PO. 301

Yaw Control: The Forgotten Controls Problem

Dr. Pri Mamidipudi, Dr. Elizabeth Dakin, Dr. Andrew Hopkins, Frederick C. Belen, and Dr. J. Gordon Leishman*
Catch the Wind, Inc.

*RotorSystems Research, LLC.

Abstract

This poster presents yaw misalignment and power data collected from a utility-scale wind turbine. We further present statistics indicating that all of the wind farms considered in this study demonstrated similar results. Finally, we demonstrate that accurate alignment with the inflow increases the captured power and energy.

Objectives

The goal of this work is to study the amount of yaw misalignment with the wind on a utility scale operational wind turbine and assess the yaw effects in terms of power curve and energy output, develop a methodology to measure average yaw misalignment over time and to assess the efficacy of wind velocity measurements taken on the nacelle. Power output when legacy wind direction and laser look-ahead wind direction data is used for yaw control is studied to further evaluate the consequences of the yaw misalignment.

Methods

Long-term data has been collected from several utility scale wind turbines and was analyzed using various techniques to determine the extent of yaw misalignment over time. The effect of yaw misalignment on the turbine was studied by analyzing the power output of the turbine as a function of yaw angle. Two metrics were used to quantify the misalignment of the utility scale turbines. The first metric is an integrated yaw error, which is defined as the mean of the absolute value of the yaw error from zero degrees. The second metric is an RMS yaw error, which is defined as the square root of the mean of the squares of the yaw misalignment values. A forward-looking Vindicator® Laser Wind Sensor (LWS) was installed on a Nordex N60 turbine in Alberta Canada, where wind speed and direction data was collected ahead of the turbine. The wind velocity data from the forward looking sensor was compared to that of the sonic anemometer on the nacelle of the turbine to determine if the two are related by a linear transfer function. To determine the effects of better yaw alignment on the power output of the turbine, the wind sensor was connected into the control loop of the turbine in such a way that the only parameter varied during this experiment was the wind direction input to the original Nordex controller. The power curve for the turbine operating under legacy instrument (ultra-sonic anemometers) wind direction input to the controller was compared to the power curve when look-ahead laser wind direction provided improved yaw control.

Results

Figure 1 presents the turbine output power versus wind direction for two wind speed bins, (a) represents the 7-8 m/s bin and (b) represents the 10-11 m/s wind speed bin. The power was measured by an after market, calibrated power meter and the wind direction is the average of the two sonic anemometers on the rear of the nacelle. The figure shows that in the range of +/- 20 degrees, the power falls off as the $\cos^3$ of the yaw angle.

