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A Review of Onshore and Offshore Wind Energy Potential in Nigeria

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Abstract. As a result of continued growth in demand for energy in Nigeria and the need to augment fossil fuel sources with renewable energy, this paper review research trends on Offshore and Onshore wind energy potentials in Nigeria, for possible power generation. Researches on development and design of small scale-wind turbine as well as their application for small-scale electrification were also discussed. This paper further examined the suitability of different geographical zones in Nigeria for offshore and onshore power generation, using results of prior researches and also stressed that Wind Energy Technology (WET) is widely underutilized in Nigeria. Several factors militating against this development were briefly highlighted and some suggestions were raised for future work within the realm of wind energy technology.
Keywords: Offshore wind; Onshore wind; Wind speed; Windfarm.

1. Introduction

In order to fulfill the requirement of Sustainable Development Goal (SDG) 7, which encourages the United Nation member states to focus on access to ecofriendly, sustainable and readily available renewable energy source [1], it becomes necessary to assess the potential in the renewable energy sources available at our disposal such as Wind, Waves, Solar, Tides and Geothermal. Wind as a source of renewable energy is gaining prominence around the world since it can be can be harness in small or commercial to meet the present-day energy demand. Wind Energy Technology (WET) serves as a suitable supplement and alternative to the rising cost of power generation from fossil fuel source and as well contribute towards global legislation against Greenhouse Gas (GHG) emission.

Wind as a source of power generation provides clean, ecofriendly, nontoxic and readily available renewable energy source. For effective generation of energy from wind, certain conditions must be met such as; availability of substantial amount of wind within a site, appropriate statistical analysis of the wind to study the nature of wind speed distribution within a site, multi-criteria assessment of the site to ensure the viability of the location for installation of wind energy conversion systems (WECs), cost implication of installing wind energy conversion systems and other logistic analysis. Furthermore, wind is stochastic in nature, hence it is necessary to develop models in accessing long term variation of wind within a particular site before concluding on whether the site poses the requisite wind resources for power generation.

Another important parameter in wind energy studies is the wind power density. Wind power density is the amount of energy available at a particular site for conversion to useful wind energy by a wind turbine and it is measured in watts per meter square, and it is a direct function of the mean value of the wind speed available in that particular site. It is necessary to ascertain the wind power density of particular site prior to installation of wind turbines.

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In order to convert the available wind resources in a region into useful energy, an important device; Wind turbine is required. A wind turbine converts the available wind speed in a particular location into wind energy which is then fed into the electricity supply systems. Wind Energy Conversion Systems (WECS), operates at its maximum capacity if its design is based on the wind characteristics of a particular site [2].

1.1 Wind Energy Research Trends in Nigeria

Wind as a renewable energy source is underutilized in West Africa most especially in Nigeria. According to a recent study by African Development Bank (AFDB) [3], North African countries like Morocco, Egypt and Tunisia remain the leaders in wind energy market in Africa, while South and Eastern African countries are projected to reduce the gap soon. Central Africa and West African countries are still lacking in terms of wind farm implementation. Taking Nigeria as a case study, the notion to seek for a sustainable alternative to the intermittent energy situation of Nigeria has prompted the government as well as independent researchers to evaluate the nation's potentials for power generation using wind energy.

Reports on researches shows that some regions within Nigeria have potential for power generation. Oyedepo *et al.* [4], carried out an analysis of wind speed data and as well, evaluate the wind power density in three south-eastern locations in Nigeria (Enugu, Owerri and Onitsha) at a hub height of 10 m above sea level with an annual mean wind speed of 5.42, 3.36 and 3.59 m/s respectively using wind speed data that spanned between 24 and 27 years. From this research, a wind speed value of 5.42 m/s recorded from Enugu is sufficient for power generation according to Batelle-Pacific Northwest Laboratory (PNL) wind power classification scheme [5]. A statistical assessment of wind energy potential in Ibadan, Nigeria was carried out by Fadare [6], and the analysis was based on Weibull distribution model using 10 years (1995-2004) daily wind speed data. It was inferred from this research that the site analyzed, possesses an annual power density of about 15.484 W/m^2 which according to Akpinar and Akpinar [7], is only suitable for lower power consumption application such as battery charging and water pumping.

