Stand-alone wind energy systems for power generation in Nigeria

Uguru-Okorie D. C.*
The Department of Mechanical Engineering, Landmark University, Omu Aran, Kwara State, Nigeria.

Kuhe A
University of Agriculture Makurdi, Department of Mechanical Engineering.

Ikpotokin I.
The Department of Mechanical Engineering, Landmark University, Omu Aran, Kwara State, Nigeria.

Abstract-The realization of a stable and adequate electricity generation and supply has been a serious challenge in Nigeria, especially in the remote areas of the country. The interest of the government and private firms has been on the installation of power plant running on fossil fuel while neglecting the renewable energy resources the country is endowed with. To achieve adequate generation and supply of electricity to the populace in urban and remote areas, appropriate stand-alone wind energy systems are recommended for installation in wind sites, on buildings and communication masts based on the wind pattern of the various locations in the country. A brief review of the wind potentials of the various locations in the country is done. A review on the HAWT and the various configurations of the VAWT is done with emphasis on its merits and demerits and also a brief review on building-mounted wind power systems is done, with recommendations on appropriate wind energy systems for installation.

Keywords: Building-Mounted, Electricity, Nigeria, Wind Energy, Wind Energy Systems

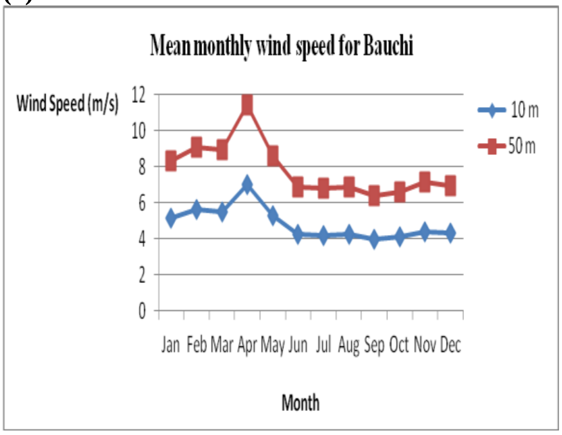
I. INTRODUCTION

The processes of industrialisation and economic development require energy. The demand for energy is expected to increase at a faster rate in upcoming years, partly due to the exponential growth of the world's population. This has led to a huge supply–demand gap in the power sector. The scarcity of conventional energy resources, rise in the fuel prices and harmful emissions from the burning of fossil fuels has made power generation from conventional energy sources unsustainable and unviable [1]. This has led to the drive to explore unconventional energy resources to meet these demands. Energy resources have been divided into three categories: fossil fuels, renewable resources and nuclear resources [2]. Nigeria being endowed with the three categories of energy resources still battles with the problem of inadequate electric power supply in regions connected to the national grid while the remote areas which makes up over half of the regions of country are without electric supply due to the challenges involved in connecting them to the national grid and inadequate power generation. Remote areas here are not limited to locations that are far away from the national grid network. Any site for which the grid extension is not economical compared to the alternative options can be classed under this region. As such mountainous, river-delta regions and isolated desert locations could all fall into this category [3].

Over the years, successive governments have invested in the construction of power plants that run on fossil fuel and compressed natural gas [4,5] in a bid to increase electric generation and supply. According to Musiliu [6] the installed capacity of the power plants in Nigeria as at 2011 was 6000MW with about 40% generation output. Efforts by the government to improve the power generation and supply in the country has always suffered setbacks as a result of inadequate supply of fuel for the running of the plants which has been majorly management and security issues. The fact still remains that even if all the installed power plants where in full production output, the total output will still be inadequate for the industries, transport sector, health sector, homes etc. Lately, the government has indicated plans to build nuclear reactors for the purpose of power generation without considering the risks involved. Nuclear energy can cause serious problems for the environment [7-9] and human health; for example, those caused by nuclear accidents such as Chernobyl and Fukushima in 1986 and 2011 respectively [10,11]. While countries of the world move toward environmental friendly power generation, Nigeria has its own part to play in ensuring our means of energy generation does contribute to ensuring a clean environment.

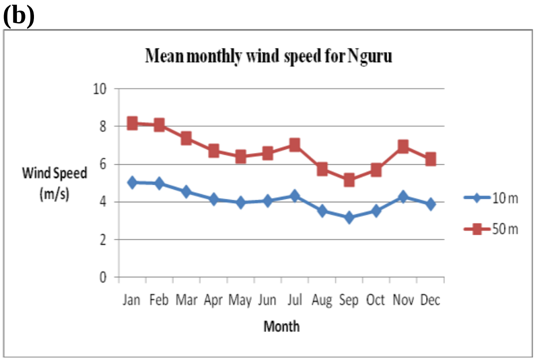
Wind energy is a major renewable energy generation source for remote areas. Over the years, research has been carried out to assess the renewable energy potentials of Nigeria. Lots of scholarly articles have been published on the country's renewable resources like (i) Solar (ii) Wind (iii) geothermal (iv) hydro (v) Biomass [12-17]. According to Bugaje, [18] only over a- third in Nigeria have access to electricity, in spite of the renewable energy resources the country is endowed with. If there will be a solution to the country's energy problem in the nearest future, with the populace both in remote and urban areas having access adequate electric supply, decentralized stand-alone renewable energy systems must be invested into by the government, private companies and individuals.

