Wind Resource Classification and Economic Feasibility of Distributed Generation for Rural Community Utilization in North Central Nigeria

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Abstract— **This study analyzed the electricity generation potential from wind at Abuja, Bida, Ilorin, Jos, Lokoja, Makurdi and Minna all in North-central, Nigeria. 21 years monthly mean wind speed data at a height of 10 m were assessed from the Nigeria Meteorological Department, Oshodi. The data were subjected to different statistical tests and also compared with the two-parameter Weibull probability density function. The outcome shows that the 21 years monthly average wind speeds ranged between 2.2 m/s in November for Bida and 10.1 m/s in December for Jos. The yearly average ranged between 2.1m/s in 1987 for Bida and 11.8 m/s in 2002 for Jos. Also, the power density for each site was determined to range between 29.66 W/m^2 for Bida and 864.96 W/m^2 for Jos, while the two parameters of the Weibull statistics distribution were found to range between 2.3 in Lokoja and 6.5 in Jos for k, while c ranged between 2.9 in Bida and 9.9m/s in Jos. These outcomes points to the fact that wind speeds at Jos, Minna, Ilorin, Makurdi and Abuja are compatible with the cut-in speeds of modern wind turbines and hence, may be economically feasible for wind-to-electricity at and above the height of 10 m. The study further assessed the potential and economic viability of standalone wind generation systems for off-grid rural communities located in each of the studied sites. A specific electric load profile was developed to suite hypothetic communities, each consisting of 200 homes, a school and a community health centre. An assessment of the design that will optimally meet the daily load demand with a loss of load probability (LOLP) of 0.01 was performed, considering 2 stand-alone applications of wind and diesel. The diesel standalone system (DSS) was taken as the basis of comparison since the experimental locations have no connection to a distribution network. The HOMER® software optimizing tool was utilized to determine the optimal combination of system components that will yield the lowest life cycle cost. Sequel to the analysis for rural community utilization, a Distributed Generation (DG) analysis that considered the possibility of generating wind power in the MW range in order to take advantage of Nigeria's tariff regime for embedded generation was carried out for each site. The DG design incorporated each community of 200 homes, freely catered for and offset from the excess electrical energy generated above the minimum requirement for sales to a nearby distribution grid. The wind DG systems were found suitable and viable in producing environmentally friendly energy in terms of life cycle cost and levelised value of producing energy at Jos ($0.14/kWh), Minna ($0.12/kWh), Ilorin ($0.09/kWh), Makurdi ($0.09/kWh) and Abuja ($0.04/kWh) at a turbine hub height of 124m. These outputs reveal the value retrievable from the project after breakeven point as a function of energy consumed and sold in kWh. Therefore, these values provides a good way of comparing the relative viability amongst these sites and also serves as a means of measuring the returns on producing wind energy in the MW range from actual grid sales.**

Index Terms— **Wind Speed, Wind Power, Distributed Generation, Cost per kilowatt-hour, clean energy, North-central Nigeria.**

I. INTRODUCTION

Availability and access to modern energy have continued to drive industrial and socio-economic growth of a nation [1 - 3]. The impact of energy access on the sustainable development goals (SDG) and national technological advancement cannot be overemphasized. However, the imbalance between energy demand and supply, especially in developing countries, is a challenge that requires consistent effort and innovation in order to develop adequate national energy mix [4]. The situation in developing countries is usually such that the cities and towns are connected to centralized national electricity (grid) system, while the villages and remote/rural areas meet their energy need from private sources. These sources, most times, range from the unsustainable open burning of traditional biomass and fossil fuels [5, 6].

Moreover, electricity supply has majorly been generated from hydropower, fossil sources of coal, natural gas and in recent past from nuclear resources [6]. Apart from hydropower, other sources have been reported to have environmental issues. International conventions and debates have suggested a shift away from these generation approaches as a result of their deleterious environmental actions. This has invariably elicited

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growing interests from some developed nations and China towards adoption of renewable energy resources for power generation. The increasing installed capacities per annum of wind power across countries in Europe, United States of America and China lend credence to this. Figs 1 and 2 show the leading nations and regions of new installed mega-watt (MW) wind power capacities across the globe. The Figures show that China and Asia are the leading country and continent while for Africa, only South Africa has new installed wind power capacity throughout the year 2016. This shows that Africa is lagging behind in the adoption of wind as a veritable source of renewable power with South Africa, Egypt, Morocco, Ethiopia and Tunisia the leading nations. The total cumulative installed MW wind power capacities up to 2016 for these countries are 1471. 810, 787, 324 and 245 respectively.

