Assessment of Wind Potential Energy at Height 100 m in Minna, Niger State, Nigeria

Moses Abiodun Stephen   Oyedum Onyedi David   Oyewumi Emmanuel Babatunde
Department of Physics, Federal University of Technology Minna, P.M.B. 65 Minna, Niger State, Nigeria

Abstract
The reliance of a developing nation like Nigeria on hydro-electricity over time has led to power shortage which has hampered her economic and technological advancement because of its seasonal variation. The use of fossil fuel will not also be a better alternative since it is not environmental friendly. However, wind energy is free, clean, cheap and does not contribute to acid rain or global warming. The aim of this research is to carry out an assessment of wind potential in Minna, Niger State, Nigeria for power generation. The characteristics of the wind speed and energy potential in Minna, were examined using daily wind speed and direction data of 2 years, obtained using a metrological instrument; Davis 6162 Wireless Vantage Pro2 positioned at 100 m height. The collected data was analysed statistically and summarised in a simple and concise manner. The results show that the most probable wind speed was 0.4 ms^{-1} with extractable energy density of 25.04 Whm^{-2} while the wind speed corresponding to the maximum energy was 10.70 ms^{-1} delivering 45.96 kWh of energy. The average of the annual wind speed was 10.35 ms^{-1} which produced energy of 38.03 kWh. Though the average wind speed value revealed that the wind is suitable for wind-electric generation but has a low frequency, hence the power generation will do well for irrigation purposes. The prevailing wind direction was in the North-East direction with 14.84 % of the wind direction frequency. So a wind station will be more efficient if it is stationed in this predominant North-East direction.
Keywords: Wind speed, wind direction, energy density, power, electricity
DOI: 10.7176/APTA/76-01
Publication date: March 31st 2019

1.0 Introduction
Over the years, the applications of wind power has grown tremendously to such as operating wind powered generators in various sizes and ranges for battery charging at isolated residences, electrification of farm sites and irrigation. In fact, wind powered generators are now connected to the electric power grids for distant use of power and regular electrical works. However, today, about 1.6 billion people predominantly in the developing nations still have no opportunity to access commercial energy as a result of its exponentially growing demands (UNDP, 2007a and b).

The problem of obtaining a sustainable energy supply to drive the economic developments is a global "headache". Nigeria with a population of over 140 million depends heavily on hydropower for electricity supply (Julia *et al*., 2008). This large growing population power demands keep growing day by day without the available energy generation to meet it. Niger State which is the power state of Nigeria has been struggling to meet the needs of her state engulfed with epileptic power supply. Meanwhile other sources of energy exist such as burning of fossils, biogas, crude oil, coal, etc. but the environmental effects such as pollution, greenhouse effects, etc. result from these sources, hence the need for an alternative energy source. The source of wind power is free, cheap, exclusively pollution free and renewable. So an evaluation of wind potential in Minna will go a long way in providing adequate information about the capacity of the wind in generating wind energy for the city and contribute immensely to Niger state wind Atlas. Therefore, this research is targeted at assessing the available wind resources for electric power generation in Minna, Niger state, located in the North-Central part of Nigeria.

2.0 Methods of Evaluating Wind Potential Energy
To investigate the feasibility of the wind energy resources at any site, there are basically two ways. The first and the most accurate method to calculate wind power potential is based on measured values that are recorded at meteorological stations. The second method is by using probability distribution functions. In this work, the assessment of wind potential energy is based on the measured values obtained using metrological instrument.
Using the experimental approach, the wind energy is therefore the kinetic energy of air in motion. The kinetic energy of the wind is given as (Cheremisinoff, 1979):

$$K.E = \frac{1}{2}\rho v^3 t$$

where;

        ρ is the density of air.
        v is the velocity of the wind.
        t is the time during which the wind transverse the surface.

Because there is no such system with 100% efficiency, then the maximum energy that can be recovered from a system performing optimally is restricted by the coefficient of performance known as Betz's limit (16/27 = 0.593). Hence for a wind turbine system about 59.3% of the theoretical energy can be possibly extracted (De Renzo, 1979).

3.0 Materials and Method

This study was carried out using the data obtained from a metrological instrument; Davis 6162 Wireless Vantage Pro2. The equipment is a state-of-the-art device that has the capacity to measure a wide variety of weather and climate parameters. It is made of three major components: the integrated sensor suit (ISS), wireless console and a solar panel (with an alternative power source).

