WIND POWER IN FIJI:
a preliminary analysis of the Butoni wind farm

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Abstract

The Fiji Islands sit in the trade winds of the Pacific Ocean. These provide a reliable, pleasant but relatively low-speed sea breeze; in most locations, too little wind to justify installing a wind turbine. At the other extreme, Fiji experiences an average of one tropical cyclone (typhoon) every southern summer: too much wind for many designs of wind turbine. In a few favourable locations, the mean wind speed is high enough to justify a wind power system, provided it is of cyclone-proof design. This is illustrated by a preliminary analysis of the first year of operation of the '10 MW' Butoni wind farm, commissioned in August 2007, the design of which was strongly influenced by the above considerations. Butoni was commissioned in November 2007 and has already ridden out one severe storm.

Introduction

The Fiji Islands lie in the tropical trade wind zone. Thus there is almost always a gentle sea breeze, enough to moderate the tropical heat , but this breeze is much weaker than that prevailing in places like 'windy Wellington', and thus only marginally strong enough to be used for wind-power. In short, 'too little wind power'.

On the other hand, Fiji experiences about 2 tropical cyclones per year on average. With winds exceeding 100 km/h these can severely damage wind turbines unless special protective measures are applied. In short, 'too much wind power'.

The Butoni wind farm is operated by the Fiji Electricity Authority (FEA), and feeds directly into the grid for Viti Levu, which has a total capacity of about 140MW, and is operated by the FEA. The farm was commissioned in August 2007. Each of the 37 turbines is fitted with an anemometer, and its electrical output is individually recorded. FEA have kindly made available to us the records of all these instruments for the first year of operation.

This paper focuses on a preliminary analysis of the first year of operation of the '10 MW' Butoni wind farm, commissioned in August 2007, the design of which was strongly influenced by the above considerations.

Geography

The map in Figure 1 shows the location of Butoni It is 4 km north of Sigatoka town (18.3S,177.5E) in the south-west corner of Viti Levu, the main island of the Fiji group. In round figures, Fiji Islands has more than 300 islands (counting at high tide) and a total population of 800,000. About two-thirds of the population lives on Viti Levu, half of them clustered around the Suva-Nausori corridor in the south-east corner. Electricity to Suva and the other main towns of Viti Levu is supplied by the Fiji Electricity Authority through a single grid. The base power comes from the Monasavu dam on the high plateau in the middle of the island, where the mean annual rainfall exceeds 7 metres! The Wailoa power station fed by Monasavu has a rated capacity of 80MW, but in recent years has supplied only about half of the total MWh, with the rest coming from diesels.

Mean wind regime

Figure 2 shows the monthly mean wind speed in Fiji, according to NASA (2008) . This indicates that for most of the year, the mean wind speed lies between 6.0 m/s and 7.0 m/s (at a height of 50 m). According to most authorities (e.g. Manwell, McGowan & Rogers 2002), this is just about high enough to make a wind-power station viable. The mean wind speed is highest during the trade wind season (April to October) and slightly lower (5.3 -6.0 m/s) from November to March. The mean wind speed may be lower then, but November-March is in fact the cyclone season, so it is also the season of highest extreme wind speed.

Limitations of NASA wind data

But the NASA wind-speeds have to be regarded as only indicative.

NASA use satellite data to estimate the wind speeds at a nominal 50 m above the ground (or sea), which is about the hub height of many modern turbines. Note that this is different from standard meteorological practice, in which wind speeds are measured 10 m above the surface.

The spatial resolution of the NASA data is very limited: the data shown are nominally averages over a 1-degree square. Since most of the Fiji locations indicated in Figure 2 are within 1-degree (~100km) of each other, it is not surprising that the NASA estimates for all locations are very close to each other. However, given the topography of Fiji, this is unlikely to be the case in reality. In particular, in the centre of Viti Levu is a rugged 'plateau' about 1000 m above sea level, with markedly different climate on each side: a wet side (on the south-east, facing the prevailing wind) and a (relatively) dry side on the west . Annual Rainfall on the high ground is as high as 7 to 8 meters, which is why Monasavu (which lies on the windward edge of the central plateau) is the site of the main hydro-electric facility in the country.

The NASA data also ignore the surface texture. For example, Monasavu is surrounded by rainforest, whereas Suva (Laucala Bay) is on the south-east coast with the prevailing wind approaching over the sea, i.e. a flat and fairly smooth surface.

