Vetas V15 Wind Turbine Performance Optimization:
Sensitivity to Blade Pitch Angle in Moderate Wind Regimes

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Introduction:

In August 2004, a Vestas V-15 (65kW, 3-phase, 480VAC, 4200rpm) wind turbine, remanufactured by Energy Maintenance Systems (EMS) of Gary, South Dakota, was installed by Seventh Generation Energy Systems on the campus of Lakeshore Technical College. The turbine was equipped with a data acquisition and recording system to monitor system performance. LTC staff and SGES soon observed that the turbine's energy production was lagging the estimated performance based on the Focus on Energy site assessment and EMS supplied power curve.

On March 17, 2005, in an attempt to achieve higher turbine power performance and thus increase annual energy production, the turbine blade pitch angle was adjusted from 3.6° to 5.2°

This report is based on power output and wind speed data collected from August 30, 2004 to July 28, 2006.

Objective

The purpose of this project was to determine if a more aggressive blade pitch setting would improve the low wind speed performance of the remanufactured Vestas V15 wind turbine.

Results:

The turbine's post re-pitch power output was consistently higher, on average, than the power output before the re-pitch (See Chart 1 and Table 3). Estimated Annual Energy Output[T] (AEO) using the turbine's pre and post power curves shows **a 7.8% increase in energy production after the blades were re-pitched**. (With an estimated pre re-pitch AEO of 42,540 and post re-pitch AEO of 45,870, the re-pitching of the blades should result in a net increase in energy production of about 3,300 kWh per year.)

A secondary observation during this analysis was that the estimated AEO from the initial site assessment (70,037 kWh) is significantly higher than both the actual AEO and the AEO estimated in this report. There are several reasons for the exaggerated AEO from the original site assessment. The first is the inaccuracy of assumptions about wind characteristics at the site, including an assessed wind speed of 11.7 miles per hour (mph) at hub height. (The actual average wind speed over a 12-month period was 11.1 mph) Differences between assumed and actual values of wind probabilities, turbulence, and wind shear also play a role in the initial overestimate (these differences are shown in Table 1). The most significant source of the overly optimistic, assessed AEO, however, is in the use of the original power curve from the manufacturer. As shown in the Table 1, below, the EMS power curve overestimates the actual AEO of the V-15 turbine by 25%. The inaccuracy of the original power curve is also clearly shown by comparing the power curves in Chart 1.

Table 1: Wind Characteristics, Actual AEO, and Estimated AEO Before and After re-pitch

	Wind characteristics	7th Wind Output based on original EMS power curve	7th Wind Output based on observed power curves	Actual Output
Site Assessment *(Estimated output is over a 12 month period)*	K=2.000 Average wind at hub height = 11.7mph Elevation = 700 Wind Shear = 0.24 Turbulence = 15%	70,307 kWh	NA	NA
Before Re-pitch *(Actual and estimated output is over a 6.5 month period)*	K=2.265 Average wind speed at hub height= 12.2 mph Elevation = 700 Wind Shear = 0.261 Turbulence = 17%	39,584 kWh (26% overrated from actual output)	29,128 kWh (8.1% underrated from actual output)	31,494 kWh
After Re-pitch *(Actual and estimated output is over a 12 month period)*	K=2.100 Average wind speed at hub height= 11.1 mph Elevation = 700 Wind Shear = 0.292 Turbulence = 17%	58,913 kWh (25% overrated from actual output)	45,868 kWh (2.5% underrated from actual output)	46,996 kWh

[T] Estimated annual energy output was calculated using the 7th Wind performance calculator with the following constants: Site Wind Speed 11.1PMH, Map Wind Speed Height 33.5 m, Tower Height 110 ft, Site Altitude 700 ft, Turbulence Factor 0.17, Wind Shear Exp. 0.292, Weibull K = 2.1000
Turbulence, Wind Shear, and Weibull values were calculated by analyzing 1 year of data after the turbine was re-pitched using the software program Windographer.

The data:

Monitoring equipment gathered both instantaneous power generated from the LTC turbine and instantaneous hub height (110 ft) wind speed from a Met tower installed at a distance of five rotor diameters from the V15 wind turbine. Data was logged at intervals of one minute. The data used in this report was collected from 8/30/2004 to 7/28/2007. About 5% of the raw data points were flagged by the data logger as erroneous (during turbine fault conditions), and these were not used in the final data set. The final set of data included 147 days of data before the re-pitch and 147 days of data after the re-pitch.

