Anemometer Calibration Speed Range for Wind Energy Applications

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A study was conducted through the California Wind Energy Collaborative to investigate the establishment of an anemometer calibration program for wind energy applications. This project was funded by the California Energy Commission (CEC) through its Public Interest Energy Research (PIER) program. Currently, there are two standards organization that provide published protocols on cup anemometer calibration, the International Electrotechnical Committee (IEC) and the American Society for Testing and Materials (ASTM). The IEC recently approved IEC 61400-12-1, first edition, 2005-12: “Power Performance Measurements of Electricity Producing Wind Turbines”, which was initially introduced by MEASNET (the international Measuring Network of Wind Energy Institutes). This particular document provides the steps in conducting the performance evaluation of a wind turbine. It also discusses the procedures in performing a cup anemometer calibration along with the various tests that would evaluate the instrument’s sensitivity to certain terrain and atmospheric conditions. An anemometer test protocol for general meteorology applications is also provided by ASTM through ASTM D 5096-02: “Standard Test Method for Determining the Performance of a Cup Anemometer or Propeller Anemometer”, which was originally published in 1996. Like the IEC document, this standard also defines a method of obtaining the anemometer transfer function and the sensitivity tests to determine its overall performance. The difference in application between the two standards is that IEC is focused on turbine performance evaluation while ASTM is intended for all other general meteorology applications. This investigation determined that the calibration test speed range is a critical protocol in the resulting linear transfer function of an anemometer due to range of speeds the anemometer is subjected to in the field and to the performance of the anemometer in terms of its linearity.

A. Introduction

Accurate wind readings are critical in wind turbine power performance testing and site assessment. In power performance evaluation, a series of measured turbine power at various corresponding measured wind speed is used to produce a power curve for the turbine. In site assessment, the distribution of measured wind speed is used to determine the predicted annual energy production from the wind. Since wind power is proportional to the cube of the wind speed, a slight error in the wind reading could translate to a much greater error in the predicted wind energy, which emphasizes the importance of having accurate wind speed readings. To acquire such precision in wind data, it is recommended that calibrated wind measuring anemometers be employed. Most anemometers sold today are commonly provided with the manufacturer’s standard calibration transfer function, which is obtained from multiple and various types of experimental testing. However, the calibration transfer function of any particular anemometer may vary from its published transfer function depending on the manufacturer’s quality control. In typical quality control processes, only a few anemometers are calibrated per population. If such anemometers fall within a particular acceptance criteria, a certain population of anemometers is only assumed to also pass. Due to the critical reporting in wind power, it is essential that each anemometer used for any type of wind energy assessment should have its own calibration.

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Several types of anemometers are currently being used in the wind energy industry from the classic rotating cups or propellers to the newer sonic sensors. Since cup anemometers are the most widely used type, this paper will only address standards relating to such instruments and procedures that pertain to the use of a linear transfer function. Two calibration standards are available for cup and propeller-type anemometers. One is the ASTM D 5096-02: “Standard Test Method for Determining the Performance of a Cup Anemometer or Propeller Anemometer”. Originally published in 1996, this ASTM standard defines the procedures necessary for anemometer manufacturers to study the sensor performance, including wind speed calibration. A second standard which is directly related to the wind energy industry is the IEC 61400-12-1, first edition, 2005-12: “Power Performance Measurements of Electricity Producing Wind Turbines”. Although primarily focused on wind turbine measurement methods, this IEC standard defines the necessary procedures for calibrating cup anemometers and for determining performance through a classification system. Due to its specific application and the only one of its kind to the wind energy industry, the IEC 61400-12-1 has been utilized as the major compliance for calibration of cup anemometers not only used for turbine power performance measurements, but also for site assessment and monitoring. The IEC standard does provide major guidelines and requirements for test facilities, however, it also specifies for a calibration speed range of 4 to 16 m/s. At this instance, the purpose of this range is to cover the power ramp up stage of a typical turbine power curve.

