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Turbine Selection and Estimates of Unit Cost of Wind Generated Electricity in Kano, Nigeria

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Abstract: An assessment study on the wind power potential of Kano has been made. It has been shown that the wind speed distribution of Kano is very suitable and economical for utility-scale power generation. At a height ≥80 m, a Neg Micon NM 82 turbine may generate at least 40% of its installed capacity at any particular instance. A utility-scale wind farm made of 20 Neg Micon NM 82 wind turbines installed at 100 m in Kano may generate about 338,400 kw h of electricity daily and can service about 112,800 homes each consuming at most, 3 kw h of electricity daily. With this generation capacity such a wind farm can recover its investment cost within its lifetime at competitive unit costs of electricity with those supplies from the fossil fired power stations. Hence, the possibility of wind generated electricity in Nigeria.

Key words: Wind power potemtial, investment cost, electricity, power, station, turbine, utility scale, Nigeria

INTRODUCTION

Sites required for harnessing wind for utility-scale power generation is dependent on the capacity factor a wind turbine would have at the site. The energy delivery factor (capacity factor) is the figure of merit that measures how hard the plant is utilized to deliver the maximum possible energy (Patel, 1999). It as well determines investors' willingness for wind generated electricity. Most literatures on wind potentials in Nigeria (Enibe, 1987; Orji and Anusionwu, 2003; Asiegbu and Iwuoha, 2007) focused on the yearly average wind speed at a height of 10 m as a determinant of the wind power potential of a site. A few (Iheonu *et al*., 2002; Amusan *et al*., 2007; Fadare, 2008) have been able to fit the wind speed data to some probability distribution functions but ended their works at only determining the parameters of the distribution functions.

No attempt has been made to determine how much the suitability and attractiveness of the sites for wind power generation. The suitability and attractiveness of a site is a focus on the performance of wind turbines at the site. It is required to determine how much of its rated capacity be utilized and at what height the turbine be installed for optimum performance based on the site's wind availability.

It also answers how economical an investment would be over the life time of a wind turbine with respect to a competing cost of electricity produced from existing fossil fuel fired power stations. In this research, the unit cost of electricity and the variations of the actual electrical power output at each wind speed lying between the cut-in and rated (or the site's maximum) wind speeds of some selected wind turbines were determined by firstly modeling the performance data of the turbines before determining its suitability and the average electrical power, it can generate at each wind speed distribution at the site. Its economics for a possible grid connected or an off-grid electricity investment opportunity also highlighted.

MATERIALS AND METHODS

The mesa scale 3 hourly records of wind speeds at height of 3 m for Kano (latitude: 12.05°N, longitude: 8.533°E, altitude: 472 m) are collected from the Nigerian Meteorological agency. Elsewhere (Aidan, 2010), the wind speed data of Kano have been shown to be Weibull distributed with an estimated shape parameter k = 6.6415 and predicted scale parameters; c = 6.49, 7.46, 8.84, 9.08 and 9.49 m sec^{-1} at 15, 30, 70, 80 and 100 m, respectively using the Hellmann's power law (Musgrove, 1987) with an assumed ground frictional coefficient of 0.2 that depicts the nature of the land surface in Kano. Performance data of some selected wind turbines were also used.

Model fitting for the electrical power output of wind turbines: The performance data of some selected wind turbines were fitted to a 3rd degree polynomial in order to obtain mathematical expressions for the turbines electrical output power, P(v) at each wind speed between the cut-in v_{in} and the rated, v_r.

