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Techno-Economic Evaluation of Standalone Hybrid Renewable Power System for a Remote Location in Nigeria

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ABSTRACT
The application of an off-grid hybrid renewable energy-based power systems for rural electrification has become an attractive solution for areas where grid electricity is either not feasible or the cost of the grid extension is relatively high. A hybrid system uses one or several renewable energy technologies as primary energy sources and a conventional fossil fuel-based or biofuel-based generator as a backup source. Therefore, this hybrid system reduces the dependence on one energy source, resulting in reliable and affordable electricity for the rural consumers. As hybrid systems use several energy technologies, the selection of proper technologies and optimum sizing of the selected components is important in reducing the overall cost and increasing the reliability and availability of the service. The aim of this work is to evaluate the optimum configuration of a hybrid system which can supply electricity to a rural community in Abuja, Nigeria. A rural community, Dafara in Abuja containing approximately 102 households with a daily electricity demand of 165.24 kWh and a night-time peak of 23 kW has been chosen as target. Several electricity generating technologies, including solar, wind and diesel generators has been studied, and simulations was performed for a number of system configurations using the Hybrid Optimization of Multiple Electric Renewables (HOMER) software. The total net present cost (NPC) of each system configurations were evaluated for 20 years of systemic lifetime in order to examine the lowest energy cost option.

Keywords: *HOMER, Hybrid system, Optimization, Photovoltaic, Simulation, Wind energy*

1 INTRODUCTION

The application of renewable energy technologies for rural electric power supply has been increasing in recent years. However, due to large fluctuations and the intermittent nature of renewable energy resources, its applications as a standalone single source system is relatively expensive and unreliable; moreover, there is sometimes the need for long term storage, especially due to these resources' seasonal variations. Therefore, hybrid systems have been considered a cost-effective and reliable approach to providing electricity for remote communities (Olatomiwa, Mekhilef, & Ohunakin, 2016).

More than 60% of the world's electricity is generated by fossil fuels (Khan & Iqbal, 2005). The larger part of this is generated via coal, while oil and natural gas also make large contributions to electric power productions. The two main problems of using fossil fuels as energy sources are, (1) it is finite, so it will be depleted over time and (2) burning fossil fuels releases pollutant gases into the environment. The pollutant gases CO, NO and NO_2 are harmful to animals and plants, and they also cause health problems in humans (Olatomiwa et al., 2016). Indeed, CO_2 emissions have resulted in "the green-house effect" by increasing the earth's temperature, which can lead to several problems such as climate change and the melting of glaciers, resulting in the rise of sea-water levels.

In the attempt to find a solution to these problems, the world's inhabitants have been looking to renewable energy resources for fulfilling their energy needs. Renewable energy sources include solar, wind, hydro, bio-energy as well as geothermal energy and tidal power. The source of all these renewable energy resources; for example, hydro power, solar and wind energy have been widely used for electricity generation in many countries (Farahat, Jahromi, & Barakati, 2012; Nafeh, 2010; Roland & Glania, 2011).

Development of renewable energy system has opened the door for small community electrification in remote rural areas. There are many remote communities all over the world without electricity; in many developed countries as well as developing ones. The major reason for remaining without electricity in such communities is the unavailability of a nearby national grid, due to the high cost involved in the extension of the transmitting and distributing infrastructure in these remote areas (Olatomiwa, Mekhilef, Huda, & Ohunakin, 2015).

In some developing countries, rural inhabitants generate their own electricity using diesel generators (Nayar, 2010). However, the cost of the kWh generated by this type of generator is substantially higher than the cost of electricity from the utility grid; therefore, several inhabitants in remote communities cannot afford it. Due to the high cost involved with extending the national grid, it is not economical for utility companies to extend the grid to remote areas. When compared to the cost involved in grid extension, renewable energy systems have now become a cost-effective solution for supplying remote communities with electric power (Kolhe, Ranaweera, & Gunawardana, 2015)

Widely used renewable energy systems are the Photo-Voltaic (PV) systems and small wind turbines. In addition, bio energy and mini hydro are also used. PV systems can be installed in almost any location because sunlight is sufficiently available in most of the earth's areas. But the other technologies can only be used in locations where the resources are sufficiently available. For example, a mini hydro plant requires a river with a sufficient flow rate, and a bio energy plant requires a sufficient amount of biomass plantation. Therefore, a suitable energy system in a certain geographical location must be chosen by considering the availability of resources throughout the year.