Figure 3 compares the NASA estimates of wind speed with observations by Kumar & Prasad (2010) at Laucala Bay. These land-based observations are taken from an instrument at 10 m height, right on the water front, and exposed directly to the prevailing SE winds which come across a sea which (being inside the fringing reef) is usually fairly smooth. The observed data (3-year averages over the period 2005-2008) has been extrapolated to 50 m height using the standard formula

$$u_z = u_s (z/10\text{m})^{0.14} \qquad (1)$$

Where u_z is the wind speed at height z and u_s is the wind speed at the 'standard' height of 10 m. (Twidell & Weir, 2006, p.294) . The NASA data plotted here represents averages over the period 1983-2005.

Worryingly for anyone who wants to estimate the feasibility of wind power from the NASA data, Figure 3 shows that the NASA process over-estimates the mean wind speed by about 25%, at least for this location.

Fiji meteorological data

At three of its observing stations, the Fiji Meteorological Service (FMS) has a long-term record of wind-speed extending over a 50 –year period or so, namely Nadi Airport, Nausori Airport and Suva (Laucala Bay).

Unfortunately the wind record from Laucala Bay meteorological station is marred because although the instrument was exposed on all sides when the station was built in 1942, 'the current exposure of wind instrument is poor to moderate considering the large trees in the neighbouring residential properties' (FMS 2008a). That was a major reason why Kumar & Prasad (2010) found it necessary to establish a fresh observational record at a nearby site. For what it is worth, FMS (2008a) report monthly mean wind speeds at Laucala Bay ranging from a low of 4.9 knots in March to a high of 6.5 knots in October, with an annual mean of 5.5 knots. In accordance with standard meteorological practice , these means are based on observations which are average speeds over a 10 minute period at intervals of 3 hours, and at a height of 10 m above the surface. Converted to a height of 50 m using equation (1) , those values correspond to monthly means ranging from 3.1 m/s to 4.2 m/s, with an annual mean of 3.5 m/s. In short, the FMS figures at Laucala Bay are 10 to 20 per cent lower than the observations of Kumar & Prasad shown in Figure 3. The discrepancies are greatest for the higher wind speeds, which are the most important for wind power. This illustrates the importance of a properly sited anemometer.

The FMS data from Nadi airport does not suffer these interference problems. The data from FMS (2008b) correspond to an annual mean wind speed of 3.6 m/s at 50 m height. This is well below that required for wind power purposes; most commercial wind turbines would not be rotating at all at a wind speed of 3.6 m/s! (Compare Figure 6.)

Indeed, for purposes of wind power, the ideal location is one where the wind blows strongly but not too strongly – say, at about 15 m/s – all day every day. This description fits the 'Roaring Forties', which is why the west coasts of New Zealand and Tasmania are regarded as excellent sites for wind power. But it would not be a good regime for an airport, so it not surprising that Nadi Airport (on the west coast of Viti Levu, and sheltered from SE winds by a nearby range of hills) is not a good wind power site. (FMS data for

Nausori airport, some 20 km from Suva, indicates that it would be an even less suitable site for wind power, with a mean wind speed of only 2.7 m/s at 50 m height.)

But the Nadi data does illustrate another problem for wind power at many sites in Fiji, namely the prevalence of calm periods. Figure 4 illustrates that for nearly 25% of the observations at Nadi (notionally taken every 3 hours from 1960 to 2007) the wind is ‘calm’ (i.e. less than 0.5 m/s).

The Butoni wind farm: turbines

The Butoni wind farm sits on top of a ridge just outside Sigatoka town in the south west of the island of Viti Levu. It comprises 37 Vergnet turbines (model GEV-MP 275) each rated at 275 kW, making a total rated capacity of 10 MW. A few of these turbines are shown in the photo (Figure 5). These turbines are horizontal axis, 2-bladed downwind rotor with two speed generator. The turbine has a teetering hub with a hydraulic pitch control. The cut–in speed is 3.5 m/s with a cut–out of 20 m/s. The turbine during its operation can withstand a wind speed of 42.5 m/s and at lowered position a maximum of 85 m/s. The turbine is designed for maximum output at a hub height of 55 m. It has a two stage planetary gear box and 2 stage asynchronous squirrel cage generator and has a hydraulic active yawing mechanism, which turns it automatically in the direction of the wind. Their nominal power curve (Figure 6)supplied by the manufacturer shows the power output from each turbine at given wind speed.