(a)

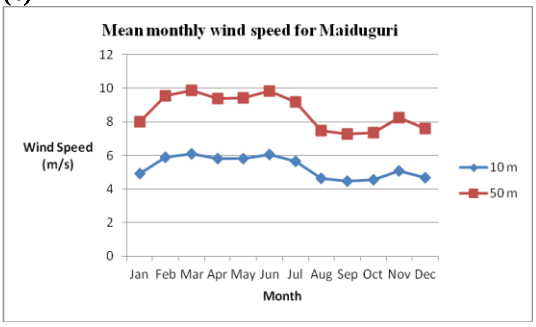


While a lot of research has been done on the analysing the renewable energy resources the country is endowed with, little has been done in recommending appropriate wind energy systems for various regions depending on the wind pattern. This paper looks briefly into the wind potential of some locations in Nigeria and suggests appropriate energy generation systems for harnessing these renewable energy resources by reviewing briefly existing wind energy systems and also recommends a decentralized approach for energy generation noting that more than over half of the Nigerian populace live in the remote areas where there is little or no access to electricity [18].

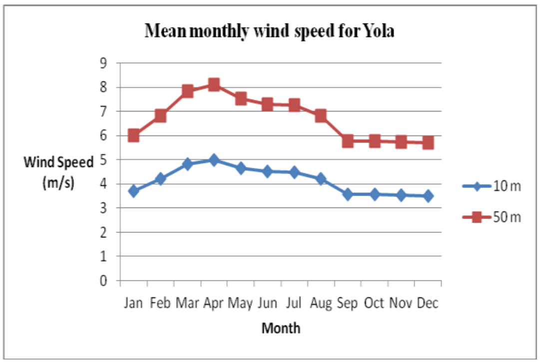
(b)



(c)



(d)



(e)

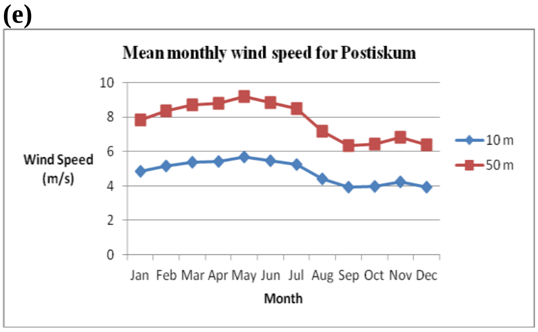


Figure1. The measured and estimated wind velocities at a hub height of 10 m and 50 m respectively for locations [14] (a) Bauchi (b) Nguru (c) Maiduguri (d) Yola (e) Postiskum

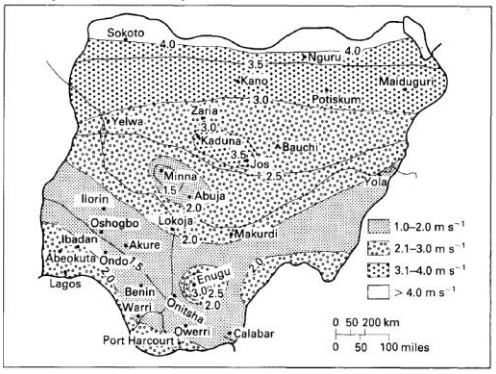


Figure 2. Regional distribution of annual wind speeds (m/s) at 10 m height [4]

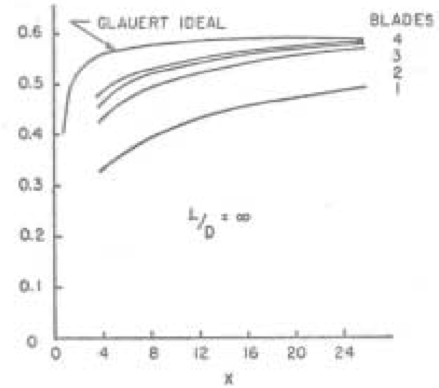


Figure 3. Aerodynamic efficiency versus tip-speed ratio as affected by blade number [24].

II. WIND ENERGY POTENTIAL IN NIGERIA

Wind energy is one of the renewable energy resources Nigeria is endowed with. It is inexhaustible, free and clean. Harnessing it for power generation will contribute greatly to ensuring a reduction in the emission of greenhouse gases which are major contributors to global warming which effect has been attributed to climatic changes as evident in flooding and desert encroachment. According to Turbines info, [19] for every kilowatt hour of electricity produced by wind energy or other green means, approximately 1.5 pounds of carbon is prevented from going into the atmosphere if that electricity had been sourced from coal fired power plants.

Some parts of Nigeria are endowed with strong wind conditions like the coastal areas and the offshore States namely Lagos, Ondo, Delta, Rivers, Bayelsa, Akwa-Ibom, the inland hilly regions of the North, the mountain terrains in the middle belt and the northern part of the country [12]. Accurate wind resource assessment is very important and must be well understood for harnessing the power of the wind since wind speeds and directions present extreme transitions at most sites, thus requiring detailed study of spatial and temporal variations of wind speed values [13]. Over the years, several journal articles have been published on the wind potentials in regions in Nigeria.