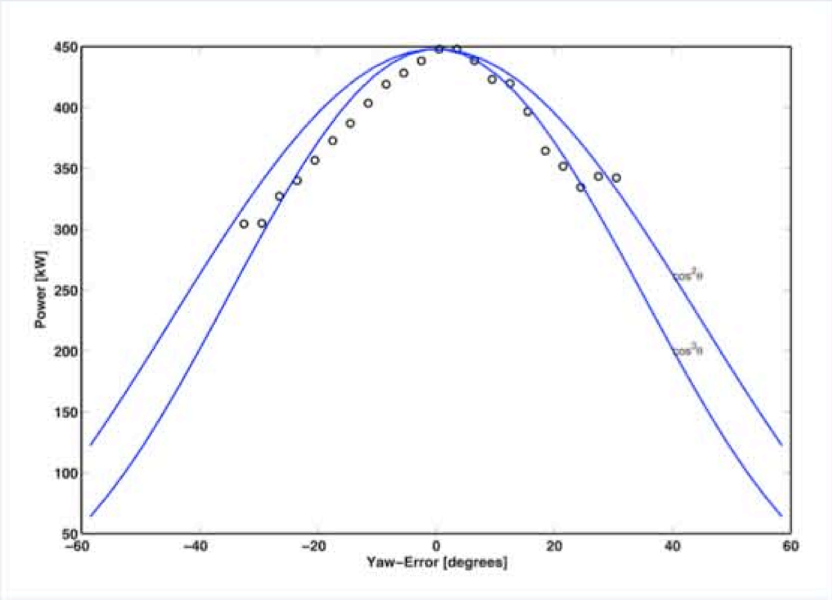

Figure 1a: Slice of Power vs. Yaw Angle for 7-8 m/s Wind Speed Bin

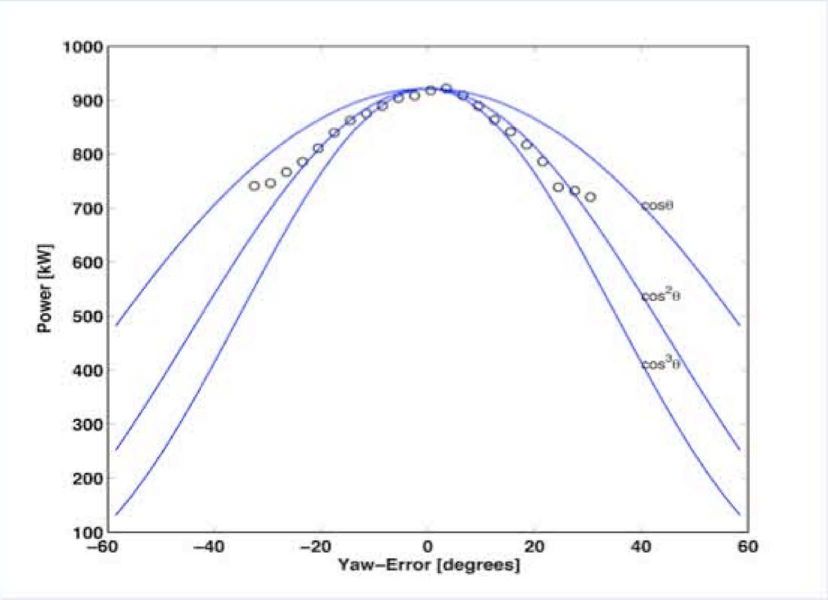

Figure 1b: Slice of Power vs. Yaw Angle for 10-11 m/s Wind Speed Bin.

The average integrated yaw error and RMS yaw error of several utility scale wind turbines was measured and are presented in Table 1. While the average integrated yaw error represents the average turbine yaw angle from zero, the RMS error highlights excursions. The data show that each turbine has an integrated yaw error of between 12-15 degrees and the RMS error of between 16-21 degrees, regardless of manufacturer or location.

Table 1: The Integrated Yaw Error and RMS Error for Six Utility Scale Wind Turbines Throughout North America and Europe

Turbine Model	Avg. Integrated Yaw Error	RMS Error
Vestas V-82	15°	21°
Nordex N60	13°	16°
Vestas V-82	15°	19°
Other 2.0 MW	15°	19°
Other >2.0 MW	12°	17°

Results

This high average yaw error can be accounted for by the location of the wind velocity measurement instruments. Figure 2 shows a comparison of the wind velocity between the nacelle instrumentation and the measurement of the free stream wind; (a) represents the speed correlation and (b) represents the direction correlation. As demonstrated by these curves, there is significant scatter in the wind speed and direction comparisons that cannot be accounted for with a simple linear transfer function. Further research was done to look into this matter using a study correlating wind speed comparisons with the power output of the turbine. This research shows that the correlation between the free stream wind and the wind behind the rotors depends on aerodynamic effects of the rotor and is thus also correlated to the power that the turbine produces.[1]