Average annual electrical power output: The annual average electrical output power of turbines is theoretically given as:

$$P_{average} = \int_{V_{in}}^{V_{out}} P(v) f(v) dv \quad (1)$$

Where:

P (v) = The power at each wind speed at the site
f (v) = The fitted distribution function for the site

Equation 1 can be re-written as:

$$P_{average} = \int_{V_{in}}^{V_r} P(v) f(v) dv + \int_{V_r}^{V_{out}} P(v) f(v) dv \quad (2)$$

For Kano, the predicted maximum average wind speed, v_m at a height of 100 m is ~12.86 m sec^{-1}; this means that most turbine operations might be below rated wind speed in Kano. Hence:

$$P_{av} = \int_{V_{in}}^{V_m} P(v) f(v) dv \quad (3)$$

Where:

$$P(v) = \begin{cases} 0 & v < v_{in} \\ a_0 + a_1 v + a_2 v^2 + a_3 v^3 : v_{in} < v \le v_m \end{cases} \quad (4)$$

Therefore, the annual average electrical output power of the turbine in kano P_{av} will now be:

$$P_{av*} = \int_{V_{in}}^{V_m} (a_0 + a_1 v + a_2 v^2 + a_3 v^3) \left(\frac{k}{c} \left(\frac{v}{c} \right)^{k-1} \exp\left[-\left(\frac{v}{c} \right)^k \right] \right) dv \quad (5)$$

The constant coefficients in P(v) were determined from the fitted 3rd degree polynomials to the manufacturer's performance data of each turbine. With values of the coefficients obtained and those of the parameters of the distribution functions, Eq. 5 was solved numerically for the possible average wind electrical output power of the various turbines.

The hypothetical wind farm: The production of large quantity of electricity requires the installation of many wind turbines. For m number of wind turbines, the total yearly energy production, E of the hypothetical wind farm is:

$$E = mP_{av.} \times 8760 \quad (6)$$

The overall capacity factor, CF of the wind farm is then:

$$CF = \frac{E}{mp_r \times 8760} = \frac{P_{av.}}{P_r} \quad (7)$$

Hypothetical wind farm economics: Determination of the unit cost of electricity, C_u requires the knowledge of the present value or worth of an investment. The present value, PV of a uniform and periodic payments, A_n at an interest rate i over n years is given (Ramakrishnan and Srivatsa, 2008) as:

$$PV = A_n \frac{(1+i)^n - 1}{i(1+i)^n} \quad (8)$$

and the unit cost of electricity is then determined from:

$$C_u = \frac{A_n + OMC}{E} \quad (9)$$

Where, OMC is the operation and maintenance costs. In this research, the lifetime of a wind turbine is assumed to be 20 years and an interest rate on loan for a repayment period of 10 years is taken as 10 and 40% of the total investment cost is taken as an investor's equity contribution (or a down payment); total installation costs is taken as the average between a minimum of 984 € kW^{-1} and maximum of 1,885 € kW^{-1} (IEA, 2009) for larger/medium size turbine and the operation and maintenance costs as 1.4% of the capital cost per year (IEA, 2009). About 1 € is assumed to be exchanged at ₦ 216.9. For the smaller turbines, total installation cost is taken as an average of ₦351,000.00 kW^{-1}.

RESULTS AND DISCUSSION

The coefficients of the fitted 3rd degree polynomials to the manufacturer's performance data of the selected wind turbines are show in Table 1. The high values (>0.98) obtained for the coefficient of determination, R^2 gives the degree to which the performance data of the individual turbines were well fitted.

Table 2 gives the average electrical power output that could possibly be generated by the selected turbines in Kano. The smaller-turbines, Proven WT6000 and Iskra AT5-1 can generate >25% of their installed capacities at their individual hub heights (=15 m) making them the most suitable smaller wind turbines for use where <2 kW electricity is required (e.g., residential homes). These turbines are not too robust; they can be easily managed by home owners as off-grid electricity supply. However for utility scale power generation, a medium-size turbine, Suzlon S.64/950 is the most suitable and economical. About 37.27% can be generated at hub heights of 70 m. Larger size turbines like Nordex S77, G.E. 1.5 SL 77 and Neg Micon NM 82, respectively generates in the range of