Data analysis methodology:

Power curves (see Chart 1) were generated from wind speeds ranging from 8 mph to 30MPH. (At speeds lower than 8 mph no power was generated. At speeds over 30 mph the relatively small number of data points led to unreliable averages.)

Wind speeds were binned at 0.5 mph and all power data falling into each bin was averaged using a simple mean.

Trend lines were fit to the resulting averaged data points using a 3rd order polynomial equation. These trend lines are the power curves that demonstrate the difference in power output before and after the turbine blades were re-pitched. The accuracy of these power curves was evaluated by comparing the AEO as estimated by each power curve with the actual measured energy output. This comparison (as shown in Table 1) shows that the before-re-pitch power curve predicted output to be 8.1% less than the actual output, and the after-re-pitch power curve predicted output 2.5% less than the actual output. This margin of deviation was considered acceptable for the purposes of this analysis.

Assumptions & deficiencies of this report:

Accounting for air density: Wind speed and power output data were used in a raw form, not taking into account the variability of the density of the air from one day to the next. As shown by Table 2 the majority of data before the re-pitch were collected during cold months and the majority of data after the re-pitch were collected during warm months. A more accurate analysis would suggest that the power curves be modified to factor in the air density based on the average daily temperature. (Note: Temperature data that corresponds with the wind speed and power data is available should further analysis be needed.)

Table 2: Number of days of data collection by month

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Before Re-pitch	0	21	17	0	0	0	0	0	27	30	30	20
After Repitch	8	0	9	19	39	28	26	0	2	0	15	0

Reliability of data: In this analysis, the only filter to eliminate corrupt data was to remove data points which contained an error code next to the logger channel that recorded power. More sophisticated methods of evaluating the reliability of data could be applied in the future.

Conclusion:

The results indicate that modest improvements were achieved, with a 7.8% estimated increase in annual energy production. Table 3 shows that at all wind speeds the power production increased, but that the increase was especially pronounced at lower wind speeds. The average post-re-pitch power output increase at lower wind speeds (10 –13 mph) was 1.5 times higher than the average post-re-pitch power increase at higher wind speeds (14 to 20 mph). This observation validates the objective of this study.

With these results we conclude that any future V15 65kW turbine installations include the more aggressive 5.2° blade pitch angle to maximize performance. In practical terms however, the performance of any V15 project will realize better annual energy output if it can be supplied with the aftermarket 35kW, 900RPM generator available with 240VAC single or three phase and 480VAC three phase windings. The 35kW generators installed in Wisconsin have demonstrated consistently higher energy production levels than their 65kW counterparts. This is explained by the 25% lower RPM of the 35kW generator and its resulting effect on the airfoil's (Aerostar 7.5) tip speed ratio and coefficient of performance.

A secondary conclusion that should be noted is the inaccuracy of the original power curve. As shown in Table 1, Table 3 and Chart 1, the manufacturer's original power curve overestimates the AEO. It was determined that the EMS power curve was the same power curve as provided by Vestas when the turbine was originally produced. However, the V15 was originally supplied with a 22kW "pony" generator used to achieve higher efficiency during start-up and low wind speed operation. Many of the V15s installed in the wind farms of California had the pony generator removed due to service and maintenance problems. The performance of the V15s in California was not adversely affected due to the nature of the wind resource there. But in Wisconsin's moderate wind regime, turbine performance is reduced without the smaller start-up generator. This should be taken in to account during future site assessments where a V15 65kW turbine is being considered for installation.

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Chart 1: Observed Power Curves Before and After Re-pitch, with Theoretical Power Curve as Supplied by Manufacturer

