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The Application of Homer Optimization Software to Investigate the Prospects of Hybrid Renewable Energy System in Rural Communities of Sokoto in Nigeria

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ABSTRACT

This paper investigates the prospects and cost-effectiveness of implementation of standalone PV/wind system in sokoto state Nigeria. Daily electricity demand, yearly solar radiation and wind speed were applied to determine the optimum sizing of the renewable energy (RE) system. To design optimum RE with proper sizing of system components, meteorological data obtained from the National Aeronautics and Space Administration were applied as input for this study. In Nigeria, sokoto is a region with solar radiation of 6kWh/m^2/day and wind speed of 5m/s at 10m above height. Using the Homer optimization software, the optimum integrated RE system is 35.21kW PV, 3 x 25kW wind turbines, 12 x 24V lead acid battery and 17.44kW converter. The system has a total capital cost of $249910.24, the replacement cost of $82914.85 and maintenance cost of $53802.80 for 25 years. Though the initial capital cost is high but the long term benefits are enormous, considering the high cost of implementing rural electrification scheme, coupled with ahike in electricity tariff. There is also a payback period of 5 years. The results imply a standalone PV/wind system is feasible in rural communities of sokoto with 100% pollution free energy system.

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1. INTRODUCTION

The global consumption of fossil fuel and its finite nature has raised concern for the need to find alternative sources to satisfy the growing world energy demand. In most parts of the world, power generation is mostly by the fossil fuels. Studies show that renewable energy (RE) sources can be an alternative to the lingering power crisis problem in some developing countries [1]. Among these RE sources, solar and wind have shown significant progress for power generation in recent years, as they are regarded to be freely available environmental friendly sources [2]. Electricity from the wind is becoming gradually economical as compared to conventional power generating systems and is generally accepted as one of the inexpensive global RE source [3]. Solar energy has shown unique benefit in the rural communities with little or practically no power supply, even though solar resource in a suitable mix can solve issues related to irregular nature and reliance on climatic conditions [4].

The hybrid power system as implemented globally is essentially a combination of wind generators, solar photovoltaic (PV) array and back up battery supply. It has several advantages over the single system as it is more efficient and reliable. To effectively utilize solar and wind for an economic power generation, optimum selection of the hybrid combination on the correct information of wind speed and solar radiation is desirable [5].

To design appropriate combination of hybrid system to satisfy certain load demand requirements, there must be proper evaluation of power system reliability and cost effectiveness. For instance, wind turbines are effectively utilized if they are mounted at high elevation and exposed to high wind speeds. It is also known that wind turbines are more effective in coastal regions, but micro wind turbines are normally mounted at roof top as a single source. Currently, there is no visible hybrid power system at any location in the northern part of Nigeria, despite having regions with high wind speed and solar radiation. Jos located in the north central part of Nigeria was found to have the highest wind speed of 3.6m/s [6]. Contrary to that, Ojosu and Salawu [7] reported that Sokoto in the north western part of Nigeria have wind speed reaching 5.2m/s annually. Solar energy was reported to be highest in the northern part of the country up to 7 kWh/m^2 but has only being utilized for street lighting and home power supply with no visible solar power plant on a larger scale [6]. To date, there is no feasibility research carried out to investigate the possibility of hybrid RE system in Nigeria.

The major objective of this investigation is to assess the potentials of hybrid power systems in the rural communities of sokoto. Subsequently, the possibility of hybrid system PV-wind system will be investigated by the application of the Hybrid Optimization Model for Electric Renewable (HOMER) [8]. The National Aeronautics and Space Administration (NASA) meteorological data will be used for analysis. Sokoto is chosen for investigation because of its high wind and solar potentials as compared to other parts of the country.

This paper is organized as follows: Section 1 is the introduction. Section 2 describes the electricity demand in the northern part of Nigeria. Section 3 evaluates the utilization of RE sources in Nigeria. Section 4 is the description of the Homer optimization software. Section 5 is the Energy analysis of rural communities in Nigeria. Section 6 describes the modelling and simulation of the Hybrid solar/wind system components. Section 7 is the simulation results and section 8 cocludes the paper.

