter. The option represents renewable energy fraction of 74% with total net present cost of $9,605,548 and cost of energy of $0.373/kWh. The result also reveals saving of 1,186,082kg/yr of carbon dioxide (CO_2) and 2,928kg/yr of carbon monoxide (CO).

ACKNOWLEDGMENT

The author wants to thank the Nigerian Metrological Agency for making both the solar irradiation and wind speed data available for this research work. The author will also like to thank the NREL, Colorado, USA for their initiative on the HOMER simulation tool.

REFERENCES

Akella, A.K., Sharma, M.P. & Saini, R.P., 2007. Optimum utilization of renewable energy sources in a remote area. Renewable and Sustainable Energy Reviews 11: 894-908.

Akpinar, E.K. & S.Akpinar, 2005. A statistical analysis of wind speed data used in installation of wind energy conversion systems. Energy Conversion and Management 46: 515-532.

Al-Badi, A.H. & Bourdoucen, H., 2011. Study and design of hybrid diesel-wind standalone system for remote area in oman. International journal of Sustainable Energy 31 (2): 85-94.

Anon, 2013. Retail price of inverters. http://www.solarbuzz.com/facts-and-figures/retail-price-environment/inverter-prices (Accessed 28th August).

Anwari, M., Rashid, M.I.M., Muhyiddin, H.T.M. & Ali, A.R.M., Year. An evaluation of hybrid wind/diesel energy potential in pemanggil island malaysia IEEE Conference on Power Engineering and Renewable Energy, Bali, Indonesia 17-21.

Ashok, S. & Balamurugan, P., Year. Biomass gasifier based hybrid energy system for rural areas IEEE Canada Electrical Power Conference, Canada.

Barra, L. & Coiante, D., 1996. Renewable enewrgy capability to save carbon emissions. Solar Energy 57 (6): 485-491.

Barsoum, N.N. & Vacent, P., Year. Balancing cost, operation and performance in integrated hydrogen hybrid energy system First Asia International Conference on Modelling & Simulation.

Bentouba, S., Boucherit, M.S., Bourouis, M., Coronas, A., Draoui, B. & Hamouda, M., Year. Environmental evaluation of typical house situated in the south of algeria by using photovoltaic system 2012 2nd International Symposium on Environment-Friendly Energies and Applications (EFEA), Northumbria University 641-645.

Bin, Y., Jie, T., Liji, Huang Jiemin, H. & Xiaomei, L., Year. International conference on computer distributed control and intelligent enviromental monitoring Feasibility Study of Renewable Energy Powered Island-HainanIEEE Computer Society 330-333.

Castañeda, M., Fernández, L.M., Sánchez, H., Cano, A. & Jurado, F., 2012. Sizing methods for stand-alone hybrid systems based on renewable energies and hydrogen. IEEE Mediterranean Electrotechnical Conference (MELECON). Yasmine, Hammamet, Tunisia.

Dalton, G.J., Lockington, D.A. & Baldock, T.E., 2009. Feasibility analysis of renewable energy supply options for a grid-connected large hotel. Renewable Energy 34: 955–964.

Dekker, J., Chowdhuryand, S. & Chowdhury, S.P., Year. Economic viability of pv/diesel hybrid power systems in different climatic zones in south africa IEEE Power and Energy Society General Meeting, Minneapolis, MN.

Demiroren, A. & Yilmaz, U., 2009. Analysis of change in electric energy cost with using renewable energy sources in go¨kceada, turkey: An island example. Renewable and Sustainable Energy Reviews.

Di Piazza, A., Di Piazza, M.C., Ragusa, A. & Vitale, G., Year. Statistical processing of wind speed data for energy forecast and plahhing International Conference on Renewable Energies and Power Quality (ICRPQ'10), Granada (Spain).

Dursun, B. & Gokcol, C., 2012. Economic analysis of a wind-battery hybrid system: An application for a house in gebze, turkey, with moderate wind energy potential. Turk J Elec Eng & Comp Sci, 20 (3).

Dusabe, D., Munda, J.L. & Jimoh, A.A., 2009. Rural village electrification in south africa: Role of energy efficient in off-grid pv/dg system. active.cput.ac.za/energy/past_paper.

Enercon-E33, 2013. G2 energy renewable developments project design. http://www.enercon.de/en/e33.htm.-33 Accessed 28th August 2013.

Gabler, H., 1998. Autonomous power supply with photovoltaics:Photovoltaics for rural electrification - reality and vision. RenewableEnergy 15 (4): 512-518.

García-Valverde, R., Miguel, C., Martínez-Béjar, R. & .Urbina, A., 2009. Life cycle assessment study of a 4.2 kwp stand-alone photovoltaic. Solar Energy 83 (9): 1434-1445.