The ISS houses sensors for measuring atmospheric parameters such as temperature, pressure, relative humidity, solar radiation, UV index and dose. The fixed measuring method by a high tower is employed for the measurement with the ISS positioned 100 m on the tower. A wind vane and an anemometer are also attached for measuring wind direction and speed respectively. The sensor interface module (SIM) coupled to the ISS contains electronics device that measures and stores the measured variables. The output of the SIM is transmitted to the console via the SIM Antenna, the data logger antenna attached to the console then intercepts the transmitted information. Figure 3 shows the pictorial diagram of the integrated sensor suit.

Figure 3: Integrated sensor suit (ISS)

Figure 4 reveals the front view of the console and it was kept indoor. The measured values received by wireless connection are logged in to the console by the data logger. This result is displayed and stored in the console where it was downloaded in to an external device for analysis.

The instrument was stationed at a height 100 m on the Nigerian Television Authority (NTA) transmitting mast at Tunga, Minna, Niger State (9.60970°N, 6.55862°E) which is about 150 m tall (Figure 5).

The measurements were taken twenty four hours each day beginning from 0.00 hour local time at every thirty minutes interval.
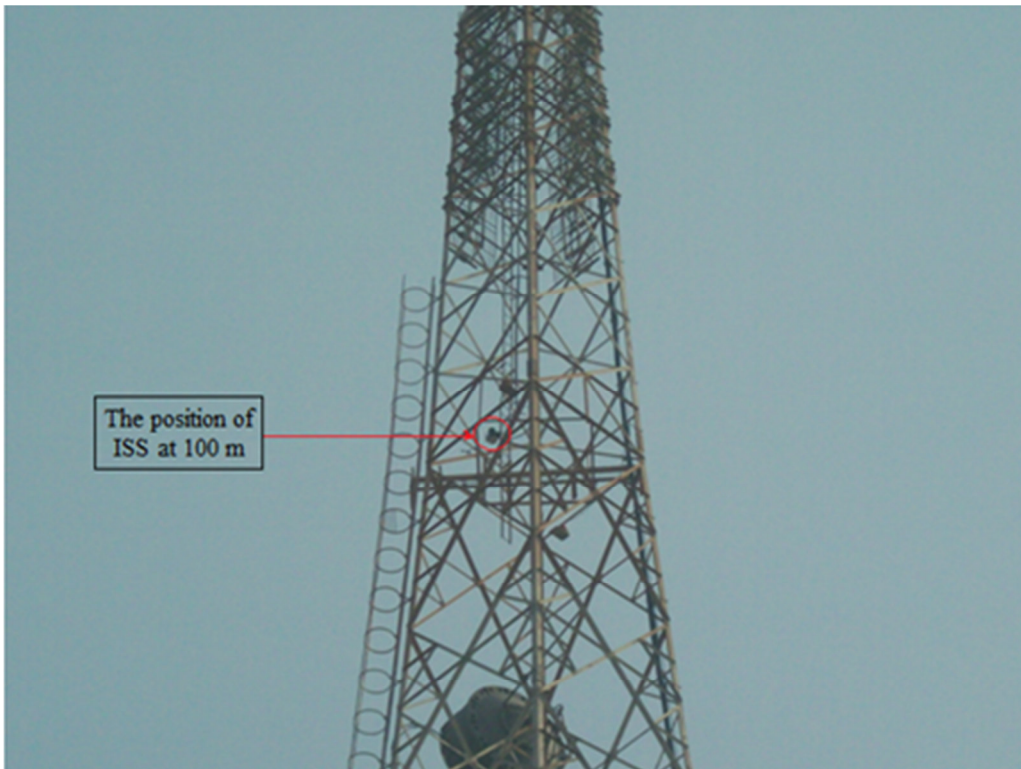

Figure 4: The Console.

Figure 5: Communication mast showing the position of the ISS at 100 m height.

3.1 Data Analysis

Two years (2008-2010) data was obtained using the metrological instrument for daily wind speed and wind direction. This was processed and analysed using computer spread sheet program. The descriptive statistics was used for the data analysis in order to summarise the collected data in a simple and concise manner. The wind direction was first converted to 16 cardinal points format for easy manipulation, then the data was sorted out into months and years with missing data in October, after which the frequency of the wind speed and wind direction were determined.

