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Prospects of Establishing Small Wind Turbine Systems in Kano State, Nigeria

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ABSTRACT
Wind regimes are being investigated in different locations of Nigeria by Nigeria Meteorological Agency (NIMET). One year data was collected from the only NIMET synoptic station in Kano State, located at MallamAminu Kano International Airport, and analyzed. The results indicated an average minimum wind speed of 3 m/s for September and October and a maximum wind speed of 5.6 m/s for June. The study established an annual average wind speed of 4.3 m/s over the year 2007 in the municipality and some rural areas of Kano State, Nigeria. Major contributions of prevailing winds in the year were found out to be from South-West wind (56%) in May, East wind (52%) in January, and North-East wind (46%) in February. The South-West wind predominantly gave a major contribution from February to July across the year. These findings prove the prospects of establishing Small Wind Turbine System in the State. This could assist in power supply within Kano State for domestic use and cottage industries, particularly to supplement the grid supply in remote locations.

Keywords-small, wind turbine, average wind velocity, prospects, rural area

I. INTRODUCTION

Energy is an essential input to all aspects of modern life. It drives human life as it is extremely crucial for continued human development [1]. The availability of electricity for urban and rural populace is low in Nigeria. However, there seems to be adequate wind regime in some rural areas that suggests the opportunities of electricity generation. Remote locations are most likely to be found in rural areas. They can be described as isolated areas that are characterized by near nothing in terms of infrastructural amenities. Utilities like electricity, road networks and portable water supply are rare inthese areas. Some of the causes may be attributed to the locations peculiarities, such as, natural phenomenon like topography (i.e. mountainous or rocky locations, coastal regions etc.). Wind and solar represent two excellent sources of energy that have the potential of taking care of the domestic andcottage industry needs in remote locations. The importance of Small Wind Turbine Systems as power source in the remote locations of the northern and coastal States of Nigeria, where the average wind speed is up to 4.5 m/s cannot be overemphasized. This is sequel to the general fact that, average annual wind speeds of at least 4.0-4.5 m/s are needed for a small wind turbine to produce enough electricity to be cost-effective [2].Abundant wind regime is a major characteristic of rural areas or remote locations.In urban locations, where it is difficult toobtain predictable or large amount of wind energy, smaller systems may still be used to run low power equipment. Distributed power from rooftop mounted wind turbines can also alleviate power distribution problems.

Nigeria Meteorological Agency (NIMET) investigates wind regimes in different locations of Nigeria. The aim of this paper is to investigate the prospects of establishing small wind turbine systems in rural areas of Kano State, Nigeria.

II. LITERATURE REVIEW

2.1 Wind Turbine

Wind turbines range from small 400W generators for residential use to several megawatt machines for wind farms and offshore installations. The small ones, sometimes, have direct drive generators, direct current output, aero elastic blades, and life time bearings; and use a tail-vane to point into the wind. Small scale wind turbines for residential use are approximately 2m to 8m in diameter and produce electricity at the rate of 900w to l0kw at their tested wind speed. Wind turbine plants can be grouped into three applications, namely:

i. Large grid connected wind turbines: to compensate for the varying power output; grid-connected wind turbines may utilize some sort of grid energy storage.
ii. Intermediate size wind turbines: connected to a hybrid energy system with other energy sources

such as photovoltaic, hydro and diesel or storage used in small remote grids or for special applications such as water pumping, battery charging or desalination.

iii. Small "stand alone" wind turbines: for water pumping, battery charging, heating, etc.

2.2 Classification of Wind Turbine Systems

2.2.1 Small Wind Turbine Systems (SWTS)

Small wind turbine systems require less robust wind resources than large wind turbine systems. In Denmark, Mongolia, and in Arctic areas, records show tremendous use of Small Wind Turbine Systems of less than 5kw for battery charging. The power is used for TV sets, communication systems and small refrigerators[3]. Wind Turbine System thrives better in remote areas as offshore; onshore, near shore, mountainous areas, and non-developed areas without obstructions. Small-scale wind energy refers to wind turbines rated less than 50 kW which are generally intended to supply electricity to buildings, and which may or may not be connected to the grid. This is distinct to 'utility-scale' wind turbines, generally rated between several hundred kilowatts and a few megawatts each, which form wind farms onshore (predominantly in rural areas) and offshore, and are almost always grid-connected [4].