Renewable energy resources are highly intermittent in nature, meaning that most of them experience periodical as well as seasonal variations, thus being unable to guarantee a reliable and uninterrupted supply of electricity. On the other hand, the initial cost of investment in solar and wind systems is still relatively high in comparison to fossil fuel-based electricity.

Interestingly, using multiple options of renewable energy resources provides more reliable electricity than a single renewable energy source; this has been identified as being one solution to these problems. By using a conventional energy source in connection with renewable sources, the system becomes cost effective and more reliable (Olatomiwa, 2016). Combinations of such different but complementary energy generation systems based on renewable or mixed energy (renewable energy with a backup bio-fuel/diesel generator) are known as hybrid renewable energy system. The grid formed by this system is known as a micro-grid due to its size when compared to the main grid.

Figure 1 illustrates a typical hybrid system. It uses a wind turbine and a PV system as a primary energy sources and a diesel generator as a backup energy source. In addition, a battery bank is used as an energy storage medium.

The combinations of electricity generation sources and components selected for a hybrid system have great influence on both the lifetime of the system and its affordability to the end users. In order to increase the efficiency of the system while reducing its cost, it is very important to correctly determine the system's size.

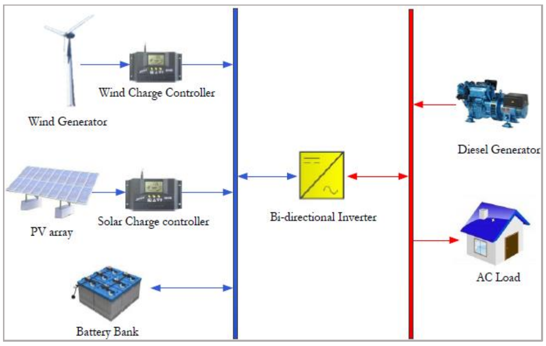

Figure 1: Hybrid system

The most important element is the selection of energy sources. As mentioned earlier, several types of renewable energy technologies can be utilized in a hybrid system, such as solar energy, wind energy, micro hydro and bio energy. Batteries and conventional fossil fuel-based generators are the other important components of a hybrid system. Batteries are required to store surplus energy during times of high energy production from the renewable energy sources, which is used later for supplying the load when the power production from renewable sources is low.

The generator is important to ensure quality of service when the output from other technologies is low or when the demand is high. In addition, there should be some kind of automatic management technology built into the system to protect critical components from damage, for example, total depletion of the battery charge (Roland & Glania, 2011).

The total net present cost of the hybrid power system for its technical lifetime determines the energy cost and depends on the size of the generating systems and types of the energy resources used. Therefore, selecting the proper combination of energy sources and the sizes of each generating system according to the electricity demand of the community is very important in order to make the system efficient and economical. This selection requires a detailed technical and economic analysis of the possible hybrid system configurations that can be applied to the given site location according to the availability of the renewable energy resources throughout the year.

A number of software have been developed by different institutions for analyzing the hybrid energy systems (e.g. HOMER, PVsysts, Geospatial Toolkit, Hybrid2… etc). Currently, these tools are widely used in sizing and analyzing the hybrid systems in several countries. Unfortunately, in Dafara community (the selected case study) there has not been any successful hybrid energy systems in operation; and the focus on studies of hybrid systems for rural electrification is minimal even though there has been a rapid growth in the renewable energy sector in Nigeria over the past few years.

2 METHODOLOGY

The research method primarily consists of collecting renewable resource data, determination of community load profile, studying component characteristics and costs, studying hybrid system configurations, modeling and simulation of the hybrid system, selection of optimum system based on simulation results and the performance evaluation of the selected system. Figure 2 is a flow chart representing the research method.

It is required to determine the daily load profile of the community. The seasonal variations of the load profile should also be taken into consideration if applicable. Determination of the load profile of the community could be done via conducting a survey in the community using parameters such as, the number of households and public utilities, family income, tendency and willingness to buy electrical appliances and possible small businesses that can arise if electricity is available will determine the load curve of the community.