Because wind has relatively homogeneous characteristics within a month, most of the wind designs system assessments are carried out on a monthly basis, although monthly mean wind speed may not reveal a reasonable amount of wind energy obtainable in a particular area. Therefore, daily and even hourly variations must be put in to consideration, though this is more tedious to analyse due to unpredictability of the wind. As a result of this, often times wind assessment is based on monthly wind speed (Abdul *et al.*, 2014).

The data were used to estimate the monthly mean wind speed, percentage and cumulative frequency of the wind speed, energy density of the wind speed, monthly wind energy and the percentage frequency of the wind directions.

4.0 Results and Discussion

Figure 6 shows the variation of the monthly mean wind speed across the year. The highest mean wind speed was obtained in January, 4.9 ms^{-1} while the lowest value was obtained in November, 1.3 ms^{-1}. Minna, being in the northern part of Nigeria, the month falls within the dry season when heavy wind is usually experienced. Since the wind potential energy is proportional to the third power of the wind speed (STEP, 2015), consequently, the highest percentage of the wind energy will be concentrated in January while the lowest percentage in November. The peak mean wind speed is of great advantage because hydro-electricity power can be supplemented by wind power since the water level for hydro-power generation would experience a high fall at this period.

For water pumping applications, cut-in wind speed for viable utilization has been put between 2.2 ms^{-1} and 3.1 ms^{-1} (Youm *et al.*, 2005). Hence, wind powered irrigation projects will experience a tremendous impact during this period in Minna and its environs. The minimum value in November has shown consonance with the result obtained for Southern part of Nigeria (Nnawuike and Emmanuel, 2014).
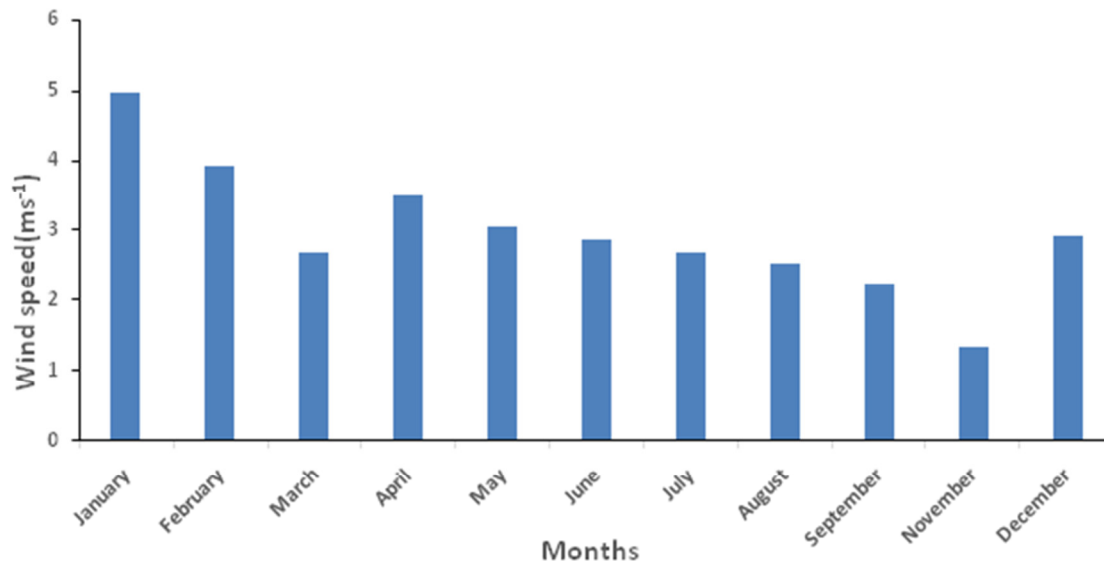
Figure 6: Monthly mean wind speed