There are two possible limitations that may cause errors in an anemometer calibrated at the specific range of 4 to 16 m/s: 1) wind speed distribution at the site and 2) anemometer performance. In the free atmosphere, winds could historically range from calm (1 to 2 m/s) to as much as peaks of 50 to 60 m/s gusts. Without gusts, maximum winds could reach to about 30 m/s. Wind speed is customarily acquired based on 10 minute averages. In a typical 10 minute acquisition resulting a 16 m/s average, an anemometer would more likely observe much higher speeds such as gusts. If an anemometer was calibrated only for the 4 to 16 m/s range, the instrument’s linear transfer function is generally only valid for those particular speeds. Thus, the calibration speed range may be based on the winds the anemometer may be subjected to in the field. Additionally, depending on design performance, an anemometer calibrated at 4 to 16 m/s could introduce significant errors at faster speeds. Typically, rotating anemometers possess an inherent non-linear range at the low speeds above threshold. For a high performance anemometer, the non-linear range falls below 4 m/s sometimes much lower to below 2 m/s. For general use anemometers, the non-linear range could extend to as much as 16 to 20 m/s. If a calibration was only done at the specific IEC range of 4 to 16 m/s, the resulting linear transfer function would be biased to the non-linear response of the anemometer. Thus, in order to capture the linear spectrum, it would be preferred to increase the calibration test speed range. For this case, ASTM D 5096-02 defines a compliant protocol in which the calibration test speed range covers from the low speed level near anemometer threshold to as high as the application speed comparable to the appropriate speed range introduced in the free atmosphere.

B. Review of Current Calibration Standards

A. IEC 61400-12-1

The IEC (International Electrotechnical Committee) is a global standards organization formed of electrotechnical committees that review operational practices done in the electrical and electronic industry and research. The IEC also publishes international standards in conjunction with the International Organization for Standardization (ISO). A key publication related to the wind power industry is IEC 61400-12-1, ed. 1, released in 2005. This particular standard was introduced for approval to IEC by MEASNET (the international Measuring Network of Wind Energy Institutes). The purpose of this standard is “to provide uniform methodology that will ensure consistency, accuracy, and reproducibility in the measurement and analysis of power performance by wind turbines”. It is intended to assist manufacturers, purchasers, operators, and planners in the evaluation of wind turbines. One of the most important measurements that the IEC standard requires is the wind speed. As specified, the wind speed shall be measured using a cup anemometer mounted on a meteorological tower positioned at a location near the wind turbine but undisturbed from the turbine’s dynamics. Along with other atmospheric variables, the wind speed is acquired simultaneously with turbine power output in order to generate the wind turbine power curve. The resulting power curve is then used to determine the annual energy production (AEP). Thus, the wind speed measurement is critical in the evaluation of a wind turbine. Since cup anemometers have proven to be the most durable instruments to measure wind speed in wind turbine applications, this IEC standard requires its use and also provides the guidelines for its calibration and classification. Using these guidelines, the turbine evaluator can determine the best type of anemometer to be used for power performance testing. According to IEC 61400-12-1, cup anemometers used for turbine power performance testing must be calibrated and classified. Calibration must be conducted in a wind tunnel, before and after the turbine test phase. “The difference between the regression lines of
calibration and recalibration shall be within +/- 0.1 m/s in the range of 6 m/s to 12 m/s”. However, during the turbine performance test, the calibration prior to the field installation will be applied. In order for a turbine evaluator to determine how well a particular anemometer responds to certain terrain environments, the IEC standard specifies that the anemometer be classified based on three types of sensitivity tests: 1) angular response, 2) dynamic effects due to rotor torque acceleration and deceleration, and 3) bearing friction torque for a range of environmental temperature conditions. Such classification tests are generally conducted only once per anemometer type prior to field installation and turbine testing and require the use of the initial calibration test results. Under IEC 61400-12-1, anemometry classification is calculated for two types of terrain, Class A and Class B, the latter being the more complex terrain. For turbine power performance evaluation and depending on terrain conditions for the test installation, an anemometer of Class 1.7A or Class 2.5B or lower class number shall be employed. For conditions not specified under Class A or B terrain, an anemometer of Class 1.7S or lower will be used. This IEC guideline provides several details for calibration and classification procedures; however, a key note is that the document specifies a calibration wind speed range of 4 to 16 m/s.

B. ASTM 5096-02

ASTM (American Society for Testing and Materials) is a standards development organization originally established over a century ago to develop standardization of steel manufacturing used in railroad tracks. Today ASTM provides various standards for quality assurance in not only the manufacturing industry but also laboratory testing. For the measurement of atmospheric winds, there is ASTM D 5096-02, a guideline for the calibration and performance evaluation of cup and propeller anemometers in a low turbulence wind tunnel. This standard not only provides the procedures for calibration but also methods in evaluating performance of a cup or propeller anemometer which include determining the starting threshold, the off-axis (angular) response, and the distance constant. Starting threshold is the lowest speed in which the anemometer would begin to continually rotate. Other than the angle response test, IEC and ASTM require different sensitivity tests to determine the performance of a dynamic anemometer. IEC also defines a method of classification while the ASTM standard does not. A major difference is that ASTM requires anemometer calibration to be conducted for the speed range for which the anemometer would be subjected to in the atmosphere. This range begins at a speed two times the starting threshold of the anemometer to the maximum speed predicted at the installation site.