2. ELECTRICITY DEMAND IN NORTHERN NIGERIA

Nigeria is located between latitude 10°N and longitude 8°E. The country power supply is predominantly hydro and thermal. In Nigeria, thermal power plants constitute 79% of power generation while the remaining is from hydro [10]. The hydro stations are affected by seasonal changes in water flow for effective performance of these hydro turbines. There is also irregular power supply in the country due to insufficient supply of natural gas to the thermal power plants [9]. These problems led to the current situation where Nigerians looked for an alternative power supply using petrol and diesel power generating machines. Despite the populous nature of the country, these issues continue to decline the Nigeria’s electricity sector when compared to different parts of the world as shown in Figure 1. According to the IEA report of 2009, 80 million Nigerian do not have access to electricity [11]. The government of Nigeria had already planned to include RE sources as alternative power sources in the future energy mix of the country [12]. Solar and wind are the most viable to achieve these objectives.

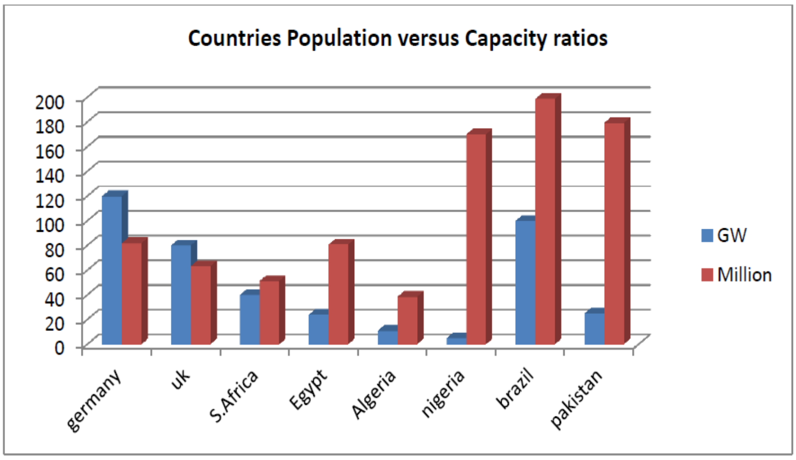


Figure 1. The ratio of countries population to their generation capacities [adapted from 10]

3. UTILIZATION OF RENEWABLE ENERGY SOURCES IN NIGERIA

Research and development relating to RE in Nigeria are driven by recent fall in global oil price coupled with erratic power failure and most recently the high electricity tariff. It was reported that energy received in Nigeria from the sun per day amounts to 5.08×10^{12} kWh and this is equivalent to 4.66 million barrels of oil per day [13]. In Nigeria, solar energy is currently used for power supply in homes and other public places such as street lighting and hospitals. The current PV installed capacity in Nigeria is 15MW, mostly for standalone applications with no visible solar plant connected to the country's power network [14]. Feasibility studies in wind show that the maximum extractable power for a region in sokoto is 21.97 watts per square meter of blade area [15]. Recently, tremendous efforts have been made to develop some pilot wind projects for rural electrification. Several visible wind projects in Nigeria include 10kW power station at Danjawa (solar and wind energy), wind mill in kadawa village, 5kW aerogenerator in sayya village in sokoto state [12].

4. THE HOMER OPTIMIZATION SOFTWARE

In this paper, the Homer software is applied to model hybrid system for rural communities in sokoto state Nigeria. Sokoto is a hybrid renewable energy potential region. In applying the Homer software for hybrid power system design, certain considerations must be taken i.e. the number of components, their rating and sizes for optimum application. The Homer software is a power optimization software that eases the task of assessing power system related to off-grid or grid-connected applications [15]. It offers capabilities for evaluating different configurations by a number of optimization techniques. It provides best possible combination of modules that meet particular electrical and thermal loads [16]. For optimum results using Homer software, selection variables are the PV module size, type of wind turbines, size of the inverters and the quantity of batteries required.

5. ENERGY ANALYSIS OF RURAL COMMUNITIES IN NIGERIA

5.1. Average Load Profile of Sokoto

The average daily load demand for rural communities in the northern part of Nigeria, sokoto inclusive is shown in Figure 1. It was reported that rural communities in Nigeria have an average consumption of 1.4kWh/day [17], [18], with the maximum daily load reaching as high as 46kW. In agreement with the literature [17], this paper estimates the energy demand of the rural areas based on the individual power rating of household appliances (Table 1), and electricity consumption analysis of 200 homes in rural communities [18].