However, wind as a source of renewable electricity can be accepted as viable source provided it meets certain preliminary acceptable assessment standard of magnitudes of site's average wind speed, modal and maximum energy carrying wind speed and techno-economic viability. This is reported as the bane of Africa's wind power development. The continent is adjudged to lack adequate wind power assessment report or database [8]. The absence of enough assessment studies to establish the potential and feasibility of harnessing wind energy for power generation in Africa hinders domestic and foreign wind energy investors who desires to make informed business decisions on the viability of establishing wind farms across the continent [9]. To this end, a preliminary wind resource valuation is imperative to determine its potential as a precondition to garnering wind resources for power generation.

For Nigeria, various study reports exist that established the wind profile signatures of different sites across the six geopolitical zones of the country [1, 3 – 6, 8-15]. Of particular interest to this study are the reports that focussed on sites in the North Central zone of Nigeria [1, 12, 15,]. Most of the existing studies on the region's wind profile distribution only focused on sites in Jos (Plateau State). Studies on other sites across the states of the zone are scanty. In addition, the existing studies majorly focused on determine the magnitudes of wind speeds and the suitability of the wind profiles with practical wind turbines. No many have focused on the techno-econometrics of generating wind electricity from different sites across the zone. This is the focus of this study. It assessed wind profile distribution across six states of the north central zone and designed wind power system suitable for rural communities, with 200 homes, having a school and community health centre. The prevailing wind speeds as captured by cup-generator anemometer at 10 m height were obtained and analysed to determine the potential for wind power generation in Abuja, Jos, Minna, Bida, Lokoja, Ilorin and Makurdi, all in North-Central Nigeria. Further to this, it employed the renewable energy policy of the federal government as captured in the multi-year feed-in tariff order covering year 2012-2017 to carry out the techno-econometrics analysis and determine the economic benefit of generating wind power from the sites.

II MATERIALS AND METHOD

A. Data Collection

The twenty-one years (1987 – 2007) wind speed data utilized for this research were obtained from the Nigeria Meteorological agency (NIMET), Oshodi, Lagos, Nigeria. Table 1 and Figure 3 present the location parameters and location of the chosen sites.

B. Estimation of Wind Power Density

The wind power density for each site can be evaluated from the Weibull parameters as:

$$p(v) = \frac{1}{2}\rho c^3 \left(1 + \frac{3}{k}\right)$$

where $p\ (v)$ = wind power density (W/m^2) and ρ = air density at the site.

C. Evaluation of Useful Site Specific Wind Speeds

There are two wind speeds which are of utmost importance to wind energy researchers and investors. These wind speeds are referred to as, the most probable (v_{mp}) and maximum energy carrying ($v_{E_{max}}$) wind speeds given as:

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

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

III. WIND ENERGY OPTIMIZATION

A. Load calculation

In developing nations where data storage techniques have not been appropriately developed, it is difficult to easily determine or recover the electric load consumption profiles for rural communities unconnected to the national grid from the electric utility company's database. However, electricity utilization usage amongst rural families in developing countries have been recorded to comparatively low, with an average of about 1 kWh/day per home [32]. A number of reasons have been credited to this discovery. They include; absence of expensive appliances, and extreme level of poverty prevalent in this areas. Notwithstanding, research has shown that an average of 96 kWh annually is required per person in rural areas [33]. This corresponds to about 315 kWh per day for the studied communities of 200 homes in north central Nigeria. Due to the unavailability of electric load consumption from the utility company's database, the energy demand of each rural community was projected via an evaluation of the individual power rating of the basic appliances in use in such homes. Hence, the supposed average electricity consumption value reached and made use of per home was estimated at 1.4 kWh per day.

