NATIONAL RENEWABLE ENERGY LABORATORY

Wind Turbine Generator System Safety and Function Test Report for the Ventera VT10 Wind Turbine

Joe Smith, Arlinda Huskey, Dave Jager, and Jerry Hur
National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Technical Report
NREL/TP-5000-56586
November 2012

Contract No. DE-AC36-08GO28308

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Prepared under Task No. WE110308

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Conducted for

U.S. Department of Energy
1617 Cole Blvd.
Golden, CO 80401

Conducted by

National Wind Technology Center
National Renewable Energy Laboratory
15013 Denver West Parkway.
Golden, CO 80401

Joe Smith, Arlinda Huskey, Dave Jager, and Jerry Hur

12 June 2012

Notice

This report was prepared by the National Renewable Energy Laboratory (NREL), operated for the United States Department of Energy (DOE) by the Alliance for Sustainable Energy, LLC (Alliance), as an account of work sponsored by the United States government. The test results documented in this report define the characteristics of the test article as configured and under the conditions tested.

NREL is a DOE Laboratory, and as an adjunct of the United States government, cannot certify wind turbines. The information in this report is limited to NREL's knowledge and understanding as of this date.

NREL is accredited by the American Association for Laboratory Accreditation (A2LA) and the results shown in this test report have been determined in accordance with the NREL's terms of accreditation unless stated otherwise in the report.

Approval By: ______________________________

Arlinda Huskey, NREL Test Engineer — Date

Review By: ______________________________

Jeroen van Dam, NREL Test Engineer — Date

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1. Background

This test was conducted as part of the U.S. Department of Energy's (DOE) Independent Testing project. This project was established to help reduce the barriers to wind energy expansion by providing independent testing results for small turbines. Five turbines are being tested at the National Wind Technology Center (NWTC) as a part of round 1 of this project. Safety and function testing is one of up to five tests that may be performed on the turbines, including duration, power performance, noise, and power quality tests. Test results provide manufacturers with reports that can be used for small-wind-turbine certification.

The test equipment includes a Ventera VT10 wind turbine mounted on a 60-ft free-standing lattice tower manufactured by Rohn. The inverter is a GALE-12, manufactured by Diversified Technology. The concrete pier foundation was installed by a third party, under contract with Ventera Energy. The system was installed by the NWTC Site Operations group with guidance and assistance from Ventera Energy.

2. Test Objective

The objective of this test was to:

- Verify whether the test turbine displays the behavior predicted in the design
- Determine whether provisions relating to personnel safety are properly implemented
- Characterize the dynamic behavior of the wind turbine at rated and higher wind speeds.

The National Renewable Energy Laboratory (NREL) does not limit safety and function tests to features described in the wind turbine documentation. NREL also inspects—possibly tests—and reports on features that are required by IEC 61400-2 and that might not be described in the wind turbine documentation. NREL conducted this test in accordance with Section 9.6 of the IEC standard, "Wind Turbines—Part 2: Design Requirements for Small Wind Turbines," IEC 61400-2, second edition, 2006-03.

3. Description of Test Turbine and Setup

The test turbine was a Ventera VT10 wind turbine. The VT10 is a downwind, 3-blade, passive yaw, permanent magnet, horizontal-axis wind turbine. It is manufactured by Ventera Energy Corporation. It uses a Diversified Technology, Inc. GALE-12 inverter to deliver electrical energy to the a 60-Hz grid. To control rotor speed, each blade has a tip that begins to pitch at its rated rotor speed. It was mounted on a 60-ft Rohn SSV self-supporting lattice tower.

Table 1 lists the configuration of the Ventera VT10 that was tested at the NWTC.

