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Application of Hybrid System for Improved Power Quality in Ajoki Community

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ABSTRACT
The study examined the application of hybrid power network in Ajoki community located in Edo state Niger Delta region of Nigeria. Power supply to Ajoki community is very unstable and unreliable due to high operation and maintenance cost, and fuel cost associated with diesel generator. This has impacted negatively on the educational, economic, medical and social services required for the livelihood of Ajoki community with a population of 2845. This research proposes a Distributed Hybrid Renewable Energy Sources (DHRES) comprising of Solar, wind and diesel generator were modeled using the HOMER Software. The solar irradiance and wind speed data were collected from NIMET data base and fed into HOMER software. The result obtained shows that in the base case when only diesel generator is in use for 24hrs/day for a year, a total of 959,220 kWh/yr of Electricity was produce and consumed. The total Net Present Costs (NPC) is ₦1.64B with breakdown as follows capital cost ₦80.0M, O&M cost ₦363M, replacement cost ₦546M, and fuel cost ₦661M. Similarly, the total greenhouse emission (GHE) in the base case is 675,803.2kg/yr. However, after optimization of the hybrid system, a total of 241409 kWh/yr of Electricity was produce. With 24.3% from PV, 9.97% from diesel generator, and 65.7% from wind turbine. The total Net Present Costs (NPC) is ₦288M with breakdown as follows capital cost ₦220M, O&M cost ₦18.2M, replacement cost ₦44.9M, salvage-₦17.3M, resource ₦22.7M. The total greenhouse emission (GHE) is 23220.75kg/yr. Therefore, the total harmful emission saved using DHRES = (675803.2kg/yr-23220.756kg/yr) = 652582.444kg/yr. The DHRES simulation and optimization indicates that DHRES are feasible with a low NPC, Operating and Maintenance cost, and Cost of Electricity (COE) compared to the existing power supply from a 320kW Caterpillar (CAT) diesel generator which operates for 12hrs from 1800hrs to 0700hrs when the generator is healthy.

Keywords: *Hybrid System, Power Quality, HOMER Software, Grids, Distributed Hybrid Renewable Energy Sources (DHRES).*

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I. INTRODUCTION

Over the years, conventional means of power generation using fossil fuel is besieged by the lack of political will to develop the power sector in Nigeria. There are technical and socio-economic challenges confronting the present-day power sector, these includes insufficient power generation capacity, low power distribution rate to customers, lack of capital for investment, limited access to infrastructure, inefficient usage, ineffective regulation, insufficient transmission and distribution facilities, high technical losses, and vandalism(Barros *et al.,* 2014).

The global concern of climate change and anticipated scarcity of fossil fuel have prompted most countries to develop sustainable and clean energy system to provide growth and development (Shaaban & Petinrin, 2014). It is imperative for Nigeria to look into the use of renewable energy for safe, reliable, efficient, affordable and clean means of providing electricity in order to improve power supply, especially in remote off-grid rural areas like Ajoki community for economic development and growth in the country.

This study focuses on the Optimization of Distributed Hybrid Renewable Energy Resources (DHRES) like solar, wind, hydro, biomass, biogas, and fuel cells etc. that are abundant in Nigeria. Preliminary studies indicate some major challenges that hinder the massive deployment of renewable in Nigeria and Africa at large. These include, cost, technology and the willingness of the government to adopt and implement hybrid renewable energy (HRE) systems in the country.

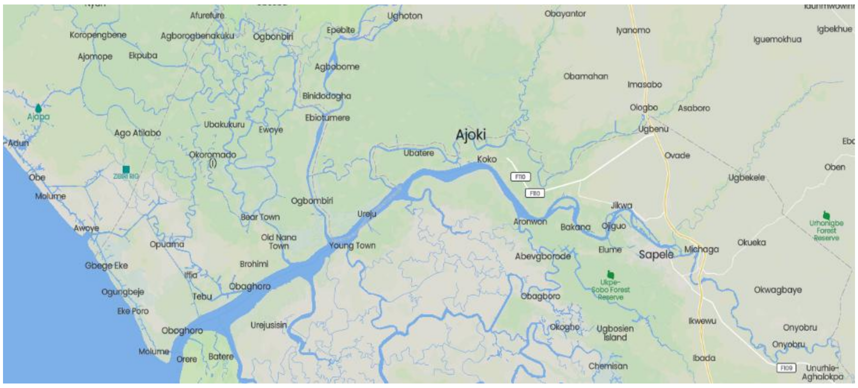


Figure1: Map of Ajoki Community

The case study location is Ajoki community in Edo State. Ajoki is a coastal oil producing community located on (46°48.3"N) and (65°2.3"W) about 5km (1 hour' boat drive) from Koko, Delta State. Presently, Ajoki is powered by Caterpillar 400kVA (320kW) D3306 diesel generator for 12hrs each day from 7 pm to 7 am. National Petroleum Development Company (NPDC)/Enageed Resources Limited (ERL) maintains and manages the diesel generator as part of its Cooperate-Social Responsibility (CSR). There is no direct gas line passing through Ajoki community. The closest gas pipeline is the ELP (Oben-to-Sapele Pipeline) located about 25 km from the community with a pressure of 90bars, thus the gas manifold may require some modification before it can be used for power generation, if there is the political will to embark on such project.

II. TYPES OF RENEWABLE ENERGY RESOURCES:

a. Solar Energy

The sun is 93 million miles (1.497 x 10^8 km) away from Earth provides a huge energy source that sustains our hydrologic cycle. It consists of thermonuclear reactions, which produces helium by fusion of hydrogen atoms; the process converts about 4 billion kilograms of mass/second into energy. The energy given off is described by Albert Einstein's renowned relationship $E = mc^2$, the solar energy left can still sustain the earth for another 4 or 5 billion years to come (Masters, 2013).

The sun's energy reaching the earth surface in one hour can nearly provide the energy demand for almost a year. Due the massive thermonuclear fusion reactions, the sun maintain a surface temperature of 5800K.

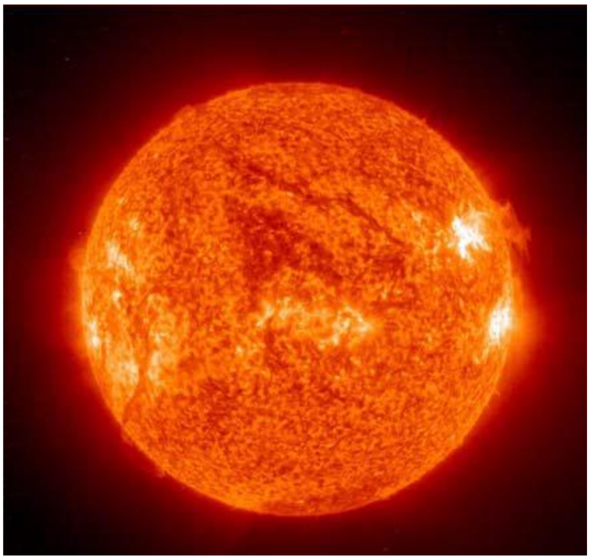


Plate 1: The Sun, the source of Solar Energy [source: IakovosTzanakis, 2006]

Solar radiation is basically the output of the sun, these radiations range from short-wavelength gamma rays (high-energy) to long wavelength radio wave (low energy) and between these extremes of the spectrum lies the x-rays, ultraviolet radiation, visible light and infrared radiation(heat). About 40% of the sun release energy is infrared and 55% visible light, which travel to the Earth in 8.3 minutes at a speed of 2.99 x 10^5km/second (186,000 miles/sec) through a distance of 1.59 x 10^8km (93 million miles); 99% of the harmful ultraviolet solar radiation is absorbed by the ozone (O_3) layer(Chiras, 2010).

