Boosting Power Production Update

Follow-Up Project Report on Nebraska Public Power District Vindicator® LWS Field Trial

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Abstract

A Vindicator® Laser Wind Sensor (LWS) was installed on a Vestas V-82 turbine in Ainsworth, Nebraska and the wind direction measurement was integrated into the yaw control. A report analyzing the data collected during a one month field trial program, Boosting Power Production, was released in December 2009. This report provides an update with aggregate data from August 2009 through March 2010. During this period, when under Vindicator® LWS control, the turbine produced 10.7% more power in Region II than when the turbine's yaw control was based on wind direction data from the turbine's existing wind vane. This provides the final report on Phase 1 of the Nebraska test, which used a non-optimized control algorithm. Phase 2 of the Nebraska test will now commence, which will implement an optimized control algorithm.

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1 Introduction

Accurate knowledge of inflow wind is necessary for optimal turbine operation. The most efficient and accurate way to measure the incoming wind is with a sensor that can measure the undisturbed inflow at the height of the blades. In July 2009, a nacelle mounted, forward-looking, multiple point reporting remote laser wind sensor called the Vindicator® Laser Wind Sensor (LWS), manufactured by Catch the Wind, Inc. (CTW) in Manassas, Virginia, USA, was mounted to a Nebraska Public Power District (NPPD) Vestas V-82 Turbine in Ainsworth, Nebraska. As part of the Phase I testing, the wind sensor utilized the wind measurement taken 100m to 200m ahead of the turbine. The controller used the Vindicator® LWS wind direction data input to control the yaw direction of the turbine approximately 50% of the test period.

Preliminary results of the Phase I testing were published in Boosting Power Output (CTW 2009). That report presented data, which demonstrated that, by helping the turbine to point accurately into the oncoming wind and detect gust presence, the sensor increased the turbine's power production by over 12% using a non-optimized, very conservative control algorithm during August 2009. This power improvement was observed during the same period as the reduction in stress loads on the turbine, as measured by condition monitoring sensors (Swantech).

After this preliminary report, the Vindicator® LWS continued to control the turbine throughout the following fall and winter. The Vindicator® system continues to increase power production, with aggregate power increase values from August 2009 through March 2010 of 10.7% in Region II winds, while still using a non-optimized control algorithm.

2 Equipment

The Vindicator® LWS is a Class I eye-safe laser product designed to remotely measure wind speed and wind direction at 100 m, 150 m, and 200 m ahead of the sensor. CTW installed one Vindicator® LWS on Turbine T22 at the NPPD Ainsworth Wind Energy Facility in Ainsworth, Nebraska. The Vindicator® sensor was commissioned on July 8th, 2009 and the preliminary NPPD 30 day field trial of the sensor was conducted during the month of August 2009.

The Vindicator® system consists of four individual sub-assemblies: (1) Base Laser Unit (BLU), (2) Remote Lens Unit (RLU), (3) Environmental Control Unit (ECU), and (4) Programmable Logic Controller (PLC). The mounting locations of these units within and on the nacelle are identified in Figure 2. The BLU is located inside the nacelle and securely mounted to the side of the generator housing, as shown in Figure 2. It is connected to the RLU which is secured to the top of the nacelle (shown in Figure 1) and is oriented facing forward such that the RLU window has a clear line of sight ahead of the turbine. The ECU is located inside of the nacelle and controls the environmental functions for the RLU.

The PLC is installed in the nacelle as shown in Figure 2. Electrically, it is placed logically in series with the existing turbine PLC (TOI) such that the yaw control functions of the turbine are managed by the Vindicator® PLC. Through the PLC, data was recorded at 1 Hz from the Vindicator® LWS and the existing anemometer and wind vanes. Data was also analyzed from the site Supervisory Control and Data Acquisition (SCADA) system from which the 10-minute averaged relative wind direction, anemometer wind speed, yaw angle and average active power production data was obtained.