Table 1. Test turbine configuration

Turbine manufacturer and address	Ventera Energy Corporation 1302 W. 5th St. Duluth, MN 55806
Model name	VT10
Production date	October 2009
Generator serial number	100993
Design nominal voltage at terminals	240 Vac
Maximum current at terminals	60 A
Design frequency at terminals	60 Hz
SWT class	III
V_{ave} as defined by SWT class	7.5 m/s
Design 50-year extreme wind speed, Ve50	55 m/s
Rotor Diameter	6.7 m
Hub Height (vertical center of rotor)	21.7 m
Tower Type	60-ft Rohn SSV series, 3-legged, self-supporting tower hinged on two legs; plus 10-ft extension tube for total height of 70 ft.
Rated Electrical Power	10 kW
Rated Wind Speed (lowest wind speed at which turbine produces rated power)	13 m/s
Rated rotor speed (lowest rotor speed at which turbine produces rated power)	260 rpm
Rotor speed range	100-280 rpm (governing 260-280 rpm)
Fixed or variable pitch	Fixed, but uses mechanically pitching tips to govern rotor speed
Number of Blades	3
Blade Tip Pitch Angle	4.5° (3° pitching range during governing)
Blade make, type, serial number	Injection molded glass fiber plastic w/ nonlinear and optimized taper and twisted airfoil FX63-137; set numbered 1408
Description of inverter	Diversified Technology, Inc.'s GALE-12 model: AMFA00100000000027AH Serial Number: 57583

The test turbine is located at site 3.3c at the NWTC, which is approximately 8 km south of Boulder, Colorado. The terrain is mostly flat with short vegetation. The site has prevailing winds bearing approximately 290 degrees relative to true north. For measurements requiring accurate wind-speed data, the NWTC used data obtained when the wind direction was between 160 and 353 degrees true. In this measurement sector, which was established in accordance with IEC 61400-12-1, terrain and obstructions do not significantly differ between wind measured with the anemometer and the wind experienced by the turbine.

Figure 2 shows the general electrical arrangement. The wire run from the base of the tower to the met tower junction box is approximately 15 m of #6 American Wire Gauge (AWG) wire. The wire run from the met tower junction box and wind brake[1] to the data shed is approximately 75 m of #6 AWG wire. The data shed houses the inverter, instrumentation, disconnect switch, and a breaker panel. Outside and adjacent to the data shed is a transformer that steps up the voltage to 13.2 kV for the NREL grid.

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[1] The "wind brake" is a required component supplied with the turbine. It shorts the generator's three phases, thereby creating an electromagnetic force in opposition to the generator's rotation.