Olayinka S.O., [14] evaluated the wind speed data over 37 years from five meteorological stations in the North-East geo-political zone of Nigeria and found out that Bauchi, Maiduguri, Potiskum, Yola and Nguru had a monthly wind speed ranging from 3.96 to 7.04 m/s, 4.49 to 6.10m/s, 3.92 to 5.68m/s and 3.18 to 5.04m/s respectively at a height of 10 metres as shown in Figure 1 with some other wind data in other parts of the North as shown in Table 1. Olayinka S. O, [14] went further to give analysis of the yearly probability distribution of wind in these five locations for the months of January, June and December. Ojosu and Salawu [17] and Mohammed et. al, [4] reviewed the wind potentials in various parts of the country and gave a statistical analysis of a 15 year data on the average wind speeds of the various regions. The country was divided into four regions based on the average wind speeds ranges of 1.0 – 2.0, 2.1-3.0, 3.1 – 4.0 and >4.1m/s in twelve sites as shown in figures 2. Oyedepo, [15], gave analysis of the renewable energy potentials in some cities in Nigeria, with the analysis of the annual wind speeds and wind power densities in Port Harcourt and Sokoto and he also gave the power estimates of 24.5MWh/year, 25.7MWh/year, 97MWh/year and 50MWh/year for a 25m diameter wind turbine operating at a 30% efficiency in Port Harcourt, Lagos, Sokoto and Kano respectively. He decried lack of investment into harness energy from wind inspite of the large amount of potential wind energy in the Northern and coastal areas of the country. From the data gathered over the years on the mean wind speeds in the various regions in the country, it is seen from Figure 2 that over two-third (2/3) of the country have a mean wind speed >2.0m/s throughout the year; which, if properly harness, could solve or go-a-long way in solving the electricity crisis in Nigeria.

Inadequate information on the appropriate wind energy systems to harnessing this renewable energy resource may have contributed to the lack of interest on the part of government, private establishment and individual to explore this freely available renewable natural resource. Existing wind energy systems have factors that make them inappropriate for installation/operation in an environment. This has prompted the author to briefly review existing wind energy system and make recommendation on the best fit for various locations in the country based on the wind speed pattern.

III. WIND ENERGY SYSTEMS

Wind energy systems are mechanical systems designed to convert kinetic energy from wind for electric energy generation [20,21], pumping water for irrigation and milling operation as is seen in windmill. A renewable energy system which converts the kinetic energy from the wind into electricity is called a wind turbine.

Mathematically, the useful wind power extracted by a wind turbine rotor is given as [22]:

$$P = \frac{1}{2}\rho A V^3 C_p \qquad (1)$$

Where:

P = wind power in Watts, V = wind velocity in m/s, A = rotor swept area in m^2, ρ = density in Kg/m^3 and C_p = Power coefficient.

Wind turbines are classified into two broad ranges:

- The Horizontal Axis Wind Turbine

- The Vertical Axis Wind Turbine

Over the years much interest has been focus on the HAWT because of its advantage of a higher efficiency over the VAWT but its limitations and improvements on the performance of the VAWT have aroused interest in VAWTs.

Horizontal Axis Wind Turbine (HAWT)

The Horizontal Axis Wind Turbine (HAWT) is a type of turbine that has the main rotor shaft and electrical generator at the top of a tower and may be pointed into or out of the wind. It has a rotor which rotates perpendicularly to the wind and its operation is lift based. A simple wind vane is used for small turbines while for larger turbine a wind sensor coupled with a servo motor is used to move the rotor in and out of the wind. The high speed two-bladed HAWT can have efficiencies as high as 47% power extraction from the wind [23]. For an efficient performance of the HAWT, the large wind turbine requires a mean speed of 5m/s while the smaller requires a mean speed of between 3 to 4 m/s [19].

The rotor of a HAWT could come as single-bladed, two-bladed, three-blade or multiple-bladed configuration. Tangler [24], reported that aerodynamic efficiency significantly increases from a one-bladed rotor to three-bladed and a further increase in the number of blades sacrifices the blade stiffness with a slight increase in aerodynamic efficiency as shown in Figure 3. The HAWT has been the leading type of wind energy system for installation in most onshore and offshore wind sites around the world. The merits and demerits of a HAWT are shown in Table 2.

Vertical Axis Wind Turbine (VAWT) configurations

The VAWT has the main rotor shaft arranged vertically. According to Islam et. al., [25], it is estimated that within the next 2-3 decades, the Vertical Axis Wind Turbine (VAWT) will likely to dominate the wind-energy technology. Existing VAWTs operations are either lift-based, drag-based or a combination as seen in the Darrieus, Savonius and Darrieus-Savonius configuration respectively [26]. The vertical axis wind turbine comes in various configurations with varying efficiencies, advantages and disadvantages. The earliest VAWT was the savonius in 1921 invented by the Finnish engineer, S. J. Savonius while Darrieus configuration was invented in 1931 [27]. Over the years modifications have been made on these turbines to improve its efficiency and operation and lately the configurations have been combined to produce a turbine of improved power coefficient of about 0.33.

Table 1

Seasonal variation of wind characteristics for six sites in Nigeria from 1971 to 2007 [4,14].