For operation in Fiji, one of the most important design features of these turbines is that the tower hinges at the base, so that the turbine can be laid nearly horizontal – i.e. safely out of the destructive force of the wind - in storm conditions (Figure 7). This ‘cyclone proofing’ capacity has been well demonstrated earlier by Vergnet installations in New Caledonia, which is another Pacific Island subject to cyclones. This tilting is accomplished by a winch at the base, and takes about 30 minutes per turbine. The winching arrangement also allows the turbine to be raised to the vertical without the need for an external crane, which is a considerable advantage in remote areas.

The turbine is robust and is designed with extreme condition protection such as flexible architecture (guyed tower) and shock absorbent anchors for earthquake protection. It is equipped with a lightning arrester on the nacelle and is protected against marine corrosion. It has an aerodynamic brake and a disc on the high speed shaft for emergency braking and parking.

Butoni : wind regime

The diurnal variation of wind at Butoni on a typical day in the trade wind season is illustrated in Figure 8. The mean wind speed in August is a bit above 5.5 m/s, which is the annual mean wind speed at the site (at the hub height of 55 m), as determined by measurements over 12 months before installation.

The lower three curves show wind at hub height for 3 separate turbines. There is a significant variation in wind speed between them - about 1m/s – depending on precise location along the ridge. The measured wind speed is greatest in the early evening, which is typical of the trade wind season, and a commercial advantage for FEA as this is the time of greatest power demand.

The top curve is the NASA estimated wind speed for this location. Again, NASA overestimate the actual wind speed, though not by as much as at Laucala Bay (compare Figure 3).

Actual measurements at 10 minute intervals (Figure 9) show that the actual wind varies much less smoothly through the day than the mean curves of Figure 8. Figure 8 also illustrates the variation of wind speed from month to month: strongest in winter (August), weakest in summer (December) - unless a cyclone is nearby in summer, which is the cyclone season! Figure 8 also suggests that totally calm periods are less frequent on the exposed ridge at Butoni than at the relatively sheltered site of Nadi airport (compare Figure 4).

The Butoni wind farm: performance

From an economic perspective, the most important result is the monthly electricity output (Figure 10). In each of its two best months of operation, Butoni produced over 1000 MWh of electricity. If it had operated at its rated capacity of 10MW, the output per month would have been

$$10\text{MW}\times(24\text{h/day})\times31\text{day} = 7440\text{MWh}$$

The *capacity factor* (CF) of an electricity system is the ratio of actual energy output produced to the output that would have been produced if the system had run full-time at its full (rated) power. Thus in these 'good' months, the CF is a little more than 1000/7440 = 13.4% . The manufacturer's performance contract calls for an annual CF of at least 12%. In the first year of operation, the capacity factor in some months is close to zero, so that the CF for the year as whole is far below 12%. There are two main reasons for this.

Firstly, the capacity factor is much less than 100% for all wind power systems because a turbine produces its rated power only at its rated wind speed (or a little above it, but below storm speeds). Lower wind speeds give (much) lower power output. For these particular turbines, the rated speed is 15 m/s (see Figure 6). So at a steady 15 m/s (which is quite a strong wind: 30 knots for yachtsmen) each turbine would produce its rated power of 275 kW, but at 7 m/s it produces only 60 kW.

Secondly, the output in Jan-Feb 2008 was almost zero, because the turbines were folded down during Cyclone Gene. Although, as it happened, the centre of the cyclone missed the Butoni area, there were still strong winds, and the tilt-down was still a worthwhile precaution and served to show that the storm protection system worked in practice.

In March, the output remained very low because the FEA was performing maintenance and checking on the turbines (which requires the turbines to be in the lowered position) . Although this was a scheduled part of the first year of operation, it would have been better for power production to stagger these checks rather than do them all at once. This results in a low availability factor (the ratio of hours for which the system is available for operation to the hours in the period).

Further examination of the records should reveal whether the below-expectation performance in September –October 2007 and May-June 2008 was due to low wind input or to other causes.

Preliminary economic analysis

The capital cost (total installed cost) of a single 275 kW GEV MP wind turbine is reported to have been about $FJ 920,000 (= AUD 700,000) when the system was purchased in 2007 (Islands Business, 2007) (They would cost more in Fiji dollars if purchased today because of a 20% devaluation of the FJD in April 2009.) Thus the total capital cost of the '10 MW' wind farm would be about F$34m, which is consistent with press reports at the time.