However, an estimated load curve can still be derived through making reasonable assumptions if actual survey data are not available (Nayar, 2010).

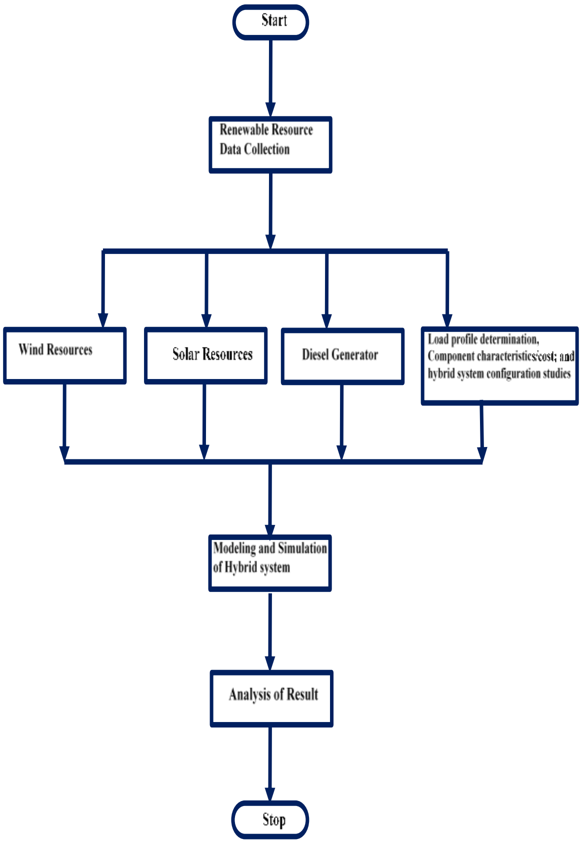

Figure 2: A Flow Chart representation of the research method

The annual renewable resource variation data were collected during the previous years to analyze the renewable resource potential of the site. Renewable resource data can be obtained from the local meteorological stations or from the Internet. Several internet-based renewable resource databases are available including meteorological data for worldwide sites (Nayar, 2010).

Subsequently, the different hybrid technological configurations for the interconnection of the system components were studied and the required components selected accordingly. The specifications, characteristics and costs of these components were studied and the system subsequently modeled in a hybrid system optimization software. In this study, a micro grid optimization software "HOMER", developed by the National Renewable Energy Laboratory (NREL) of the USA was utilized (Sureshkumar, Manoharan, & Ramalakshmi, 2012).

The simulations are required to make a large number of hybrid system configurations that consider several combinations of renewable resources, a diesel generator and battery bank with different capacities. The lifetime net present cost of the hybrid systems that can supply the community's load with the required level of availability were calculated to determine the lowest energy cost of the hybrid configuration. The sensitivity analysis of the uncertainties regarding the system inputs (primarily the wind speed and solar radiation) were evaluated to examine the best system that can supply the load at the lowest energy cost for various conditions.

2.1 DATA COLLECTION

Hybrid system design and optimization requires evaluation of load profile of the selected community and the renewable resources in the region. This section of the paper discusses the estimation of the community load and the assessment of renewable resources; solar and wind at the site.

Dafara community among several other communities in Abuja has been selected for studying renewable hybrid energy system for supplying electricity. The map of the community is given in Figure 3 and Figure 4. The community is located at 80 51' 54.62" N (8.865172) latitude and 70 17' 18.24" E (7.288400) longitude; a distance of about 8.6 km from Kuje, the nearest developed urban centre with some thick jungle and poor road network (Figure 5).

Dafara is a community with a population whose income is mainly derived from agricultural activities. Unavailability of basic facilities and the low-income level has greatly affected the living standards in the community. Therefore, in order to improve the living standards of the inhabitants in this community, it is very important to provide basic facilities including electricity for them. The electrical loads are scattered all over the community.