Location/season	Mean wind speed (m/s) at 10 m height	Average power density (W/m^2)	Monthly seasonal duration range
Gusau			
Rainy season	5.45	120.83	June-September
Dry season	6.42	207.31	October-May
Kaduna			
Rainy season	4.78	74.61	June-September
Dry season	5.52	126.7	October-May
Katsina			
Rainy season	7.96	391.31	June-September
Dry season	7.19	314.13	October-May
Kano			
Rainy season	7.81	371.03	June-September
Dry season	7.74	367.86	October-May
Bauchi			
Rainy season	4.39	80.37	June-September
Dry season	5.16	149.17	October-May
Potiskum			
Rainy season	4.02	46.21	June-September
Dry season	5.20	89.57	October-May

Table 2: Comparative study of HAWT and VAWT [25]

HAWT	VAWT
01 Rotating axis of the wind turbine remains horizontal, or parallel with the ground	Rotating axis remains vertical, or perpendicular to the ground
02 It is able to produce more electricity from a given amount of wind	It produces up to 50% more electricity on an annual basis versus conventional turbine with the same swept area
03 It is suitable for big wind application	it is suitable for small wind projects and residential applications
04 Comparatively heavier and not suitable for turbulent winds	Lighter and produce well in tumultuous wind conditions
05 HAWT only are powered with the wind of specific direction	Vertical axis turbines are powered by wind coming for all 360^0, and even turbines are powered when the wind blows from top to bottom
06 Not suitable to generate electricity from the wind speed below 6 m/s and generally cut out speed 25 m/s	Generates electricity in winds as low as 2 m/s and continues to generate power in wind speeds up to 65 m/s based on the model
07 They cannot withstand extreme weather conditions due to frost, freezing rain or heavy snow plus heavy winds in excess of 50 m/s	Withstands extreme weather such as frost, ice, sand, salt, humidity, and very high wind conditions in excess of 60 m/s
08 Birds are injured or killed by the propellers since they are not solid objects so the birds fly into the blades	Does not harm wildlife as birds can detect a solid object and can be seen aircraft radar
09 Most are self-starting	Low starting torque and may require energy to start turning
10 Difficult to transport and install	Lower construction and transport costs

The details of the design and performance of the various configurations of VAWT can be seen in [28,29]. In recent years interest in VAWT for commercial power generation has increased with the installation of the Darrieus type wind turbine, Eole in France in 1986 with a rated maximum power output of 3.8MW . Riegler [29-31] reported the design and test of a hybrid H-rotor (Giromill) VAWT by Ropatec AG, Italy which is self-starting, has a power rating of 6KW, a cut-in speed of 2 m/s and operated effectively at speeds of over 250km/h as shown in Figure 8a. He also claimed that for wind generation systems of rated power less than 10KW, VAWTs have significant advantages over HAWTs [32]. A German company, Neuhauser, also developed a VAWT of the H-rotor type turbine installed on a rooftop in Munich with a rated power of 40 kW. The Savonius rotor has also found its place in the application for electric power generation. Al-Bahadly [23] constructed a cheap Savonius rotor VAWT with an overall of 11.2% and stated some of the advantages of this type of VAWT configuration which includes: cheap to construct, simple to design and it serves as a stand-alone renewable electric generation system for homes. U. K. Saha, M. Jaya Rajkumar, [33] did a wind tunnel testing of various degrees of twist for a Savonius rotor blades and concluded that a blade twist angle of $\alpha = 12.5^{\circ}$ gave a better performance than a normal Savonius rotor as shown in figure 4.

The cost of tower as seen in the HAWTs is eliminated which make the maintenance and repair of this VAWT less difficult. While the HAWTs have higher efficiencies, the VAWTs have the following advantages as seen in Table 2 over the HAWTs. Additional advantages can be seen in [19,23,26,32].

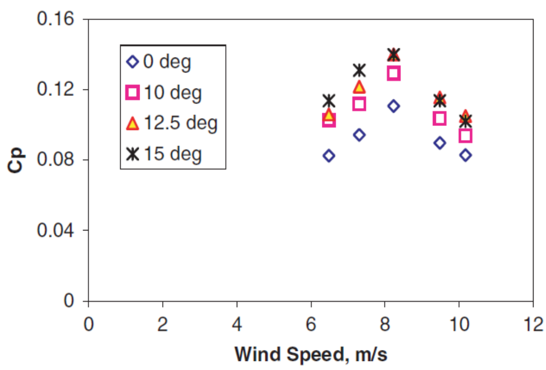


Figure 4. Variation of coefficient of performance with velocity for various twisted bladed rotors [33,34].

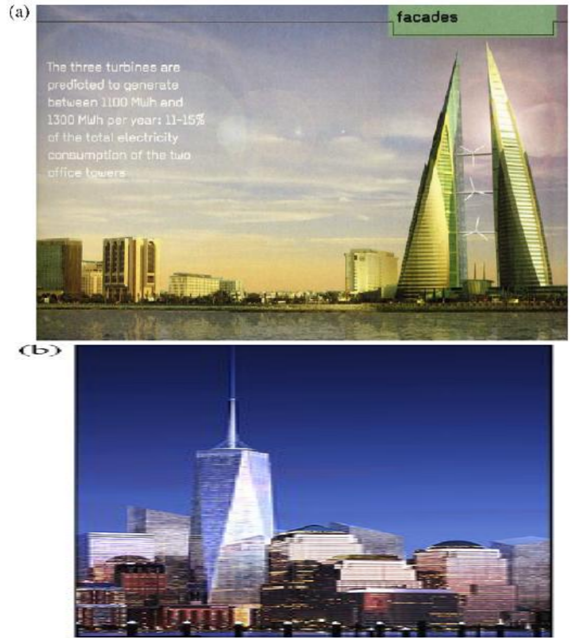


Figure 5. Building-integrated wind turbines (a) On Bahrain World Trade Center of Dubai and (b) Planned on rebuilt New York World Trade Center [38].

Figure 6. A 6.5 kW rated Gorlov type VAWT, with a height of 5 m and diameter 3m in Bristol [21].