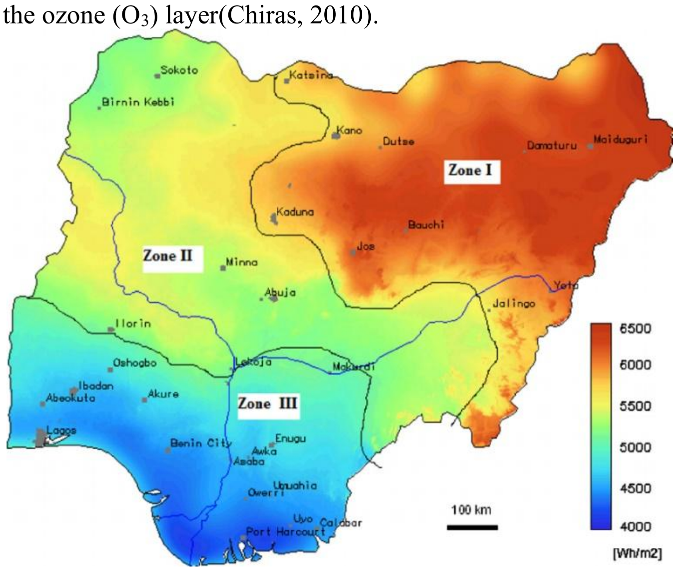


Figure 2 Solar Irradiance on the Map of Nigeria showing three zones of different irradiance

Irradiance is the amount of solar radiation striking one square meter of the Earth atmosphere or surface and it is measured in watt per square meter (W/m^2). Due to water vapor and dust particles in the earth atmosphere 30% of solar radiant is lost, such that before the earth's atmosphere the solar radiation is about 1366W/m^2 and on getting to the surface of the earth it reduces to about 1000W/m^2. Solar irradiance is zero at night, increases at sunrise, it peaks at noon and decreases at sunset. This change is because of the angle at which the sun strikes the earth surface due to energy density and the sunlight travelling a longer distance through the atmosphere before reaching the surface of earth (Chiras, 2010).

The available maximum solar irradiance on a clear day at most location on Earth is referred to as Peak sun, peak sun hour or solar isolation is a measure of solar irradiation in watts per m^2 per day (Chiras, 2010).

The most promising renewable energy resource in Nigeria is solar energy resource; the country has an average 1.804 x10^{15} kWh of incident solar energy yearly (Shaaban & Petinrin, 2014). Moreover, the annual average irradiance varies from about 7kWh/m^2/day along the far north semi-arid area to the coastal are of about 3.5kW/m^2/day. The average sunshine is about 6 hour per day, which gives 5.5kWh/m^2/day as average solar irradiation level (Sambo, 2009). In the Benin (Niger Delta) a city very close to the research location and Ajoki community the research location the annual average GHI is 4.53kWh/m^2/day and (NASA, 2017) which sufficient for solar- electric generators.

For centuries in Nigeria and other part of the world, this energy has been in use domestically for heating and cooking even before the renowned Frenchman -Antoine Lavoisier, who was the first to develop a solar furnace in the late 1700s. The Egyptian developed irrigation water pumps in 1913 using solar energy, while in the USA hot water solar heaters were in use since the 1930s. However, the first photovoltaic (PV) cells that convert solar energy directly to electricity were developed and manufactured in the late 1950s. These PV cells were mainly used to power satellites around earth's orbit and in the 1970s, PV power systems were used with utility grid-connected application around the world; solar became a viable energy source (Smith & Taylor, 2008).

There are three major methods of utilizing solar energy: Solar thermal system, the Central Solar Power (CSP) and the Photovoltaic. The solar thermal system is mostly used in buildings to capture solar energy either passively or actively. The passive technique involves capturing of maximum heat and daylight from the sun through specially placed windows in buildings, while the active solar heating involves the use of collectors that enable thermal energy transmission through the liquid medium for space heating, water heating, and cooling.

The CSP system concentrates the solar energy with the use of parabolic trough, sun-tracking mirrors or parabolic dishes to generate steam, which runs a turbo generator (Smith & Taylor, 2008).

b. Wind Energy

Wind energy is a form of solar energy, the differential heating of the earth's surface by the sun result in wind. The differential is brought about by the difference between heat absorbed by water surfaces and that absorbed by land. Available wind energy varies as the cube of the wind speed (Burton, *et al.,* 2001). Investigation shows that wind speed of 4-25m/s range produced power; and it is virtually inexhaustible, emission free and can be harnessed with wind turbines/ windmills that rotate as the wind blows. Electrical or Mechanical energy can be generated by wind turbine for different applications. Wind energy is the most economically viable source of renewable energy and has highest potential to compete with conventional fossil fuel.(Smith & Taylor, 2008).

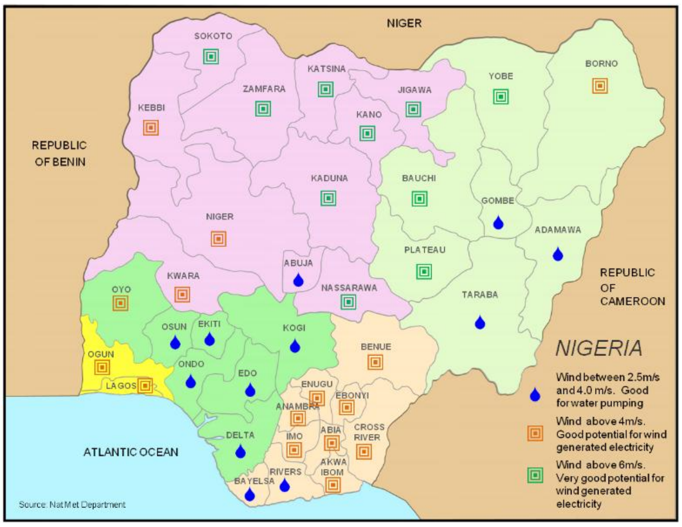


Figure 3: Wind Resource Distribution Across Nigeria

Wind energy at its rate of development and adoption currently is likely to supply 10-20% of the world electricity by 2050 (Smith & Taylor, 2008).The size of the wind turbine has rapidly increased over the years , with the largest presently producing power of about 4MW compared to the early design of the 1970s with power below 20kW. Variable speed system with power electronics are incorporated in wind turbines rated 1.0 MW and above to overcome mechanical stress. However, most wind turbines generators (WTG) are currently located off shore in massive parks and are linked to high voltage levels; some are tied to the transmission system (Akorede, *et al.,* 2009). They are classified by the axis in which the turbine blade rotates, the Horizontal Axis Wind Turbines (HAWTs) which are large machines and the Vertical Axis Wind Turbine (VAWTs) which are mostly small wind turbine generator.

In Nigeria, commercially viable electricity production is limited and varies with the seasons, since commercially viable electricity from wind resource require about 7m/s wind speed. With this limitation, it is difficult for large-scale production of electricity across Nigeria because the maximum wind speed recorded in a 10-year period at 10m height is between 3.78-3.98m/s in North (Northwest & Northeast) and average wind speed of 3m/s across other part of the country. However, the wind speed is not suitable for commercial electricity but sufficient for rural electrification, water pumping, etc. (Aliyu, *et al.,* 2013). Ajoki (research location) has an annual average wind speed of 3.47m/s (NIMET, 2017) that can drive wind turbines for rural electrification.

Wagner and Pick (2014) in their work computed the energy yield ratio and a cumulative energy demand for two wind turbines of capacity 1.5 and 0.5 MW respectively.

The study was carried out in three different locations namely; coastal, near the coast, and inland. Based on the findings, it was reviewed that the energy payback time would be 3-7months and with an energy yield ratio of 38-70. Crawford (2019) in his work proposed a methodology known as hybrid embodied energy analysis approach to examine the energy life span and GHG emissions for 850 kW and 3.0 MW wind turbines respectively. Furthermore, theimpact of turbine size on the yield ratio was examined. Based on the result on the findings it was noted that the method used inearlier research examining the energy life span was incomplete due to some limitations anderrors in the quantifying key parameters.

Plate 2: Wind Turbine Technology

c. Hydro Energy

Energy captured from running or falling water is called hydropower. Hydropower can be developed from large or small-scale dams. Large scale hydropower is captured through massive water dams, while small scale hydropower is captured through the use of smaller dams and rivers turbines; dams with less than 50MW of electricity are referred to as SHP (Small Hydro Power) (Smith & Taylor, 2008). The main advantage large hydropower plant is low operating cost and long operating lifetime, however, SHP are very useful in remote rural communities for electrification and irrigation.

Gagnon (2015) in his presentation noted that hydro power technology reduces greenhouse emission is 30-60 times compared to conventional fossil fuel power plant thereby making it a good substitute.

In Nigeria, there are abundant streams, rivers and waterfalls with high potential for small hydro power (SHP). Small hydropower are the most affordable means of generating electricity for off-grid remote locations(Sambo, 2009), the can be used in distrusted hybrid renewable system. Sambo (2009) investigate 12 state and 4 basins of over 278 prospective SHP sites, it was discovered that SHP has a potential of generation 734.3MW across the research site; however, Nigeria has a total SHP potential of 3500MW.