Figure 7 depicts the percentage frequency of wind speed. From the figure, it is obvious that the most probable wind speed is 0.40 ms^{-1}. This corresponds to the most frequent wind speed experienced in the year. The effect of this wind value can be better explained from Figure 8 which depicts the wind speed cumulative frequency. Since the minimum cut-in wind speed for viable utilization, in water pumping, have been put at 2.2 ms^{-1}, then only 54.8% of the wind speed frequency will be useful. So, no wind turbine will operate at speed lower than 2.2 ms^{-1} as it cut-in speed (Premono *et al*., 2017). The frequency distribution also shows that there is no zero wind speed which implies that there is no calmness throughout the entire year in Minna.
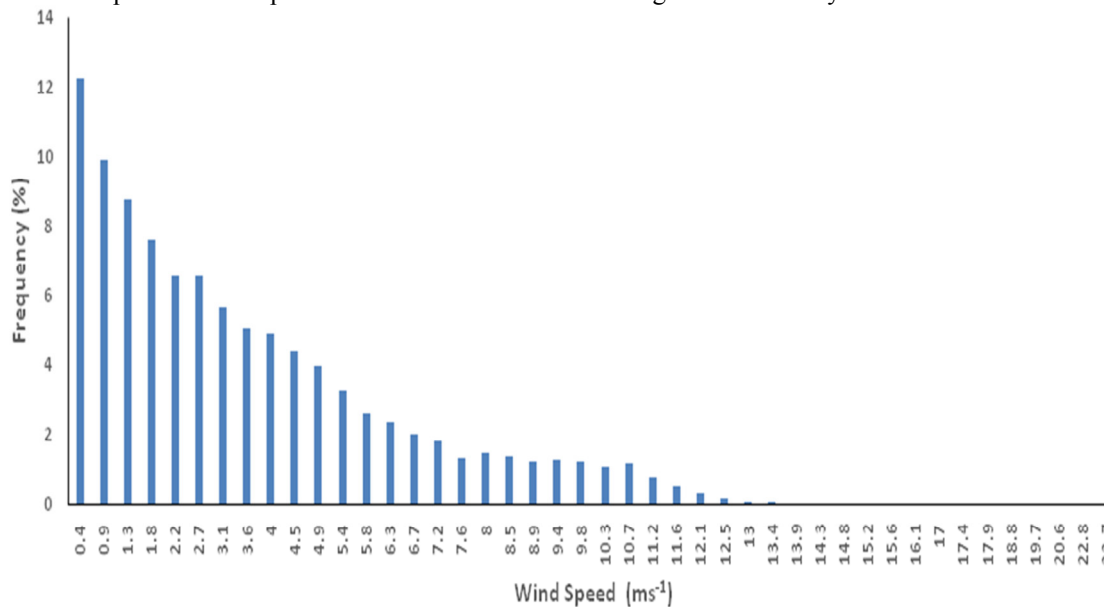