2.2.2 Large Wind Turbine Systems (LWTS)

These are industrial and commercial wind turbine systems with rotor diameters of up to 45m and mounted on towers of up to 6.0m and above. They produce powers in multiples of megawatts. They are not applicable to households and rural farms. The only way they can serve household is through connecting them to national electric grid.

2.3 Principles of Wind Turbine System

A turbine generally comprises of a wheel with attachment baffles which absorb the impingement of high pressure energy of moving fluid (water, air or steam) to continuously rotate. The energy in the rotating wheel is then either directly utilized to do work or is converted to useful electricity. Hence, we have the steam turbine, hydro-turbine and wind turbines; all working on the same basic principles. Each turbine has a wheel (otherwise called rotor), a framework and the machine it drives.

In the special case of an electric generating turbine, the machine it drives is an electrical alternator. Specifically, a wind turbine has a rotor (comprising of blades and a shaft); a tallframework preferably called tower, for mounting the rotor and the machine it drives (e.g. water pump, grinding wheels, or electrical alternator).

The engineering of wind turbine construction entails designing and manufacturing of rotor blades whose airfoil properties permit easy propulsion of the rotor by low wind speed. It also demands the design and fabrication of a smooth moving rotor shaft in the requisite size of bearing to withstand weight and achieve a frictionless motion. It calls for a tower design to withstand extreme wind conditions, as well as form a formidable framework for the rotor bearing housings, gear boxes (as the case may be) and the machine or alternator. A wind turbine transforms kinetic energy in moving air to rotary mechanical energy that can be converted to electricity.

2.4 Wind Energy

Wind is a natural phenomenon related to the movement of air masses caused primarily by differential solar heating of the earth's surface. Closer to the land surface the wind patterns change due to resistance and roughness of the terrain, houses, and hills; which affects the movement and makes it very hard to predict. At ground level, the wind speed is more or less zero [5]. Seasonal variations in the energy received from the sun affect the strength and direction of the wind. The ease with which aero turbines transforms energy in moving air to rotary mechanical energy suggests the use of electrical devices to convert wind energy to electricity. The first wind powered electricity was produced by a machine built by Charles F. Brush in Cleveland, Ohio in 1888. It had a rated power of 12 kW (direct current - dc). Direct current electricity production continued in the form of small scale, stand-alone (not connected to a grid) systems until the 1930's when the first large scale alternating current-ac turbine was constructed in the USA [6]. Wind energy has also been utilized, for decades, for water pumping as well as for milling of grains.

A study on the wind energy potentials for a number of Nigerian cities shows that the annual average wind speed ranges from 2.32 m/s for Port Harcourt to 3.89m/s for Sokoto[7]. The maximum extractable power per unit area, for the two cities was estimated at 4.51 and 21.97 watts per square meter of blade area, respectively.Wind energy used to be relied upon in the 1950s and 1960s for provision of water in many locations of the northern part of Nigeria. However, this was largely abandoned when the development of petroleum products reached advanced stages. In recent years, there are a few modern water pumps in some parts of the country. There is also one wind electricity generator of 5kW capacity supplying electricity from wind energy at SayyaGidanGada in Sokoto State [8].

2.5 Wind Turbine Power

The power in the wind is extracted by allowing it to blow past moving wings or blades that exert a torque on a rotor shaft. The amount of power transferred is expressed as:

$$: P = \frac{1}{2} C_p A \rho v^3 [9] \quad (1)$$

Where: P = power in watts, C_p= coefficient of performance, A = swept area of blade(s), m^2
ρ = *density* of air, kg/m^3,and v = average wind velocity, m/s

The wind power available to a wind turbine varies as the cube of the wind speed [9]. When the wind speed is doubled the power is multiplied eight times (power equation). As wind speed increases linearly with height above sea level, it is also a fact that extractable power available in wind increases with height.