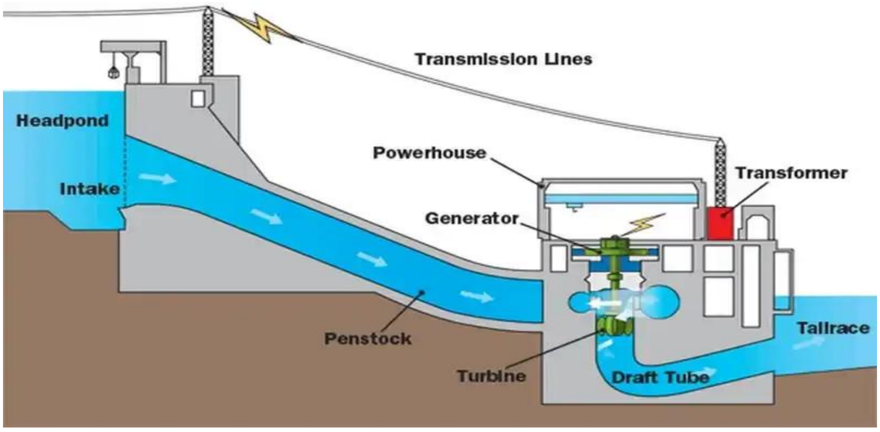


Plate 3: Hydro Power Technology

d. Biomass

Biomass is an important energy source and considered one the most promising renewable energy sources in the future (Akorede, *et al.,* 2009). Biomass is actually living plants and organic waste from human and plant sources. Through photosynthesis solar power is stored in which products with high-energy potential are created, for instance, carbohydrate can be combusted and used as energy source.

Biomass power plants are usually small and are normally located close to fuel source that prevents it from taking advantage of the economies of scale as compared to large steam plant (Masters, 2013).

In Nigeria, biomass resources like wood, shrubs, waste from forestry, forage grasses are abundant as well as aquatic biomass. Presently the country has an estimated biomass of $8x10^2$ MJ. However, about 80 million of fuel wood is used for cooking, heating and other domestic purposes. This biomass can be converted to liquid and used for various renewable purposes, thus remarkably reduce GHG emission (Shaaban & Petinrin, 2014).

According to (Smith & Taylor, 2008) the four different forms of biomass are:

i. **Biogas**: which is gotten from decomposition of organic waste, an example is methane.
ii. **Solid Biofuel:** these are derived from the forest, agricultural crops, hay and organic waste.
iii. **Liquid Biofuel:** These are biodiesel and ethanol and are becoming very popular in renewable energy technology (RET).
iv. **Energy Crops:** Crops cultivated to use as solid or liquid biofuels are referred to as Energy crops, e.g. corn and sugar that are commonly grown for ethanol making.

e. Ocean Energy

Ocean energy is derived from temperature differences in water, the wind that create waves and gravitational pull of the sun and the moon, that creates tides (Smith & Taylor, 2008). The technology of converting wave energy to electricity is a fabulous milestone in the renewable energy mix achievements. According to (Charlier & Fink, 2009) ocean energy comprises of tidal power, marine wind, wave power, ocean thermal energy conversion (OTEC), Marine current, Salinity Gradient and Hydrogen power. All these are source could generate electricity to meet various load demand. The main advantages of ocean energy are the ability for the ocean to provide predictable (tide) and endless energy.

Ocean energy especially wave energy converting (WEC) technology are mostly located offshore reducing the visual and land impact. As the methods for generating energy for the future becomes efficient and sustainable ocean energy will play a major part of energy generation. Ocean energy is technically feasible, economically viable and useable when modern design innovations take the center stage. Presently, Wave energy converting (WEC) technologies are quite expensive compared to solar and wind. Since they are offshore located, their development process is long, time consuming and capital intensive due to harsh offshore conditions. Thus, there is the need to benchmark project cost and economic benefit before commencing any ocean energy project.

WECs Machines converts ocean wave energy into useable electricity to meet a load demand, this energy is always available but in actual practice, it is very difficult to predict and reproduce offshore environments because of large amount complex parameter that can influence offshore ocean environment. Figure 2.10 below shows the primary sub-system of marine energy conversion (Pecher & Kofoed, 2016).

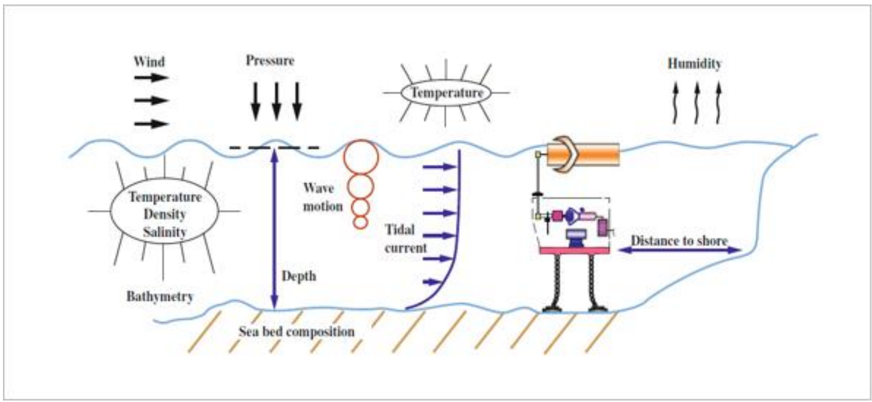


Figure 4 Primary Subsystem of Marine Energy Conversion

f. Geothermal

Geothermal energy is heat energy captured from the earth's mineral radioactive decay, which does not vary with time like other renewable energy resource. The earth's core is very hot in with temperature in excess of 6000ºC, this heat travels towards the surface of the earth through mantle at about 1000ºC .The heat then flows from the mantle to the earth crust which is 30km thick, energy flux of 0.06w/m2 is delivered at the surface which is far lower than solar, wind, wave etc.(Masters, 2013). Dry steam power plants, binary cycle power plant and flash stream power plants are means by which geothermal can generate electricity. Presently, 70 countries are using geothermal heating and 24 countries for geothermal electricity generation. The current total installed capacity worldwide is 10,715MW and the largest installed geothermal plant is the USA with capacity of 3,086MW followed by Philippines and Indonesia. (Pierce, 2011).

Nigeria has unexplored geothermal potential for geothermal electricity generation. However, the country has geothermal sites; the Wikki Warm springs at Bauchi State and the Ikogosi warm spring at Ondo State (Brimmo, *et al.,* 2017).

Concerning geothermal energy assessment in Nigeria, very few studies were found.
Murphy and Niitsuma (2016) noted the use of fiscal policy, carbon tax and monetization as a compensation mechanism in reducing the high cost of geothermal electricity. It was further noted that counties like Japan, Indonesia and thePhilippines have supportive government policies.
In the same vein, Stefansson (2012) proposed a statistical model for estimating the cost of investment necessary for building a geothermalpower plant. From the result obtained, a total of 1,247 USD/kW was obtained for a geothermal power plants, between 20-60 MW.

Hybrid Renewable Energy System (HRES)

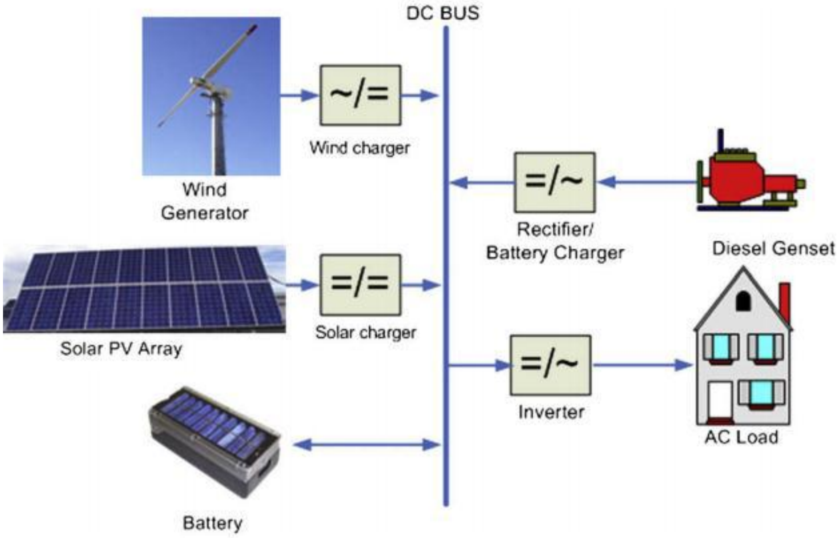


Figure 5: Hybrid Renewable Energy System

RE resources like solar, wind, hydro, tidal, biomass etc. are not always constant because they depend on various natural variables. For instance, Solar PV system requires steady supply of sunlight, while the wind turbines are dependent on the speed of the wind, which in turn depends on the differential heating of the sun. The variation in energy supply is a major disadvantage in designing a single RE system. Thus, it becomes relevant to combine two or more renewable energy resources and conventional energy resources to improve efficiency and availability of power supply. This combination is referred to Hybrid Renewable Energy System (HRES), the major advantage is to enable the various energy source to complement each other during shortfall period hence allowing for constant power supply.