At the contractual capacity factor of 12%, Butoni would produce

12% x 10 MW x (8760 h/ yr) = 10500 MWh per year

With diesel fuel costing the FEA about 25c for each kWh generated (= F$250/MWh), according to its public statements in 2008 and 2010, the cost of fuel saved by the wind farm substituting for diesel generation would be F$2.7m per year. Based on this avoided cost an indicative payback time of $34m / (F$2.7m /y) = 13 years is anticipated.

Clearly this figure can be only indicative, because we do not have the commercial details of FEA's capital repayment timing and currency, or operating and maintenance costs for Butoni (which are however small relative to the capital cost) , and especially of the future price of diesel fuel. However, almost all projections are that the price of diesel fuel is unlikely to decrease significantly and will almost certainly increase faster than general inflation; this would lower the payback time.

Conclusions

The bad news is that because the wind speed at Butoni is only marginal for power production, the capacity factor of the wind farm is bound to be fairly low – at best around 14-15% . In its first year, the wind farm did attain this performance in some months, but its CF over the year as whole was only about half this, for reasons given above. With more experience of operation, it is likely that FEA will obtain better performance in later years. Even at a CF of 12%, the payback period of the system is about 13 years, which is long enough to have persuaded FEA's initial commercial partner to withdraw.

The good news is that the storm- proofing system has been proved to work in practice, thereby giving confidence that the system will reach its economic payback time without being destroyed by a cyclone.

FEA have persisted with the system, partly to gain experience in operating wind systems and integrating them in to the grid, and partly because every Megawatt-hour (MWh) of electricity it generates is a MWh that does not have to generated from expensive imported fuel. (The FEA base load is met by hydro, but the marginal generation – up to 50% in 2007-08 – is from diesel.) When the oil price was at its highest in 2008, the fuel cost of each marginal MWh of electricity was greater than the price FEA could sell at, as the electricity price in Fiji is subject to government control. That is a great incentive to develop renewable energy and to promote end-use efficiency, both of which FEA is actively pursuing. Since the data used for analysis was for its first year of operation, the writers are confident that after its first year of operations, the availability factor of the turbines would increase and consequently increase the CF of the wind farm.

We look forward to carrying out a more detailed analysis of data from both the first and subsequent years of operation at Butoni.

Acknowledgements

We thank the Fiji Electricity Authority, and in particular the Chairman Mr Nizam ud Dean, for making available the operational data from Butoni for us to analyze.

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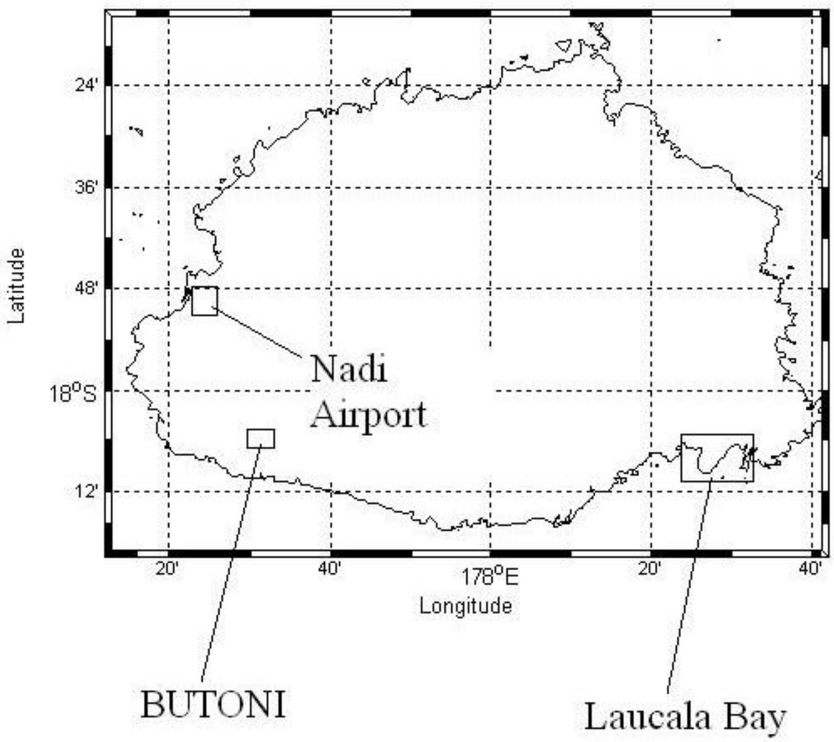

Figure 1. Outline map of Viti Levu, the main island of Fiji, showing location of Butoni wind farm.