Figure 1 shows the Vindicator® LWS mounted on the top of the V-82 Vestas NPPD Turbine T22. As shown in the picture, it was mounted in front of the heat exchanger, below the current anemometers and wind vane so as not to disturb the airflow over the legacy instrumentation.

Figure 1 Vindicator® LWS Installed on T22

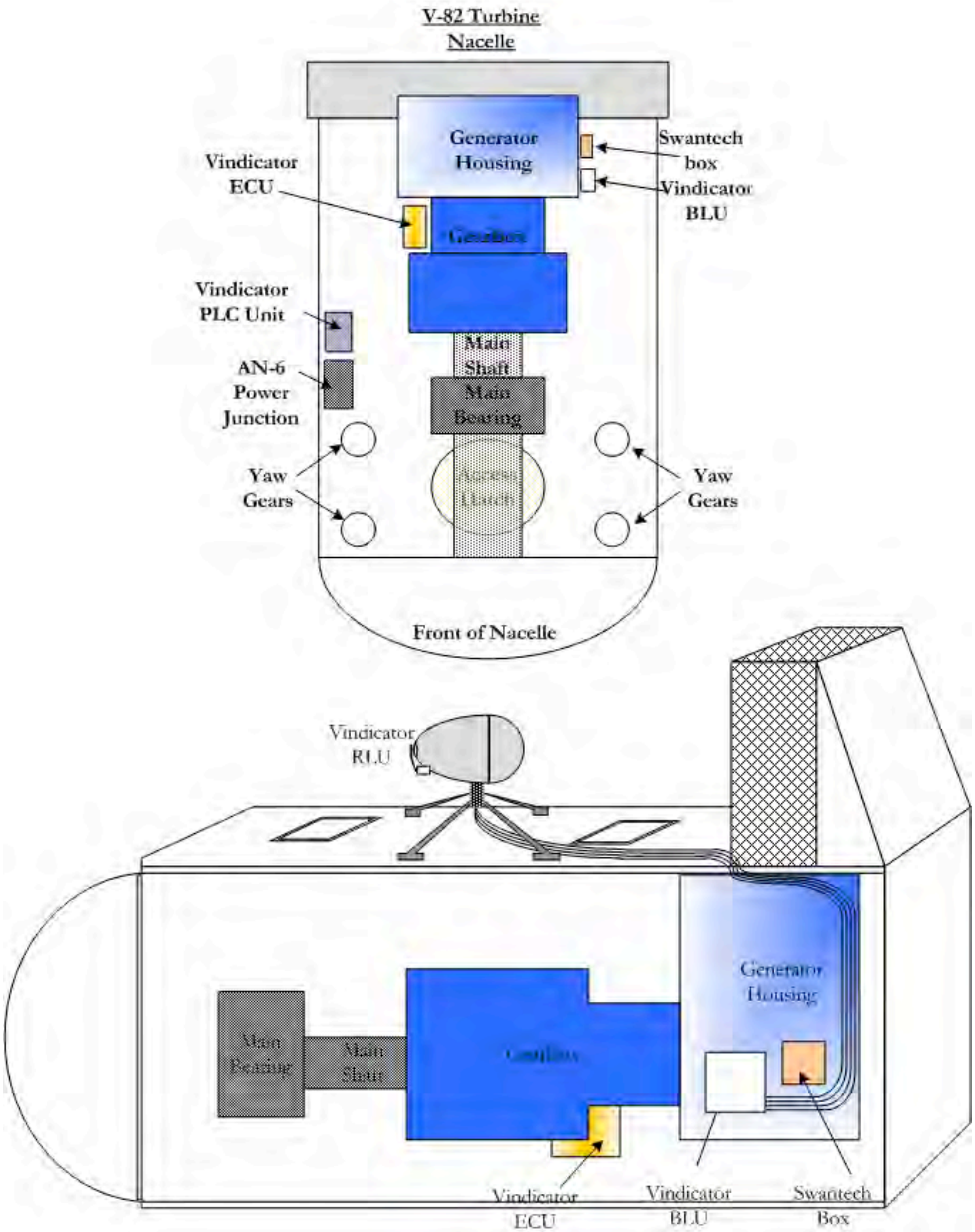

Figure 2 Mounting Locations of the Vindicator® LWS in the T22 Nacelle (not to scale)