Various HRES investigations have been carryout to demonstrating the benefits of HRES, (Sen & Bhattacharyya, 2014)used HOMER a software developed by NREL to analyse the technical and economic viabily of using HRES - solar , Small Hydo plant (SHP), wind, biodiesel generator (BDG) and batteries in remote locations. Polari ,a remote village in Bastar district , Chhattisgarh state in India load was assessed and separated into three: Load-1 (Medical, Domestic and school): 222kWh/d with peak 51.2kW; load-2 (community center, shops, local businesses) and load-3 (Agricultural): 59kWh/d with 69kW. The HOMER analysis indicated that off-grid remote locations HRES option is econmically viable provided the CoE is high that the conventional grid system.

Omorogiuwa & Ekiyor (2017) investigated the technical and economic feasibly of using HRES – Solar PV -Diesel and battery, to power Ofubu-New Patani, a small remote village in Bayelsa State, Nigeria. The community load was assessed to be 80.76kWh/d with peak load of 12.01kW; the data collected was fed into HOMER software for analysis and optimization. It was concluded that, for a remote location with bad terrain that is far away from the conventional grid, Hybrid Renewable System (HRES) is economically viable.

PV –Wind – storage (battery) HRES for Santa Catalina island 2 miles off coast of long beach, Los Angeles, California in bid a to reducing the high fuel transportation cost with a ship for running a diesel generator that provides power through three 12kV distribution circuit separate from mainland grid. HRES was model to replace the diesel with SPV –wind –Battery, using risk limiting approach and cost. HOMER software was used to simulate the design with a load of 39MWh/d with peak load of 5.3MW and an optimal CoE of 0.172$/kWh (Huang, Low, & Ufuk Topcu, 2011).

Gupta *et al* (2006) developed a hybrid energy system for remote location, Jaunpu block of district TehriGarhwal of Uttaranchal state, India; procedures involve the clustering of the rural, load demand assignment, required supply assessment, unit cost estimation, appropriate sizing, optimization and modeling. It was proposed that hybrid energy systems optimized for rural area, which should comprise of renewable energy resources and conventional energy resources. The main limitation is in the use of conventional energy resources and analysis based only on cost.

Distributed Energy Resources (DER)

According to the Electric Power Research Institute (EPRI) distributed energy resources (DER) are smaller power sources that can combine to provide power required to meet regular load demand. DER or Distributed Generation (DG) comprises of units of small-scale generators that are within the range of 3kW-10MW from many energy sources used to provide power close to consumers. With the traditional electric power system efficiency is low, there is high power loss through transmission and distribution network, and not environmentally friendly.

In Distributed energy system, variety of energy sources e.g. wind, solar thermal, solar PV, hydro wave power, fuel cells, tidal, geothermal and cogeneration (CHP) are connected in a distributed network close to the users. Some benefits derived from DER are voltage improvement, reduction in power loss through transmission and distribution network, reduction in CO^2 emission, increased reliability and availability, etc.

Figure 6: A Distributed Renewable System

The Fig 6 above illustrate the traditional centralized system of power network (a) and the future DER, clean power network where renewable hybrid generation is distributed and storage system kept in different location to meet load demand.

III. MATERIALS AND METHODS

Materials

The following materials were used for this work

i. Hybrid Optimization of Multiple Electric Renewable software (HOMER 3.11.2) developed by the National Renewable Energy Laboratory (NREL).
ii. Load data of Ajoki Community
iii. Generator data of Ajoki Community
iv. Solar GHI resource is collected from national renewable energy database.
v. Wind speed resource

Methods

The following methods were adopted for this work:

i. Load Assessment
ii. Component Selection
iii. Resources Assessment

iv. System Modeling
v. Economic Analysis

Load Assessment

For a community like Ajoki in Edo State Nigeria, the major electricity demand is from the guest house, health center and agricultural processing and storage facilities that make use of domestic appliances like radio sets, television sets, lights, fans, phones and refrigerators. In this study, the load assessment was done by data collection from an existing 400kVA (320kW) CAT D3306 diesel generator. The generator is operated for 12hrs each day from 7pm-7am by NPDC contractor, hence data can only be recorded for 12 hours daily. The 12 hourly kWh data was collected from the generator's Electronic Management Console (EMC) Panel and converted to kWh/day by multiplied the daily reading by 2 to compensate for the remain 12 hours; this data was collected for three months (92 days) and averaged to 1380 kW as shown Table 1.

Table 1: Annual Average Load of Ajoki Community

No of Days	Wh/12hrs
1	742
2	634
3	725
4	719
5	646
6	670
7	778
8	846
9	645
10	598
11	698
12	631
13	695
14	694
15	513
16	694
17	752
18	757
19	704
20	608
21	688
22	756
23	687
24	725
25	696
26	749
27	751
28	650
29	711
30	663
31	671
32	712
33	582
34	654
35	679
36	747
37	606
38	689
39	661
40	623
41	799
42	675
43	738

44	698
45	730
46	807
47	721
48	726
49	668
50	594
51	663
52	810
53	660
54	727
55	742
56	758
57	768
58	677
59	664
60	687
61	630
62	684
63	741
64	714
65	690
66	739
67	697
68	720
69	712
70	725
71	727
72	686
73	742
74	713
75	750
76	674
77	640
78	646
79	790
80	628
81	728
82	661
83	632
84	740
85	594
86	580
87	598
88	616
89	733
90	608
91	515
92	661
Total Peak Load@12hr	**63475 Wh**
Total Peak Load @24hr	**126950 Wh**
Average Daily Load/day	**1380 Wh**

From information gather during the study, Ajoki Community is mostly populated during the festive periods, from December – January. This period is considered to require optimum load demand due to the heightened commercial and social activities, thus the peak month was identified as December -January. The peak load was also recorded to be 179kW during the 92-day data collection; these data were fed into HOMER to give a load profile as show in Figure 6 and 7 below:

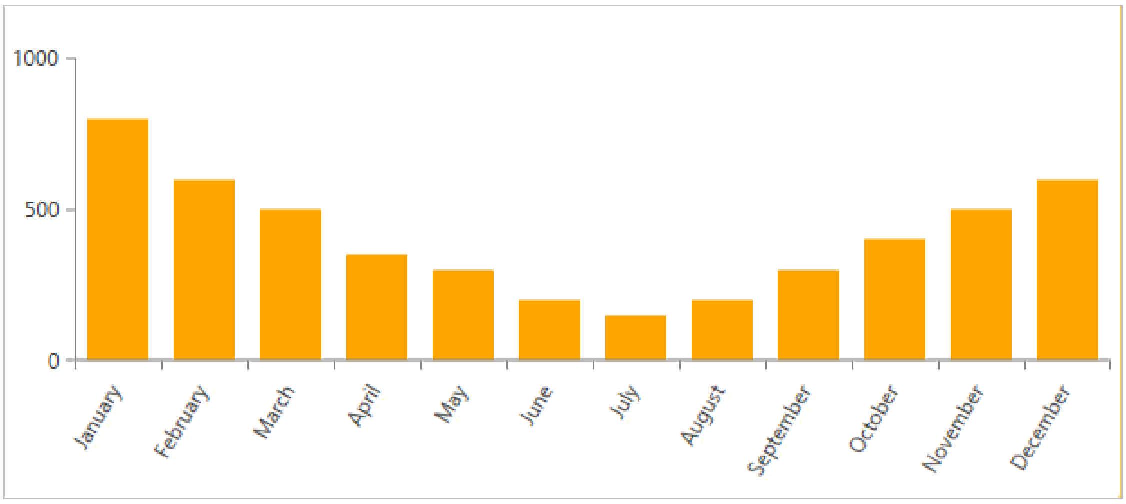


Figure 7: Seasonal Load Profile of Ajoki Community

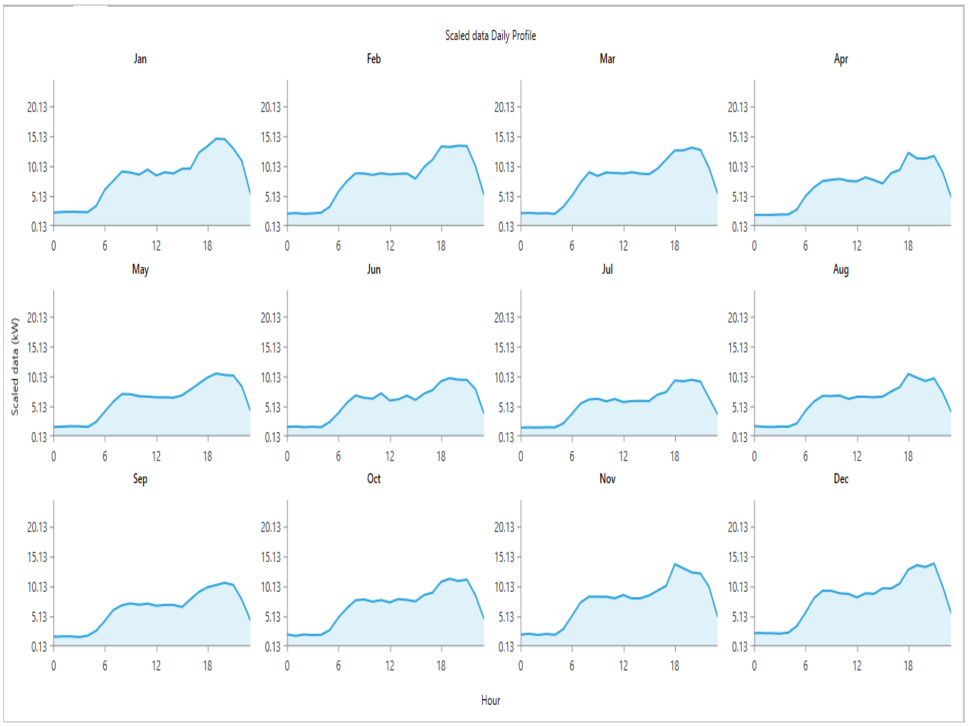


Figure 8: Daily Load Profile of Ajoki Community

IV. Component Selection

In a Distributed Hybrid Renewable Energy System (DHRES) energy is generated, delivered, converted and store from various components to meet the energy demand. In this study, solar PV and wind turbine are the intermittent source while the diesel generator is for backup. The battery stores excess energy to be used during shortfalls and the converter, convert the electricity as required. The cost and performances of the system components are a major factor for the design.

Generator System

The diesel generator used is the already existing generator set provided by NPDC for Ajoki community. It is a 400kVA (320kW) D3306 Caterpillar generator, with capital cost of N25M, replacement cost of ₦23.5M and Operation &Maintenance (O&M) cost of N1000/hr. This generator runs with diesel and provides power for 12hrs in the community.

The Generator Fuel Consumption is Calculated by Homer using the Equation

$$FC_G = A_G \times P_G + B_G \times P_R \quad (1)$$

where
FC_G = fuel consumption
P_G = output power of the generator in kW
PR = the rated power ofthe generator in kW
BG and AG are coefficients of the consumption curve in (1/kWh) for the diesel generation
AG = 0.246 1/kWh
BG = 0.08145

Table 2: Generator Specification

Rating	Units	Rating
Model		D3306
Prime Output	kW/kVA	320/400
Power factor		0.85
Rating Speed	rpm	1500
Rating Frequency	Hz	50
Rating Voltage	V	400
Engine Model		QTA4320-G5
Displacement	I	70.8
Configuration		16V
Genset Size	mm	6000x2220x2900
Genset Weight	Kg	13600

Source: Research desk under study

PV System

The Solar PV (SPV) is connected in series to a DC output which matches the 96V DC-bus design, the estimated Capital cost of 1kW of SPV is ₦ 270,000 with replacement cost of ₦ 260,000 while the operational and maintenance (O&M) is taken as ₦1000/year due to the minimal maintenance required by SPV systems. The SPV panels have a lifetime of 25 years and de-rating factor of 90% that approximates the varying effect of dust and temperature. There are no tracking systems installed, rather the panels are modeled as fixed, sloped at 45° and tilted North at angle of ***5°36'N*** latitude of the location. The cost per kW in all components in the design includes the cost of installation, dealers' mark-up and logistics.

The power output of the PV array is calculated by Homer using the equation

$$P_{pv} = Y_{pv} * f_{pv}\left(\frac{\bar{G}_T}{\bar{G}_{T,STC}}\right)\left[1 + \alpha_p(T_c - T_{c,STC})\right] \quad (2)$$

where
P_{pv}: Output of the PV Array
Y_{pv}: Rated capacity of the PV array [kW]
f_{pv}: PV derating factor [%]
$\bar{G}_T$: Solar radiation incident on the PV array in the current time step [kW/m^2]
$\bar{G}_{T,STC}$: Incident radiation at standard test conditions [1 kW/m^2]
α_p: Temperature coefficient of power [%/°C]
T_c: PV cell temperature in the current time step [°C]
$T_{c,STC}$: PV cell temperature under standard test conditions [25°C]

The PV Operating Temperature is calculated by Homer using the equation

$$T_c = \frac{T_a + (T_{c,NOCT} - T_{a,NOC}) * \left(\frac{G_T}{G_{T,NOCT}}\right) * \left[1 - \frac{h_{mp,STC}(1 - \alpha_{pTC,STC})}{\tau\alpha}\right]}{1 + (T_{c,NOCT} - T_{a,NOC}) * \left(\frac{G_T}{G_{T,NOCT}}\right) * \left(\frac{\alpha_p h_{mp,STC}}{\tau\alpha}\right)} \quad (3)$$

where
$\eta_{mp,\,STC}$: The maximum power point efficiency under standard test conditions [%]
α_P : The temperature coefficient of power [%/°C]
$T_{c,\,STC}$: The cell temperature under standard test conditions [25°C]
$T_{C,\,NOCT}$: The nominal operating cell temperature [°C]
$T_{a,\,NOCT}$: the ambient temperature at which the NOCT is defined [20°C]

$T_{G,NOCT}$: the solar radiation at which the NOCT is defined [0.8 kW/m^2]
G_T: the solar radiation striking the PV array [kW/m^2]

The Radiation Incident on the PV Array is calculated by Homer using the Equation

$$\bar{G}_T = (\bar{G}_b + \bar{G}_d A_i) * R_b + \bar{G}_b(1 - A_i) * \left(\frac{1+\cos\beta}{2}\right) * \left[1 + f\sin^3\left(\frac{\beta}{2}\right)\right] + \bar{G}\rho_g\left(\frac{1-\cos\beta}{2}\right) \quad (4)$$

where
β: the slope of the surface [°]
ρ_g: the ground reflectance, which is also called the albedo [%]
$\bar{G}_b$: the beam radiation [kW/m2]
$\bar{G}_d$: the diffuse radiation [kW/m2]
A_i : anisotropy index
R_b: ratio of beam radiation on tilted surface to the beam radiation on the horizontal surface
θ : angle of incidence [°]
θ_z : zenith angle [°]

Table 3Suniva ART245-60 ModulesSolar Module Specification

PV Description	Symbol	Values
Maximum Power	Pmax (W)	240
Voltage @ Maximum Power	Vmp (V)	30.65
Current @ Maximum Power	Imp (A)	7.82
Open Circuit Voltage	Voc (V)	37.08
Short Circuit Current	Isc (A)	8.33
Voltage-derating factor	β,Voc (%/°C)	-0.332
Current-derating factor	α,Isc (%/°C)	+0.035
Power-derating factor	γ,Voc (%/°C)	-0.465
Cell per Module		60
Module Dimension		1657x987mm
Module Thickness (Depth)		42mm
Approximate Weight		19kg
Max. System Voltage	Vdc	1000
Operating Module Temperature	°C	-40 to +90
Module Efficiency		14.9%
Fill Factor		77.6%
Irradiance		1000w/m^2
Normal Operating Cell Temperature	NOCT	45°C
Base Temperature		25°C
Type of Solar Cell	Monocrystalline cells of 156 x 156 mm	

Source: Suniva incorporation USA online

Wind Turbine System

The availability of wind turbine electricity depends greatly on the wind speed. The Northern Power - NPS100C-21 that is rate 100kW is used in this study, with hub height of 30m and lifetime of 20 years. The capital cost for 100kW wind turbines is ₦8M respectively while the replacement cost is ₦7.2M, the O&M cost is ₦50,000. These values are fed into HOMER software for simulation and optimization. In each time step, HOMER calculates the wind speed at the hub height of the wind turbine using the inputs you specify in the Wind Resource window and the Wind Shear window. If the logarithmic law is applied,

The Hub Height Wind Speed is Calculated by Homer using Equation

$$U_{hub} = U_{anem} * \frac{\ln\left(\frac{z_{hub}}{z_0}\right)}{\ln\left(\frac{z_{anem}}{z_0}\right)} \quad (5)$$

where
U_{hub}: wind speed in m/s at the hub height of wind turbine
U_{anem}: wind speed in m/s at anemometer height
Z_{hub}: hub height in meters of the wind turbine
Z_{anem}: anemometer height in meters

Z_0: surface roughness length in meters
ln(..): natural logarithm

Converter System

The converter used in this study is the **ABB** converter, which converts the DC from the Solar PV, wind Turbine and batteries to AC; it also rectifies power from the available Diesel generator for charging the battery bank during shortfall periods. However, the capital cost of 100kW converter is ₦10M and replacement cost of ₦8M; these cost values are fed into HOMER software for simulation. The O&M cost for the converter is not considered because of its minimal required O&M, which is done during battery bank maintenance.