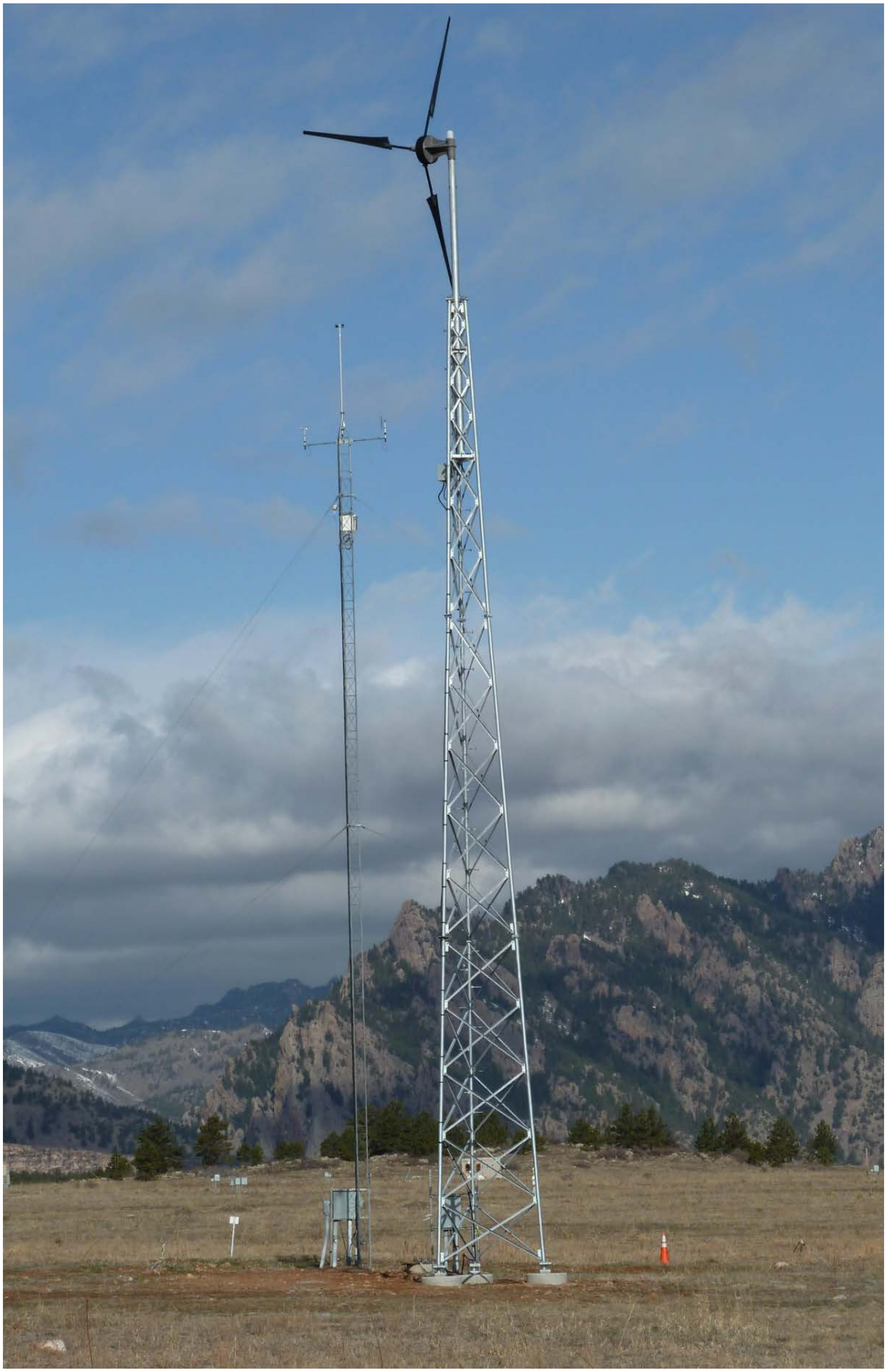

Figure 1. Ventera VT10 test turbine at the NWTC (PIX# 22251)

