More Accurate In-Flow Measurement With Nacelle-Mounted Remote Sensing

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1. Introduction

As turbines increase in size it becomes more and more difficult to erect meteorological towers with instrumentation at or above hub height in wind farms. It has also been shown through simulations that the wind speed and direction readings taken from the top of the turbine nacelles tend to be influenced by the structure of the nacelle and the turbine blades, thus requiring data from points outside of the influence of the turbine for comparison and truth (Ref. 1). The quantification of the problem has not been well established due to the difficulty of getting data during turbine operation comparing the inflow wind versus the readings on the top of the nacelle regardless of yaw.

Through the use of a turbine mounted laser wind sensor, the quantification of this problem is now possible. Because the sensor rotates with the nacelle, it can measure the wind that is approaching the turbine as it yaws, allowing for direct comparison with the other nacelle mounted wind-sensing instrumentation. This report will document the difference in the inflow wind as compared to the wind measured on top of the nacelle. This data will have a significant impact on the future control of wind turbines.

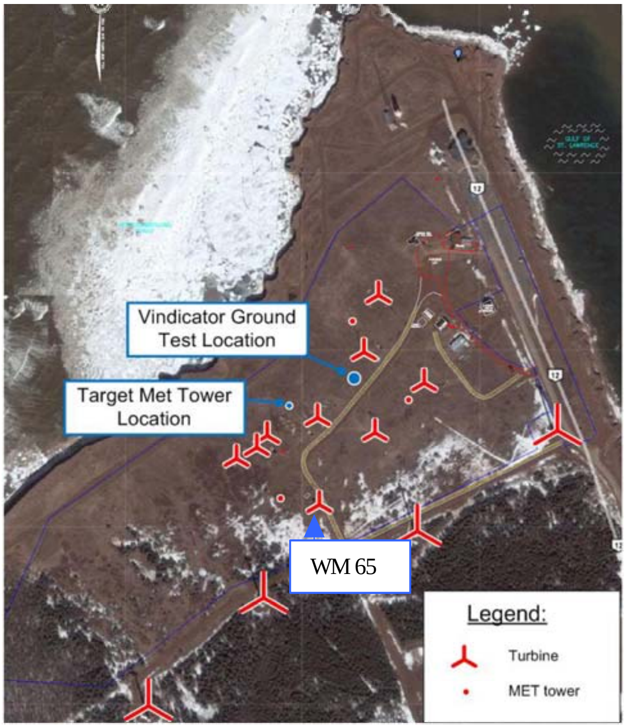

Figure 1 Map of WEICan wind farm

In control algorithms, the fidelity of input data is critical. Errors in the data can wreak havoc on the control outputs and can impact the safety and efficiency of turbines. In order to compensate for uncertainties in measurements, long period averaging is often used. However, this is at the cost of responsiveness as it introduces lag into the input data. The turbine mounted laser wind sensor allows for direct comparison of 1 Hz wind data under actual turbine operating conditions.

It also illustrates the difficulty encountered when comparing different types of instrumentation that have different measurement techniques and data resolution.

2. Test Method

This test utilizes a Vindicator® Laser Wind Sensor (LWS) manufactured by Catch the Wind, Inc. Testing was performed at the Wind Energy Institute of Canada on the North Cape of Prince Edward Island. The layout of the test site is shown in Figure 1. An initial ground test was performed to establish that the sensor was performing within acceptable limits. The Vindicator® wind velocity readings from the ground were compared to 2 calibrated RISO anemometers and a Met1 wind vane mounted on the "target met tower location" in Figure 1, as described in Ref 2. The sensor was deemed to have adequate measurement reliability for wind measurement on the turbine. The data from this test is shown in Figures 3, 4 and 5.

Figure 2 Vindicator® LWS mounted on WindMatic turbine

The Vindicator® was then placed on a mounting structure attached to the turbine nacelle of the WindMatic Wind Turbine as shown in Figure 2. The laser beams are aligned so that they are measuring a volume of air 80 m ±13 m directly in front of the turbine. While the turbine is pointing at its associated meteorological tower, which is 73 m away from the turbine, the inflow of wind to the turbine is known. However, a laser wind sensor mounted on the nacelle can measure the inflow of wind to a turbine pointed in any direction. The inflow wind is recorded along with the wind measurements from anemometers and wind vanes on both the nacelle and the meteorological tower using a Campbell Scientific Model CR3000 2 data logger at a rate of 1 Hz. The data logger collects the data and averages it for 1 minute for use in the turbine control algorithms.