Figure 3: Map of Dafara community in Abuja

Figure 4: Closer view of the selected community (maps.google.com)

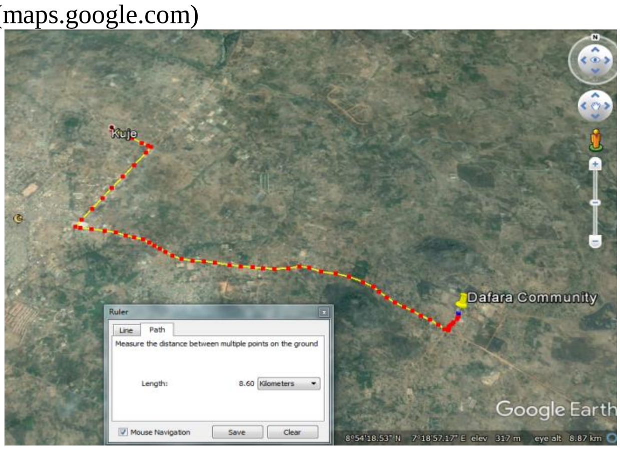

Figure 5: Map of Dafara community showing the distance of the community from the urban centre

2.1.1 Community Load Profile

The proposed hybrid system is for supplying electricity to Dafara community consisting of about 102 houses. In order to derive the load profile of the community, it is required to understand the living conditions of the people in the community. Basically, the income of a family mainly affects the load profile of a house. Other than income, factors such as lifestyle of the people, willingness of buying electrical appliances and the size of the house will also affect the load profile.

2.1.2 Electrical Load Survey Of Dafara

For ease of power evacuation, knowledge of the power demand of the community to be electrified is needed. In this work, this was estimated through interviews of the village head (Mai Angwa), community inhabitants and farmers. The following factors were considered during the electrical load survey of the selected location for this study.

- Number of houses
- Average daily electrical energy consumption
- Miscellaneous demand

2.1.3 Load Estimation and Demand

The data obtained are based on the electrical load survey conducted in the selected community through communication feedback from the inhabitants of the community on the 1st of March, 2017. The primary load is residential with some miscellaneous load. As at the time of survey, there was no industrial or commercial load demand. The load is composed of the household devices such as lighting points, fans, Television (TVs) and radios. Note that refrigerators, ironing devices and other heavy electric equipment are not included in this survey.

The estimated energy consumed by each of the categories is shown in the Table 1. The table shows estimation of each appliance's rated power, its quantity and the hours of use by each house in a single day. The miscellaneous load is for unknown loads in each category.

Based on the estimated energy consumed by each of the categories as in Table 1, a typical load curve for this community has been derived and it is given in Figure 6 below. According to the derived load profile, the maximum load of the community is 23 kW and daily energy consumption is 165.24 kWh.

From Figure 6, the hourly load profile between the hours of 00:00am to 06:00am reflects low load, less than 5 kW. This is attributed to insignificant usage of lightings as this period is when the inhabitants of the community are sleeping. From 07:00am to 04:00pm, the load increases and remain stable at 6 kW. The load profile suggests that the kW consumption during this period were mainly due to small electrical loads engaged by few of the community inhabitants who do not embark on daily farm activities. Between the period of 05:00pm to 10:00pm, the load demand is increased, as majority of the inhabitants who are farmers have returned from their various farming activities; hence the load profile depicts an increased kW consumption trend; up to 10 kW and above.

Table 1: Load Types and Estimation

Type of Consumers	Load Type	Rated Power (W)	Quantity	Hours	Energy (Wh/Day)	Total Energy (kWh/day)
Residential (Per household)	TV	80	1	5	400	1.62
	Radio	15	1	6	90	
	CFL	20	3	5	300	
	Fan	70	1	5	350	
	Miscellaneous	20	1	24	480	

Note: CFL is Compact Fluorescent Lamp, and TV is Television

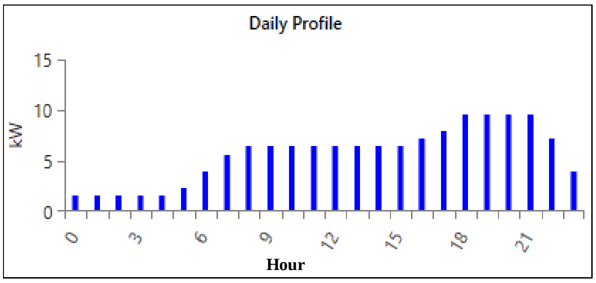

Figure 6: Load profile of the selected community

2.1.4 Solar Resource

Dafara is a community located closer to the equator, therefore it receives an abundant supply of solar radiation throughout the year. Due to the unavailability of ground measurement data of solar radiation at the selected location, data have been obtained from the NASA renewable energy resource website (NASA/SSE, 2013). Monthly average insolation data on a horizontal surface including the clearness index obtained from the NASA database are in Table 2. The clearness index is a measure of the clearness of the atmosphere (i.e. the fraction of the solar radiation that is transmitted through the atmosphere to the earth's surface).