3 Control Algorithm

The control algorithm has not been changed since the report Boosting Power Output (CTW 2009). The PLC controls all yaw functions for the turbine when the Vindicator® LWS is in control, but takes inputs from the legacy controller for yaw events initiated by emergencies. After an initial averaging study when the Vindicator® LWS was first in control, three-minute running averages provided the optimum wind direction information. Since this was the first time a Vindicator® system was used to control a large-scale wind turbine, very conservative control laws were put in place. These control laws are outlined below.

The Vindicator® LWS three-minute running average wind direction was used to control the yaw unless the following conditions were met:

1. If the wind speed measurements of the Vindicator® LWS and the nacelle anemometer differed by more than 3 m/s, the control shifted to the wind vane until the two measurements agreed to within 3 m/s for 30 minutes, although the Vindicator® LWS wind speed measurement was not used as a control input.
2. If the wind direction measurements of the Vindicator® LWS and the raw wind vanes disagreed by greater than 60 degrees input shifted to the wind vane until the two measurements agreed to within 60 degrees for 15 minutes.
3. If Vindicator® LWS indicated a bad data flag, wind direction input was provided by the wind vane until the flag cleared.

In Phase II of the project, the control algorithm will be revised to take greater advantage of the improved wind direction data to further increase power production and reduce stress loads.

4 Power Calculation Methodology

4.1 Power Output Comparison

Comparing power data from large wind turbines presents challenges. First, wind characteristics and wind change timing vary measurably, even between adjacent wind turbines. Second, actual operational performance varies among even like models of in-service turbines because of differences in the quality of initial construction/erection of a particular turbine, turbine age, wear and tear on components, and service/repair/replace cycle of the equipment. Therefore, each turbine can generate slightly different amounts of power in response to similar winds. Additionally, a natural variance in wind speed and direction is experienced by adjacent turbines caused by orographic turbulence and embedded gusts. The variances can be very dramatic, even in apparently steady wind. Therefore, for the Nebraska project, it was concluded that the best analysis of power output was on the same turbine (T22), comparing periods when the Vindicator® LWS was in control with periods when the wind vane was in control. The average power output data from the T22 turbine was sorted according to which instrument's inputs were used to control the yaw motor. The control logic determining which inputs were used in the algorithms did not depend on the wind condition, except at wind speeds below the turbine cut-in.

4.2 Data Quality Assurance

The data presented in this update is an aggregate of all of the data collected from August 1, 2009 through March 31, 2010. During this time, the equivalent of 68 complete days of usable data was recorded.

Data points were taken in 10-minute samples as reported by the SCADA system. Each data point, representing a 10-minute time interval, has

- An average wind speed measured by the cup anemometer
- An average electrical power output
- A flag that indicates which device, Vindicator® LWS or wind vane, was in control of the nacelle yaw during that time interval.

The ten-minute average power records in each category were binned by wind speeds in bins from 3.6-4.5m/s to 12.6-13.5 m/s. Each wind speed bin is identified by its mean speed, i.e. 4m/s to 13m/s. Throughout the 68 days (cumulative) of usable data taken, between 140 and 580 data points were recorded in each wind speed bin and control category (see Figure 6). Throughout the relevant wind speed range of Region II, there were sufficient statistics of usable data points for a power comparison analysis.