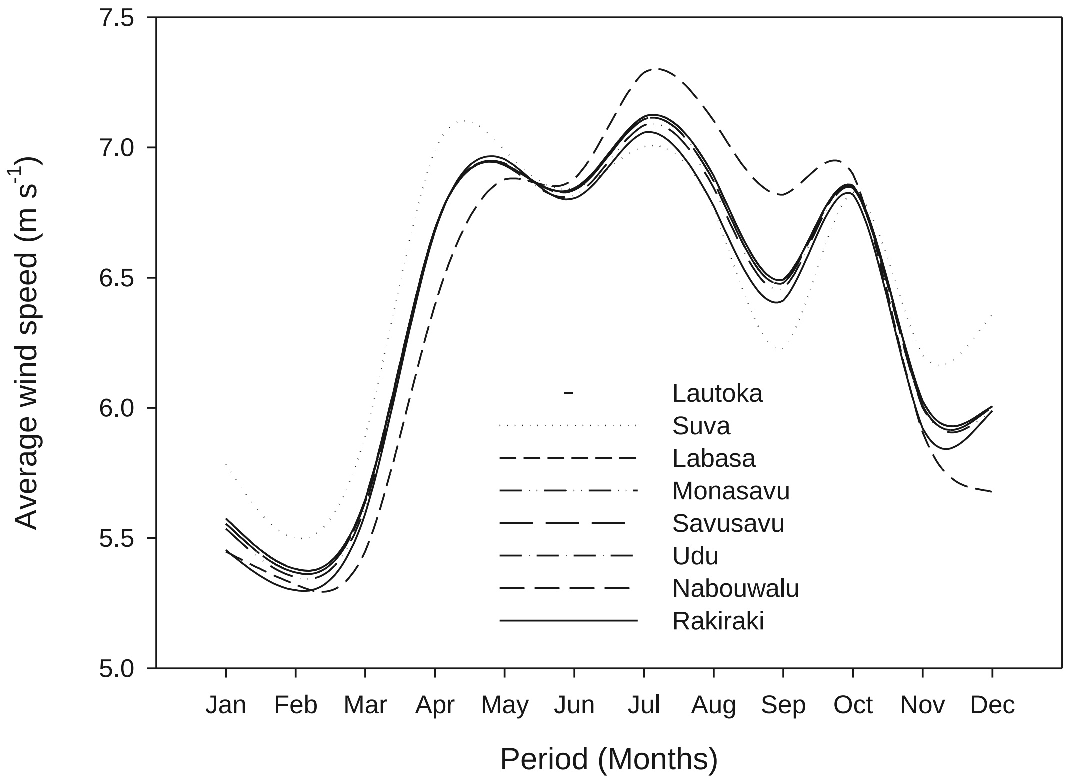

Figure 2. Monthly mean wind speeds in Fiji, as determined from NASA (2008) . Notionally at 50m above the surface.