Table 1. Power rating chart for some house hold apparatus [17]

Ratings (Watt)	Household apparatus
55-90	19 CRT Television
150-340	Desktop computer and monitor
60	Incandescent light bulb
18	CFL light bulb
24	Low speed ceiling fan

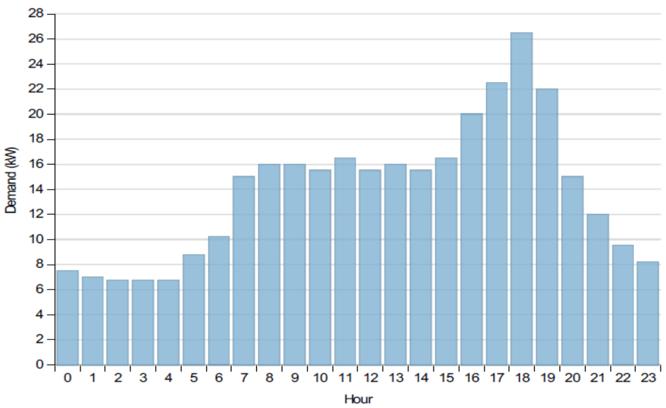
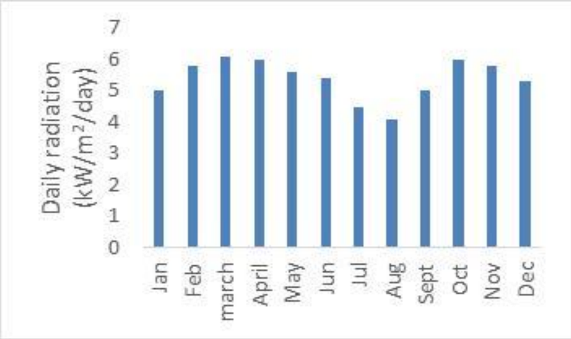
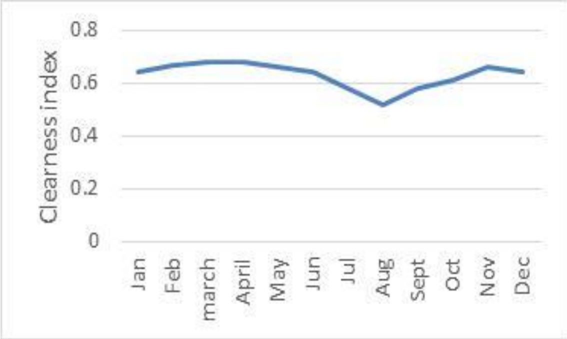


Figure 1. Average hourly load demand for a typical rural area in Sokoto

5.2. Solar Resources

The global horizontal radiation profile for sokoto is illustrated in Figure 2 [19]. Sokoto has an average of eight sunshine hours per day. The solar radiation appears to be high in March and April while low in July and August. The utmost range of clearness index appears to be within October to February, with the maximum reading of 0.68 in March. August has the least clearness index value of 0.53. This is an indication of brighter cloud over the year with high solar potentials.





(a) (b)

Figure 2. (a) monthly solar radiation and (b) clearness index

5.3. Wind Resources Data Analysis

The yearly wind speed profile for sokotois shown in Figure 3 [19]. The mean wind speed for sokoto varies between 4.5m/s to 5.2m/s at 10m above height. It is higher in January and lower in December. According to the literature, wind speed in sokotofalls within class 4 which is sufficient to produce electric power [20].

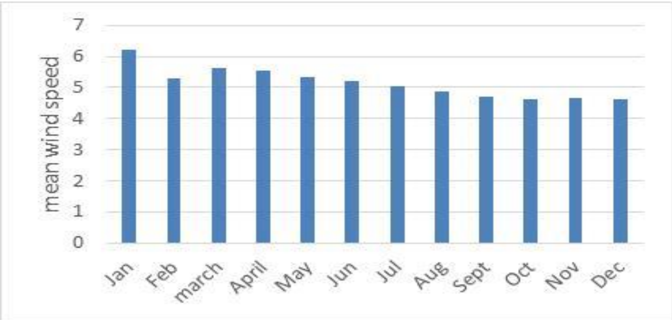


Figure 3. Wind resource profile for sokoto

6. MODELLING AND SIMULATION OF THE HYBRID SOLAR/WIND SYSTEM COMPONENTS

The Homer software applies general techniques to model several components of the hybrid system as follows.

(a) The PV array output is calculated using Equation 1. This Equation ensures maximum output from the PV array system [20].

$$P_{PV} = H_{PV} U_{PV} \left(\frac{V_T}{V_{T,STC}} \right) \left[1 + \beta_P (T_C - T_{C,STC}) \right] \quad (1)$$

where H_{PV} represent the PV array power capacity in kW. U_{PV} represent the derating factor of the PV. V_T and $V_{T,STC}$ represent the incident solar radiation upon the PV array on kW/m^2 and based on standard testing conditions respectively. β_P represent the coefficient oftemperature based on power. T_C and $T_{C,STC}$ represent the cell temperature and that based on standard temperature conditions.