The anemometers mounted on the meteorological tower used in the turbine-mounted study are a Vector Model A100LK and a Riso Model P2546A. The direction vane on the met tower is a Thies Clima Model 4.3150.00.212. The anemometers on the nacelle are 2 NRG #40s.

The data from the laser wind sensor was compared with the data recorded by the instrumentation on the nacelle. When the turbine is pointed at the meteorological tower, the laser wind sensor data can also be compared to the data collected on the tower. Measurements have been taken for approximately 3 months.

3. Results and Analysis

Figure 3 shows 42 hours of 1 minute averaged unfiltered data from the ground measurement study. A full report on this data can be found in Ref. 2. Figure 4 shows the correlation between the Vindicator® and the RISO 1 anemometer with 1 minute averaging. The overall r^2 of the correlation for the full 42 hours is 0.9210. However, at approximately 2100 seconds, the prevailing wind suddenly shifts direction and drops in speed, as is shown in Figures 3 and 5. If the test is broken up into 2 pieces, before the event (represented in purple in Figures 3,4) and after the event (represented in blue), then 2 correlations can be calculated as shown in Figure 3. This emphasizes the need for filtering for these types of occurrences in comparison testing. Figure 5 shows the direction comparison of the Vindicator® with the Met1 wind vane. The tests demonstrated adequate data reliability for turbine mounted testing to commence.

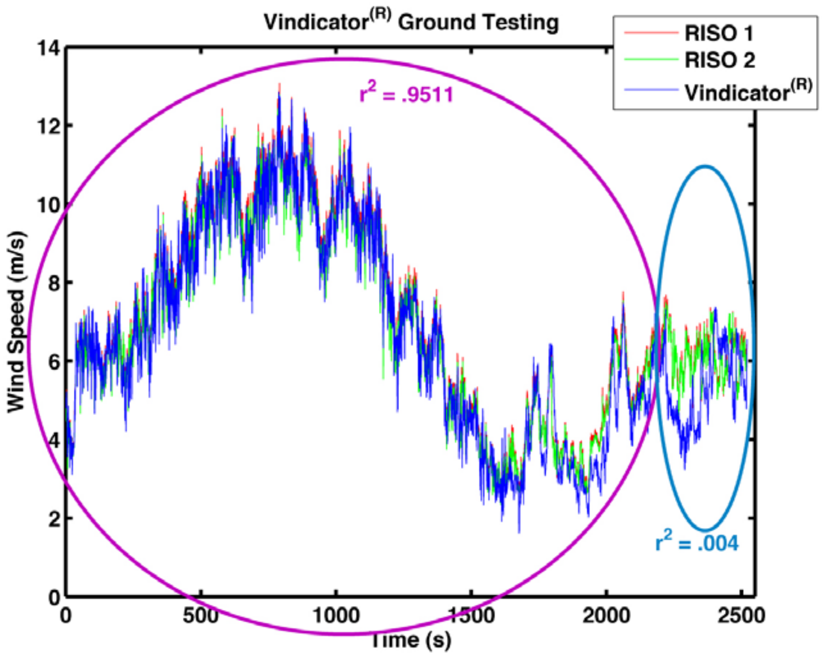

Figure 3 Wind Speed vs Time from Ground Test Comparison of Vindicator® LWS and RISO Anemometers