IV. RESULTS AND DISCUSSION

The results of wind profile analysis at the site are as shown in Figs. 1 and 2. The figures demonstrate that the 21 years' monthly average wind speeds ranged between 2.2 m/s in November for Bida and 10.1 m/s in December for Jos. The yearly average ranged between 2.1m/s in 1987 for Bida and 11.783 m/s in 2002 for Jos. Additionally, the hours equaled or exceeded for a range of mean measured wind speeds (Fig. 3) across the period revealed that 38.6% of the data spread are values above 3.0 m/s for the poorest site (Bida) in terms of wind profile, and 92% for the best wind profile in Jos. Thus, with a good percentage of wind speeds over 3m/s, the values proof that most of the sites are compatible with modern wind turbines for power generation throughout the year. In addition, the period of highest potential for wind energy harvest lay between February and July for Abuja, with March, April and May having the greatest potential. The average monthly mean wind speed variation for this site ranged from 3.2 (in December) to 4.3 m/s (in March, April and May). For Bida, the period of highest potential for wind energy harvest lay between February and June, with April having the greatest potential, and the average monthly mean wind speed variation for this site ranged from 2.2 (in November) to 3.4 m/s (in April). For Ilorin, the period of highest potential for wind energy harvest lay between March and August, with April having the greatest potential, and the average monthly mean wind speed variation for this site ranged from 3.2 (in December) to 6.2 m/s (in April). For Jos, the period of highest potential for wind energy harvest lay between November and May, with December having the greatest potential, and the average monthly mean wind speed variation for this site ranged from 7.7 (in October) to 10.1 m/s (in December). For Lokoja, the period of highest potential for wind energy harvest lay between February and July, with April having the greatest potential, and the average monthly mean wind speed variation for this site ranged from 2.3 (in December) to 4.4 m/s (in April). For Makurdi, the period of highest potential for wind energy harvest lay between January and July, with April having the greatest potential, and the average monthly mean wind speed variation for this site ranged from 3.2 (in November) to 5.7 m/s (in April). Finally, for Minna, the period of highest potential for wind energy harvest lay between December and May, with February having the greatest potential, and the average monthly mean wind speed variation for this site ranged from 3.1 (in October) to 6.8 m/s (in February). Seasonally, as shown in Fig. 4, the wet season average mean wind speed ranged between 2.9 (Bida) and 5.1 m/s (Ilorin), even as Abuja, Bida, Ilorin and Lokoja appeared to have a higher potential for wind energy harvest during the wet season. On the other hand, the dry season revealed a higher potential for wind energy harvest for Jos, Makurdi and Minna. In order to determine whether the mean wind speed data distribution followed the Weibull two-parameter statistical distribution, the K–S goodness-of-fit test was employed. The outcome revealed that for the considered period, all sites yielded K–S P values larger than 0.05, thus indicating that the Weibull two-parameter statistical distribution was suitable for analyzing the wind profiles of all the sites. As a result, statistical Weibull evaluations were carried out on wind speed datasets. The study reveals that R^2 values for the whole analysis are spread between

0.77 to 0.98. Additionally, the values of k and c are ranged between $2.3 \leq k \leq 6.5$ and $2.9 \leq c \leq 9.9$ annually. The values of k and c ($k \geq 2$ and $c \geq 2$) point to the fact that the dataset is spread in the perfectly normal distribution [21] with small scatter.

V. CONCLUSION

Based on the results, wind energy standalone and embedded generation systems should become a priority for both government and private corporations in providing environmentally friendly and non-depleting renewable energy to the rural poor in north central Nigeria. This will help improve the gross energy deficit prevalent in Nigeria that has slowed down economic growth. Also, investors can consider investing in wind energy embedded generation systems as profitable ventures, thereby taking advantage of the favourable feed-in tariff covering wind distributed generation.

