Memorandum

From: Erik Hale, Meteorology Group Assistant Manager

Date: January 8, 2010

Re: NRG #40 Transfer Function Recommendation

Introduction

Precise project energy production estimates depend primarily on accurate wind speed measurements, proper adjustment of the data to the long-term conditions, and detailed modeling of the wind flow across the project area. Cup anemometers are currently the standard for wind speed measurements associated with wind energy resource assessments. Several cup anemometer models are available to measure wind speed. However, the response of each depends on the cup geometry, bearing type and lubrication approach, and electronic signal, among other factors. Wind turbine power performance tests, which define the turbine's power curve and set the standard for any performance guarantee, are generally executed under the guidelines of IEC 61400-12-1. The IEC test standards require the use of IEC Class I anemometers, such as Vector A100LK, WindSensor P2546A (formerly known as the Risoe P2546A), and Thies First Class sensors. However, this not withstanding, in North America the NRG #40 anemometer has been the standard for wind resource assessment since the 1980s. Therefore, particularly in North America, it is important to understand and quantify the fundamental differences between the anemometers used in power performance tests and the NRG #40 sensors that are often used for on-site wind speed measurements, and normalize any resource related measurements to the standard upon which performance estimates and guarantees are based.

Each anemometer model available to measure wind speed has unique performance characteristics. Therefore, it is important to quantify any systematic variations between different models. Such variations can be result from differences in the type of bearing (i.e. lubricated or un-lubricated) and cup geometry. Atmospheric conditions such as turbulence, flow angle, and temperature are other factors known to cause anemometer response to vary. Such conditions may impact anemometer models differently, leading to some degree of uncertainty when translating wind tunnel results to field results for different anemometer models.

Aside from systematic differences, another source of potential discrepancy is in the choice of a transfer function used to convert the raw data to wind speed values. A unique transfer function is provided for each calibrated anemometer based on individual instrument calibration by wind tunnel testing facilities such as OTECH Engineering, Svend Ole Hansen, and the German Wind Energy Institute (DEWI). The calibration process itself carries uncertainty, as detailed by Coquilla and Obermeier in 2007. According to this work, AWS Truewind found the uncertainty of a calibrated NRG #40 anemometer to typically reside between 0.9% - 1.3%, during the calibration test; translating the wind tunnel result to the field yields additional uncertainty.

It could be argued, however, that the anemometer manufacturing process is more consistent than the calibration test itself. Therefore, a consensus, or mean, transfer function could be a valid alternative to a wind tunnel based, calibration-derived, anemometer specific transfer function. In particular, if such a consensus function is validated in the field against performance test standard instruments (IEC Class I), it may more accurately represent the appropriate conversion to be used for wind resource assessment purposes.

Analysis and Results

NRG #40 and WindSensor P2546A anemometers were paired at the same monitoring height on thirty tall towers in varying environments across the United States. A total of 78 pairs were available for study. Anemometers were deployed at seven potential wind project locations across different geographic climates with unique wind environments, including masts in New Mexico, Texas, Wyoming, Michigan, Washington and a marine environment in the Northeast US. All of the sensors were new as of their deployment. The NRG #40 anemometers serial numbers range from 95,000 to 125,000, and were manufactured with new specifications to avoid the Dry Friction Whip (DFW) phenomenon experienced in anemometers manufactured between May 2006 and December 2008 (serial numbers 29,000 - 94,999).

We examined the mean wind speed difference of each anemometer pair using the calibrated and consensus transfer functions for each #40 sensor. The calibrated transfer functions yielded a mean difference of -1.9% (NRG - Windsensor) with a standard deviation of 0.9%; the consensus transfer function reduced the difference to -1.1% with a standard deviation of 0.8%. None of the 78 NRG #40 sensors produced higher wind speeds than the P2546A using the calibrated transfer functions. The distribution of biases from the sample for each transfer function are shown in Figure 1.