When wind turbine extracts energy from air flow, the air is slowed down, which causes some of it to spread out and divert around the wind turbine to some extent without participating in the work of turning the rotor blades. This is the basis for the Betz limit. Albert Betz, a German physicist determined in 1919, that a wind turbine can extract at most 59% of energy in wind that flows through the turbine's cross section. The Betz limit applies to any wind turbine regardless of the design of the turbine. Wind speed is the most important parameter in the design and study of wind energy conversion devices [10].Because so much power is generated by higher wind speed, much of the average power available to a wind mill comes in short bursts. The consequence is that wind energy does not have as consistent an output as fuel-fired power plant. This is why it is customary to tap wind turbine electrical energy through batteries, whereby the output to supply remains constant.

2.6 Environmental Aspects of Wind Power Utilization

In many countries the public in general favors renewable energy sources such as wind power. On the other hand, deploying a wind farm in a local community sometimes raises local resistance due to the neighbor's', uncertainty and negative expectations about the wind turbines. This is rooted in the fact that the environmental advantages of wind power is on a global or national level, whereas, the environmental disadvantages of wind power is at a local or neighborhood level that is associated with the presence and operation of the wind turbines.

2.6.1 Environmental Advantages of SWTS

- No direct atmospheric emissions
- No liabilities after decommissioning
- Good energy balance
- Limited use of land

2.6.2 Environmental Disadvantages of SWTS

- Noise
- Visual impact on landscape
- Moving shadows
- Erosion
- Impact on birds
- Interference with electromagnetic communication
- Personnel safety

III. MATERIALS AND METHOD

Wind data for Kano State, was collected from the Nigeria Meteorological Agency (NIMET) at MallamAminu Kano International Airport, Kano. The collected data covered the year 2007[11]. A Sample of the wind data is presented in Table 1 and 2. The cup-anemometer was used for wind speed measurement. This data forms the basis for any chance of success in the establishment of SWTS in Kano State. Simple mathematics for obtaining a mean and percentage was used to analyze the data. The data was obtained, from the Synoptic Station in Kano, with the following parameters:

i. Latitude 12°03' North
ii. Longitude 08°32' East
iii. Altitude 475,8M (above sea level)

Table 1: Wind Speed for January, 2007
(NIMET, 2008)

Time of reading, hours	Wind Velocity Range, knots				
	34 or more	22-33	11-21	1-10	0
	Number of Occurrence (frequency) of Velocity Range at the Hour of Observation				
0	0	0	8	23	
3	0	0	7	23	1
6	0	0	11	19	1
9	0	3	25	3	
12	0	3	25	3	
15	0	2	22	7	
18	0	0	5	26	
21	0	0	0	31	
Total	0	8	103	135	2

Table 2: Occurrence on Prevailing Winds for January, 2007 (NIMET, 2008)

Time of Reading, hours	Number of Occurrences of Prevailing Winds							
	NE	E	SE	S	SW	W	NW	N
0	23	6	0					2
3	17	11	0					2
6	6	23	1					0
9	3	26	2					0
12	9	19	3					0
15	16	14	1					0
18	12	19	0					0
21	21	9	0					1
Total	107	127	7					5

Within the first hour (0 hour) for a given month; thirty one, thirty or twenty eight readings were taken: depending on the number of days in the month under consideration. Readings at hours 3, 6, 9 and etc. were similarly taken. For Table 1, thirty one readings were taken. Speed of wind between (1 - 10) knots occurred twenty three times, while speed of wind between (11-21) knots occurred eight times, making a total of thirty one readings taken (i.e. 23 + 8 = 31). Similarly Table 2 shows the number of occurrences of each prevailing wind during the thirty-one times readings for the month. At zero hour North-East (NE) wind prevailed twenty three times while East (E) wind, six times, and the North (N) wind prevailed only twice, (i.e. 23+ 6 + 2 = 31 readings).