According to solar radiation data shown in Table 2, it can be seen that the average solar radiation in Dafara community is relatively high. This would give a relatively good possibility and opportunity to employ the photovoltaic technology as a component of the hybrid renewable energy system.

2.1.5 Wind Resource

Wind resource is an important resource in a hybrid power system. The power in the wind is converted to electrical energy with the aid of a wind turbine. In practice, the amount of energy generated is a function of the wind speed. Ground wind speed measurement data for Dafara community is not available; hence, the wind speed data have been obtained from the NASA renewable energy resource website (NASA/SSE, 2013).

Table 2: Monthly average insolation incident on a horizontal surface

Month	Clearness Index	Monthly Radiation (kWh/m2/day)
January	0.652	5.89
February	0.628	6.07
March	0.595	6.11
April	0.55	5.77
May	0.522	5.4
June	0.481	4.89
July	0.442	4.52
August	0.412	4.27
September	0.447	4.6
October	0.522	5.12
November	0.634	5.8
December	0.662	5.82
Annual Average	0.55	5.36

The data obtained from the NASA website is tabulated in Table 3. It is obvious from the average wind speed (3.19 m/s) that the selected community does not have the potential for wind energy generation. Generally, average annual wind speeds of at least 4.0-4.5 m/s are needed for a small wind turbine to produce enough electricity to be cost-effective (Hossain, Mekhilef, & Olatomiwa, 2017).

Table 3: Monthly average wind speed at 50m above the ground

Month	Average Wind Speed (m/s) at 50m
January	3.01
February	2.92
March	3.2
April	3.07
May	3.14
June	2.82
July	3.64
August	3.85
September	3.74
October	2.66
November	3.52
December	2.71
Annual Average	3.19

2.2 HYBRID SYSTEM COMPONENTS

(1) Wind Turbine

A wind turbine is a machine which converts the power in the wind into electricity. The generation capacity of modern wind turbines range from a few watts to megawatts (2MW). The larger wind turbines are typically used in utility scale applications and smaller wind turbines are used in residential and commercial applications either as grid connected or off grid. In modern wind turbines, the conversion process uses the basic aerodynamic force of lift to produce a net positive torque on a rotating shaft, resulting first in the production of mechanical power and then in its transformation into electricity in a generator. The wind turbine can produce energy in response to the wind that is immediately available.

The power output of a wind generator at a particular wind speed could be estimated by Eq. (1) (Akinyele, Nair, Rayudu, & Seah, 2014; Sureshkumar et al., 2012)

$$P_o = \frac{1}{2} C_p \rho A V^3 \quad (1)$$

where ρ, C_p, A and V stand for the air density in kg/m^3, maximum power coefficient, the swept area by the generator's blades and the wind speed, respectively.

(2) PV Panels

The photovoltaic effect is the process of producing direct electrical current from the radiant energy of the sun using semiconductor cells. Semiconductor cells are basically large area p-n diodes and have a very small power output. The most common semiconductor material used for producing solar cells is the Silicon. The power output from a typical solar cell is about 1W. Hence, to generate the required amount of power, a large number of cells are connected in series and parallel on a module.

The output of a PV array could be estimated by Eqs. (2) and (3) (Akinyele, Rayudu, & Nair, 2015; NREL, 2009).

$$P_o = P_r.d_{rf}.n_m.(1+\alpha(T_c - T_{t,stc})).\left(\frac{G_i}{G_{stc}}\right) \quad (2)$$

$$T_c = A_t + \left(\frac{NOCT - 20°C}{G_r}\right) \quad (3)$$

where P_r, d_{rf}, n_m, α, T_c, $T_{c,stc}$, G_i, G_{stc}, G_r, A_t and $NOCT$ represent the module's rated power, derate factor, number of the PV modules, PV module's temperature coefficient of power, cell temperature, cell temperature at standard test condition (STC), solar irradiance of the site, solar irradiance at STC, reference solar irradiance, ambient temperature and the nominal operating cell temperature. The solar irradiance at STC, reference solar irradiance, and $NOCT$ are 1000 W/m^2, 800 W/m^2 and 45 ± 2 °C, respectively(NREL, 2009).