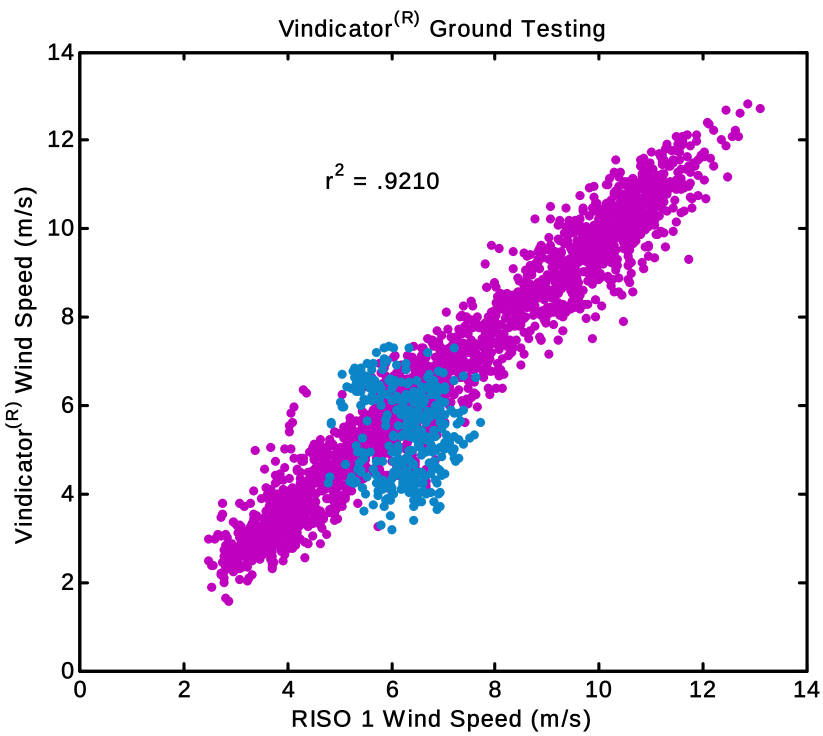

Figure 4 Vindicator® Wind Speed vs. Met Tower Wind Speed from Ground Test Comparison. Colors correspond to circled areas in Figure 3

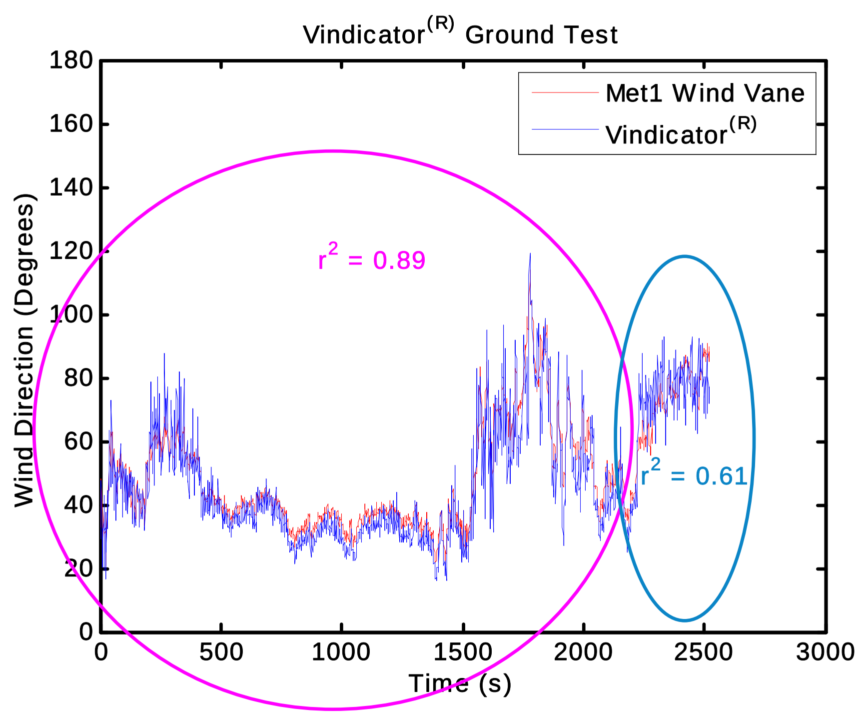

Figure 5 Wind Direction vs. Time from Ground Test Comparison of Vindicator® LWS and the Met1 wind vane

The top graph in Figure 6 shows the nacelle mounted Vindicator® 1 minute averaged wind speed data versus the anemometers mounted on the nacelle and the wind turbine's associated met tower. As is evident, the speed as measured from the laser sensor and the met tower is consistently higher than the speed measured from the anemometers on the back of the wind turbine. This can also be seen in the correlation plots in Figure 7. The upper plot shows that there is good correlation between the wind speeds as reported by Vector anemometer on the tower and the Vindicator® by the proximity of the correlation to the slope equals 1 line. All of the points from the Vindicator®/turbine mounted anemometers fall below the slope equals 1 line indicating that the turbine mounted anemometer consistently reports low.