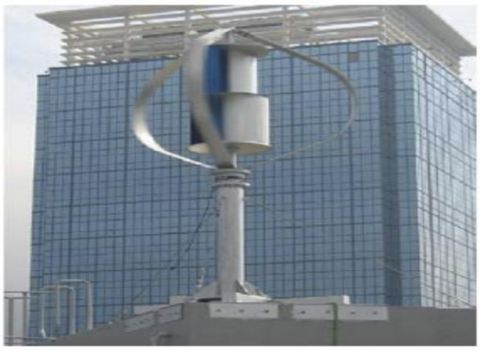


Figure 7. (a) 1.5kW VAWT [38]

Figure 7. (b) 1 kW HAWT [38]

Wind turbines on buildings and communication masts

In the drive to harness energy from wind in urban areas, both the HAWTs and VAWTs have been installed on communication masts, roofs and walls of builds for the purpose of generation of electric energy [35-37]. This approach has increased the profitability of the external surfaces which includes the roof and the wall which serve as enclosure and electricity generation has helped in the reduction of greenhouse gas emissions that would have been release to the atmosphere if the electric generation was from a power plant running on fossil fuel [32].

Lin Lu and Ka Yan Ip, [38] reported the integration of three large-scale wind turbines measuring 29 m in diameter, supported by bridges spanning between the complexes two towers as shown in figure 5; the rebuilding plans of the New York World Trade Center which will have wind turbines incorporated that will generate 20% of the building's electrical needs and a 1 kW horizontal axis and 1.5 kW vertical axis wind turbines installed on the roof of the EMSD headquarters building.

The near ground level of the components of the VAWTs gives it better stability on the roof of a building when mounted over the HAWTs owning to the requirement of a tower of length greater than the rotor radius for installation and this limits the capacity of a HAWT that can be installed. The moment developed as a result of the wind force on the tower height, the rotor and generator mounted on the tower could be detrimental to the structure of the building roof. In order to minimize the effect of mounting wind turbines on buildings,[32,36] proposed the use of higher numbers of low-power wind turbine.

In an urban environment, the buildings and its roof designs affect wind velocity and sudden changes in its direction and turbulence intensity and studies have shown that heights of buildings could enhance power by increasing the wind speed and wind power density by a multiple of between 1.5 - 2 and 3 – 8 respectively [32,35,38]. Efforts have been made by researcher to analyse the behaviour of the wind turbine these wind varying conditions. Eriksson et al.,[30] and Walker, [37] stated that VAWTs maybe more appropriate for urban scale, due to the following required in the HAWT: yaw, nacelle, blade construction, power control, aerodynamics and noise issues. Figures 5 to 7b show building mounted wind energy systems.

IV. ENERGY DISTRIBUTION AND STORAGE FOR WIND ENERGY SYSTEMS

Wind turbines and PV solar panels have an advantage of it being integrated into building and communication masts for electrical energy generation [1,35,37,39-44]. Wind generators installed on buildings, communication mast and wind farms sites, power ratings range from Watts to Megawatts. Wind turbine unlike solar panels generates electricity continuously both in the night and during the day as long as there is wind. It is a known fact that, in electricity consumption, there are always the peak and the off-peak periods [5,42]. During the off-peak period, there is always a need for the storage of the excess electricity generated. Grietus Mulder et al.,[42] stated the approach adopted by the German government in the management of electricity generated by the PV solar panels installed in private buildings and the consumption.

Installation of storage batteries in each building or communication mast with an installed wind turbine might not be cost effective, therefore the approach adopted by governments in some parts of the world will be the best. This entails having the various renewable energy systems being linked to the local gird with a central storage system. During the off-peak period, the excess electricity generated is fed back to the grid for storage and this in-turn compensate for shortage in supply by the turbines during the peak period. Therefore, installation of appropriate storage systems is required. E. S. Sreeraj, et. al.,[40] recommended a method to determine the battery capacities for isolated renewable energy systems. For appropriate battery selection for the battery bank, for the storage of excess electricity produced by renewable energy systems during the peak and off-peak periods, the references [45-55] give relevant information on the selection of appropriate batteries.

Figure 8a. A Ropatec AG hybrid VAWT [31].

Figure 8b. Hybrid VAWT generator (Darrieus and Savonius) [32]

I. DISCUSSION

From the data gotten from the metrological stations over the years [4,12-14], it is evident that various regions in Nigeria are endowed with wind energy resource which could be harnessed for electric power generation as shown in figure 1 and Table 1. The monthly wind data for six locations in the North-East geopolitical zone at 10 m showed that Bauchi, Maiduguri, Potiskum, Yola and Nguru had a monthly wind speed ranging from 3.96 to 7.04 m/s, 4.49 to 6.10m/s, 3.92 to 5.68m/s and 3.18 to 5.04m/s respectively at a height of 10 metres. Extrapolation to a hub height of 50 m as shown in Figure 1 of the mean wind speed gave the following ranges of 6.82 to 11.41 m/s, 7.27 to 9.89 m/s, 6.35 to 9.21 m/s, 5.70 to 8.10 m/s and 5.16 to 8.19 m/s. The extrapolation of the wind speed at the hub height of 50 m was done using the power law method which is the most commonly used to adjust wind velocity from one hub height to the other [14]. The power law is given as:

$$\frac{v}{v_0} = \left(\frac{h}{h_0}\right)^n \qquad (2)$$

Where h_0 is the reference height, h is the New height in focus, v_0 is the reference wind velocity, v is the required wind velocity at the new height in focus and n is the surfacce roughness coefficient which lies in the range of 0.05 to 0.5. A value of 0.3 was used for n in the extrapolation [14]. Using the power law, the extrapolation of annual mean wind velocity at a hub height of 50 m for the various regions of the country where obtained as 1.62 to 3.24 m/s, 3.04 to 4. 86 m/s, 5.02 to 6.48 m/s and over 6.5 m/s for regions with annual mean wind speed distribution of ranges 1.0 to 2.0 m/s, 2.1 to 3.0 m/s, 3.1 to 4.0 m/s and above 4 m/s at a height of 10 m as shown in Figure 1.