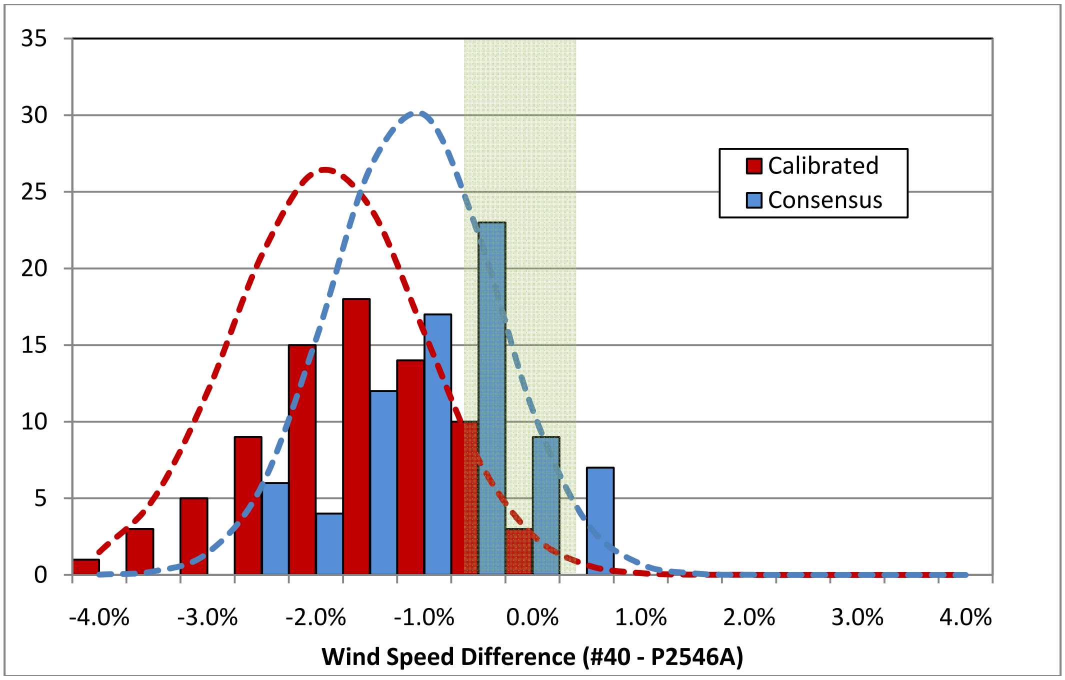

Figure 1. Comparison of differences in mean wind speed between NRG #40 and WindSensor P2546A anemometers using the NRG #40 calibrated and consensus transfer functions.

The cause of the discrepancy lies in the difference between the calibrated transfer function slope and that of the consensus value. The mean slope from the calibration tests of the sensors examined is 0.758 m/s/Hz, and is substantially lower than the consensus value, 0.765 m/s/Hz. The mean offset is 0.36 m/s, very close to the consensus value of 0.35 m/s.

Errors in the transfer function slope would likely be manifested in increasing absolute errors at higher wind speeds. We evaluated the wind speed difference as a function of wind speed at the test sites. As expected, we found that at each of the sites, the NRG #40 sensor's negative bias was larger at higher wind speeds. Figure 2 depicts the mean bias versus wind speed of anemometers at each of the seven unique project locations using the calibrated slopes and offsets. A clear downward trend with wind speed exists at six of the seven sites. Use of the consensus transfer function essentially eliminated this dependence on wind speed; Figure 3 shows the biases when the consensus values are used. In both cases, there is a non-trivial amount of scatter in the differences from site to site. This scatter could be attributed to other atmospheric factors, including flow angle, humidity, temperature, etc., or could be a result of random anemometer behavior due to manufacturing or differential wear on the bearing.