(b) The wind speed is measured using the power law based on 10m height by the following Equations [20].

$$\left(\frac{W_2}{W_1}\right)=\left(\frac{Y_2}{Y_1}\right)^{\alpha} \tag{2}$$

where W_2 represent the wind speed at height Y_2 and W_1 represent the wind speed at height Y_1. A represent the power law exponent.

c) The homer software applies the following Equation to obtain the generators fuel consumption as follows [21].

$$F = F_O Y_{GEN} + F_1 P_{GEN} \tag{3}$$

where F_O represent the fuel curve intercept coefficient, Y_{GEN} is the generator rated capacity in kW, F_1 is the fuel slope curve and P_{GEN} represent the electric output in kW

(d) In order to determine the net cost of the hybrid system, the Homer software determine the cost of the system over its lifetime and then subtract the cost of the incurred revenue over its operational lifetime. The net current cost is calculated by the Equation:

$$C_{NPC}=\frac{C_T}{CRF} \tag{4}$$

where CRF represent the capital recovery factor and C_T is the total yearly cost in \$/year.

To design any hybrid renewable energy system in the Homer optimization software, it is essential to estimate the payback period for implementing the PV-wind hybrid system. Assuming that the project lasts for 25 years at annual interest rate of 6%. In Nigeria, the current electricity tariff stands at N23.6 per kWh equivalent to \$0.082 (exchange rate of \$1 to 285). The average monthly demand for the rural communities in sokoto is 172.85 k kWh amounting to N4079.26 (\$334.5) equivalent to \$48955.2 annually.

7. SIMULATION RESULTS

7.1. PV Panels

The recommended PV panels are rated at 35.21kW. The modules initial capital cost is \$105604.91 with operation and replacement cost of \$4501.66. The PV panels have penetration percentage of 86.5 and are expected to be operational for 4386 hours per year. Figure 4 indicate that solar irradiance is more prevalent from 8am to 4pm throughout the year.

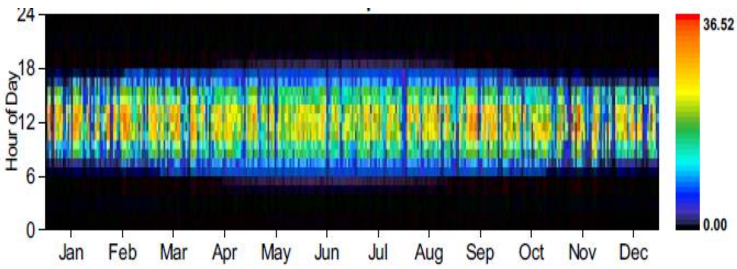


Figure 4. PV output

7.2. Wind Turbine

The wind turbine has rated capacity of 25kW with mean output of 4.75kW. The initial capital cost for the turbine is $58333.33 with maintenance and replacement cost of $33102.53. The wind turbine penetration is simulated to be 67% and expected to operate for seven hours in a year. In the winter the wind speed is higher as illustrated in Figure 5, and solar radiation is less making it possible to fully utilize the hybrid system for electric power generation. Solar and wind can supplement each other during lean periods

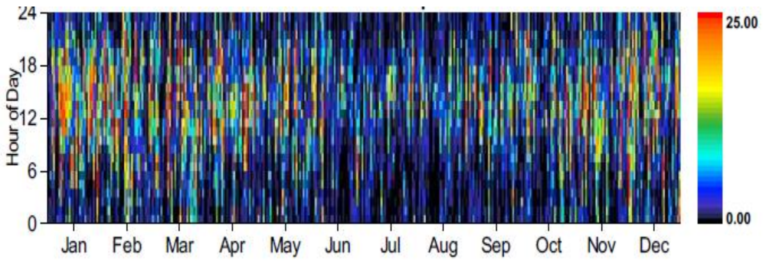


Figure 5. Wind turbine output

7.3. Lead Acid Battery

The battery has maximum capacity of 83400Ah and rated at 12V. 24 batteries will be used at the cost of $80700. These batteries are estimated to have maintenance and replacement cost of $96930.33. The batteries have yearly throughput and losses of 24868.87 kWh and 5453.64 kWh/yr respectively.

7.4. Converter

The converter comprises of the inverter and the rectifier units each having capacity of 17.44kW and 15.66kW respectively. The converters initial capital cost is $5232 with the total operation, maintenance and replacement cost of $2183.13. The converter is expected to operate for 8742 hrs in a year with losses of 6638 kWh/year.