The regions with mean annual wind speeds of 5 m/s and above are viable regions for the installation of larger horizontal axis type wind turbines in wind farms far from residential areas [19] while the hybrid VAWT generators will as seen in figures 8a and 8b will be appropriate for windsite close to residential areas because of their advantage of lower noise production compared to the HAWTs and higher efficiency over the VAWTs.

In regions with with mean wind speed range of 2.1 – 3.0m/s at a hub height of 10 m and 3.04 - 4.86 m/s at a hub height of 50 m, hybrid VAWT generators and other VAWTs as shown in Figures [6-7b], will be appropriate because of their advantage of low cut-in speed and less operational noise, while small HAWTs could be installled on roof of buildings, regions with mean wind speeds of 2.1 m/s, hybrid VAWT generators and other types of VAWTs are more appropriate because of its advantage of low noise, acceptance of wind from all direction, efficiency in gusty wind, self-starting ability and low cut-in speed.

The VAWT installation has the advantage of low noise which makes it suitable to be mounted on buildings both in urban and rural areas and to be sited at wind sites closed to dwells as opposed to the large HAWT which its noise effects are considered before siting.

II. CONCLUSION

In this article, a solution to the electricity supply crisis in Nigeria has been proffered with emphasis on the harnessing of the wind energy, which is one of the renewable energy resources Nigeria is endowed with for the production electricity. A decentralized wind generation systems approach is recommended as a solution to making electricity available to urban and remote areas in Nigeria. Remote areas being classified as sites which the grid extension will not be economical compared to the alternative options can be classed under regions such as mountainous, river-delta regions and isolated desert locations could all fall into this category. The wind speed and wind energy of the potential at heights of 10m and 50 m in regions of the country based on 25 year data and 37 year data where reviewed briefly. The coastal areas and the offshore States namely Lagos, Ondo, Delta, Rivers Bayelsa, Akwa-Ibom, the inland hilly regions of the North, the mountain terrain in the middle belt and the northern part of the country were seen to have strong winds making them viable wind farm sites for large HAWT generators.

In the brief review done on wind energy systems, large HAWT generators were found to be appropriate for regions with strong wind speeds of 5 m/s and above at a hub height of 50 m, for wind farm sites located away from residential areas while the hybrid VAWTs were found suitable for wind farm sites close to residential areas because of its lower operational noise compared to the HAWT and higher efficiency compared to the VAWTs. For lower speeds regions and for installations on buildings and telecommunication masts, the hybrid VAWTs and the other types of VAWTs were recommended because of its advantage of low noise, acceptance of wind from all direction, efficiency in gusty/turbulent wind, self-starting ability, simplicity compared to the HAWTs, access to maintenance and low cut-in speed.

A centralized electricity storage bank was recommended againts the installation of battery systems for each of the wind energy systems because of its cost effectiveness.

REFERENCES

[1] Prabodh Bajpai, Vaishalee Dash. Hybrid renewable energy systems for power generation in stand-alone applications: A review. Renewable and Sustainable Energy Reviews **16**, 2926 – 2939 (2012)

[2] F. Manzano-Agugliaro, A. Alcayde, F. G. Montoya, A. Zapata-Sierra, C. Gil. Scientific production of renewable energies worldwide: An overview. Renewable and Sustainable Energy Reviews **18**, 134 – 143 (2013)

[3] I.M., Bugaje. Remote area power supply in Nigeria: the prospects of solar energy. Renewable Energy, **18**:491-500 (1999)

[4] Y.S. Mohammeda,n, M.W.Mustafa a, N.Bashir b, A.S.Mokhtar. A Renewable energy resources for distributed power generation. Renewable and Sustainable Energy Reviews, **22**, 257-260 (2013)

[5] Oseni, Musiliu O. An analysis of the power sector performance in Nigeria. Renewable and Sustainable Energy Reviews, **15**, 4765- 4774 (2011)

[6] Oseni, Musiliu O. Households' access to electricity and energy consumption pattern in Nigeria. Renewable and Sustainable Energy Reviews, **16**, 990- 995 (2012)

[7] Vinichuk M., Rosen K, Johanson KJ, Dahlberg A. . Correlations between potassium, rubidium and cesium (133Cs and 137Cs) in sporocarps of Suillus variegatus in Swedish boreal forest. Journal of Environmental Radioactivity, **102**(4), 386 -392 (2011)

[8] Galvan I, Mousseau T. A., Moller AP. Bird population decline due to radiation exposure at Chernobyl are stronger in species with pheomelanin-based coloration. Oecologia, **165**(4), 827-835 (2011)

[9] Kuchma O., Finkeldey R. Evidence for selection in response to radiation exposure: Pinus sylvestris in the Chernobyl exclusion zone. Environmental Pollution, **159**(6), 1606-1612 (2011)

[10] Toshihiro Wada, Yoshiharu Nemoto, Shinya Shimamura, Tsuneo Fujita, Takuji Mizuno, Tadahiro Sohtome, Kyoichi Kamiyma, Takkami Morita, Satoshi Igarashi. Effects of the nuclear disaster on marine products in Fukushima. Journal of Environmental Radioactivity, **124**, 246 – 254 (2013)