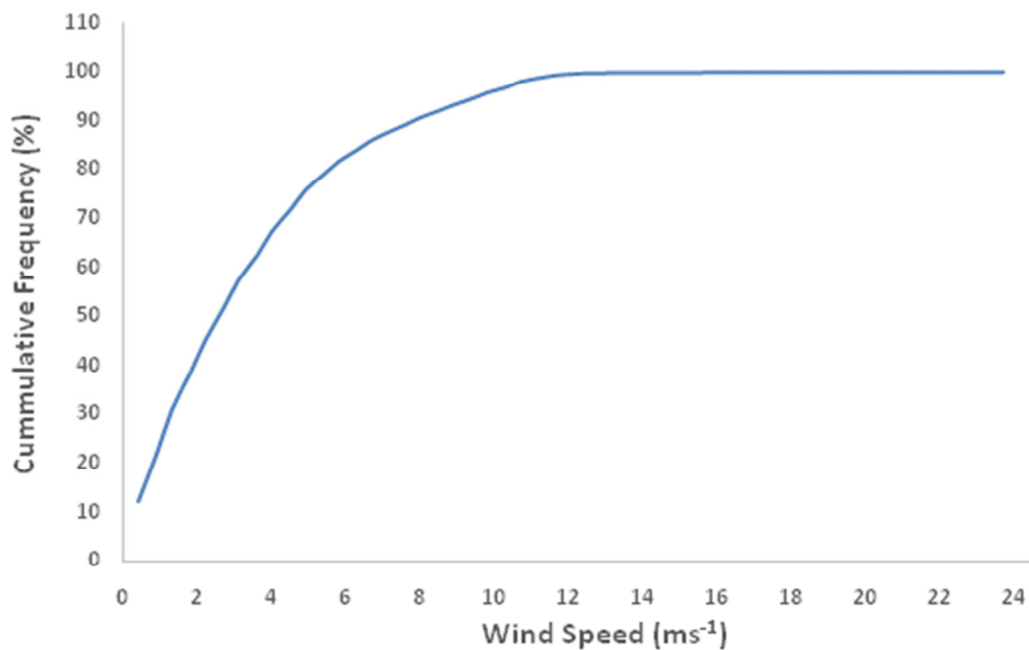
Figure 7: Wind speed frequency

Figure 8: Wind speed cumulative frequency

Figure 9 shows the energy density of the wind speed; it reveals that the energy density of the most probable wind speed is 25.04 Whm^{-2}. The wind speed corresponding to maximum energy is 10.70 ms^{-1} with energy density 45.96 $kWhm^{-2}$. This wind speed value is an essential value in estimating the wind turbine design or rated wind speed.

Previous research works have shown that wind turbine system functions most ably at its rated wind speed. Consequently, it is required that the optimal wind speed carrying maximum energy and the rated wind speed should be as close as possible (Mathew *et al.*, 2002). The annual average wind speed measured is 10.35 ms^{-1}, generating energy density of 38.03 $kWhm^{-2}$. This value is high compared with the values obtained by other researchers' in Nigeria (Nnawuike and Emmanuel, 2014). One of the factors responsible for this is the high height at which the data were measured. This is expected since wind speed increases with altitude on the earth surface (Rogers, 2009). In general, the annual mean wind speed of 6 ms^{-1} is necessary for utility-scale wind power plant (Youm *et al.*, 2005). The obtained value is far above this stipulated value but the frequency is very low.
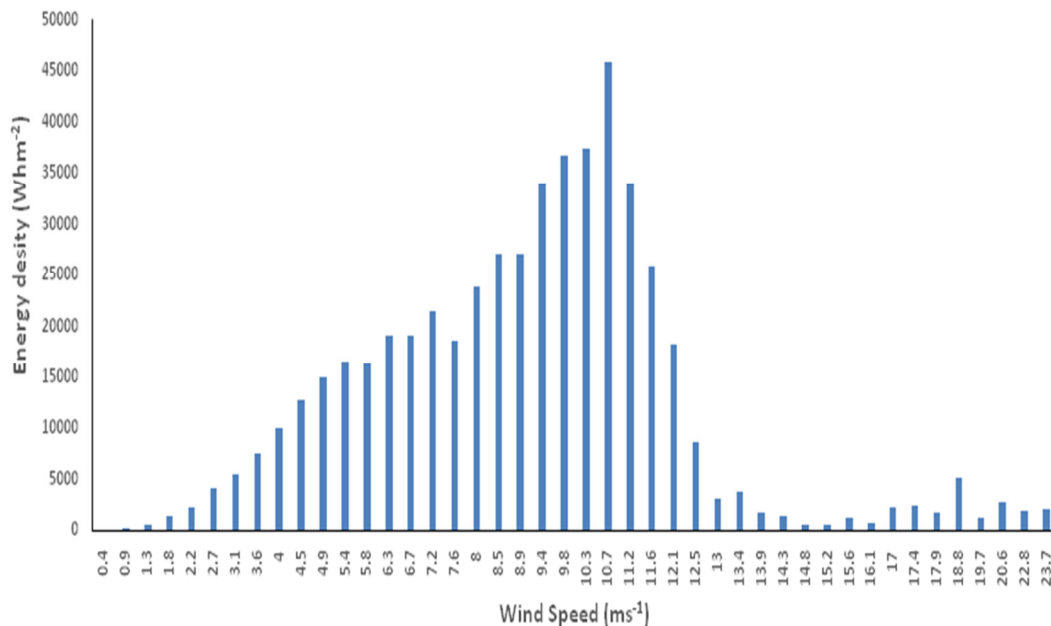

Figure 9: Wind energy density

Figure 10 reveals the percentage of the total energy available in each month of the year in Minna. It can be seen that about 12.39% of the total energy is concentrated in the month of December, 33.67% in January and