3.1 Synoptic Data Coverage

A meteorological station may be defined as a collection of instruments and observing systems, existing today or for periods of time past, which together may be considered as a common source of observations associated with a given location [12]. In any station, synoptic readings as well as climatic readings are taken by different instruments. Synoptic readings include: weather, cloud, wind and pressure. Climatic readings are for temperature, rainfall etc. A synoptic based station has an average station spacing of 50km. This means that the data from the station in respect of the synoptic readings are applicable within a 50km radius of the station [12]. Hence the data collected is applicable to the following local government areas of Kano State: (1) Fagge, (2) Dala, (3) Gwale, (4) Kano Municipal, (5) Nassarawa, (6) Tarauni, (7) Kumbotso, (8) Ungogo, (9) DawakinTofa, (10) Tofa, (11) RiminGado, (12) Minjibir, (13) Gezawa, (14) Bichi, (15) Gabasawa, (16) Madobi, (17) Warawa, (18) Dambatta, (19) Makoda, (20) Tsanyawa, (21) Wudil, (22) Dawakin Kudu, (23) Kura, and (24) GarunMalam. This gives coverage of more than 54% of the State. It is nevertheless anticipated that citing another synoptic station outside the Kano municipality will cover more areas of the state.

3.2 Wind Data Analysis

From Table 1 the mean wind speed was .computed. It should be noted that one knot is approximately equal to half a meter per second, i.e. 1 knot = 0.5m/s [13].

Mean = Total sum of observations divided by total number of observations

i.e.: $\text{Mean}=\frac{\sum x_i f_i}{\sum f_i}$ (2)

Where x_i =observed data:

f_i = frequency or number of times x_i occurred

$i = 1, 2, 3, \ldots\ldots\ldots, n$

$\sum f = f_1 + f_2 + f_3$

$\sum xf = x_1f_1 + x_2f_2 + x_3f_3 + \ldots\ldots + x_nf_n$

Hence (from Table 1):

For velocity range (34 knots or more), frequency = 0 (no occurrence)

For velocity range (22 – 33 knots), wind velocity = $\frac{22+33}{2}$ = 27.5 knots, and frequency = 8

For velocity range (11 – 21 knots), wind velocity = $\frac{11+21}{2}$= 16 knots, and frequency = 103

For velocity range (1 – 10 knots), wind velocity = $\frac{1+10}{2}$ = 5.5 knots, and frequency = 135

For (0 knots), wind velocity = 0, and frequency = 2

3.2.1 Mean Wind Speed Computation

Using wind velocities obtained for the ranges in Table 1, and equation (2), the average or mean wind speed is evaluated as follows:

Mean wind speed = $\frac{34\times0 + 27.5\times8 + 16\times103 + 5.5\times135 + 0\times2}{0+8+103+135+2}$

= 10.526 knots

From standard conversion table:

1 knot = 1.15 mph (miles per hour)

1 mph = 0.447m/s (meter per second)

Hence: 1 knot = 1.15 × 0.447 m/s

= 0.514 m/s

Table 3: Average Wind Speed, m/s and Percentage Contributions of Prevailing Winds for 2007

Months	Average Wind Speed, m/s	Contribution of Prevailing Winds, %					
January	5.4	E 52	NE 43	Others 5			
February	4.3	NE 46	E 25	N 14	Others 15		
March	4.0	NE 37	E 32	N 12	Others 19		
April	4.9	SW 30	E 14	NE 12	S-E 12	NW 12	Others 20
May	4.8	SW 56	W 18	S 10	Others 16		
June	5.6	SW 53	W 24	S 14	Others 9		
July	5.0	SW 49	W 29	S 13	Others 9		
August	3.6	SW 39	W 32	S 15	Others 14		
September	3.0	SW 43	W 14	NW 11	Others 32		
October	3.0	E 24	SW 19	W 15	NE 11	Others 31	
November	3.6	E 35	NE 28	N 16	Others 21		
December	3.9	NE 41	E 39	N 14	Others 6		

Hence, 10.5 knots = 10.526 × 0.514 m/s = 5.4m/s

Therefore the average wind speed for January, 2007 is determined to be 5.4 m/s. Similarly, the average wind speeds for each moth of the year were evaluated and presented in Table 3.