Givler, T. & 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. National Renewable Laboratory Technical Report (NREL/TP-710-36774).

Hajiah, A. & Sebzali, M., 2013. Optimal sizing of wind power systems in three high wind potential zones in kuwait for remote housing electrification. International Journal of Renewable Energy Research 3 (1): 167-171.

Jose´, L., Bernal-Agustın, R. & Dufo-Lo´, P., 2009. Simulation and optimization of stand-alone hybrid renewable energy systems Renewable and Sustainable Energy Reviews 13: 2111-2118.

Kaundinya, D.P., Balachandra, P. & Ravindranath, N.H., 2009. Grid-connected versus stand-alone energy systems for decentralized power—a review of literature. Renewable and Sustainable Energy Reviews 13: 2041–2050.

Kılınc, A., Stanisstreet, M. & Boyes, E., 2009. Incentives and disincentives for using renewable energy: Turkish students' ideas. Renewable and Sustainable Energy Reviews 13: 1089–1095.

Lambert, T. & Lilienthal, P., 2004. Homer: The micro-power optimisation model (accessed 15th august 2013). http://homerenergy.com/. National Renewable Energy Lab (NREL).

Marco, B., Maurizio, C. & Marina, M., 2007. Environmental effects of energy policy in sicily:The role of renewable energy. Renewable and Sustainable Energy Reviews 11: 282–298.

Mekhilef, S. & Chandrasegaran, D., Year. Assessment of off-shore wind farms in malaysia IEEE Region 10 conference (TENCON 2011), Bali, Indonesia, 1351-1355.

Moury, S., Nazim Khandoker, M.N. & Haider, S.M., Feasibility study of solar pv arrays in grid connected cellular bts sites. 1-5.

Nahari, A. & Dashti, R., 2011. Technical and economic analysis of different micropowers in providing network load and optimal selection with real load analysis of a 20kv/400v station in bushehr province of iran. The International Conference on Advanced Power System Automation and Protection. Beijing, China.

Nfaha, E.M., Ngundamb, J.M. & Tchindaa, R., 2007. Modelling of solar/diesel/battery hybrid power systems for far-north cameroon. Renewable Energy 32: 832–844.

Nigim, K.A. & Parker, P., 2007. Heuristic and probabilistic wind power availability estimation procedures: Improved tools for technology and site selection. Renewable Energy 32: 638-648.

Nrel, 2014. Hybrid optimization model for electric renewables (homer) http://www.nrel/gov/HOMER acessed (17th December, 2013).

Omer, A.M., 2007. Renewable energy resources for electricity generation in sudan. Renewable and Sustainable Energy Reviews 11: 1481–1497.

Rashayi, E. & Chikuni, E., 2012. The poetential of grid connected photovotaic array in zimbabwe. IEEE Mediterranean Electrotechnical Conference. Yasmine, Hammamet.

Rehman, S., Bader, M.A. & Al-Moallem, S.A., 2007. Cost of solar energy generated using pv panels. Renewable and Sustainable Energy Reviews 11 (8): 1843-857.

Sekgoele, K., Chowdhury, S.P. & Chowdhury, S., 2011. Technical and economic assessment of power generation from landfill gas in south africa. IEEE Power and Energy Society General Meeting. San Diego, CA, 1-8.

Seyed, J. & Mohammad, F., Year. Analysis of hybrid wind/fuel cell /battery/ diesel energy system under alaska condition The 8th Electrical Engineering and Electronics, Computer, Telecommunications and Information Technology (ECTI) Association of Thailand Conference Khon Kaen University,Thailand, 917-920.

Shiroudi, A., Rashidi, R., Gharehpetian, G.B., Mousavifar, S.A. & Foroud, A.A., 2012. Case study: Simulation and optimization of photovotaic-wind-battery hybrid energy system in taleghan-iran using homer software. Journal of Renewable and Sustainable Energy 4: 1-10.

Srivastava, A.K., Kumar, A.A. & Schulz, N.N., 2012. Impact of distributed generations with energy storage devices on the electric grid. IEEE System Journal, 6 (1).

Sunderan, P., Singh, B., Mohamed, N.M. & Husain, N.S., Year. Techno-economic analysis of an off-grid photovoltaic natural gas power system for a university 3rd International Symposium & Exhibition in Sustainable Energy & Environment, Melaka, Malaysia, 129-135.

.

Thompson, S. & Duggirala, B., 2009. The feasibility of renewable energies at an off-grid community in canada. Renewable and Sustainable Energy Reviews 13: 2740–2745.

Wilmann, D. & Sterling, L., 2005. Guiding agent-oriented requirements elicitation: Homer. Proceedings of the Fifth International Conference on Quality Software. Melbourne, Australia: 1-6