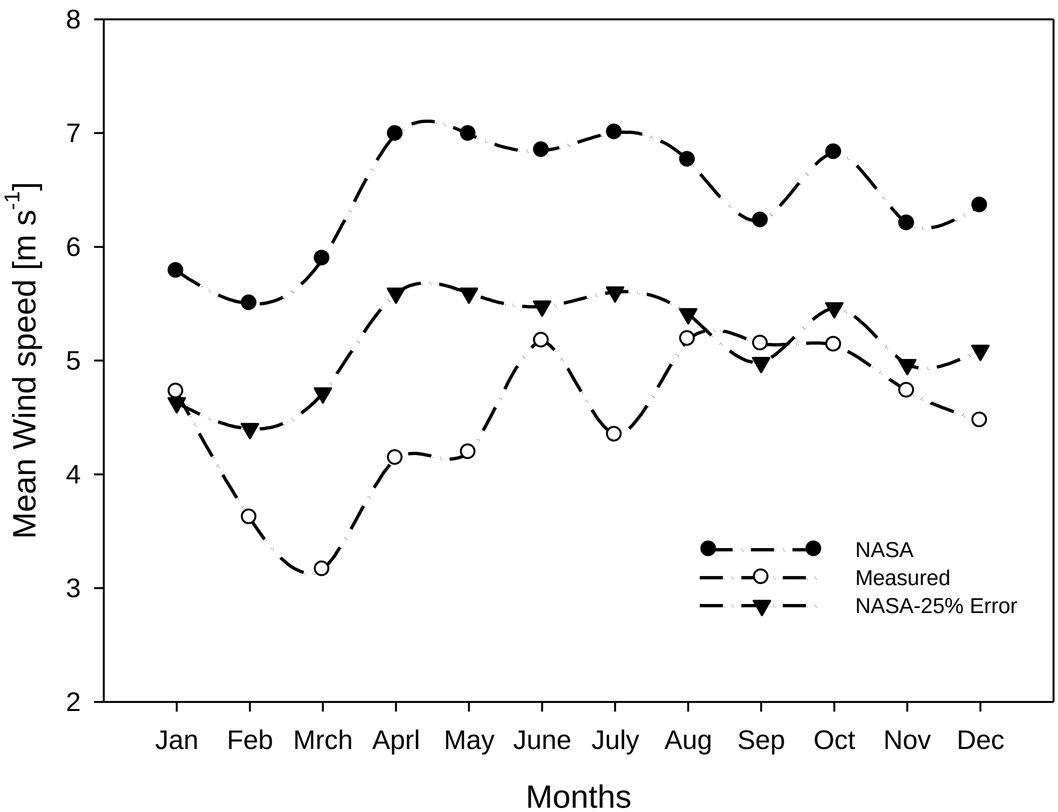

Figure 3. Monthly mean wind speeds at Laucala Bay, Suva at 50m above surface. Top curve is based on NASA (2008), as in Figure 2. Bottom curve is calculated by Kumar & Prasad (2009) from their observations from 2005 to 2008. Middle curve is 80% of top curve.

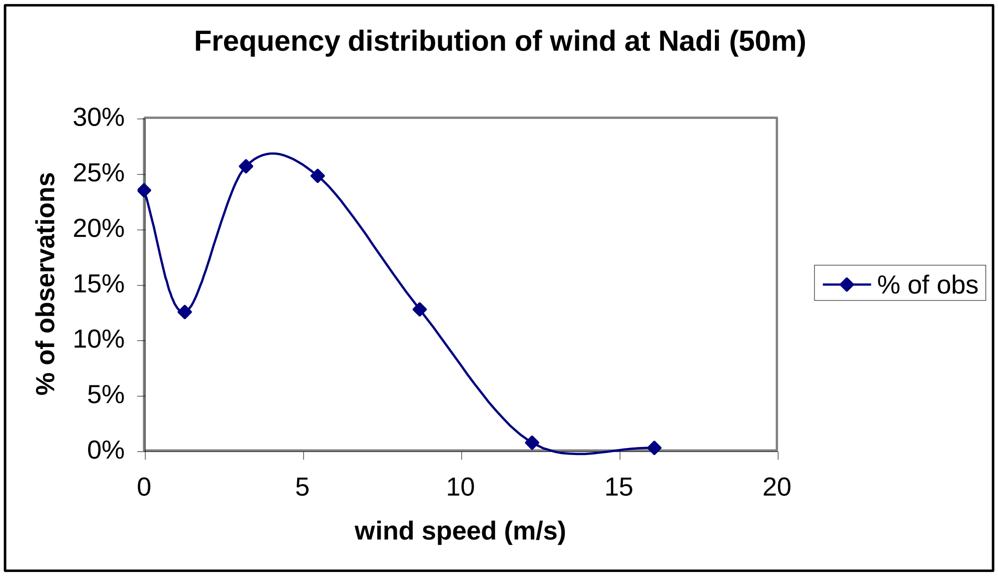

Figure 4. Frequency distribution of wind speed at Nadi airport 1960-2007. Calculated from data in FMS (2008b) , but converted to m/s and to 50 m height.

Figure 5. Photo of part of the Butoni wind farm, indicating its layout on a ridge.

