Wind regime in the proximity of the 20 kW experimental turbine site at Nabua, Fiji

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1 INTRODUCTION

Renewable energy generated as much electric power worldwide in 2005 as one-fifth of the worlds nuclear power plants excluding large hydropower that itself accounts to 16% of world's electricity (REN 21 2005). Renewable energy is gaining prominence in providing the world's primary energy needs. Solar, wind, biomass, and geothermal are considered as the premier renewable energy resources that are in direct competition with the conventional fuels. The fastest growing technology has been the photovoltaic (grid connected), however, wind power is steadily growing with an estimated existing capacity of 56 GW by the end of 2005 (REN21 2005).

Wind power has been used for many centuries to provide mechanical and electrical power for a variety of uses. Since the beginning of the last century, however, the most important use has been the generation of electricity for supply to rural and remote areas, as well as providing energy into the electrical distribution system, i.e. the national grid. World wind energy capacity has doubled every three years since 1990 and each doubling has been accompanied by a 15% reduction in the price of wind turbines (Milbrow 2005). Turbine size has increased from 600 - 800 kW to 1 - 3 MW with blade diameters from 60 - 100 m and the energy costs (c/kWh) has declined by at least 18% and is now half those of 1990. The practical size of a wind turbine is determined by the assessment of annual electrical load, site conditions, wind resource, installed cost, and utility rate (Lodge 2005).The major countries that utilize wind power for electricity generation include the USA, Spain, Germany, India, Britain, Sweden, Netherlands, China, and Denmark. However, Russia, South Africa, Brazil, and Mexico are in the transitional stage to develop large-scale commercial markets.

The basic theory of the extraction of energy from a wind turbine is found in any standard textbook on wind energy. The power in the wind varies as the cube of the wind speed. If an obstacle is placed in the path of the wind, the wind's kinetic energy does work on the obstacle and wind energy is converted to other forms, including the kinetic energy of rotating parts. Thus a turbine or rotor placed in the path of wind, with wind speed, v, will allow the turbine to extract a certain amount of energy from the wind. The theoretical maximum 59 % of energy that could be extracted was first calculated by Betz (1920) for a horizontal axis wind machine. The power output, P, from such a device is given by

$$\begin{aligned} P &= 0 & 0 < v < V_c \\ P &= \frac{1}{2}\left(C_{op}\ \rho\ A_r v^3\right) & V_c \le v \le V_r \\ P &= 0 & v > V_f \end{aligned} \quad (1)$$

Where C_{op} is the average overall power coefficient for the wind turbine between cut-in wind speed (V_c) and rated wind speed (V_r), A_r is the cross-sectional area of the wind turbine, v is the actual wind speed, and ρ is the density of air.

At any time, the wind-generator produces an output, which is dependent on the wind speed at the time. Until the cut-in wind speed (V_c) is reached, the generator does not produce any power. Between cut-in wind speed V_c and the rated wind speed V_r the power output varies essentially as the cube of the wind speed. Beyond V_r and up to the furling wind speed (V_f), the output remains constant, held at the value of the rated power output. Beyond V_f, there is no output and the system is shut down for safety.

The wind variation for a typical site is usually described using a Weibull distribution function. Wind speed can be assumed to have the two parameter Weibull distribution; however three parameter Weibull distribution fits the wind speed data in a refined manner than the two parameter version (Sahin 2004). Weibull distribution shows the probability distribution of the wind speed at a given site and mathematically given as:

$$\Phi(u) = \frac{k}{A}\left(\frac{u}{A}\right)^{k-1} \exp\left[-\left(\frac{u}{A}\right)^{k}\right] \quad (2)$$

where $\Phi(u)$ is the probability of finding the wind speed, u is the wind speed at the site, k is the shape parameter, and A is the scale factor (mean wind speed) with units of the wind speed. This function is used to determine the statistical distribution of wind speed at any site, providing mean wind speed at or close to the site. The mean wind speed or the scale factor A indicates how windy the site is on average. The shape parameter k tells how peaked the distribution is, i.e. if the wind speed always tend to a very close to a certain value, the distribution will have a high k value and will be very peaked. These parameters (k and A) can be estimated from the site data using mathematical techniques such as least squares fit method, methods of moments, maximum likelihood method or percentile estimators' method. However, Merzouk (2000) reported that this distribution is not appropriate for sites where the calm frequencies are greater than 15% and introduced a hybrid Weibull distribution to describe the wind speed for two sites in Algeria.

Table 1. Wind speed distribution at Nabua from March to September 2004.

U	0	30	60	90	120	150	180	210	240	270	300	330	All
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0
1.0	184	73	76	264	318	0	0	0	0	0	0	0	144
1.5	178	82	65	236	288	0	0	0	0	0	0	0	137
2.0	246	95	85	165	236	0	0	0	0	0	0	0	144
2.5	204	122	130	111	101	0	0	0	0	0	0	0	135
3.0	85	123	128	67	23	0	0	0	0	0	0	0	99
3.5	48	150	153	61	16	0	0	0	0	0	0	0	107
4.0	26	135	118	36	6	0	0	0	0	0	0	0	86
4.5	16	116	132	31	4	0	0	0	0	0	0	0	78
5.0	9	61	59	13	3	0	0	0	0	0	0	0	39
5.5	3	33	33	12	2	0	0	0	0	0	0	0	22
6.0	1	7	13	1	0	0	0	0	0	0	0	0	6
6.5	0	2	7	2	2	0	0	0	0	0	0	0	2
7.0	0	0	1	1	0	0	0	0	0	0	0	0	0
7.5	0	0	0	0	0	0	0	0	0	0	0	0	0
8.0	0	0	0	0	0	0	0	0	0	0	0	0	0

U is given in m/s, and the frequencies of occurrence in per mille.