Table 1: Coefficients of the fitted 3rd degree polynomials to performance data of some selected turbines between their cut-in and rated wind speeds

	Small turbines							
Turbines	Jacobs WTIC-29	Whisper H 175	Proven WT 6000	AOC 15/50	Iskra AT5-1	Micon 108 kW	Nordtank 65 kW	BWC excel-S
a_0	2.721	0.472	1.238	8.627	0.961	20.071	30.6220	1.053
a_1	-2.392	-0.469	-1.192	-8.688	-0.952	-15.667	-15.3910	-1.068
a_2	0.486	0.109	0.269	1.941	0.221	3.152	2.4910	0.247
a_3	-0.016	-0.004	-0.011	-0.074	-0.009	-0.115	-0.0871	-0.008
R^2	0.981	0.993	0.992	0.996	0.991	0.998	0.9960	0.997

	Medium/large size turbines						
Turbines	Suzlon S.64/950	GE 1.5 SL 77	Nordex S 77	Suzlon S.64/1000	Neg Micon NM 82	Suzlon S.88/2100	Nordex N 90
a_0	469.942	989.773	1505.822	370.009	1291.687	832.235	2167.361
a_1	-231.176	-477.977	-642.508	-183.345	-598.718	-438.919	-899.797
a_2	34.419	70.346	84.141	27.310	87.555	66.026	117.595
a_3	-1.015	-2.408	-2.695	-0.684	-3.118	-1.976	-3.789
R^2	0.997	0.997	0.997	0.998	0.996	0.999	0.999

Table 2: Average electrical power output, P_{av} (kW) and capacity factor, CF (%) of selected wind turbines at their various/possible hub heights, h

	Small size turbines			Medium/large size turbines		
Turbines (h^{-1})	15 m	30 m	Turbines (h^{-1})	70 m	80 m	100 m
Whisper P_{av}	0.78	1.18	Suzlon P_{av}	352.37	-	-
H-175 CF	22.29	33.71	S64/1000 CF	35.24	-	-
Proven P_{av}	1.53	2.32	Suzlon P_{av}	630.04	684.99	785.36
WT6000 CF	25.50	38.67	S 88/2100 CF	30.00	32.62	37.40
AOC P_{av}	11.51	17.83	G.E. 1.5 P_{av}	504.69	545.61	619.35
15/50 CF	23.02	35.66	SL 77 CF	33.64	36.37	41.29
Iskra P_{av}	1.37	2.06	Nordex P_{av}	455.05	497.71	576.06
AT5-1 CF	27.40	41.2	S 77 CF	30.34	33.18	38.40
Nordtank P_{av}	10.35	15.75	Neg Micon P_{av}	582.72	626.70	705.38
65 kW CF	15.92	24.23	NM 82 CF	38.84	41.70	47.02
BWC P_{av}	1.99	3.00	Nordex P_{av}	669.73	727.85	834.47
Excel-S CF	19.90	30.00	N 90 CF	29.12	31.65	36.28
Micon P_{av}	-	26.06	Suzlon P_{av}	354.05	-	-
108 kW CF	-	24.13	S 64/950 CF	37.27	-	-

Table 3: Economic evaluation of a 1500 kW Neg Micon NM 82 wind turbine investment

Years	Beginning principal (₦)	Annual payment, A_n (₦)	Interest on loan i = 10 (%) (₦)	Ending principal (₦)	Equity contribution (₦)
1	280,028,745.00	45,573,388.7	28,002,874.50	262,458,231.0	186,685,830
2	262,458,231.00	45,573,388.7	26,245,823.10	243,130,665.0	0
3	243,130,665.00	45,573,388.7	24,313,066.50	221,870,343.0	0
4	221,870,343.00	45,573,388.7	22,187,034.30	198,483,989.0	0
5	198,483,989.00	45,573,388.7	19,848,398.90	172,758,999.0	0
6	172,758,999.00	45,573,388.7	17,275,899.90	144,461,510.0	0
7	144,461,510.00	45,573,388.7	14,446,151.00	113,334,272.0	0
8	113,334,272.00	45,573,388.7	11,333,427.20	79,094,310.8	0
9	79,094,310.80	45,573,388.7	7,909,431.08	41,430,353.2	0
10	41,430,353.20	45,573,388.7	4,143,035.32	0.0	0
Total	280,028,745.00	455,733,887.0	175,705,142.00	-	186,685,830