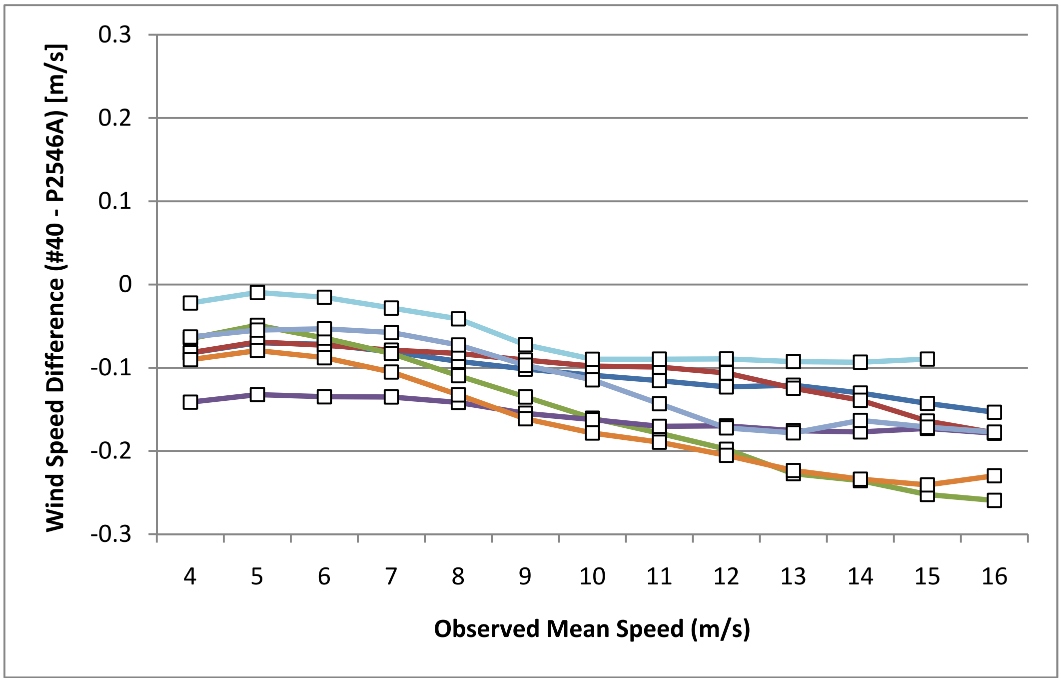

Figure 2. Mean biases of a sample of anemometer pairs in seven unique geographical locations using calibrated transfer functions. A clear downward trend with wind speed exists at six of the seven sites.

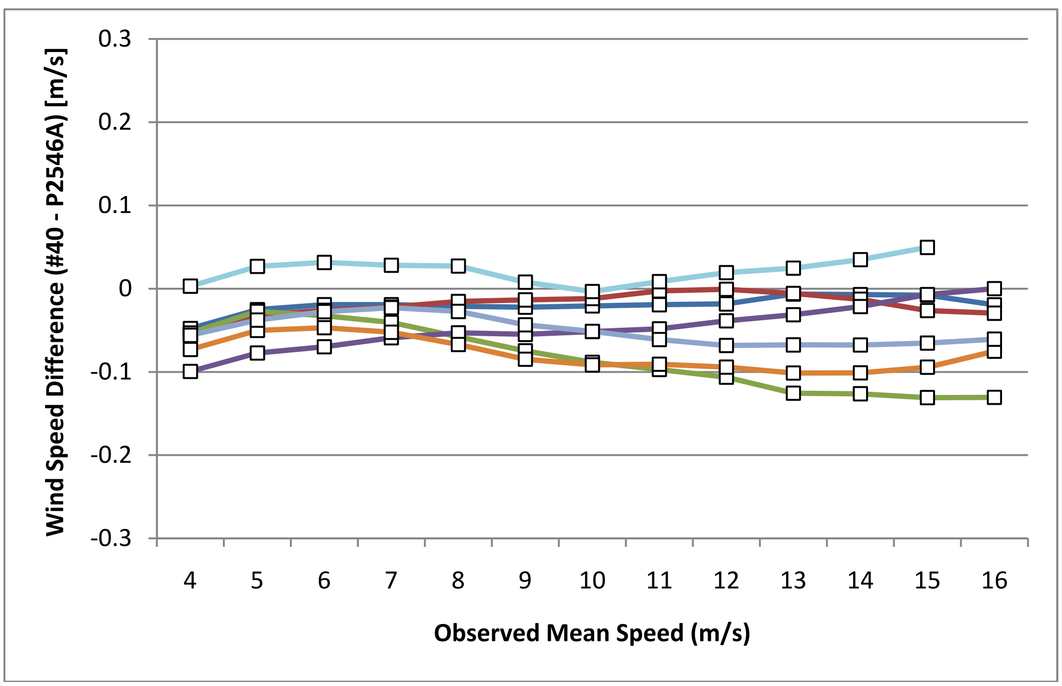

Figure 3. Mean biases of a sample of anemometer pairs in seven unique geographical locations using the consensus transfer function. There is generally a flat trend vs. wind speed.

Conclusions and Recommendations

A sample of 78 NRG #40 anemometers produced after January 1, 2009 demonstrated calibrated transfer functions with an average slope of 0.758 m/s/Hz; the consensus slope defined by Lockhart and Bailey is 0.765 m/s/Hz. NRG #40 data which is converted using a calibrated transfer function reports lower wind speeds than the Class I WindSensor anemometer data, and demonstrates an increasing negative bias at higher wind speeds. Use of the consensus transfer function removes the bias dependence on wind speed, providing better overall agreement in field comparisons with Windsensor P2546A anemometers.

In order to align wind speed observations with those from WindSensor P2546A anemometers, AWS Truewind recommends that all NRG #40 data are converted from binary data to physical values using the consensus transfer function.