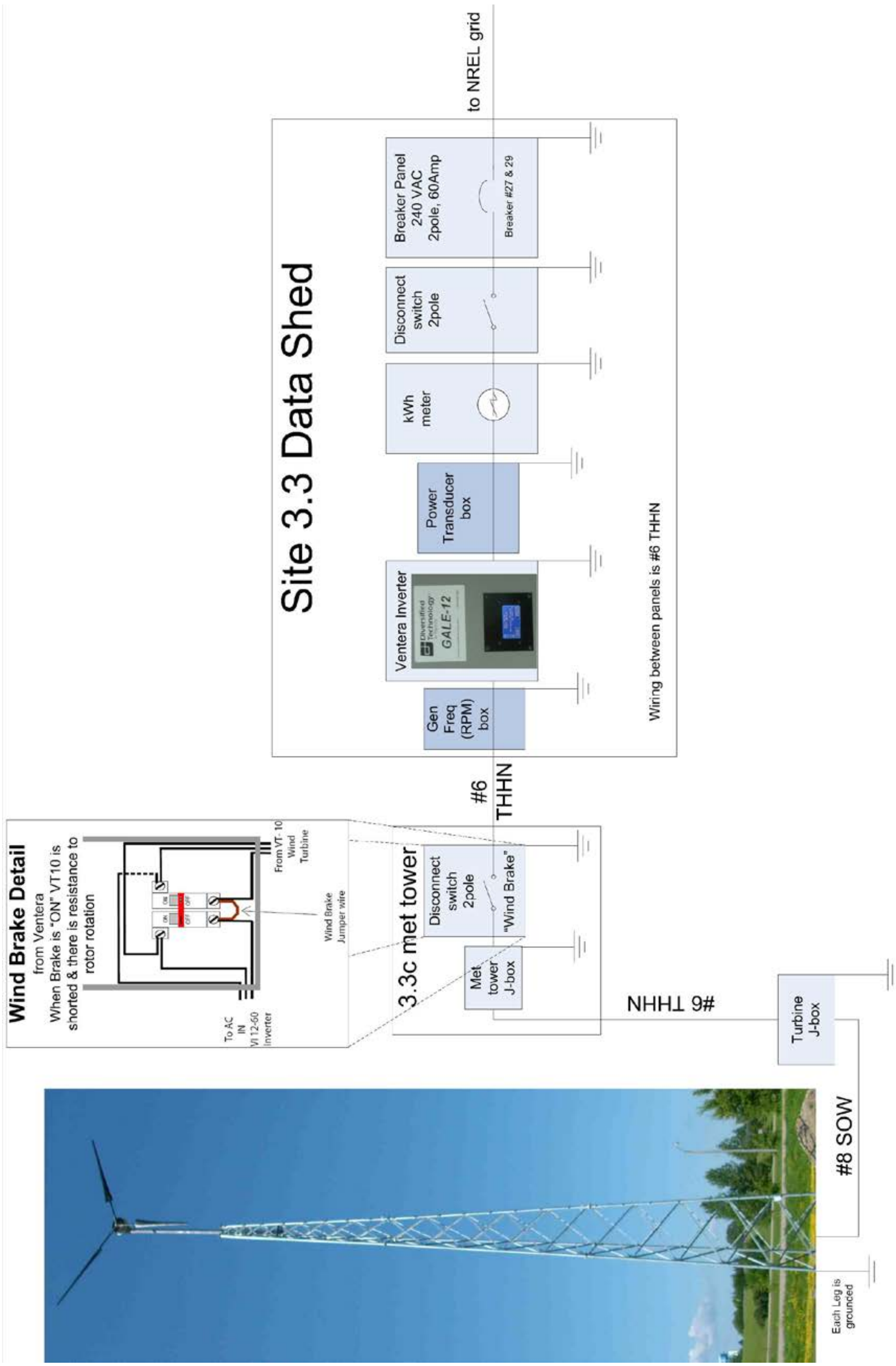

Figure 2. Electrical single-line drawing of VT10 installation

4. Instrumentation

The following parameters were measured in this test: wind speed, electrical power, rotor speed, and grid voltage. The rotor speed was calculated by measuring the frequency of the wild-AC output of the turbine and knowledge of the number of generator poles. An indication of turbine status was obtained by measuring the voltage of the grid and turbine contactor circuits in the inverter. The instruments used for these measurements are listed in Table 2. The calibration sheets for the instruments used for this safety and function test are included in Appendix A.

Table 2. Equipment used in the power performance test

Instrument	Make and Model	Serial Number	Calibration Due Date
Power transducer	Second Wind Phaser-5-4A 20	02061	9- Sep-10 28-Sep-11
Current transformers	Ohio Semitronics, 12974	001293046 001078333	Calibrated with power transducer
Primary anemometer	Thies, First Class	0609009	21-Jan-11
Reference anemometer	Met One 020	T2351	n/a
Wind vane	Met One, 020C with Aluminum Vane	G4707	18-Jan-11; with in situ comparisons
Rotor speed; voltage transducer on turbine output	Ohio Semitronics, VT7-010E-11	08010700	n/a
Inverter Status; voltage of a power supply attached to contactors (optically isolated from DAS)	Omron S83K-00312 Power Supply (grid & turbine contactors) Weidmuller WOS 1 (p/n 827539) Optocoupler	n/a	n/a
Data acquisition system	Compact DAQ w/LabView cDAQ backplane (9172) NI 9229 NI 9205	 12B5EBE 13DEC38 13E3D05	 n/a 22-Feb-11 22-Feb-11

Note: The signal for inverter status indicates if the inverter is connected to the grid and the measured value is itself not used; therefore this instrument was not calibrated. The rotor speed measurement was not calibrated either, but verified that it was working as expected.