7.5. The Complete RE System

The RE system has a total initial capital cost of $249910.24 with replacement cost of $82914.85 and maintenance cost of $53802.80 for a period of 25 years. In this region, there is high solar radiation and sufficient wind speed and vast land for installing clean energy facilities. The government can therefore utilize both resources as part of the RE system. Figure 6 shows the net current cost of the hybrid system components.

The total production in a year from all RE sources is 93300 kWh as illustrated in Table 1. Out of this, PV system constitute above 57.5% renewables in the integrated system while wind constitute the remaining 42.5% (see Figure 7). It is clearly shown that RE sources can meet up the electrical demand of rural communities, with excess electricity up to 23407kWh/year (Figure 8). This excess electricity occurs when the battery is fully charged (93% and above) and discharges less than expected [2]. This occurs from 10am to 2am on daily basis because at that time the solar radiation is at its peak and the wind speed is also high.

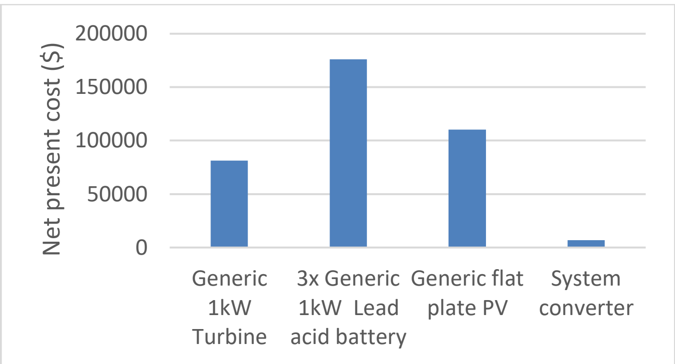


Figure 6. Net present cost of components with RE sources

Table 2. Simulation results of electrical production, consumption and quantity

System operation	PV/wind system	
Consumption	kWh/yr.	%
AC primary load	59,749	100
Total	59,749	100
Production	kWh/yr.	%
PV	53690	56.34
Wind Turbine	41610	43.66
Total	93300	100
Quantity	kWh/yr.	%
Excess Electricity	23407.6	24.6

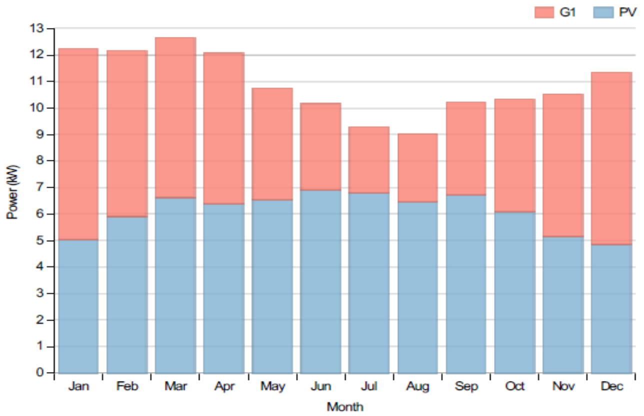


Figure 7. Monthly average electrical production of integrated RE sources

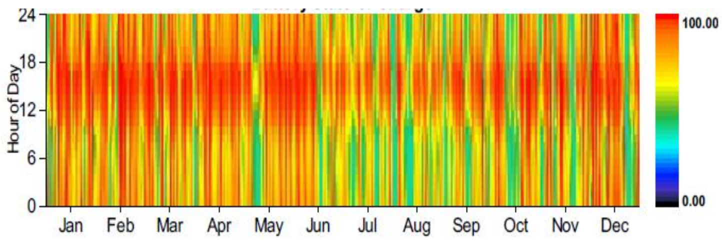


Figure 8. Battery state of charge

8. CONCLUSIONS

In this paper, the homer optimization software has been applied to evaluate the performance of standalone PV/wind power generating system for application in rural communities of sokoto state Nigeria. Average hourly load demand, monthly solar radiation and wind speed were applied as input to obtain the optimum sizing of RE sources for power generation. The result shows that for a typical rural community in sokoto, the initial capital cost for hybrid system with RE sources is $249910.24 with payback period of 5 years considering the current electricity tariff of the country. Though there is high cost of implementation of the hybrid system, but maintenance cost may be cheaper as compared to the current grid system. The grid has issues related to the transmission and distribution system losses, coupled with high maintenance cost. This RE model is capable of supplying dump load for residential application and the excess wind and solar energy system can be sold to other communities at certain feed in tariff. With this system, it is possible to implement pollution free energy system with no cost associated to fuel consumption.

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