Thus, the annual average wind speed for the year 2007 is evaluated as:

Annual average wind speed for 2007 = $\frac{5.4+4.3+4+4.9+4.8+5.6+5+3.6+3+3+3.6+3.9}{12}$ = 4.3 m/s

3.2.2 Contribution of Prevailing Winds

The percentage contribution from each wind for January, 2007 was computed arithmetically using Table 2 as follows:

The total wind occurrence is (107 + 127 + 7 + 5 = 246)

Percentage contribution from North-East wind (NE) is = $\frac{107}{246}$ × 100% = 43%•

Percentage contribution from East wind (E) = $\frac{127}{246}$ × 100% = 52%

Percentage contribution from other winds = $\frac{12}{246}$ × 100% = 5%

Similarly, percentage contributions from each wind for every moth of the year were calculated and presented in Table 3.

IV. DISCUSSION OF RESULTS

The data analysis has shown that the minimum average wind speed for the year in some parts of Kano State was realized in both September and October, 2007 at 3.0 m/s. The medium average wind speed was 4.0 m/s for March. The maximum average wind speed was obtained in June, at 5.6 m/s. The annual average wind speed for the year was established at 4.3 m/s. Major contributions of prevailing winds in the year were from South-West wind (56%) in May, East wind (52%) in January, and North-East wind (46%) in February. South-West wind predominantly gave a major contribution of the prevailing winds from February to July across the year.

V. CONCLUSION

This study established the prospects of establishing SWTS in Kano State, Nigeria. An annual average wind speed of 4.3 m/s over the year, 2007 in the municipality and some rural areas of Kano State was evaluated. This was achieved by analyzing a data collected from NIMET office in the State. The minimum and maximum monthly average wind speeds were 3 (September and October) and 5.6 m/s (June) respectively. Major contributions of prevailing winds came from South-West wind (56%) in May, East wind (52%) in January, and North-East wind (46%) in February with South-West wind being predominant in the months: February to July during the year. It can be concluded from the results that there are good opportunities of utilizing the available wind energy in Kano State and its rural areas for practical applications.

REFERENCES

[1] M. Asif and T. Muneer, Energy Supply, its Demand and Security Issues for Developed and Emerging Economies,*Renewable and Sustainable Energy Reviews, 11(7),* 2007, 1388-1413.

[2] S. Clarke, *Electricity Generation Using Small Wind Turbines at Your Home or Farm*, FACTSHEET (2003).

[3] G.T. Wrixon, A-M. E. Rooney, and W. Palz, Renewable Energy-2000, Springer Berlin Heidelberg (1993).

[4] Carbon Trust, *Small scale wind energy: Policy insights and practical guidance*, UK (2008).Available: http://www.carbontrust.com/media/77248/ctc738_small-scale_wind_energy.pdf

[5] Thorstensson E., *Small Scale Wind Turbines: Introductory Market Study for Swedish Conditions*, master's thesis, Department of Energy and Environment, Chalmers University of Technology, Gotoborg, Sweden (2009).

[6] Practical Action, *Wind for Electricity Generation*, Technical Brief, Schumaker Centre for Technology and Development, Rugby UK (2006), available: www.practicalaction.org

[7] A.S. Sambo, Empirical Models for the correlation of global solar radiation with metrological data for northern Nigeria. *Solarand Wind Technology,* 32: 89-93 (1987).

[8] A.S. Sambo, *Renewable Energy for Rural Development: The Nigerian Perspective*, ISESCO Science and Technology Vision Volume 1 (2005).

[9] J. Twidell, *A Guide to Small Wind Energy Conversion Systems*, Cambridge University Press, UK (1987).

[10] V. Yilmaz, H. Aras, and H.E. Celik, *Statistical Analysis of Wind Speed Data*, Engineering & Architecture Faculty, Eskisehir Osmangazi University, Vol. XVIII, No: 2 (2005).

[11] Nigerian Meteorological Agency (NIMET) *2007Record of Wind Speed Data for Kano State*, (2008).

[12] MIDAS Handbook, *Maintained by Desktop and Databases branch*, (1997).

[13] www.metlink.org, *Converting Metrological Units*,Available: http://www.metlink.org/pdf/teachers/converting-units.pdf