33-47% of their rated capacities at a hub heights of 80-100 m with Neg Micon NM 82 being the best. Hence, the most efficient of all the larger/medium size turbines.

Therefore, a utility-scale power generation wind farm set up in Kano with Neg Micon NM 82 installed at 100 m will add tremendous amount of electricity to the Nigerian grid system. Table 3 gives the repayment breakdown of a 10 years period of loan borrowed in addition to an investor's equity contribution to install a Neg Micon NM 82 wind turbine. The breakdown shows that ₦586,413,969 (OMC for 20 years (₦130,680,082) +20 years annual payment, A_n (₦455,733,887)) will be required to set off the loan borrowed together with accrued interest and still be sufficient for the lifetime operation and maintenance of the turbine. Therefore, the total investment costs is ₦773,099,798.00 (down payment; ₦186,685,830+586,413,969).

Table 4 shows the lifetime total energy production, total investment cost and the unit cost of electricity for the best two small-size turbines (Proven WT6000 and Iskra AT5-1) and the best two medium/larger-size turbines (G.E. 1.5 SL77 and Neg Micon NM82). The total amount of electrical energy that can be generated by Neg Micon NM 82, a 1500 kW turbine at a height of 100 m for the

Table 4: Lifetime Total Energy Production (TEP), Total Investment Cost (TIC) and unit cost, C_u

	Turbines			
Parameters	Proven WT6000	Iskra AT5-1	G.E. 1.5 SL 77	Neg Micon NM 82
Hub height, h	15	15	100	100
TIC (₦)	3,488,530.81	2,907,109.01	773,099,798	773,099,798.0
TEP (kW h)	268239.6	240188.4	108584442	123667221.6
C_u (₦ kW h^{-1})	13.01	12.10	7.12	6.25

20 years period is 123,582,576 kw h (= $P_{av}\times 24\times 365\times 20$) giving the unit cost of electricity as ₦6.25 kW h^{-1}. This could be the bursbar cost for a unit of electricity because the selling cost for a kW h of electricity may further depend on transmission, distribution and investor's profit margin. However if at the end, this unit cost is doubled (i.e., ₦12.50), it will still be economical and competitive. Although, the present cost of electricity from power stations in Nigeria is ₦4.00 kW h^{-1} but this is with government subsidy and of course the non-inclusion of the environmental pollution costs on the populace that are exposed to its effects.

For instance, victims of air pollution that spend much money year after year on the treatment of pollution related ailments that are probably not been compensated. When these incurred costs are added, the ₦4.00 might not be a realistic unit cost. The question therefore is how cheap the cost of electricity generated from power stations in Nigeria? On the other hand, wind power might look expensive but it is always better to pay for electricity that is cleaner and pollution free even if it costs more at least, the good health of the Nigerian society would have been safe guarded.

CONCLUSION

It is shown that the potential for utility-scale wind power generation at a height ≥80 m is very satisfactory in Kano. At a height of 100 m, a Neg Micon NM 82 turbine may be suitable at least 40% of its installed capacity may be generated at any particular instant. A utility-scale wind farm made of 20 Neg Micon NM 82 can generate about 338,400 kW h of electricity daily and this can service about 112,800 homes consuming 3 kw h of electricity daily. With this generation capacity such a wind farm can recover its investment costs within its lifetime and still compete very well on the unit cost of electricity with those obtained from fossil fired power stations.

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