5. Procedure

Safety and function testing can involve some risk to personnel and to equipment. By incorporating appropriate controls into testing procedures, NREL endeavors to accomplish its tasks with minimal risk. This test report documents these controls in areas where they might have influenced the results obtained.

5.1. Control and Protection System Functions

In the list below, turbine response was observed for each major response category (startup, normal shutdown, emergency shutdown). If faults or other actions caused one of these major responses, NREL simulates the appropriate input and verifies that the control and protection system appropriately a) sensed the condition, and b) provided indication of an appropriate response. This procedure enables, for example, all the E-stop functions to be checked without exposing the turbine to multiple, potentially damaging stops. These checks are designated by the term “behavior” in the list below.

1. Power control
2. Rotor speed control
3. Yaw orientation
4. Startup
    a. Normal operation – winds rising above cut-in
    b. After maintenance or fault clearance at design wind speed or above
    c. Maintenance of fault conditions at design wind speed or above
5. Normal shutdown
6. Emergency shutdown during operation
7. Behavior upon excessive vibration
8. Behavior upon loss of load
9. Turbine specific checks

5.2. Personnel Safety Provisions

The second part of the test procedure is to evaluate provisions for personnel safety. For this turbine, the following list of NWTC-standardized safety and function issues were reviewed:

1. Safety instructions
2. Climbing
3. Standing place, platforms, and floors
4. Electrical and grounding system
5. Fire resistance and control
6. Fire extinguisher
7. Emergency stop buttons
8. Lock-out / tag-out provisions
9. Interlock on electrical cabinets
10. Safety signs
11. Unauthorized changing of control settings
12. Lightning protection
13. Presence and functioning of rotor and yaw lock

5.3. Dynamic Behavior

NREL staff observed the turbine at all operating wind speeds to note the dynamic behavior of the turbine, including (but not limited to) vibration, yaw behavior, and noise.

6. Results

The results reported here are based on the test conducted from July 2010 through March 2011. The majority of braking, grid, and inverter functions were tested in late November and early December 2010.

6.1. Control and Protection System Functions

NREL limited testing to investigation of single-fault failures and has not investigated failures of “safe life” components, e.g., NREL did not investigate the tower, and considered it a “safe life” component. NREL does not make judgments on whether such failures are likely, or whether additional features in the control and protection system are needed to protect against such consequences.

Power control

Figure 3 shows that the power output of the turbine system is regulated, however it does not reach a maximum peak, above which power would decrease in higher winds. Two methods of control are used. The inverter is programmed with a look-up table for loading the rotor and extracting more power when it is available, i.e. higher winds. If the wind contains too much power for the inverter, the rotor speed increases, and this causes each blade independently to pitch at the tip toward stall. With the blades in a stall condition, less power is extracted from the wind.

Rotor speed control

The Ventera VT10 control systems performed as designed, with the minor exception that rotor speed governing occurred at a lower speed than expected. The tests showed that in high winds the rotor speed was held between 240 and 260 rpm, whereas it was designed to hold at 260 to 280 rpm. Figure 5 shows that rotor speed was controlled in normal operation. When the turbine was loaded (inverter active, i.e., normal operation), governing occurred in wind speeds greater than approximately 13 m/s. When the turbine was unloaded (inverter stopped or off), governing occurred in wind speeds greater than 7 m/s. During unloaded conditions rotor speed was controlled entirely by mechanical blade-tip pitching. Figure 6 shows the rotor speed for loaded and unloaded conditions.

As with the power, the rotor speed is controlled; however, the data does not show a peak.