Table 4 Converter Specification

Input DC		
DC Voltage Range	$Vmpp_{(DC)}$	600-850V
Maximum DC Voltage	$Vmax_{(DC)}$	1100V
Maximum DC Current	$Imax_{(DC)}$	1710A
Number of Protected DC Inputs		8-20(+/-)
Nominal Power	$P_{N(AC)}$	1000KW
Maximum Output Power		1200KW
Power @ CosΦ		950KW
Nominal AC Current	$I_{N(AC)}$	1445V
Nominal Output Voltage	$V_{N(AC)}$	400V
Out Frequency		50/60Hz

Source: Asea Brown Boveri (ABB)

Battery System

The battery bank is required for storage of energy during period when there is excess energy and provides a backup when there are shortfalls in the system. The battery considered is the CELLCUBE ® FB 20-130, with nominal voltage of 48V and nominal capacity of 130kWh (2,708.330Ah), double string. The capital cost of a single battery is ₦350,000, replacement cost of ₦300,000 and O&M of ₦1000/yr. and lifetime 10 years.

Battery Bank Capacity Ampere-hour

$$BB_{Wh} = \frac{(Wh_{AD})*(DOA)*(BM_{Temp})}{V_L*V_{Sys}} \tag{6}$$

where
Wh_{AD}: average daily [Wh]
DOA: days of autonomy
Vsys: system voltage
BM_{Temp}: battery temperature multiplier [1.19]
DL: Discharge limit [0.50]

Storage Bank Autonomy

$$A_{batt} = \frac{N_{batt}*V_{nom}*Q_{nom}\left(1-\frac{q_{min}}{100}\right)*\left(^{24hr}/_{d}\right)}{L_{prim,ave}\left(^{1000Wh}/_{kWh}\right)} \tag{7}$$

where
N_{batt}: number of battery in the storage bank
V_{nom}: nominal voltage of a single storage [V]
Q_{nom} : nominal capacity of a single storage [Ah]
Q_{min}: minimum state of charge of the storage bank [%]
$L_{prime,ave}$: average primary load [kWh/d]

Resources Assessment

Solar GHI Resources

In this case study, solar PV, wind and diesel generator are used as resource for simulation; Solar resource was taken from Nigerian Meteorological Agency (NIMET) for Ajoki Community on Latitude 46°48.3'N and

Longitude 65°2.3′W, the annual average irradiance was found to be 4.33kWh/m^2/day and the average clearness index of 0.438 as shown in Figure 3.3 below:

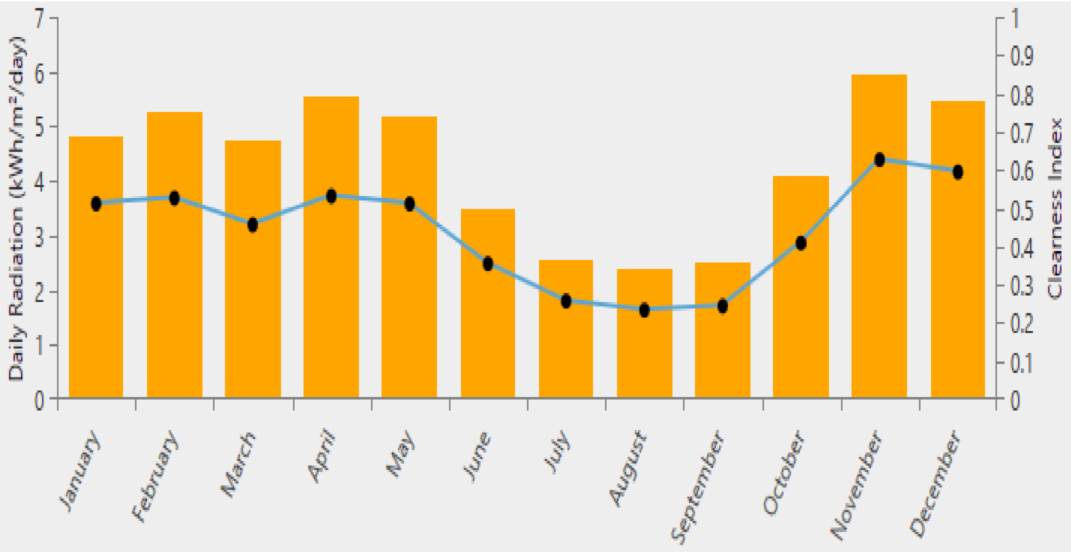


Figure 9: Monthly Average Solar GHI for Ajoki Community

Wind Resources

Ajoki Community wind resources data was taken from NIMET from an average of six years, based on the latitude and longitude of the research location with anemometer of height 2.39m, the annual average wind speed for the location is 3.47m/s. The average monthly speed and wind speed probability of the year is observed and the Hour of peak wind speed occurred at 15h, the wind speed variation throughout the day is 0.25 (diurnal pattern strength) while the randomness in the wind is 0.85 (autocorrelation factor). Figure 3.4 below gives an overview of the wind resource of the selected village.

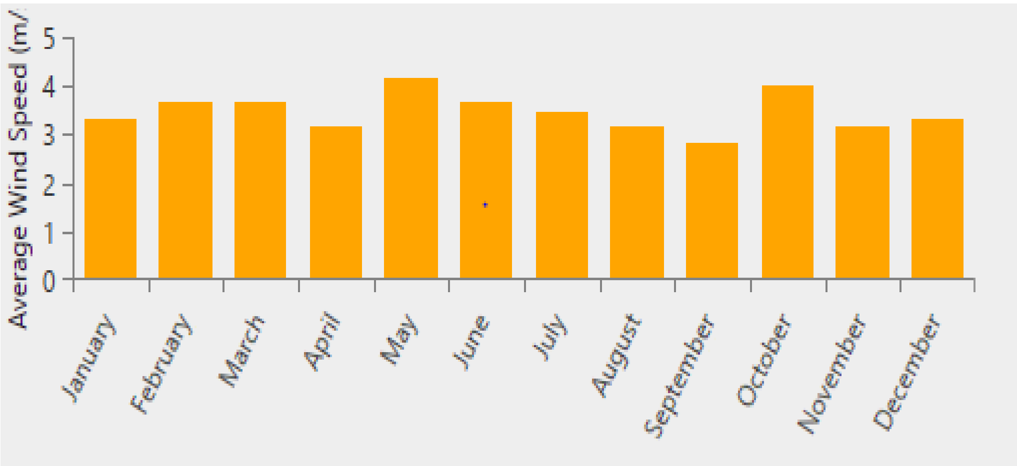


Figure 10: Monthly Average Wind Speed for Ajoki Community

System Modeling

The three main principles HOMER software uses to determine the optimal sizing and operational strategy are simulation, optimization and sensitivity analysis. HOMER simulates the designed system based on the chosen components; it performs the energy balance calculations with respect to the system configuration whilst considering the various numbers of components chosen for the analysis.

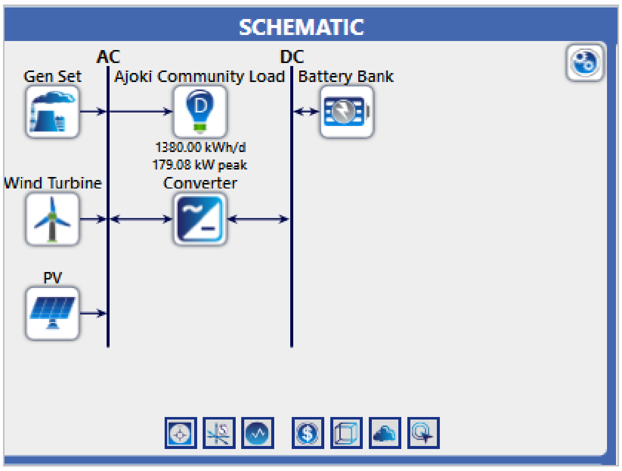


Figure 11: HOMER Design of Selected Distributed Hybrid Renewable System (DHRES)

In this case study, wind turbine, solar PV, diesel generator, battery and converter are used as components for the analysis. HOMER simulates the best feasible configuration of the designed system which can efficiently serve the load demand. The optimization process is done after simulating the complete possible solution of the DHRES configuration. HOMER displays the various combinations possible based on the Total Net Present Cost (TNPC) in ascending order leaving the lowest at top of the list, and the options of sensitivity at the upper part of the screen, for each sensitivity value there is corresponding optimization values. Also, HOMER sensitivity analysis is done by repeating the optimization process for every inputted sensitivity value like various values for wind speed, solar irradiance and the price of fuel (diesel).