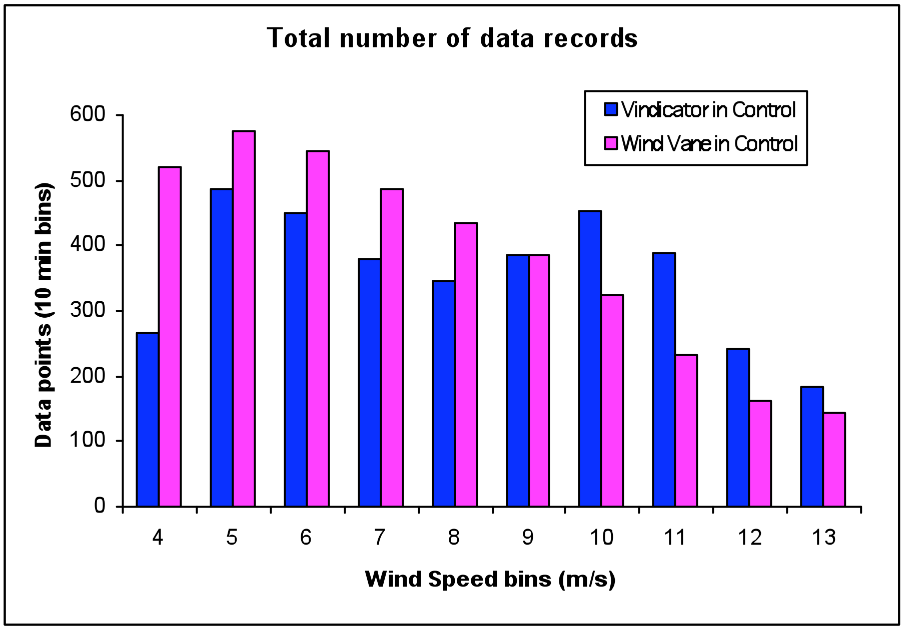

Figure 3 Total number of usable 10 min data records analyzed.

4.3 Wind Speed Distribution

The spectrum of winds speeds measured by the cup anemometer during the periods in which usable data points were taken roughly resembles the expected wind curve at the site. The power produced at each wind speed and in each of the two control modes was scaled to the full time recorded at the respective wind speed and then compared (see Figure 6). This way, the following two scenarios were compared:

1) Vindicator® LWS in control during all of the valid testing time; and
2) Wind vane in control during all of the valid testing time.

This approximated a comparison between a turbine fully controlled by Vindicator® LWS with an equal turbine using conventional, wind vane control.

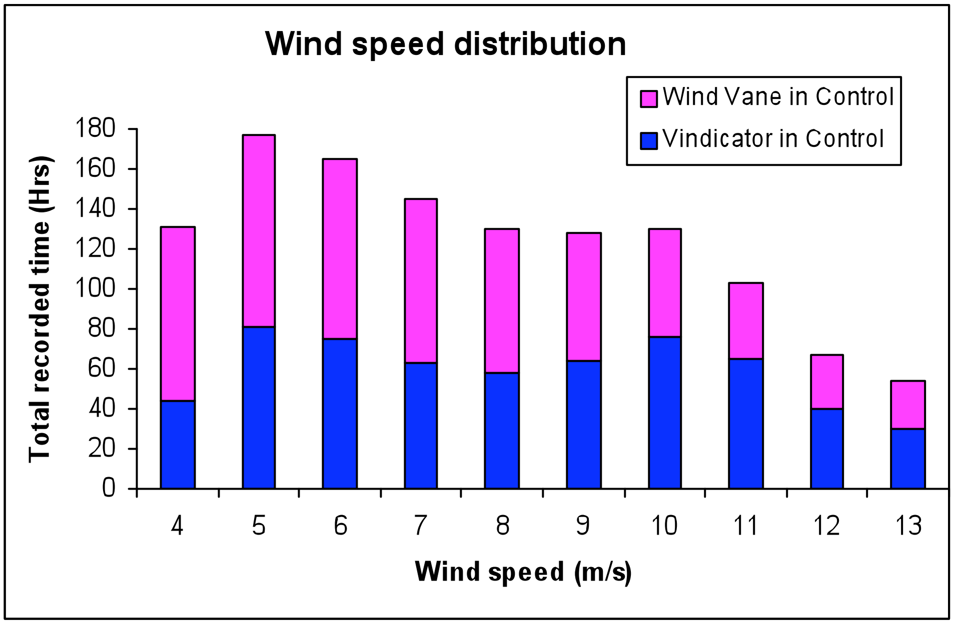

Figure 4 Wind curve for the recorded usable data used to weigh the power production in the two control modes.