15.15% in February. This implies that 61.21% of the energy generated is concentrated within December and February, while the remaining 38.79% will be available for the remaining months of the year. The effect of this is that more power will be available within these months and irrigation of farm land can be highly guaranteed for agricultural purposes. The possibility of having supply within September and November is very low due to insignificant amount of energy available within these months. So energy generated from other sources will be a better alternative for these periods.
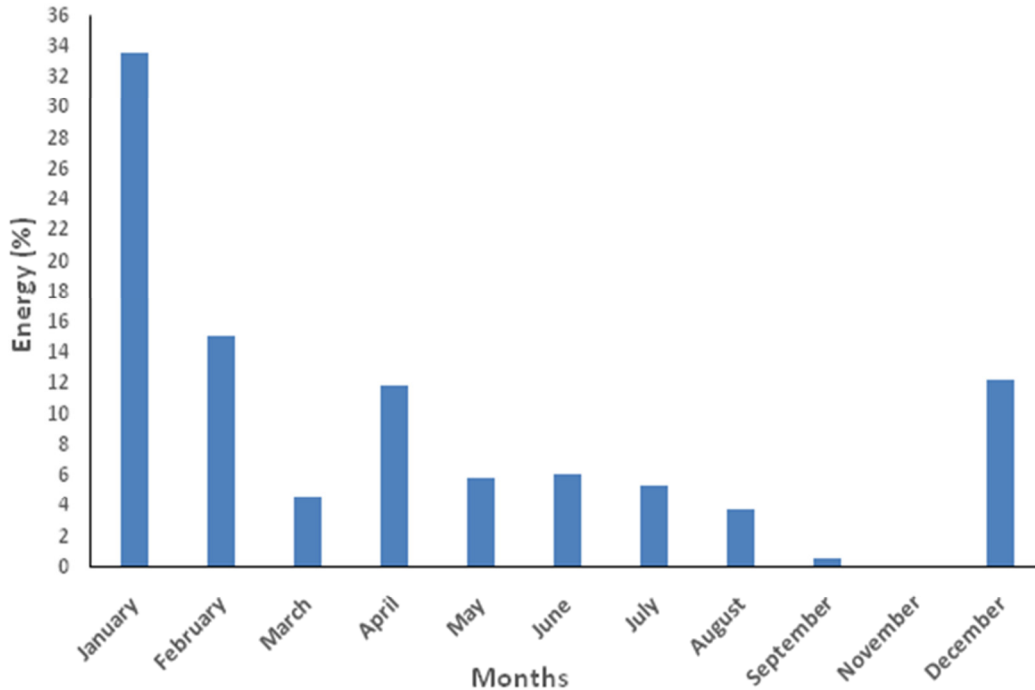

Figure 10: Monthly wind energy

Figure 11 shows the frequency of the wind direction. From the figure, it obvious that the prevailing wind direction is in the North-East direction with about 14.84 % of the wind direction frequency while the least is in the south-south-eastern direction with 1.84% of the wind direction frequency. So it will be preferable for maximum wind energy generation that the wind turbine is stationed in this predominant North-Eastern direction.
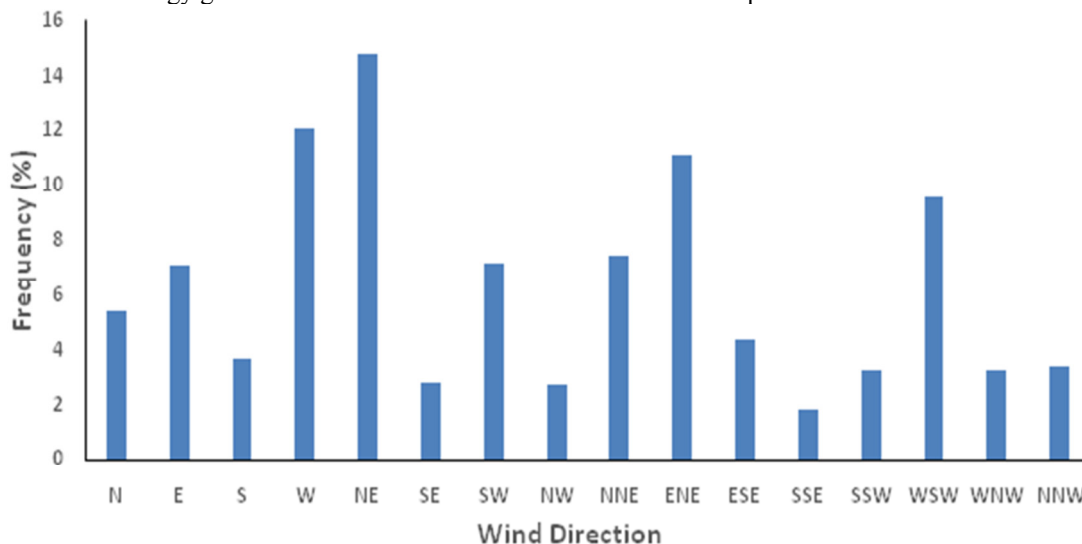