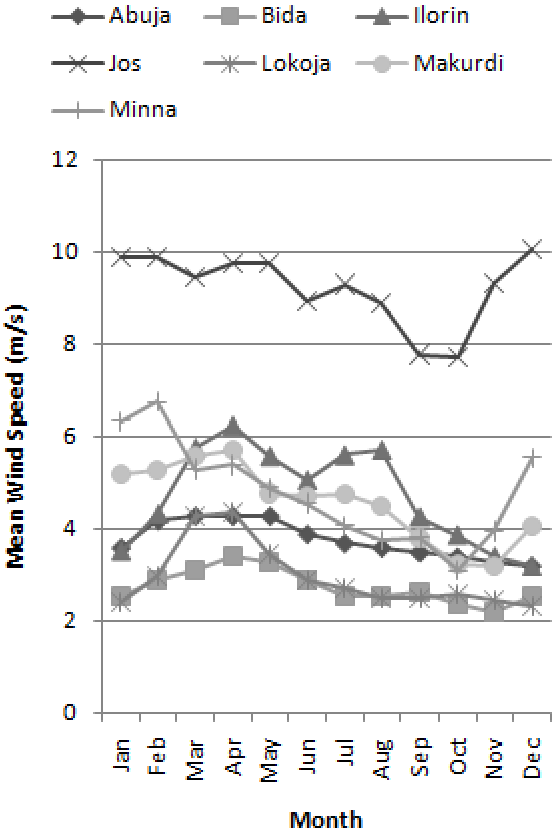

Fig. 1. Plot of annual monthly mean wind speed for the entire period

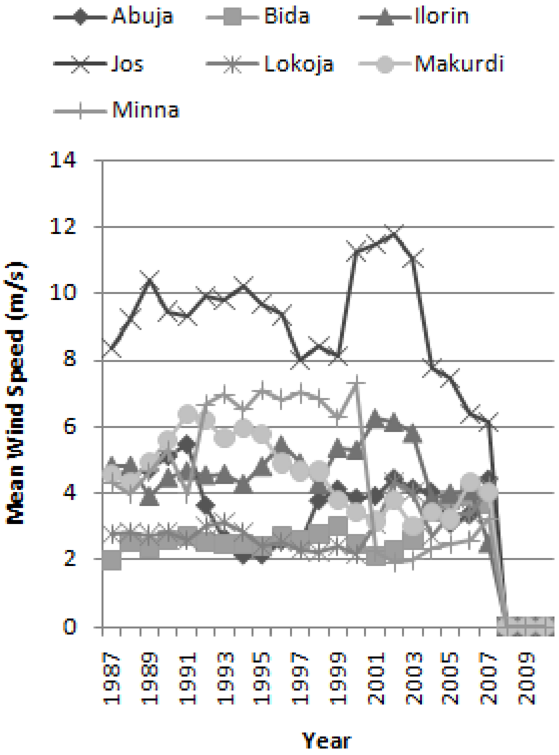

Fig. 2. Plot of yearly mean wind speed for the entire period

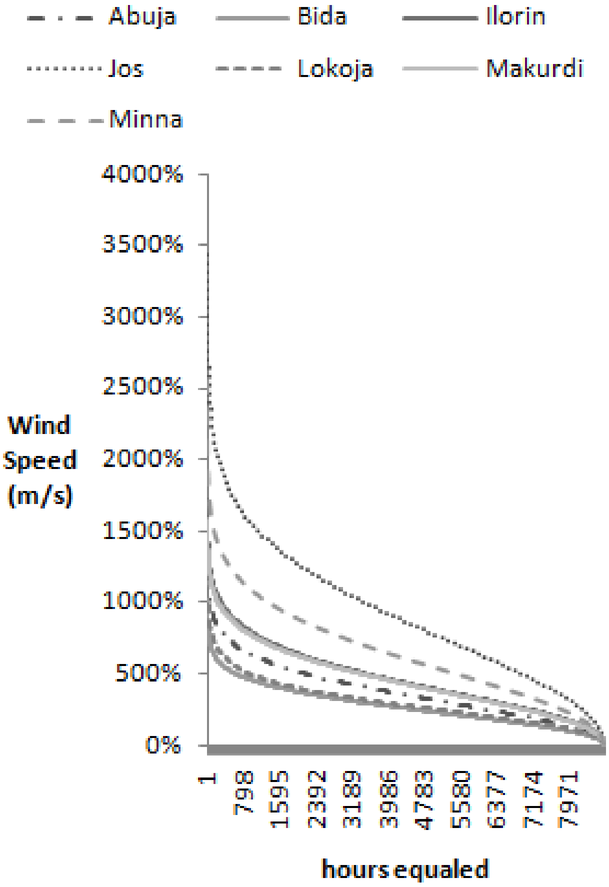

Fig.3. Plot of annual average hours equalled or exceeded for different wind speeds

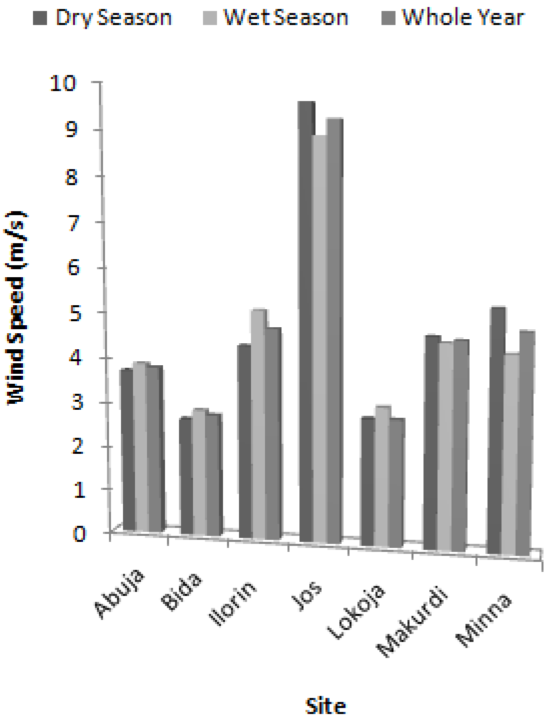

Fig. 4. Plot of 21-year seasonal mean measured wind speed

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