The bottom panel on Figure 6 shows the 1 Hz raw data from a portion of the data in the top panel. Though the same basic conclusions can be drawn from the raw and averaged data, it becomes apparent that the resolution with which the instruments report the wind speeds can impact correlation and data validity. Further testing will show whether more accurate 1 Hz data reported with very high resolution could lead to better turbine control.

Figure 8 shows the direction data taken from the Vindicator® mounted on the turbine that will be used for yaw control of the turbine. As can be seen, the turbine was undergoing testing that required that it be spun 180 degrees in each direction during the highlighted period. Following that yaw exercise, the Vindicator® LWS was used to control the turbine for a short period. This turbine control testing is ongoing.

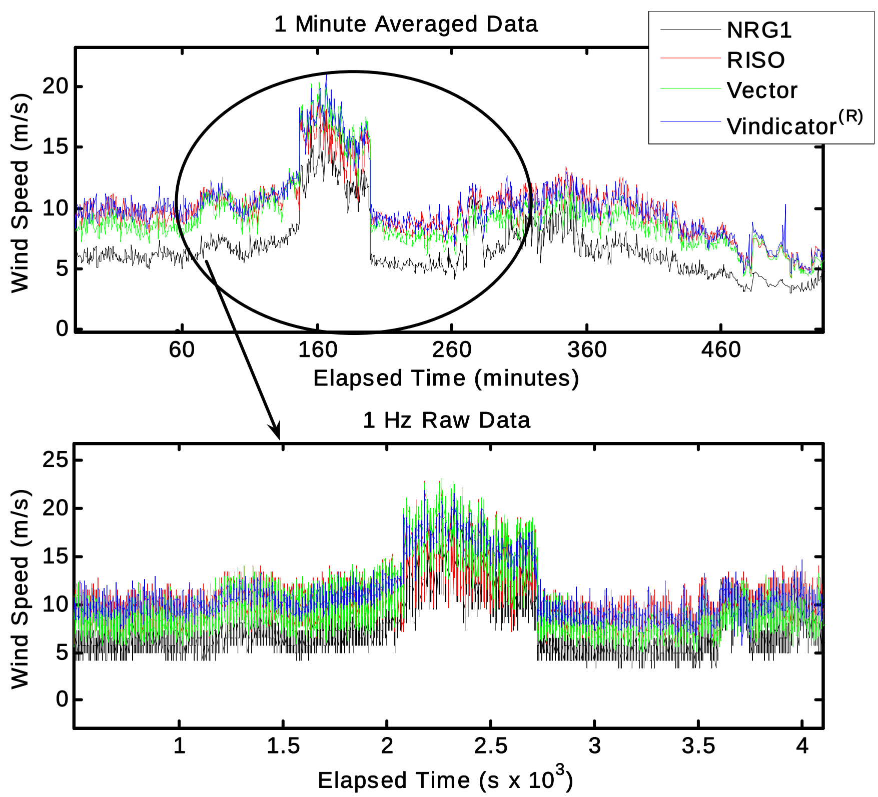

Figure 6 Wind Speed vs. Time from Turbine Mounted Comparison of Vindicator® LWS to nacelle (black) and met tower (red and green) mounted anemometers. Top panel is 1 minute averaged, bottom panel is 1 Hz raw data.