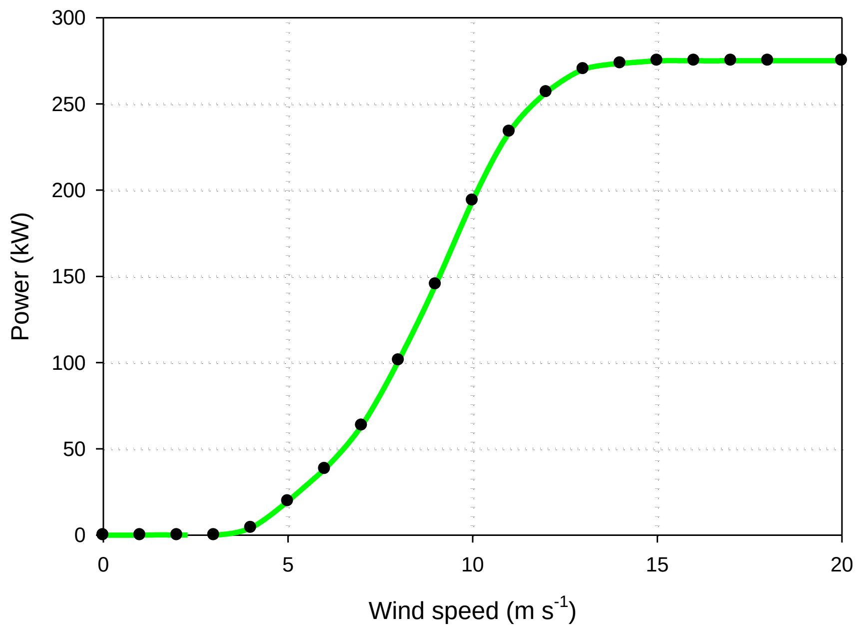

Figure 6. Power curve for a Vergnet GEV-MP275 turbine (based on manufacturer's data)

Figure 7. Turbine in partly lowered position. (In fully lowered position, it goes down to the ground). .

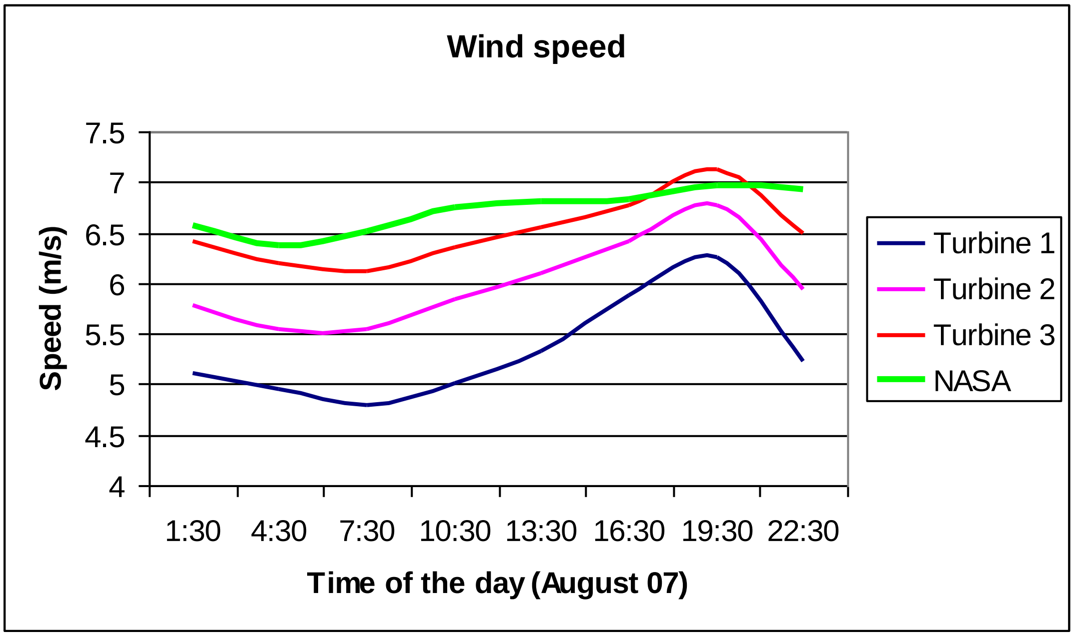

Figure 8 . Smoothed diurnal variation of wind at Butoni . Top curve is NASA estimates, others are observed at individual turbines.