Economic Analysis

The economics is a crucial aspect of the DHRES design when using HOMER software for simulations. The focus is to minimize the Net Present Cost (NPC), which is the difference between the present values of all costs, incur and the present value of all the lifetime revenue earn. NPC enable a designer determine the optimal configuration and operating the system in term of the economics. An annual discount rate of 8% and lifetime of 25years are considered in the project. A fixed capital cost of ₦800,000/yr and O&M cost ₦200,000/y are used in the HOMER simulation. Logistic, civil constructions, required license, administration and government approvals, labour wages and miscellaneous costs make the system fixed capital cost. After the HOMER simulations, the Net Present Cost (NPC), RF and Cost of Electricity (COE) are used to choose the most techno-economic viable Distributed Hybrid Renewable Energy System (DHRES). The COE of the DHRES compared with the COE of DISCOs should present any economic benefit for the designed DHRES.

Net Present Cost

$$NPC = \left(CC + \sum_{i-1}^{N} \frac{(RC+O\&MC+FC-SV)}{(1+i)^N}\right) \quad (8)$$

where

CC: Capital cost
RC: Replacement Cost
O&MC: Operating and maintenance cost
FC: Fuel Cost
SV: Salvage Cost
i: Interest rate
N: Number of years (Project life time).

Cost of Electricity

$$COE = \frac{C_{ann,tot} - C_{boiler} * H_{served}}{E_{served}} \quad (9)$$

where

$C_{ann,tot}$: total annualized cost of the system
C_{boiler}: boiler marginal cost
H_{served}: total thermal load served
E_{served}: total electrical load served

V. Results and Discussion

Result of Reliable Distributed Hybrid Renewable Energy Resources Designed for Ajoki Community

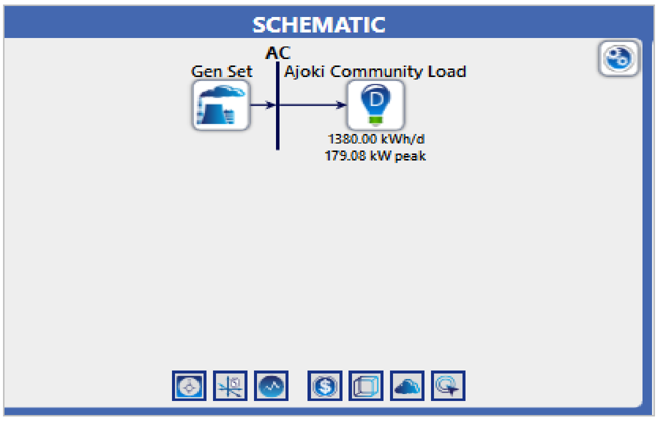


Figure 12: Base Case Design of Ajoki Community

Figure 12shows the base case or existing system architecturefor Ajoki Community which comprise of 1*320kW diesel generator. The present Caterpillar (CAT) diesel generator is dispatched for only 12hrs from 1900hrs to 0700hrs when the generator is healthy.

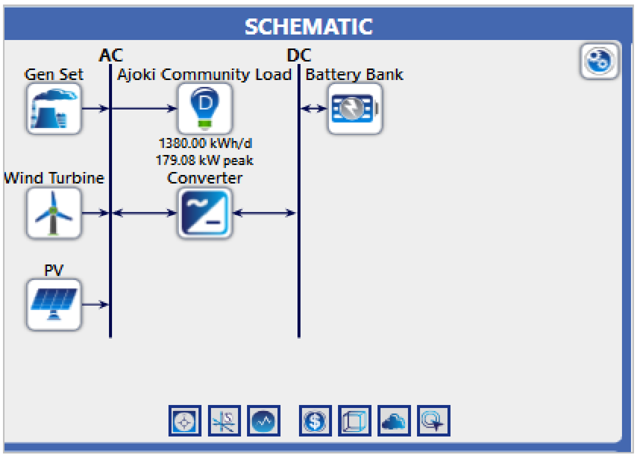
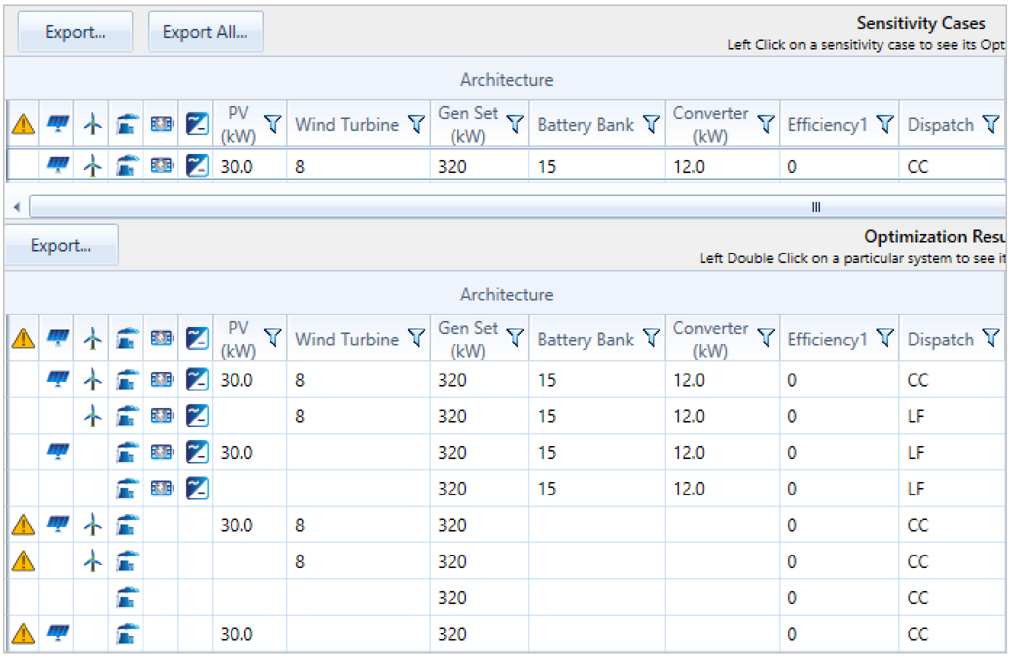


Figure 13: Improved DHRES Design for Ajoki Community

Figure 13shows the improved system architecturefor Ajoki Community which comprises of a 6*5kW array of solar PV, 8*100kW wind turbines the already existing 1*320kW diesel generator, 1*12kW converter (inverter and rectifier) and 15 strings (2708Ah) batteries. The diesel and battery bank are added to the system for backup purposes. The design is an off-grid system, due to the absence of conventional grid system nearby.

The Figure Below Showed the Result of Distributed Hybrid Renewable Energy Resources Sensitivity and Optimization


Export...
Export All...
Sensitivity Cases
Left Click on a sensitivity case to see its Opt
Architecture

PV (kW)	Wind Turbine	Gen Set (kW)	Battery Bank	Converter (kW)	Efficiency1	Dispatch
30.0	8	320	15	12.0	0	CC

Export...
Optimization Resu
Left Double Click on a particular system to see it
Architecture

PV (kW)	Wind Turbine	Gen Set (kW)	Battery Bank	Converter (kW)	Efficiency1	Dispatch
30.0	8	320	15	12.0	0	CC
	8	320	15	12.0	0	LF
30.0		320	15	12.0	0	LF
		320	15	12.0	0	LF
30.0	8	320			0	CC
	8	320			0	CC
		320			0	CC
30.0		320			0	CC

Figure 14: Sensitivity and Optimization Result

Figure 14 shows the sensitivity and optimizationresultsimulated inHOMER to obtain the best feasible configuration of the designed system which can efficiently serve the load demand. The optimization process is done after simulating the complete possible solution of the DHRES configuration.The elimination of infeasible combinations is the essences of the sensitivity analysis; it also enables the ranking of the feasible combinations considering the input parameters uncertainty or risk. HOMER displays the various combinations possible based on the Total Net Present Cost (TNPC) in ascending order leaving the lowest at top of the list, and the options of sensitivity at the upper part of the screen, for each sensitivity value there is corresponding optimization values. One of the key features of HOMER is its ability to take into account future change or fluctuations like changes in load demand, fluctuation of renewable resources (e.g. variation of wind speed and solar irradiance etc.), and changes in price of diesel. A cursory look at the figure 14 PV, wind, Generator and Battery configuration was selected as the best-suited hybrid system combination that can serve the Ajoki Community load demand.