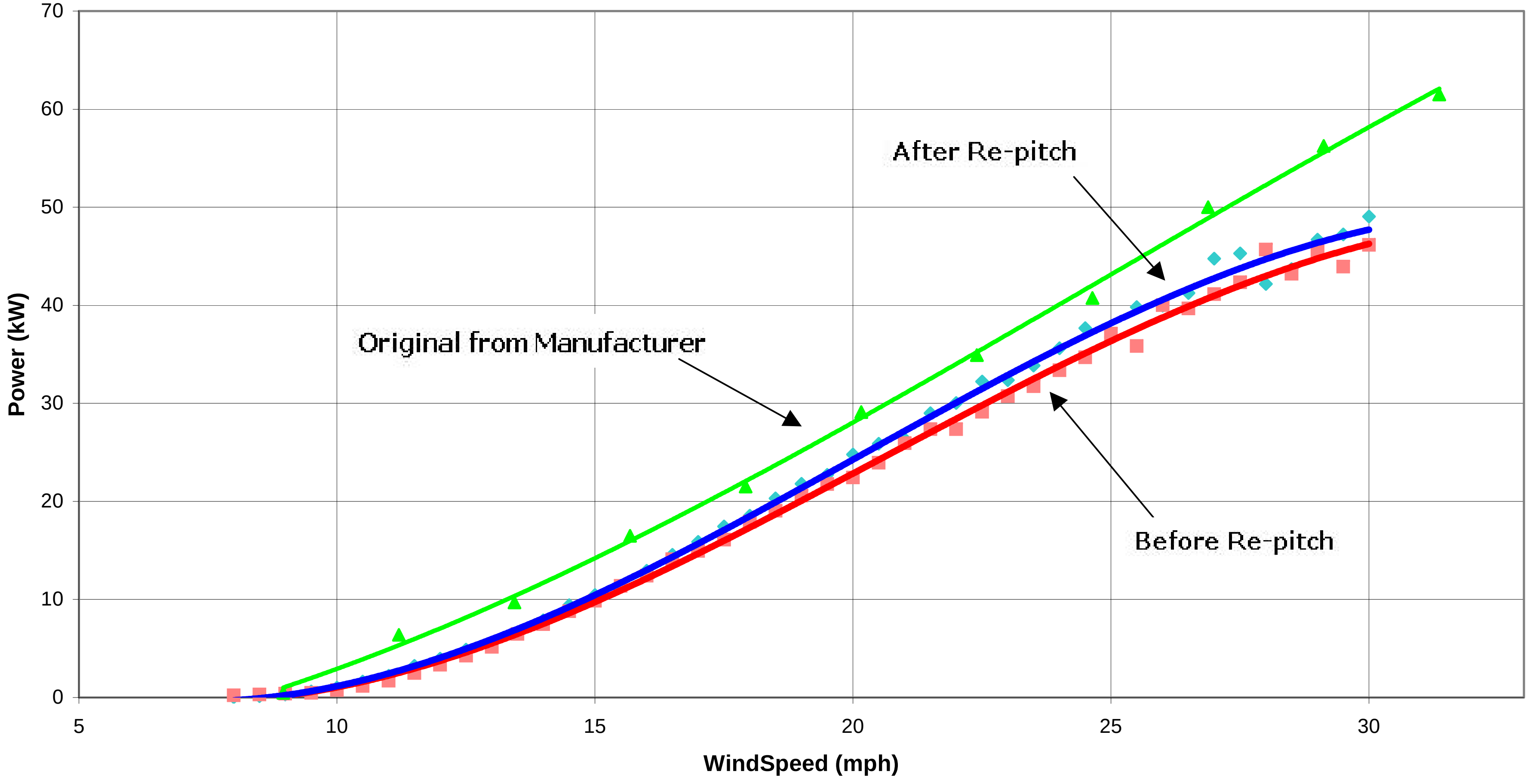

Table 3: V15 65kW Wind Turbine Power Output Based on Regression Analysis Results

WindSpeed (mph)	Power Output Based on Original EMS Power Curve (kW)	Power Output Before Re-pitch (kW)	Power Output After Re-pitch (kW)	Percent Improvement in Performance from Before to After Blade Re-pitch
8	-0.56	-0.37	-0.39	NA
9	1.12	0.14	0.20	44.0%
10	2.96	1.02	1.17	15.5%
11	4.97	2.23	2.50	12.1%
12	7.12	3.74	4.14	10.6%
13	9.41	5.53	6.06	9.6%
14	11.82	7.55	8.23	9.0%
15	14.35	9.78	10.61	8.5%
16	16.99	12.18	13.17	8.1%
17	19.72	14.73	15.88	7.8%
18	22.54	17.39	18.70	7.5%
19	25.44	20.13	21.59	7.3%
20	28.40	22.92	24.53	7.0%
21	31.41	25.73	27.48	6.8%
22	34.47	28.52	30.40	6.6%
23	37.57	31.26	33.26	6.4%
24	40.69	33.92	36.03	6.2%
25	43.82	36.47	38.67	6.0%
26	46.96	38.88	41.14	5.8%
27	50.09	41.11	43.42	5.6%
28	53.21	43.14	45.47	5.4%
29	56.30	44.93	47.25	5.2%
30	59.35	46.45	48.73	4.9%