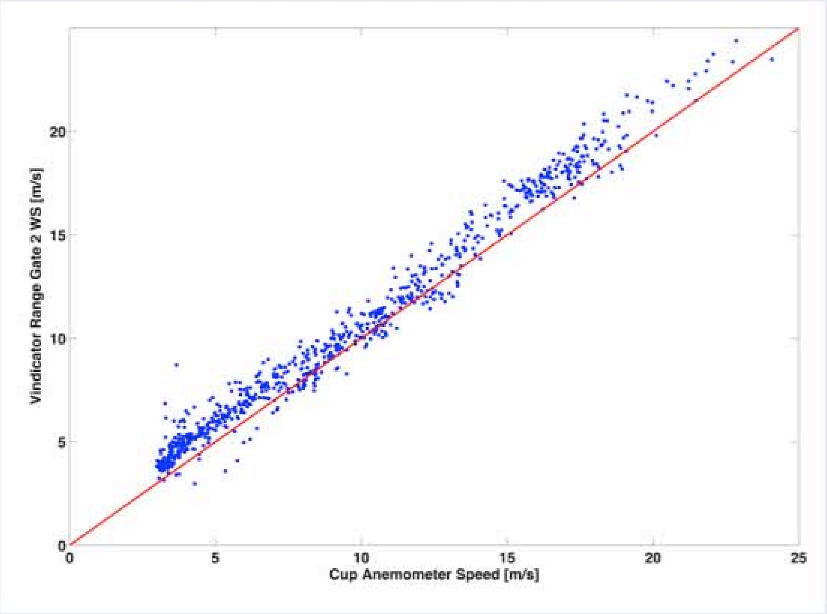

Figure 2a: Free Stream Wind Speed Measurements, Vindicator® LWS vs. Sonic Anemometer on the Rear of the Nacelle

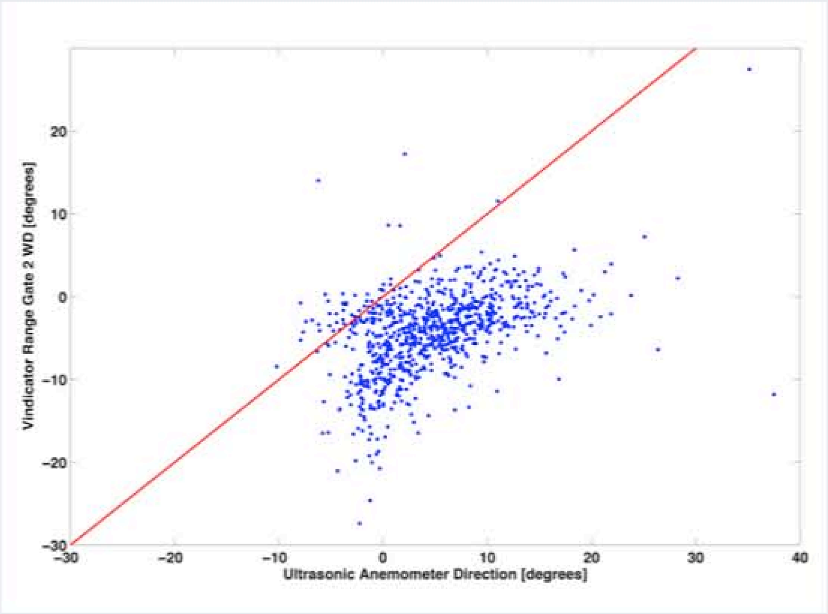

Figure 2b: Free Stream Wind Direction Measurements, Vindicator® LWS vs. Sonic Anemometer on the Rear of the Nacelle.

The power output of the turbine was then measured with the legacy wind direction input and the free stream wind direction input and binned and plotted using the free stream wind. These results are shown in Figure 3. Using the free stream wind input to point the turbine more accurately into the wind causes a dramatic increase in the amount of power that the turbine produces at each wind speed. This demonstrates the need to more accurately align turbines with the free stream wind field.