Ogbonnaya *et al.* [8] Accessed wind energy potential in Nigeria, by utilizing 4 years' wind data collected from seven different states in (Enugu, Jos, Ikeja, Abuja, Warri, Sokoto and Calabar). The annual wind speed at 10 m above the ground varied from 2.3 to 3.4 m/s for sites along the coastal areas and 3.0-3.9 m/s for high land areas and semi-arid regions. Ojosu and Salawu [9], carried out research on the identification of potential wind energy sites in Nigeria. An atmospheric model simulation was developed and applied in studying the flow of wind, so as to identify potential wind-based electrification in different locations and as well determine the viability of the prevailing wind for small and commercial scale application. Igboekwe *et al.* [10] on the other hand, researched on the stochastic modelling of hourly average wind data collected from Umudike, South-East Nigeria. Ten years of hourly average wind speed data were utilized in this research to develop a periodic autoregressive integrated moving average model. The model was then applied in simulating the collected wind data and the result showed that the simulated wind behavior was reproducible and matched well with the characteristics of the experimental values.

More researches are emerging in the analysis of wind speed for different locations in Nigeria and each of these in the limit of their uncertainties have proven that great potential exist for wind power generation in Nigeria.

It can also be seen that most of the sites analyzed are basically onshore sites, and they possess wind power for small scale power generation. In order to meet the commercial demand for wind power, there is need to research on offshore wind resources as studies have shown that offshore wind energy is twice as that onshore wind energy.

1.2 Onshore and Offshore Wind Characteristics in Nigeria

Unlike the typical usage of "Offshore", within the marine industry and wind farm sector, offshore refers to inshore water zones such as seas, lakes, sheltered coastal areas etc. hence offshore wind refers to wind resources within these locations. Contrary, onshore wind refers to wind resources on land.

Offshore wind power or offshore wind energy is the use of turbines installed offshore, usually on the Continental shelf, to harvest Wind energy for electricity generation.

As a result of the high wind speed available in offshore sites compared to onshore, offshore wind power generation is higher [11]. Offshore wind turbines offer certain advantages compared to onshore wind turbines which include: (a) When a strong wind blows, it produces electricity around 3-5 MW per hour, (b) Little variation in wind speed, (c) An offshore wind turbine is more durable compared to onshore wind turbine. It persists within a period of 25-30 years and generates about 50% more energy than an onshore turbine. The most substantial drawbacks for potential offshore wind farm constructions are costs and public acceptance.

According to results from researches and wind data from Nigerian meteorological stations, it has been established that wind speeds are generally weak in the southern part of Nigeria, except for offshore areas from Lagos through Ondo, Delta, Rivers, Bayelsa to Akwa Ibom state which were reported to have prospects for harvesting strong wind energy throughout the year. States like Jos, Katsina and Maiduguri, possesses high wind speed amidst condition such as topography and roughness of surfaces. Further research revealed that wind speed of about 8.07 m/s can be harnessed from the northern part of Nigeria [12].

According to latest report from NIMET, based on the result of 40 years (1968-2007) available average of wind data from the whole 44 stations in Nigeria (Figure 1), it was observed that high onshore wind speeds are paramount in the northern part of Nigeria.