[11] Olivier Evrard, Pieter Van Beek, David Gateuille, Veronique Pont, Irene Leffevre, Bruno Lansard, Philippe Bonte. Evidence of the radioactive fallout in France due to the Fukushima nuclear accident. Journal of Environmental Radioactivity **114**, 54 – 60 (2012)

[12] Ohunakin, Olayinka S. Assessment of wind energy resources for electricity generation using WECS in Nigeria. Renewable and Sustainable Energy Reviews, **15**, 1968-1976 (2011)

[13] Ohunakin, Olayinka S. Wind resources evaluation in six selected high altitude locations in Nigeria. Renewable Energy **36**, 3273 – 3281 (2011)

[14] Ohunakin, Olayinka S. Wind resources in North-East geopolitical zone, Nigeria: An assessment of the monthly and seasonal characteristics. Renewable and Sustainable Energy Reviews, **15**, 1977-1987 (2011)

[15] Oyedepo, Sunday Olayinka. On energy for sustainable development in Nigeria. Renewable and Sustainable Energy Reviews, **16**, 2583- 2598 (2012)

[16] J. O. Ojosu and R. I . Salawu. A survey of wind energy potential in Nigeria. Solar & Wind Technology, **7**, 155-167 (1990)

[17] J. O. Ojosu and R. I. Salawu. An evaluation of wind energy potential as power generation source in Nigeria. Solar & Wind Technology, **7**, 663 – 673 (1990)

[18] Bugaje, I.M. Renewable energy for sustainable development. Renewable and Sustainable Energy Reviews, **10**, 603-612 (2006)

[19] Turbines Info. July 5, 2011. http://www.turbinesinfo.com/horizontal-axis-wind-turbines-hawt/ (2011). Accessed 28 September 2013

[20] Andersen, Per Dannemand. Review of Historical and Modern Utilzation of Wind Power. Wind Energy Department . 7 1, 2007. http://www.risoe.dk/rispubl/VEA/dannemand.htm (2007). Accessed 4 March 2012

[21] Wikipedia. September 25, 2013. http://en.wikipedia.org/wiki/Wind_turbine (2013). Accessed 25 September 2013
[22] Carrillo C., Obando Montano A. F., Cidras J., Diaz-Dorado E. Review of power curve modelling for wind turbines. Renewable and Sustainable Energy Reviews, **21**, 572 – 581(2013)
[23] Al-Bahadly, Ibrahim. Building a wind turbine for rural home. Energy for sustainable Development, **13**, 159- 165 (2009)
[24] Tangler, James L. The Evolution of Rotor and Blade Design." The American Wind Energy Association WindPower 2000. Palm Springs, California: U. S. Department of Commerce National Technical Information Service 5285 Port Royal Road Springfield, VA22161, (2000)
[25] M. R. Islam, S. Mekhilef, R. Saidur. "Progress and recent trends of wind energy technology." Renewable and Sustainable Energy Reviews, **21**, 456 – 468 (2013)
[26] Turbines Info. June 30, 2011. http://www.turbinesinfo.com/vertical-axis-wind-turbines/ (2011). Accessed 28 September 2013
[27] Rajat Gupta, Sukanta Roy, Agnimitra Biswas. Computational fluid dynamics analysis of a twisted airfoil shaped two-bladed H-Darrieus rotor made from fibreglass reinforced plastic (FRP) . International Journal of Energy and Environment, **1**(6), 954 (2010)
[28] Muhammad Mahmood Aslam Bhutta, Nasir Hayat, Ahmed Uzair Farooq, Zain Ali, Sh. Rehan Jamil, Zahid Hussain. Vertical axis wind turbine- A review of various configurations and design techniques. Renewable and Sustainable Energy Reviews **16**, 1926 -1939 (2012)
[29] João Vicente Akwa, Horácio Antonio Vielmo, Adriane Prisco Petry. A review on the performance of Savonius wind turbines. Renewable and Sustainable Energy Reviews, **16**, 3054 – 3064 (2012)
[30] Sandra Eriksson, Hans Bernhoff, Mats Leijon. Evaluation of different turbine concepts for wind power. Renewable and Sustainable Energy Reviews,12, 1419 -1434 (2008)
[31] Riegler, Hannes. HAWT versus VAWT: Small VAWT find a clear niche. July/August 2003. www.re-focus.net (2003). Accessed 25 September 2013
[32] Francisco Toja-Silva, Antonio Colmenar-Santos, Manuel Castro-Gil. Urban wind energy exploitation systems: Behaviour under multidirectional flow conditions- Opportunities and challenges. Renewable and Sustainable Energy Reviews, **24**, 364-378 (2013)
[33] U. K. Saha, M. Jaya Rajkumar. On the performance analysis of Savonius rotor with twisted blades. Renewable Energy, **31**, 1776- 1788 (2006)
[34] G. M. Joselin Herbert, S. Iniyan, E. Sreevalsan, S. Rajapandian. A review of wind energy technologies. Renewable and Sustainable Energy Reviews, **11**, 1117- 1145 (2007)
[35] Dursun Ayhan, Safak Saglam. A technical review of building-mounted wind power systems and a sample simulation model. Renewable and Sustainable Energy Reviews, **16**, 1040- 1049 (2012)
[36] Grauthoff, Manfred. Utilzation of wind energy in urban area - Chance or Utopian Dream. Energy and Buildings, **15-16**, 517 – 523 (1990/91)
[37] Walker, Sara Louise. Building mounted wind turbines and their suitability for the urban scale- A review of methods of estimating urban wind resource, **43**, 1852 – 1862 (2011)
[38] Lin Lu, Ka Yan Ip. Investigation on the feasibility and enhancement methods of wind power utilization in high-rise buildings of Hong Kong. Renewable and Sustainable Energy Reviews, **13**, 450 – 461 (2009)
[39] A. Glass and G. Levermore. Micro wind turbine performance under real weather conditions in urban environment. Building Services Engineering Research and Technology, **32**, 245 (2011)
[40] E. S. Sreeraj, Kishore Chatterjee, Santanu Bandyopadhyay. Design of isolated renewable hybrid power systems. Solar Energy, **84**, 1124 – 1136 (2010)
[41] Erich J. Plate, Harald Kiefer. Wind loads in urban areas. Journal of Wind Engineering and Industrial Aerodynamics, **89**, 1233 – 1256 (2001)
[42] Grietus Mulder, Fjo De Ridder, Daan Six. "Electricity storage for grid-connected household dwellings with PV panels." Solar Energy, **84**, 1284 -1293 (2010)
[43] Jian Hang, Mats Sandberg, Yuguo Li. Effect of urban morphology on wind condition in idealized city models. Atmospheric Environment, **43**, 869 – 878 (2009)
[44] W. T. Chong, A. Fazlizan, S. C. Poh, K. C. Pan, W. P. Hew, F. B. Hsiao. The design, simulation and testing of an urban vertical axis wind turbine with the omni-direction-guide-vane. Applied Energy, **112**, 601 – 609 (2013)
[45] C. V. Nayar, S. J. Phillips, W. L. James, T. L. Pryor and Remmer. Novel wind/diesel/battery hybrid energy system. Solar Energy, **51**, 65-78 (1993)
[46] Jorge M. Huacuz, Roberto Flores, Jaime Agredano and Gonzalo Munguia. Field performance of lead-acid batteries in photovoltaic rural electrification kits. Solar Energy, **55**(4), 287-299 (1995)
[47] James F. Manwell and Jon G. McGowan. Lead acid battery storage model for hybrid energy systems. Solar Energy, **50**(5), 399-405 (1993)
[48] Vojtech Svoboda, Heinz Wenzl, Rudi Kaiser, Andreas Jossen, Ian Baring-Gould. Operating conditions of batteries in off-grid renewable energy systems. Solar Energy, **81**, 1409- 1425 (2007)
[49] Andreas Jossen, Juergen Garche, Dirk Uwe Sauer. Operation conditions of batteries in PV applications. Solar Energy, **76**, 759- 769 (2004)