VI. Result of Reduced Net Present Cost (NPC)

Table 5 Net Present Cost for Base Case System

Name	**Capital**	**O&M**	**Replacement**	**Salvage**	**Resource**	**Total**
Diesel Generator	₦80.0M	₦362M	₦546M	-₦7.21M	₦661M	₦1.64B
System	₦80.0M	₦362M	₦546M	-₦7.21M	₦661M	₦1.64B

Table 4.1 shows the net present cost in the base case system when the Ajoki community run on diesel generator only for 24hrs/day for a year. The total Net Present Costs (NPC) is ₦1.64B and the breakdown of the NPC are capital cost ₦80.0M, O&M cost ₦363M, replacement cost ₦546M, salvage-₦7.21M, resource ₦661M.

Table 6 Net Present Cost for Improve System

Components	Capital	Replacement	O&M	Fuel	Salvage	Total	%
PV	₦ 8.10M	₦ 0.00	₦ 387,825	₦ 0.00	₦ 0.00	₦ 8.49M	2.94
Wind Turbine	₦ 6.40M	₦ 183,633	₦ 5.17M	₦ 0.00	₦ 103,489	₦ 11.7M	4.04
Generator	₦ 80.0M	₦ 0.00	₦ 12.5M	₦ 22.7M	₦ 8.98M	₦ 106M	36.8
Battery Bank	₦ 5.25M	₦ 3.98M	₦ 193,913	₦ 0.00	₦ 539,005	₦ 8.88M	3.08
Converter	₦ 120M	₦ 40.7M	₦ 0.00	₦ 0.00	₦ 7.67M	₦ 153M	53.1
System	₦ 220M	₦ 44.9M	₦ 18.2M	₦ 22.7M	₦ 17.3M	₦ 288M	100

From Table 6 the total Net Present Costs (NPC) is ₦288M and the breakdown of the NPC for the various components includes Solar PV with capital cost ₦8.1M, O&M cost ₦387,825.00 and total NPC of ₦8.49M which is 2.94% of the total NPC. The wind turbine capital cost is ₦6.4M, replacement cost ₦183,633.03, O&M is ₦5.17M, salvages cost -₦103,488.99 with a total NPC of ₦11.7M that is 4.04% of the overall system NPC. The Ajoki community diesel generator has capital of ₦80.0M, O&M of ₦12.5M, fueling cost of ₦22.7M, Salvage cost of – ₦8.98M and total NPC of ₦106M which is 36.8% of the overall system NPC. While the Battery bank capital cost of ₦5.25M, replacement cost of ₦3.98M, O&M cost ₦193,912.75, Salvage cost -₦539,005.16 and NPC of ₦8.88M which is 3.08% of the total NPC. Finally, the converter has capital, replacement, Salvage and NPC costs are ₦120M, ₦40.7, -₦7.67M and ₦153M the NPC for converter is 53.1% of the system overall cost. The total net present cost (NPC) and cost of electricity (COE) are ₦288M and ₦369.63 respectively.

The Tables Below Showed the Result of Greenhouse Gas Emission Associated with Diesel Generator

Table 7: Emission for Base Case System

Pollutant	Quantity	Unit
Carbon Dioxide	669,045	kg/yr
Carbon Monoxide	4,552	kg/yr
Unburned Hydrocarbons	184	kg/yr
Particulate Matter	18.2	kg/yr
Sulfur Dioxide	1,640	kg/yr
Nitrogen Oxides	364	kg/yr

Table 7 shows the greenhouse emission in the base case system when the Ajoki community run on diesel generator only for 24hrs/day for a year, produces 100% (959220 kWh/yr) of Electricity consumed 371757 L/yr at an average of 1019 L/day and 42.4 L/hr. The 100 % emission per year comprises of 669,045kg/yr of carbon dioxide, 4552kg/yr carbon monoxide, 184kg/yr unburnt hydrocarbons, 18.2kg/yr particulate matter, 1640kg/yr sulfur dioxide and 364kg/yr Nitrogen oxide marking a total pollutant of 675,803.2kg/yr

Table 8: Emission for Improve System

Pollutant	Quantity	Unit
Carbon Dioxide	22,989	kg/yr
Carbon Monoxide	156	kg/yr
Unburned Hydrocarbons	6.33	kg/yr
Particulate Matter	0.626	kg/yr
Sulfur Dioxide	56.3	kg/yr
Nitrogen Oxides	12.5	kg/yr

Table 8 shows the greenhouse gas emission for improved system. From the Homer simulation and optimization result, backup diesel generator which is the non-renewable component produces 9.97% (24,080 kWh/yr) of Electricity consumed 8796.5 L/yr. This indicated that 90.03%, of energy generated per year was solely from renewable sources thus saving an enormous amount harmful emission to air. The 9.97% emission per year comprises of 22,989kg/yr of carbon dioxide, 156kg/yr carbon monoxide, 6.33kg/yr unburnt hydrocarbons, 0.626kg/yr particulate matter, 56.3kg/yr sulfur dioxide and 12.5kg/yr Nitrogen oxide, making a total of 23,220.756kg/yr pollutants. Therefore, the total harmful emission saved using DHRES = (675803.2kg/yr-23220.756kg/yr) = 652582.444kg/yr

The Table Below Showed the Result of Dystrited Hybrid Renewable Energy Resources Electricity Production

Table 9: Electricity Production

Component	Production (kWh/yr)	Percent
PV	58,752	24.3
Diesel Generator	24,080	9.97
Wind Turbine	158,577	65.7
Total	241,409	100

Table 9 shows the electricity production after Homer software optimization. The wind is actually the most preferred source of renewable energy with a contribution of 156,577 kWh/yr followed by Solar PV with a contribution of 58,752 kwh/yr which is about 24.3 % of energy used per year and the Diesel generator contributed 24,080 kWh/yr which contributed 9.97 % of energy used per year. The fraction of the energy delivered to Ajoki community that originated from renewable sources that is referred to as RF (renewable fraction) and is 90.03%, which indicates 9.97 % of energy is delivered to the Ajoki community from diesel generator that is a non-renewable source, therefore minimizing greenhouse emissions to the air.

VII. CONCLUSION

The overall aim and objectives of this research work have been achieved. Thus, the key elements of this conclusion are as follows:

i. The use of diesel generator to provide electricity to rural communities like Ajoki faces enormous logistical challenges making it less cost effective with a very high operating cost because of its swampy terrain.
ii. The existing system architecturefor Ajoki Community which comprise of 1*320kW caterpillar (CAT) diesel generator is dispatched for only 12hrs from 1800hrs to 0700hrs when the generator is healthy.
iii. This research investigated the techno-economic feasibility of Distributed Hybrid renewable energy resources (DHRES) in a view to providing reliable, cost effective and clean solution for power supply deficiency in Ajoki community.
iv. The improved system architecturefor Ajoki Community which comprises of a 6*5kW array of solar PV, 8*100kW wind turbines, the already existing 1*320kW diesel generator, 1*12kW converter (inverter and rectifier) and 15 strings (2708Ah) batteries.
v. The diesel and battery bank are added to the system for backup purposes. The design is an off-grid system, due to the absence of conventional grid system nearby.
vi. The net present cost in the base case system when the Ajoki community runs on diesel generator only for 24hrs/day for a year is ₦1.64B and the breakdown of the NPC are capital cost ₦80.0M, O&M cost ₦363M, replacement cost ₦546M, salvage-₦7.21M, resource ₦661M. After optimization, the total Net Present Costs (NPC) was reduced to ₦288M.
vii. The greenhouse emission in the base case system when the Ajoki community runs on diesel generator for 24hrs/day for a year, produces 100% (959220 kWh/yr) of Electricity consumed 371757 L/yr at an average of 1019 L/day and 42.4 L/hr. After optimization the greenhouse gas emission produces 9.97% (24,080 kWh/yr) of Electricity consumed 8796.5 L/yr.
viii. The findings after optimization of the DHRES indicated that Renewable Energy sources are feasible and viable technically and economically in remote communities. This RE sources are readily available and can be harness by the government or private sectors to provide clean, cheap and reliable electricity supply. For Ajoki community, the simulation, optimization and sensitivity result clearly shows that wind energy, with eight (8) wind turbines (100kW each) can produce 65.7% of energy to meet the community load demand at the available wind speed. While the 5kW PV and existing 320kW generator produces 24.3% and 9.97% respectively to ensure reliability.

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