C. Test Speed Range Based on Anemometer Performance

In order to investigate the effect of wind speed range in the calibration results of an anemometer, tests were conducted in the wind tunnel facility at Otech Engineering, Inc, Davis, CA. The Otech facility is an open-circuit, suction-type wind tunnel which is primarily used to calibrate one anemometer at a time in an enclosed test section of size 0.61 m x 0.61 m x 1.22 m (2’ x 2’ x 4’). The wind is driven by a 15 hp fan motor capable of generating speeds up to 36 m/s in the test section. Current test speed protocols range from 4 to 26 m/s. Wind tunnel speed is determined using four equally positioned Pitot-static tubes at the entrance into the test section. Environmental conditions (i.e., ambient pressure, temperature, and humidity) are also simultaneously measured. Flow quality in the test section is also uniformly maintained to within +/- 0.1% with turbulence levels less than 0.1%.

For this investigation, calibration tests were performed in the Otech wind tunnel for three types of anemometers, the NRG #40 cup anemometer, the R.M. Young Gill cup anemometer, and the R.M. Young propeller anemometer. Due to its most competitive cost, the NRG #40 is the most common anemometer used in the wind energy industry, covering as much as 85% of the worldwide wind energy site market with a history of about 25 years. Although much higher in cost, the R.M. Young Gill cup and R.M. Young propeller anemometer are most commonly used in weather measurements measuring wind from the most complex mountainous terrains and over unpredictable oceanic waves. R.M. Young’s wind measurement history spans over 40 years of experience.
Two sets of calibration test speed ranges were performed for each instrument. First for a range of 4 to 16 m/s and second for a range of 4 to 26 m/s. Linear regressions were then determined for each calibration test along with calculations of velocity residuals between the measured and the calculated speed. Plots of the data and the resulting transfer functions from the calibrations are displayed in the following Figures 1 to 6.
Linear regression equations or transfer functions determined for each of the plots above define how the anemometer output (whether frequency or voltage) relates to the reference wind speed in a low turbulence wind tunnel. The following Table 1 displays the resulting transfer function from each test along with the linearity in the form standard error of estimate (STE).

<table>
<thead>
<tr>
<th>Anemometer Type</th>
<th>Test Range (m/s)</th>
<th>Slope (m/s per Hz)</th>
<th>Offset (m/s)</th>
<th>STE (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NRG #40</td>
<td>4-16</td>
<td>0.7790</td>
<td>0.2798</td>
<td>0.043</td>
</tr>
<tr>
<td></td>
<td>4-26</td>
<td>0.7653</td>
<td>0.4188</td>
<td>0.073</td>
</tr>
<tr>
<td>R.M.Young Gill</td>
<td>4-16</td>
<td>11.8397</td>
<td>0.2235</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td>4-26</td>
<td>11.8120</td>
<td>0.2367</td>
<td>0.021</td>
</tr>
<tr>
<td>R.M. Young Propeller</td>
<td>4-16</td>
<td>0.0298</td>
<td>-0.0361</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>4-26</td>
<td>0.0298</td>
<td>-0.0404</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Comparing the calibrations of each anemometer between the two test speed ranges, there are distinct differences in the transfer functions. For the NRG #40, the intercept value of the 4 to 16 m/s test differs from that of the 4 to 26 m/s by 33%. The R.M. Young Gill intercepts differ by 6%, while the R.M. Young Propeller differs by 10%. According to the standard error of estimate which essentially defines the linearity of the instrument, the lower value on the propeller anemometer interprets the sensor as most linear instrument of the three tested. Based on just the calibration performance of the three anemometers, the transfer functions of the most linear instruments were the least affected by the choice of calibration range. However, for the sensor most commonly used in the wind energy industry, there is a dramatic difference in the resulting linear transfer function due to the speed range. Thus, for cup anemometers it is important to understand its degree of linearity in order to define the best calibration test range.

**D. Conclusions**

In this study, a review of the current anemometer calibration standards was presented. Two standards for calibration guidelines currently published are the IEC 61400-12-1 and the ASTM D 5096-02. The IEC standard is specifically for turbine power performance, while the ASTM standard encompasses general meteorology. An important note is that the IEC standard specifies a calibration test range of 4 to 16 m/s. The ASTM standard covers a much broader test range which covers the entire spectrum of winds an anemometer could encounter in the field. Thus, the test speed range should be considered based on the historic wind distribution for a particular site. The anemometer calibration range should also be determined based on the performance of the anemometer. Based on a comparison of three anemometers, the linear transfer function from a more non-linear anemometer was determined to be most sensitive to the selection of test speeds.

**References**

IEC 61400-12-1, first edition 2005-12, Wind turbines – Part 12-1: “Power performance measurements of electricity producing wind turbines”