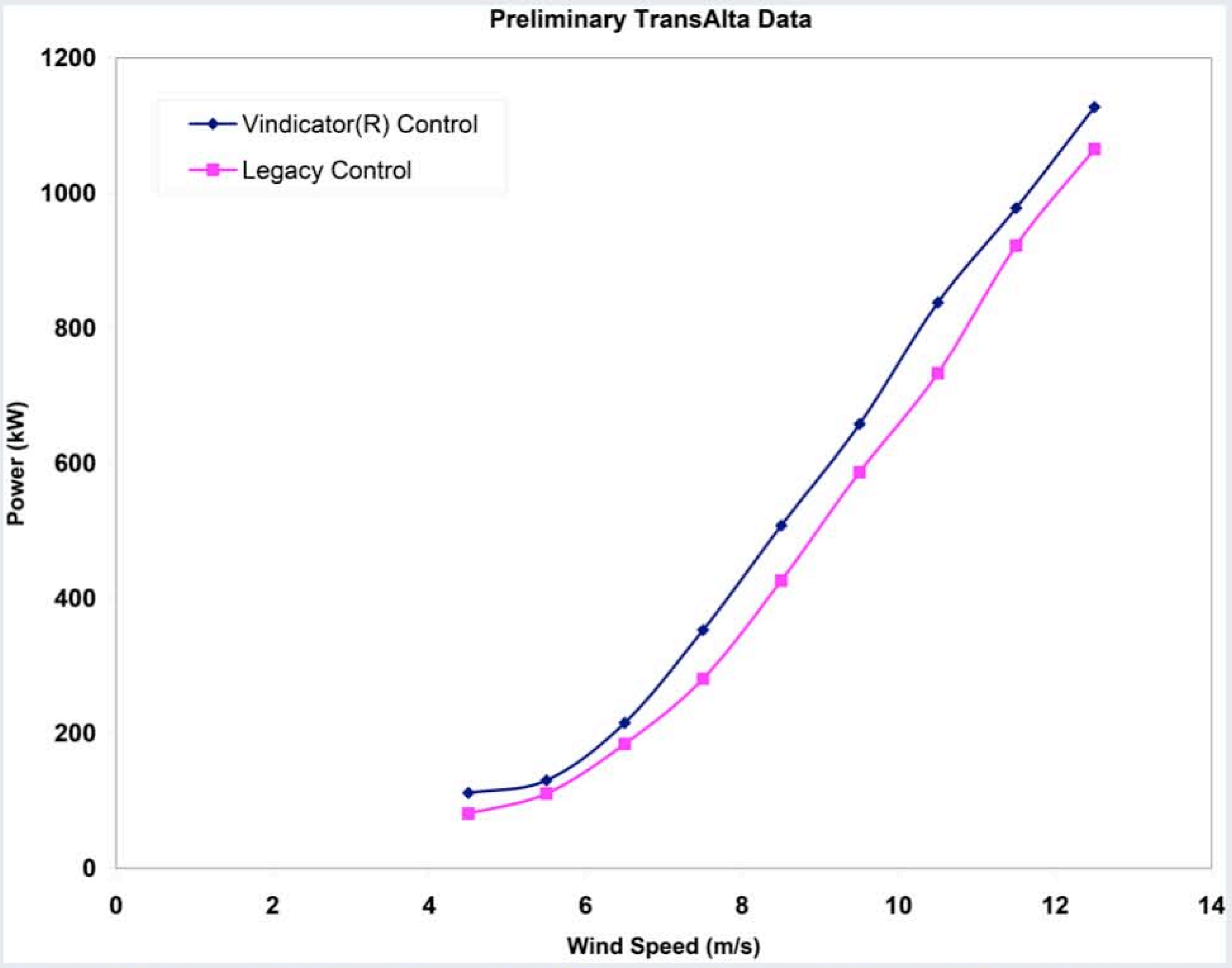

Figure 3: Power vs. Wind Speed for Nordex N60 turbine. Results: 11% Average Energy Increase

Conclusions

Timely and accurate knowledge of the inflow is essential for effective yaw control. The data shows that instruments placed on the nacelle behind the turbine rotor do not give accurate information about the free stream wind conditions and are not correctable using a pre-defined linear transfer function. Furthermore, it is not possible to use these instruments without significant averaging. With accurate look-ahead wind information, yaw control systems can perform up to their theoretical limits and can be improved to take advantage of the more timely data. This will result in overall better turbine performance.

References

1. *Unsteady Aerodynamics Experiment Phase VI: Wind Tunnel Test Configurations and Available Data Campaigns*, M.M. Hand, D.A. Simms, L.J. Fingersh, D.W. Jager, J.R. Cotrell, S. Schreck, and S.M. Larwoo, December 2001; NREL/TP-500-29955

EWEA 2011, Brussels, Belgium: Europe's Premier Wind Energy Event