[50] B. J. Huang, P. C. Hsu, M. S. Wu, P. Y. Ho. System dynamic model and charging control of lead-acid battery for stand-alone solar PV system. Solar Energy, **84**, 822- 830 (2010)

[51] Bhubaneswari Parida, S. Iniyan, Rankko Goic. A review of solar photovoltaic technologies. Renewable and Sustainable Energy Reviews, **15**, 1625- 1636 (2011)

[52] David J. Spiers and Asko A. Rasinkoski. Limits to battery lifetime in photovoltaic applications . Solar Energy, **58**, 147- 154 (1996)

[53] Francisco Díaz-González, Andreas Sumper, Oriol Gomis-Bellmunt, Roberto Villafáfila-Robles. A review of energy storage technologies for wind power applications. Renewable and Sustainable Energy Reviews, **16**, 2154 – 2171 (2012)

[54] Abdorreza Rabiee, Hossein Khorramdel, Jamshid Aghaei. A review of energy storage systems in microgrids with wind turbines. Renewable and Sustainable Energy Reviews, **18**, 316 – 326 (2013)

[55] M. E. Glavin, W. G. Hurley. Optimisation of a photovoltaic battery ultracapacitor hybrid energy storage system. Solar Energy, **86**, 3009-3020 (2012)

Authors Profile

D. C. Uguru-Okorie received a B.Eng degree in Mechanical Engineering from the Federal University of Technology, Owerri, Nigeria, an MSc. degree in Mechanical Engineering (Thermo-Fluids Option) from the University of Ibadan, Nigeria and he is currently a PhD student in the Department of Mechanical Engineering, University of Ibadan, Nigeria. He was also a visiting PhD research student in the University of Leeds, UK under the sponsorship of Petroleum Technology Development Fund (PTDF). He is currently a lecturer in the Department of Mechanical Engineering, Landmark University, Nigeria. His research interests are in the areas of Engines and Energy studies.

Dr. A. Kuhe is a senior lecturer in the Department of Mechanical Engineering, University of Agriculture, Makurdi. He is currently on sabbatical leave in Landmark University, Omu Aran, Kwara State and he holds a PhD from the University of Agriculture, Makurdi. His area of interest is in Energy studies.

I. Ikpotokin received a B.Eng degree in Mechanical Engineering from Ambrose Ali University, Ekpoma, Nigeria, an MSc. degree in Mechanical Engineering (Thermo-Fluids Option) from the University of Ibadan, Nigeria and he is currently a PhD student in the Department of Mechanical Engineering, University of Ilorin, Nigeria. He is currently a lecturer in the Department of Mechanical Engineering, Landmark University, Nigeria. His research interests are in the areas of Engines and Energy studies.