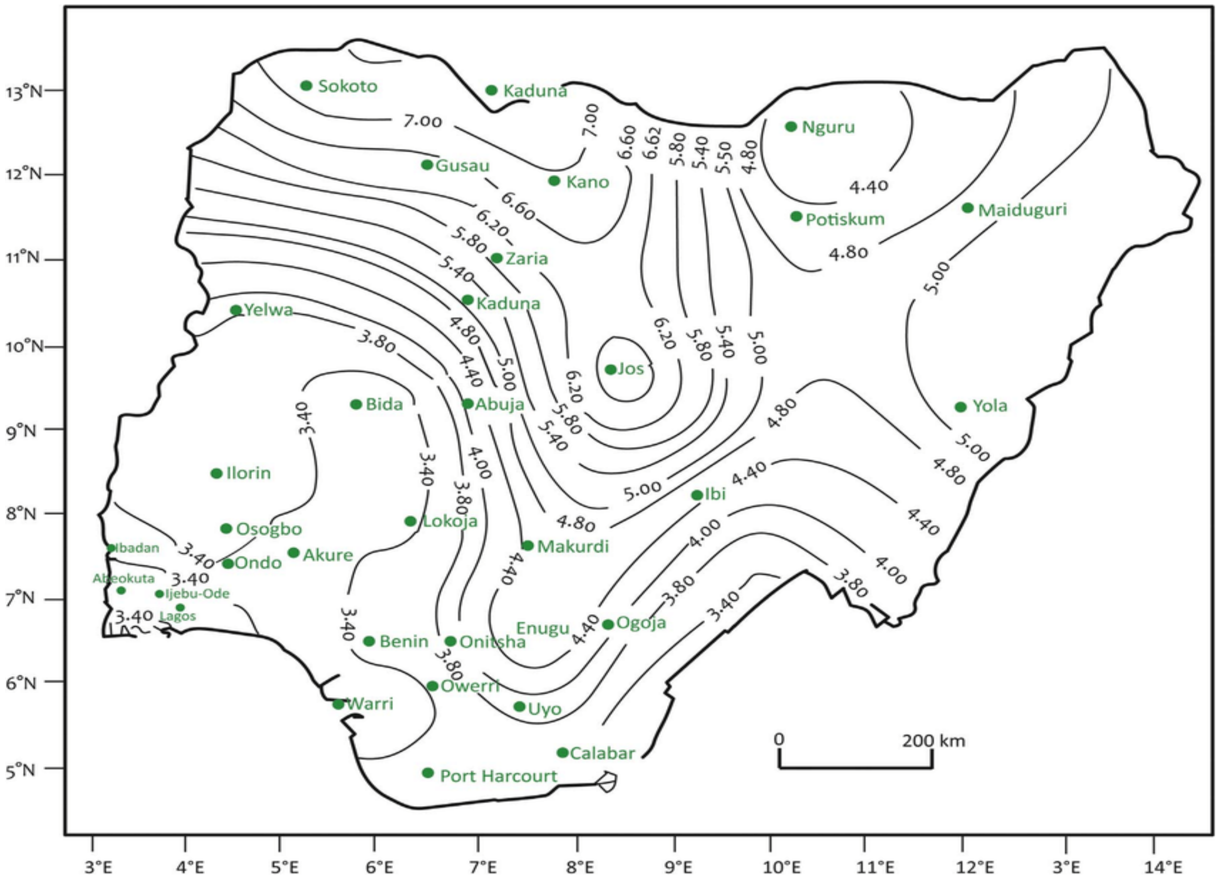

Figure 1:Isovents in m/s determined from 40 year's measurements at 10 m height, obtained from Nigeria meteorological department, Oshodi, Lagos State, Nigeria [13].

From Figure 1, wind speed within the north varies between the range of 4.0-7.5 m/s at 10 m height. Similarly, the southern part of Nigeria has moderate wind speed within the range of 3.0-3.5 m/s. Among the 44 stations operated by Nigerian Metrological Agency, there is no single offshore station despite the reported potential of offshore regions. Offshore wind data can be measured using anemometer installed in a suspended buoy system in water, as adopted in other countries around the world. Few results obtained from oil producing companies in Nigeria, with suspended buoy facilities shows that there is huge potential for offshore wind installation.

2 Research Trend on Wind Turbine Design in Nigeria and Power in Wind

Appropriate selections of design parameters for wind turbine is an important parameter in wind energy technology. Parameters such as the rated power, the cut-in speed and the cut-off wind speed must be selected based on the wind characteristics of the site and this will ensure maximum functionality of the turbine. The efficiency of a wind turbine in a particular site can be determined by the power output ($P_{ave.}$) and capacity factor (C_f) [14].

Small scale wind turbine has been designed and utilized for different purposes in Nigeria, such as water pumping, battery charging, small scale enterprise electrification and experiments. The only large scale onshore wind turbine in Nigeria is located in Rimi Local Government Area of Katsina state, with an estimated output capacity of 10 MW [15].

Owing to the low wind speed characteristics in some locations in Nigeria, several works have been done in terms of wind turbine design modification, so as to help harness the available wind resource within the locations. Osadolor *et al.* [16], Carried out a research on the practical analysis of a small scale wind turbine in Auchi, Edo state. This research was focused on the design and construction of small wind turbine to generate 250 Watts of power at a rated speed of 6.5m/s. The result of the performance evaluation shows that the turbine is efficient for power generation.

This research is limited to the fact that the wind turbine produced cannot be used for high wind speed regions except the design parameters are altered to suit the respective locations. Similarly, further work was done on the development of low cost wind turbine generators for developing countries [17, 18]. This work was focused on developing suitable low cost generators for small wind turbine applications and the result showed that the developed generators performed better than the automotive alternator system. Thou, it was observed that the generators were not performing to their maximum capacity, hence proper design optimization was recommended. Ogunjuyigbe *et al.* [19], Worked on the dynamic performance of a wind-driven, self-excited reluctance generator to obtained the desired output voltage under a stochastic speed variation and varying load. The result obtained showed that despite the variation in wind speed and load, a suitable output voltage within preset limit was obtained and this further showed that this technology provides an effective and less expensive solution for output voltage control of wind-driven, self-excited reluctance generator in rural areas. Okechukwu *et al.* [20], this study was focused on the performance evaluation of the horizontal axis wind farm turbine rotor aerodynamic system, using blade element momentum theory required for power generation at the University of Port Harcourt. The result revealed that in order to meet the total power requirement of 21 MW in the university for an estimated period of 20 years, rotor blades of each of the wind farm turbines which are designed for 1.5 MW, wind speed of 17m/s, and for airfoil shape of NACA 2412, are desired.