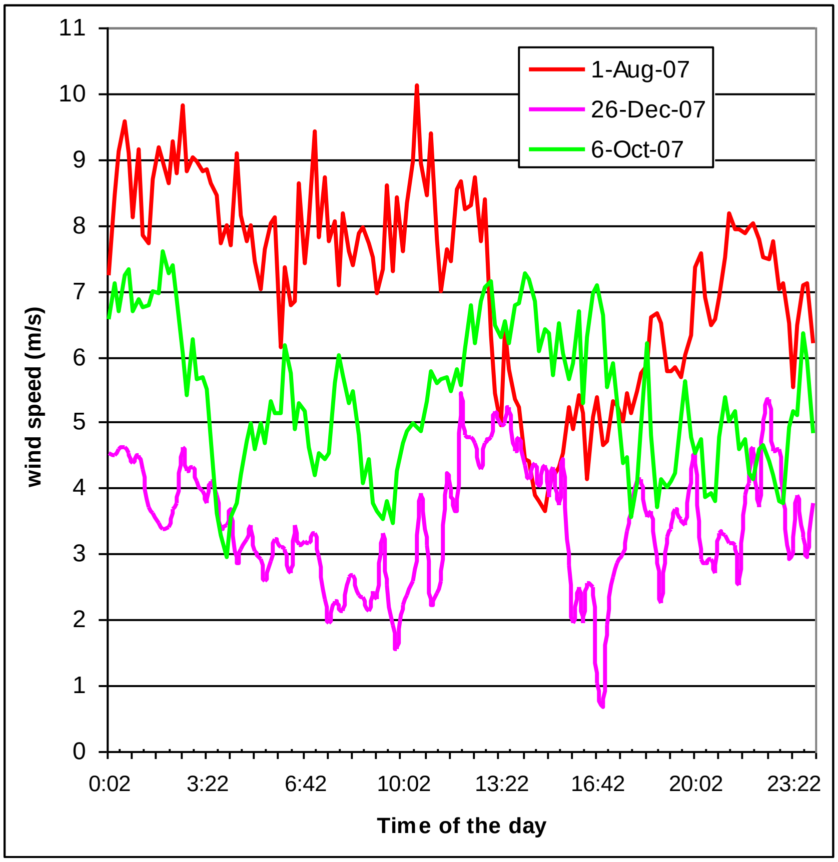

Figure 9. Actual wind speeds at 10 minute intervals on 3 days in 2007at hub of turbine 1. In early morning (left of chart) top curve is for 1 August, middle curve is for 6 October, and lower curve is for 26 December.

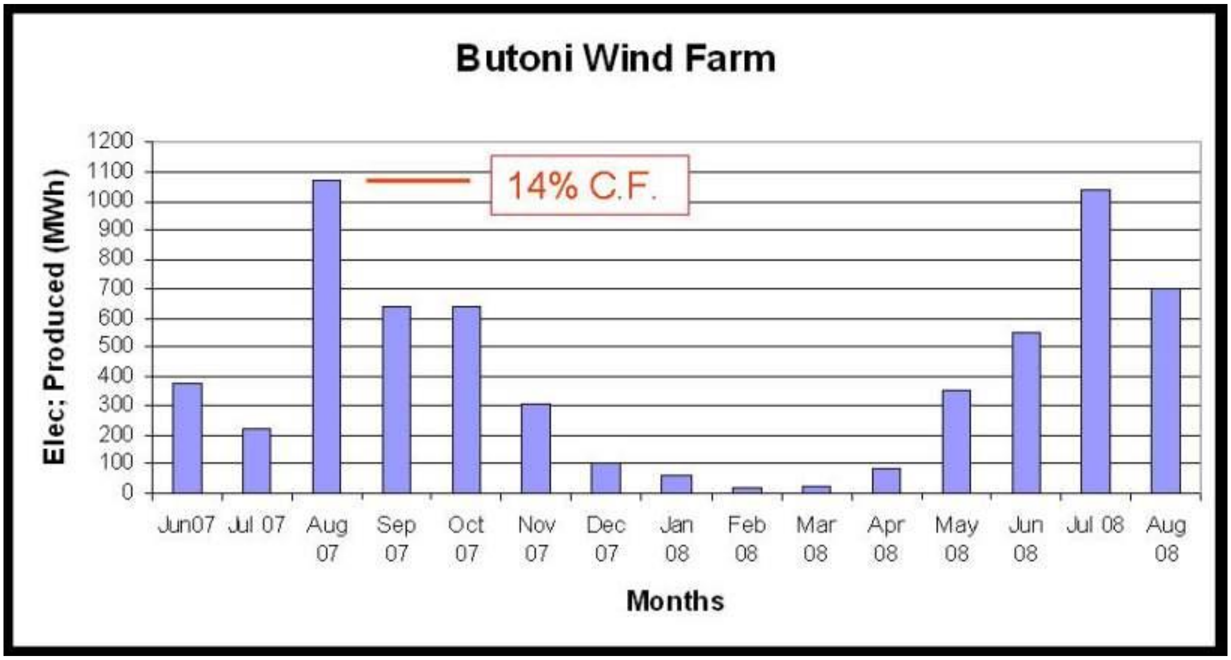

Figure 10. Monthly output of electricity (MWh) from Butoni, June 2007- August 2008. The horizontal line indicates output at a capacity factor of 14%.