Table 2. Weibull distribution for the 6 months wind data observed at Nabua

	0	30	60	90	120	150	180	210	240	270	300	330	All
A	2.1	3.4	3.5	1.9	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8
k	2.09	2.99	2.88	1.46	1.79	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.98
U	1.86	3.02	3.09	1.73	1.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.44
E	7	24	26	9	4	0	0	0	0	0	0	0	17
f	18.4	38.0	20.6	12.5	10.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100

A and U are given in m/s, E in W/m²; and the frequencies of occurrence in per cent (f).

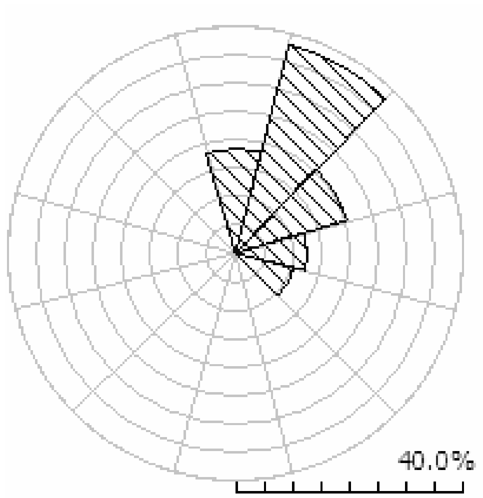

Figure 1. Wind rose at Nabua from March to September 2004.

The global advancement in the wind power market and the need for a clean, innovative, and sustainable energy for Small Island Developing States resulted in the installation of an experimental 20 kW wind turbine in Nabua, Fiji. This, a UNEP/SOPAC/USP project is a GEV 10 wind turbine (Générateur Eolien Vergnet of 10 m diameter) erected on a hilly area is overlooking the Laucala Bay. Owing partially to its altitude, it receives almost unobstructed air from the bay (upwind). However, some foliage and buildings are present on its downwind side. This communication considers the theoretical power output, determined from the actual wind speed at the site. Wind speed data for 6 months (March until September 2004) is used to predict the accumulated energy output over that period.

2 METHODOLOGY

The 20 kW Vergnet turbine system installed at Nabua is mounted at a height of 24 m on a guyed tower. The rotor, a diameter of 10 m, is a double-bladed upwind hub with variably pitch. The generator has a parallel shaft gearbox (gearbox ratio of 11:1) with rectified bevelled teeth and employs power factor compensation. The rotor can be stopped from moving via a manual control parking brake integrated to the generator.

The wind speed was measured using a *Type 40 maximum* anemometer mounted at 20 m on the tower. The anemometer had a measuring range of 0.5 to 50 m s^{-1} with an accuracy of ± 0.5 m $s^{-1}$and a resolution of less than 0.1 m s^{-1}. The wind direction was monitored using a 200 series wind vane. It is a simple mechanically constructed with a continuous rotation of 360° and a sensitivity of approximately 1 m s^{-1}. The wind data were collected by a *Symphonie* 12 channel data logger. The data logger was optimised for the needs of the wind energy assessment and has a fixed averaging interval of 10 minutes. Each of the 12 channels averages, standard deviations, maximum and minimum values were calculated from continuous 2 second data samples. Data intervals were calculated every 10 minutes and are written to the MultiMedia card (MMC) at the top of the hour. Data from MMC are retrieved and analysed using the Wind Atlas, Analysis and Applications Program (WAsP), a software developed by the RISØ National Laboratory, Denmark.

Wind data for the eight month period from August 2004 to March 2005 were analyzed to determine the gross available power in the wind.

3 RESULTS

The wind direction data were grouped into 30° sectors with respective wind speed U (m s^{-1}). The results (Table 1) show that 14.4% of the time the wind speed was between 0.0 and 1.0 m s^{-1}. Most of the time (23.4%) the wind speed was between 2.0 and 3.0 m s^{-1}. The most frequent wind speed between 0.5 and 1.0 m s^{-1} was observed in the fifth (120°) sector.

The wind rose shown in Figure 1 reveals that 37.9% of the time the wind was observed from 30 to 60° i.e. sector 2. However, no wind speed was recorded after the fifth sector. The Weibull statistics for individual sectors (Table 2) show that the mean wind speed is greatest (3.09 m s^{-1}) in sector 3 with a mean power density E of 26 W m^{-2}. However, 18.4% of the time in sector 1 the observed mean wind speed was 1.86 m s^{-1}.

The mean wind speed for all the sectors for the six month period was 2.4 m s^{-1} with a mean power density of 17 W m^{-2}. However, the Weibull distribution predicts on average the site experienced a mean wind speed of 2.8 m s^{-1}. This shows a good measure of fit of the Weibull distribution to the given data. The cut-in wind speed of the Vergnet turbine installed is 4.5 m s^{-1}, while the rated wind speed is 12 m s^{-1}. The mean speed at the site is much lower than the cut-in speed of the turbine. This indicates that the turbine is not producing any power for majority of the time.

4 CONCLUSION

The wind regime at Nabua from the six months of study shows that the majority (approximately 93%) of the time the wind speed is below the cut-in speed of the turbine. This indicates that the turbine is not producing any power most of the time. Hence, the turbine is under utilized. It is important that at least a year's time series analysis of wind speed and direction be studied to eliminate any seasonal variation. Further work on data acquisition is being carried out to better understand the wind climate at Nabua turbine site.

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