Figure 11: Wind direction frequency

5.0 Conclusion

The main objectives of this research are to: assess the wind characteristics in Minna, estimate the monthly and annual wind energy density and determine the prevailing wind direction in Minna. So at the end of this study, it was observed that, the annual average wind speed measured is 10.35 ms^{-1} and a power of 38.03 kW could be extracted. The average wind speed is above the minimum speed, 6.0 ms^{-1} needed for wind-electric generation,

but the frequency is very low, therefore the power generated will do well for irrigation purposes. Furthermore, 61.21% of the energy generated is concentrated within December and February, while 38.79% will be available for the remaining months of the year and since the demand of water for irrigation is seasonal, fortunately, the windy season coincides with the dry season.

More also, the prevailing wind direction is in the North-East direction with about 14.84 % of the wind direction frequency while the least is in the South-South-East direction with 1.84% of the wind direction frequency. So, it is recommended that a wind station is positioned in this predominant North-East direction for maximum wind energy generation.

References

Abdul, K. A., Mohammad, G. R. and Talal, Y. (2014). Statistical diagnosis of the best Weibull methods for wind power assessment for agricultural applications. *Energies*, 7, 3056-3085; doi: 10.3390/en7053056

Cheremisinoff N. P. (1979). *Fundamentals of wind energy*, 2nd Ed. Ann Arbor, MI, Ann Arbor, Science Publisher Inc.

De Renzo Editor D. J. (1979). *Wind power: Recent developments*. Noyes Data Corporation.

Julia K., Nick H., Kyle M. and Allison R. (2008). The energy crisis of Nigeria: An overview and implications for the future. Available: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwjU1qWT1pzaAhUhb5oKHSuuBDoQFgglMAA&url=http%3A%2F%2Ffranke.uchicago.edu%2Fbigproblems%2FEnergy%2FBP-Energy-Nigeria.pdf&usg=AOvVaw3D0Vw3R45XhI1BcVs7Tr3t

Mathew, S., Pandey, K. P. and Kumar, A. V. (2002). Analysis of wind regimes for energy estimation. *Renewable Energy*, 25, 381-399. http://dx.doi.org/10.1016/S0960-1481 (01)00063-5.

Nnawuike, N. and Emmanuel, C. O (2014). Assessment of wind energy potential as a power generation source in five locations of South Western Nigeria. http://dx.doi.org/10.4236/jpee.2014.25001.

Premono, B. S., Tjahjana, D. P. and Hadi, S. (2017). Wind energy potential assessment to estimate performance of selected wind turbine in northern coastal region of Semarang-Indonesia. AIP Conference Proceedings 1788, 030026; doi: 10.1063/1.4968279

Rogers J. (2009). *Wind energy explained: Theory, design and application*. 2nd ed. Chichester: Wiley.

Sustainable Technology Evaluation Program [STEP] (2015). Technical assessment of small wind turbine power generation. *Renewable Energy Series*. Available: https://sustainabletechnologies.ca/app/uploads/2015/09/WindTurb_TechBrief_Sept2015.pdf

United Nations Development Programme (UNDP) (2007a). Mainstreaming access to energy services: Experiences from three African regional economic communities. UNDP Rural Energy for Poverty Reduction Programme, 2007-05-01.

United Nations Development Programme (UNDP) (2007b). A review of energy in national MDG, Reports by Takada, M., and Fracchia, S. UNDP Publications, New York, NY, USA. Available: http://www.energyandenvironment.undp.org/undp/indexAction.cfm?module=Library&action=GetFile&DocumentAttachmentID=2088

Youm, I., Sarr, J., Ndiaye. A. and Kane, M. M. (2005). Analysis of wind data and wind energy potential along the northern coast of Senegal. *Rev.Energ. Ren*. 8, 95-108.