(3) Diesel Generator

Diesel generators are important in renewable energy hybrid systems to improve the quality and the availability of the electricity supply. Since diesel generators are dispatchable they can be used to supply the load when the energy productions from the renewable sources are low or the state of the charge of the battery bank is not sufficient for supplying the load.

The fuel consumption of a diesel generator could be determined by Eq. (4) (NREL, 2009):

$$F_c = AP_o + BP_r \quad (4)$$

where F_c, P_o, P_r, A and B represent the fuel consumption of the generator in liter/kWh, operating power output in kW and the power rating of the generator in kW, fuel curve slope in liter/kWh and the fuel curve intercept coefficient in liter/kWh, respectively. The values of A and B are 0.246 and 0.08415 (NREL, 2015) .

(4) Storage Battery

An off-grid hybrid system requires a storage to store the excess energy from the renewable sources for later utilization when enough power is not produced by the renewable sources. Batteries are the most common storage medium used in renewable applications. A battery is an electrochemical device that produces a voltage potential when placing different metals (electrodes) in an acid solution (electrolyte).

The size of the battery bank could be determined by Eq. (5) (Akinyele et al., 2015; Posadillo & Luque, 2008).

$$B_c = \frac{L_d D_a}{\eta_r.V.MDoD} \quad (5)$$

where L_d, D_a, η_r, V and MDoD represent the maximum daily load demand, days of autonomy, round-trip efficiency of the battery technology, system voltage and the maximum depth of discharge, respectively.

(5) Inverter

A hybrid system needs an inverter to convert DC voltage from the batteries to AC voltage required by the load. There are several factors needed to be considered when selecting an inverter for a certain application. Usually the inverters used in renewable applications can be divided into two; that is grid tied inverters and off grid inverters. It is important that the inverter has the capacity to support the peak load in kVA.

2.3 ECONOMIC ANALYSIS

The total Net Present Cost (NPC) of the system is the difference between the present value of all the costs incurred over the lifetime of the project and the present value of all the revenue earns over its lifetime. The present value of the costs that will make n-year later can be calculated by the following equations:

$$C_{NPC} = C\left(\frac{1+i'}{1+d}\right)^n \qquad (6)$$

where;

i' is the annual inflation rate (%)

d is the nominal interest rate (%)

In order to find the LCOE, the total NPC of the project must be converted to series of equal annual cash flows which is known as total annualized cost. The following equation is used to calculate the total annualized cost.

$$\text{Total annualized cost}(\$/\text{year}) = \text{Total NPC} \times \text{CPF} \qquad (7)$$

where, CPF is the capital recovery factor, which is the amount of equal payments to be received for n years such that the total present value of all these equal payments is equivalent to a payment of one dollar at present, and it is given by:

$$\text{Capital recovery factor} = \frac{i(1+i)^N}{(1+i)^N - 1} \qquad (8)$$

where, N is the number of years and i is the real interest rate, that is the discount rate used to convert between one-time costs and annualized costs. The lifetime of the project is 20 years. The real interest rate is determined using the nominal interest rate (d) and the annual inflation rate (i') given by

$$i = \frac{d - i'}{1 + i'} \qquad (9)$$

HOMER assumes the rate of inflation is same for all types of costs (fuel cost, maintenance cost, labour cost, etc.) occurring throughout the lifetime of the project.

The levelized cost of energy (LCOE) is the cost per kWh of electrical energy, such that the total NPC of the useful energy generated throughout the whole lifetime of the hybrid project is equal to the total net present cost of the project. LCOE of the electricity generated by an off-grid hybrid energy project can be calculated from the following equation.

$$\text{LCOE} = \frac{\text{Total Annualized Cost (USD/yr)}}{\text{Annual load served (kWh/yr)}} \qquad (10)$$

2.4 HYBRID SYSTEM MODELING AND SIMULATION

Since the aim of this paper is to propose an optimal hybrid system which can supply electricity at the lowest price with an accepted level of availability through performance evaluation. For this reason, it is required to consider several combinations of renewable energy systems and diesel generator with different component capacities.