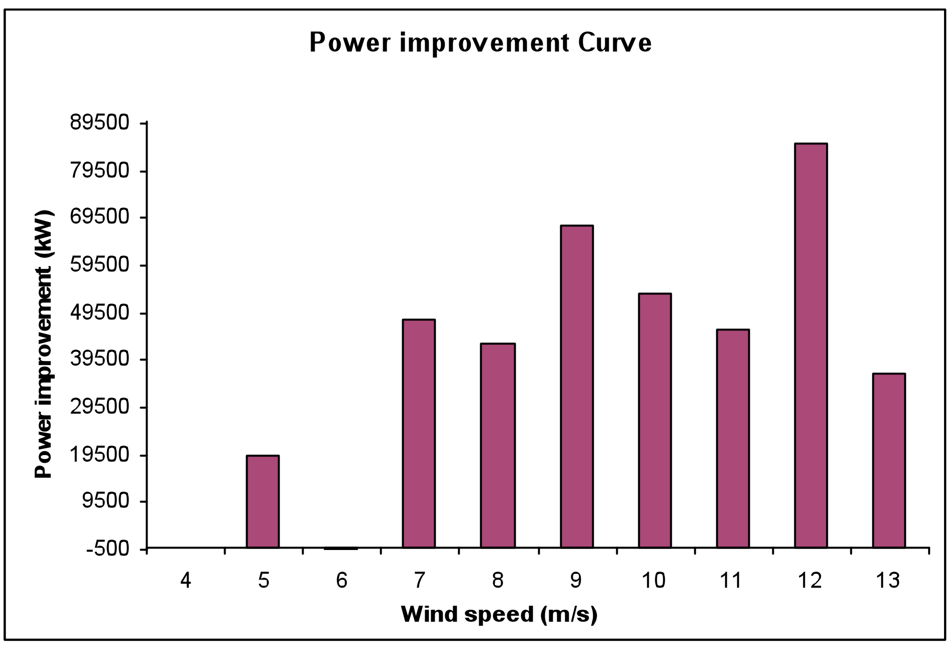

Figure 5 Average power increase by wind speed. The Vindicator® LWS wind direction control input significantly improves the power output, especially as the turbine output power increases.

5 Updated Power Production Results

Improved knowledge of the inflow led to more efficient power capture by turbine T22. Figure 6 shows the updated average power produced with Vindicator® LWS control inputs (blue) and wind vane control inputs (red), binned by wind speed, during the 8 month period from August 1, 2009 through March 31, 2010. The wind speed used to bin the power data was measured by the legacy anemometer on the nacelle, as met tower data is not available for the area around turbine T22. The figure illustrates that the turbine produced significantly more power by using the accurate inflow direction measurements of the Vindicator® LWS than it did when the wind vane input was used to control T22.