Thou a lot of work has been done in small scale wind turbine modeling to serve domestic purpose, but the pressing need to supplement the nation's energy demand calls for large scale wind turbine installations. Onshore and Offshore wind turbines will provide large scale energy harvest if appropriate design parameters corresponding to the wind characteristics in a particular location is carefully selected. Ideally, the aerodynamic power in wind is given as [21]

$$\boldsymbol{P_{ae} = \frac{1}{2}\rho\pi R^2 V_{eq}^3 C_p\,(\theta_{Pitch,}\,\lambda)} \qquad (1)$$

where P_{ae} is the aerodynamic power extracted from the airflow,

$\boldsymbol{\rho}$ is the density of air which is usually 1.225 Kg/m^3,

$\boldsymbol{C_p}$ is the power coefficient representing the fraction of power in the wind captured by a turbine blade depending on the pitch angle $\boldsymbol{\theta_{Pitch,}}$ measured in degree and on the tip speed radius $\boldsymbol{\lambda}$.

The tip speed radius is given by the expression [22];

$$\boldsymbol{\lambda = \omega_{rot.}R/V_{eq}} \qquad (2)$$

where $\boldsymbol{\omega_{rot.}R}$ is the blade tip speed, $\boldsymbol{R}$ is the rotor radius and $\boldsymbol{\omega_{rot.}}$ is the rotor speed,

$\boldsymbol{V_{eq}}$ is the equivalent wind speed in m/s,

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$\boldsymbol{C_p} = 0.59$ which suggests that 59% of wind power is the maximum power that a wind turbine can exploit.

Equation (1) indicate that a wind turbine maximum power is a cubic function of the average wind speed.

The aerodynamic torque of the wind turbine is given as [23];

$$\boldsymbol{T_{ae}} = \frac{1}{2}\boldsymbol{\rho\pi R^3 V_{eq}^2 C_p}\ (\boldsymbol{\theta_{Pitch}}, \boldsymbol{\lambda}) \quad (3).$$

In order to obtain high aerodynamic power output, high wind speed is required so as to drive the turbine. Apart from the high wind speed resources available in the north, offshore wind will effectively drive the turbine for better output efficiency.

Considering the stochastic nature of wind i.e. occurs randomly, wind behavior in a particular site is better described using statistical models. Some among such models include but not limited to; Weibull distribution, Rayleigh distribution, Log Normal distribution, Exponential distribution, Gaussian and Inverse Gaussian distribution. Among the aforementioned probability distribution models, the most widely used Probability Density Functions (PDFs) correspond to the Weibull and Rayleigh distributions because they represent, with high precision, wind speed data from various geographical locations around the World [23].

Weibull distribution is characterized by two parameters known as the shape (k) and scale (c) parameters which gives a good prediction of the energy output of a particular location. In other words, Rayleigh distribution is a modified form of Weibull distribution with a constant shape parameter of 2 and varying scale parameter. One of the limitations of Weibull distribution is its low response to low wind speed values.

3 Challenges Hindering the Prospect of Wind Energy Technology in Nigeria

Some among the several challenges militating against the prospect of wind energy technology in Nigeria includes inadequate research and technology in the field of wind energy, poor government motivation on the idea of wind energy technology, problem of land ownership and acquisition in Nigeria to mention a few, hence government at all level should work together to address issue of wind energy technology, sensitization of local community on the advantages of this initiative, developing a very good business model to attract willing investors and private sectors and as well incorporate wind energy technology into the nations independent power project plan. Synergizing the aforementioned will go a long way in promoting wind power generation technology in Nigeria.

4 Conclusion

This study reviews previous work done on wind energy technology in Nigeria and as well emphasizes on the possibility of harnessing both onshore and offshore wind in Nigeria, for power generation. In addition to the wind resources available on land, more and efficient wind resources are available in offshore sites especially in the south-south, south-east and south-west part of Nigeria. Thou a lot of researches have been done, ranging from analysis of several locations for wind power generations, logistic and cost analysis of wind energy conversion systems to development and design of small scale wind conversion systems for power generations, but wind as a renewable energy source, is not utilized to its full potential in Nigeria. The Nigerian Metrological Agency should have buoy systems on offshores water bodies for wind speed measurement, multi-criteria evaluation of prospective cite should be done to fully ascertain that the location is really suitable for windfarm installation, appropriate cost and logistic analysis should be carried out and finally, Nigeria should include windfarm technologies in her renewable energy policies and masterplan.

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