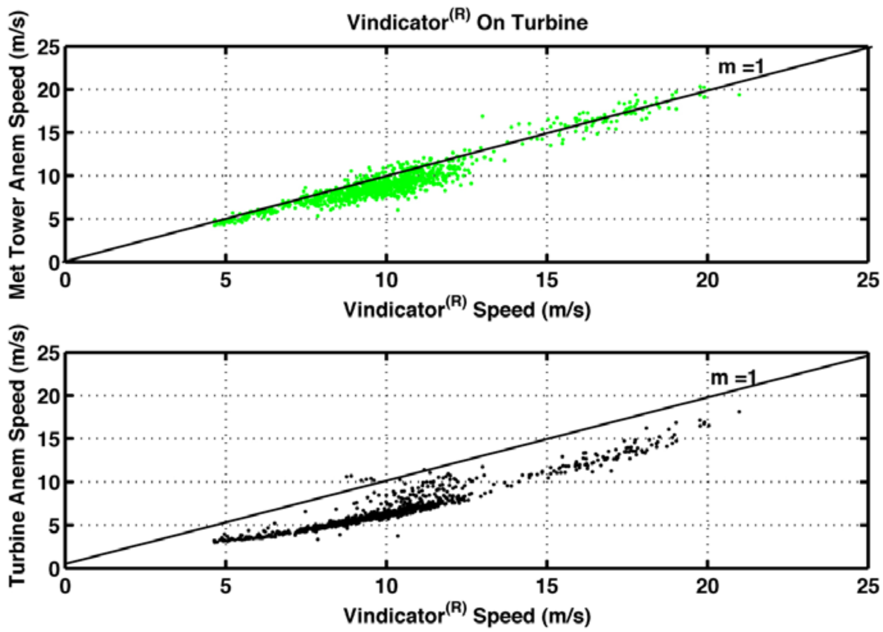

Figure 7 Vindicator® Wind Speed vs. Met Tower Mounted (Green) and Turbine Mounted (Black) Wind Speed.

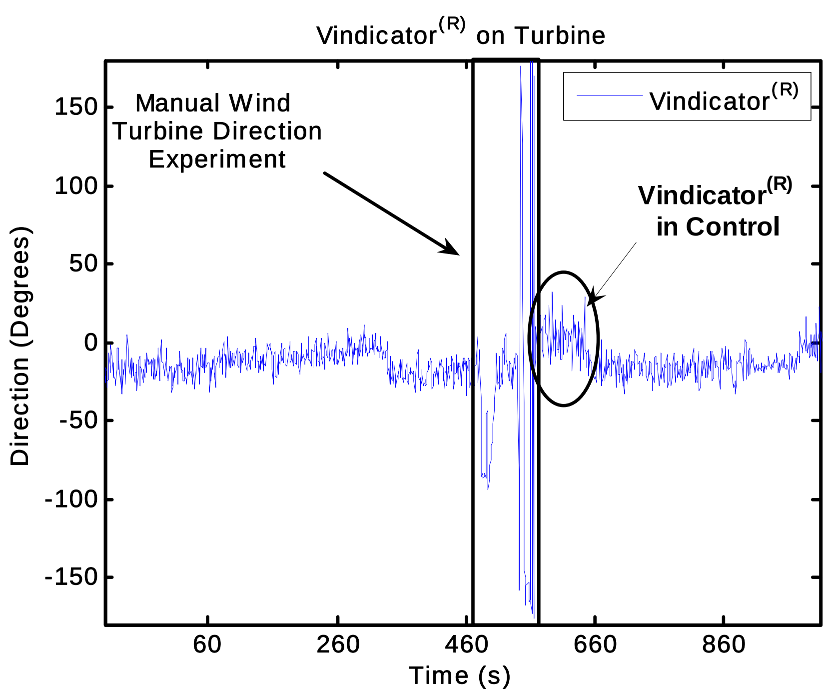

Figure 8 Wind Direction vs. Time as Measured from Vindicator® LWS mounted on the WindMatic turbine.

4. Conclusions

The use of a turbine mounted laser wind sensor allows for the measurement of the inflow wind to the turbine regardless of its pointing direction. This allows for more accurate knowledge of the wind speed and direction approaching the turbine, which can be used to validate the inflow models. More accurate knowledge of the wind speed and direction approaching the turbine may allow for better control and reduced wear on wind turbines. Further work is underway to include algorithm development taking full advantage of the accurate and timely turbine mounted Vindicator® laser wind sensor data.