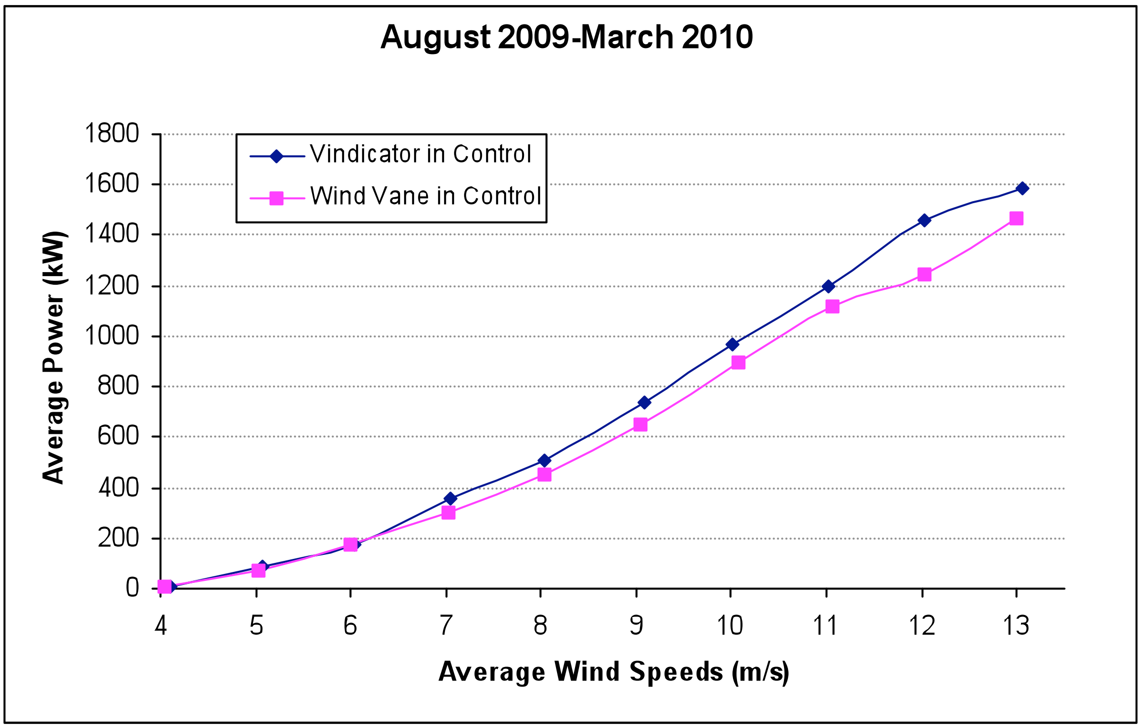

Figure 6 Power Curve showing the active power produced comparing when Vindicator® LWS was in control (Blue) and the wind vane was in control (Red) during the aggregate data collection period. T22 produced significantly more power using the wind direction measurements of the Vindicator® LWS than it did with the wind vane.

The power produced in the two control modes for the wind speed bins of 4m/s to 13m/s was compared and analyzed during the test period (as described in detail in the previous section). The overall increase in power output due to the Vindicator® LWS control was 10.7% in Region II winds, during the testing period from August 2009 through March 2010.

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6 Conclusions

This report provides an update to Boosting Power Production (CTW 2009). The updated report, based on eight months of data, shows that the T22 turbine produced an average of 10.7% more power when the control inputs from the Vindicator® Laser Wind Sensor were used, even under the constraints of suboptimal control logic. Between August 2009 and March 2010, the Vindicator® LWS wind direction measurement continued to be used as the yaw control input on NPPD Vestas V-82 wind turbine T22 in Ainsworth, Nebraska. The increased pointing accuracy and increased gust detection continued to lead to a significant power increase during the times in the aggregate period when Vindicator® LWS wind direction input was used to control T22 instead of the wind vane. It should be noted that this represents an accumulation of performance data through three seasons of operation at this test site.

CTW is continuing to collect data at the site and is optimizing various parameters of the T22 control algorithm as a part of Phase 2 of the test. The results continue to indicate that, with accurate and timely inflow measurement on the 1 Hz timescale, more sophisticated feedback control algorithms can now be developed. The data supports the previous hypothesis and conclusion that the turbine could be operated even more efficiently if averaging and filtering of the wind data were reduced. This reduction of averaging and filtering by use of feed-forward wind direction data leads to even better pointing accuracy of the nacelle, resulting in lower stress loads and increased power output.

7 Bibliography

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