The modeling and simulation of the hybrid system is achieved through the use of micro grid optimization software, "HOMER". This requires the consideration of several combinations of renewable energy systems and diesel generator with different component capacities. HOMER is a computer model that simplifies the task of evaluating design options for both off-grid and grid connected power systems for remote, stand-alone and distributed generation applications (bin Othman & Musirin, 2010). It facilitates a range of renewable energy and conventional technologies including solar PV, wind turbine, hydro power, generator (diesel, gasoline, biogas), battery bank and hydrogen. HOMER's optimization analysis algorithms allow the user to evaluate the economic and technical feasibility of a large number of technology options. The sensitivity analysis can also be performed in HOMER, and it allows finding the effect of uncertainty in the input variables to the energy cost and the optimal configuration.

HOMER hybrid model requires several inputs which basically describe the technology options, component costs, component specifications and resource availability. HOMER uses the energy balance in optimization calculations. It compares hourly electric and thermal demand to the energy that the system produces in that hour and calculates the flow of energy to and from each component of the system. This comparison is done for each of the 8760 hours in a year for each system configuration that the user wants to consider. It then determines whether the hybrid configuration can supply the demand under the conditions that the user has specified. If it can, then HOMER calculates the net present value of installation and operating cost of the project over its lifetime and the cost of the energy based on the Levelized Cost of Energy (LCOE). The resulting hybrid configuration that has the least LCOE or the least total net present value of the project is considered as the optimum hybrid system.

2.5 DISPATCH STRATEGY

The diesel generator is the only dispatchable energy source used in this hybrid energy system. Since the energy output from renewable sources is highly intermittent and cannot be controlled by the user, it must be used when it is available, to supply the load or to charge the battery bank. If renewable energy systems or the battery bank is not able to meet the load, then the diesel generator has to be turned on to supply the load without causing power interruptions. Therefore, using a diesel generator is essential in hybrid systems to supply the load in a controlled manner to improve the availability of the system. In HOMER, two dispatch strategies are available; these includes “Load following” and “Cycle charging.

In Load following strategy, the diesel generator starts when required, and produces only the required amount of power that cannot be produced by the renewable sources or battery bank to supply the load. While in Cycle charging, the diesel generator starts when required and operates at its full capacity and excess energy is sent to the battery bank to charge the batteries (Halabi, Mekhilef, Olatomiwa, & Hazelton, 2017; NREL, 2009).

2.6 Search Space

In order to find the optimal system, we need to consider several combinations of different capacities of hybrid system components. We can provide a wide range of capacities to HOMER. The larger the number of inputs, the higher the time that HOMER takes to simulate the system. Table 4 specify the capacities of the system components that was chosen for the simulation.

Table 4: HOMER search space

PV Array (kW)	Wind turbine-10 kW (Quantity)	Generator (kW)	Battery (Strings)	Converter (kW)
0	0	0	0	0
10	10	25	10	24
20	20	50	20	
30	30		30	
40	40		40	
50	50			

3. RESULTS AND DISCUSSION

HOMER simulation results of the hybrid system optimization are given in Table 6 and Table 7. Results indicate that 30 kW of solar PV can support the community’s energy demand of 165.24 kWh. The annual solar insolation in this community for energy generation is 5.36 kWh/m^2/day; which is high enough to give a relatively good possibility and opportunity to employ the photovoltaic technology. On the other hand, the annual average wind speed is 3.19 m/s; a value too low for energy generation. The size of the generator is 25 kW which is expected to supply the load when the energy productions from the renewable sources are low or the state of the charge of the battery bank is not sufficient for supplying the load.

In order to make the description easier, the system can be defined based on two terms; i.e. system type and system configuration. A system type is a combination of technologies. For example, wind/diesel/battery describes a system type that includes wind turbines, diesel generators and batteries. A system configuration is a combination of specific numbers and sizes of components. For example, a system with a 10 kW wind turbine, 15 kW diesel generator, 16 batteries and a 25 kW inverter describes a configuration of the wind/diesel/battery system type. The same system type with 32 batteries is a different system configuration.

Table 6 gives part of the overall optimization results. It displays the list of system configurations which are ranked according to the increasing NPC of the project; also, from this table, the most cost effective configuration of each system type is displayed. According to the HOMER simulation results, the optimum system type is PV/diesel generator/battery system; and its system architecture are given in Table 5. This system can supply the electricity at an LCOE of 0.5 $/kWh.

The optimum system type for this project is PV, diesel generator and battery system. From the search space, based on the simulation result from HOMER, wind turbine system does not have the potential to thrive in the selected location.

Table 5: Optimum Hybrid System Architecture

PV system capacity	30 kW
Number of 10 kW Wind turbine	0
Generator capacity	25 kW
Battery bank	30 batteries
Converter capacity	24 kW
Dispatch Strategy	Load Following
Renewable fraction	0.45

As shown in Table 7, a diesel only system requires a small capital investment ($ 12,500) compared to hybrid systems ($ 118,700) in Table 6. But due to its large operating and maintenance cost ($ 40,266), the lifetime net present cost of the system ($ 533,034) is very much higher than the hybrid system ($ 390,914). Thus, the LCOE is also becoming larger which is approximately 0.7 $/kWh and it is more than the energy cost of the optimum renewable energy based hybrid system (0.5 $/kWh) given in Table 6. Therefore, from an economic perspective, stand-alone power systems based on renewable sources, storage battery bank and a diesel generator is considerably more cost effective than systems which use diesel generators only.

4. CONCLUSION

This paper has presented the techno-economic evaluation of standalone hybrid renewable power systems for remote locations in Nigeria. It has discussed how the optimum energy configurations could be modeled for rural communities in the country. Such systems could be useful for addressing the energy shortage situation in the isolated communities of the country.

A typical load demand profile has been used to represent the community's daily consumption pattern. This has also been used to model the different energy systems from the available energy resources in the specified community. The energy yields of the energy resources have been determined by employing the historical solar radiation and wind speed data for the location. Based on the average solar insolation in the selected community, there is the potential of energy generation through photovoltaic technology; while wind energy is not feasible in this community due to the low average wind speed. It is observed that renewable energy generation is more cost-effective than diesel only system because from the simulation result, large operating and maintenance cost is incurred in diesel only system as compared to the hybrid system.

Table 6: Optimum Hybrid System Simulation Results

Architecture						Cost				Sytem
PV (kW)	Wind Turbine	Gen (kW)	Battery	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
30.0		25.0	30	24.0	LF	$0.500	$390914	$21057	$118700	45
20.0		25.0	30	24.0	LF	$0.502	$391942	$23457	$88700	38
20.0		25.0	40	24.0	CC	$0.502	$391957	$23226	$91700	34
20.0		25.0	20	24.0	LF	$0.504	$393944	$23844	$85700	35
30.0		25.0	40	24.0	CC	$0.505	$394311	$21088	$121700	41
30.0		25.0	40	24.0	LF	$0.505	$394769	$21123	$121700	47
30.0		25.0	20	24.0	LF	$0.506	$394985	$21604	$115700	41
20.0		25.0	40	24.0	LF	$0.507	$396275	$23560	$91700	39
20.0		25.0	30	24.0	CC	$0.508	$397104	$23856	$88700	33
30.0		25.0	30	24.0	CC	$0.512	$399929	$21754	$118700	40
20.0		25.0	20	24.0	CC	$0.513	$400991	$24389	$85700	32

Renewable energy-based power systems cannot provide a continuous supply of electricity without a storage medium, due to the intermittent nature of the renewable resources. Therefore, a battery bank has been added to the hybrid system. In order to ensure the continuity of supply without putting stress on the battery bank for a reduced overall cost; a diesel generator has also been included.

After selecting the appropriate components and studying their characteristics, the hybrid system has been modeled in HOMER, and simulations have been made to determine the optimum system configuration which can supply the community's load with the required level of availability. The lifetime cost of each hybrid configuration that can meet the continuous load demand has been calculated to determine the system which provides the lowest cost. Based on simulation results from HOMER, the optimum system type is PV, diesel generator and battery system.

To further evaluate the feasibility of the system, sensitivity analysis can be performed in HOMER by varying the system's input to see the effect of uncertainty in sizing the optimum hybrid system configuration.

Table 7: Simulation Result of a Diesel Only System

Architecture		Cost				Sytem
Gen (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
25.0	LF	$0.682	$533,034	$40,266	$12,500	0.0

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