Yaw orientation

The VT10 is a down-wind, passive yaw turbine. NREL observed yaw behavior frequently during the test period and compared yaw position with the nearby wind vane’s indication of wind direction. In light winds, which are not strong enough to start the rotor turning, significant yaw error was observed. As winds increased, the turbine yawed into the down-wind position, before the blades started turning (approximately 5 m/s winds are required to start turning the rotor). The VT10 was never seen to operate in the upwind position, and there is no data to indicate that upwind operation ever happened.

Also, this turbine uses slip rings to transmit power to and from the nacelle to the tower cable. Thus, droop cable over-twist is not an issue.

Startup

NREL observed that the turbine rotor starts spinning when winds increase to about 5.5 m/s. The inverter is always on, and when the rotor reaches approximately 60 rpm, it begins loading the generator and putting out electrical power. Figure 4 shows normal operation, including two normal startups over a period of 20 minutes. NREL has observed the turbine starting up over a wide range of wind speeds and has not observed any abnormal behavior during any of the startups. NREL observed similar smooth cut-ins when the turbine was returned to service after using the “wind brake” to stop the rotor.

Normal Shutdown

When winds drop below cut-in, the rotor gradually slows and stops producing power with no significant change in sound or behavior. The rotor will stop spinning in winds below 2 m/s. The turbine shows significant hysteresis in low wind startup and shutdown. Figure 4 shows normal operation including one normal shutdown in a period of 20 minutes.

This turbine does not have a cut-out wind speed; it does not shut down in high winds.

Emergency shutdown during operation from any operating condition

In wind speeds greater than 13 m/s the rotor cannot be stopped. In winds below 13 m/s the wind brake can be applied to bring the rotor to a stop. The wind brake shorts the 3-phase terminals of the generator, and this generates enough torque to bring the moving rotor to a stop and prevents a stopped rotor from spinning. Shorting the generator output terminals causes electrical energy to dissipate as heat inside the generator. Therefore it should not be applied for more than a few seconds at a time. NREL procedure was to apply the wind brake for no more than 10 seconds at a time, which was less than Ventera’s recommended maximum time of 1 minute. In winds below 13 m/s, application of the wind brake brings the rotor to a stop in a few seconds. Figure 10 shows the application of the wind brake in an unloaded condition (e.g., grid outage) for 15 seconds, which brought the rotor to a stop in winds around 10 m/s. (Note: The rotor speed signal in Figure 10 can be misleading. Because the rotor speed signal is measured from the wild-AC generator output, when the generator is shorted there is no signal, and the rotor appears to come to a stop in 1 second, but it was observed to take between 5 and 10 seconds to come to a stop.)

The wind brake was observed to hold a stopped rotor in winds of up to 43 m/s.

The inverter has a stop button on its LCD screen. This commands the inverter to disconnect from the turbine and grid contactors. It was observed to function as designed. This stop button applies only to the inverter, and does not stop the rotor. Figure 8 shows the effect of the inverter stop button when the inverter was operating at peak output. Because the winds were above 13 m/s the rotor was already mechanically governing, and there was no detectable difference in the rotor speed as it went into an unloaded condition.

Behavior upon excessive vibration

The turbine has no means to sense excessive vibration or to shut down should excessive vibration occur. The IEC turbine design standards require such sensors on large turbines but not on small turbines, which are turbines with less than 200 m^2 of swept area.

Behavior upon loss of load

When the inverter senses a grid fault or large fluctuation, it disconnects from the grid. NREL tested for this by opening the disconnect switch between the VT10 subpanel and NREL grid. The results were as expected. In winds between 7 and 13 m/s the rotor speed increases to the mechanical governing speed. Figure 7 shows a simulated grid outage, at 1-Hz data resolution, around 10 m/s, and the rotor speed was observed to increase. In wind speeds greater than 13 m/s the rotor is already mechanically governing, so the loss of load does not affect rotor speed, as can be seen in Figure 8, again, in 1-Hz resolution.

Turbine specific checks

Test of the wind brake showed expected results, which were covered in loss of load and shown in Figure 10.

6.2.Personnel Safety Provisions

Safety Instructions

The turbine operator's manual (First Edition) provides safety instructions for installation, operation, and maintenance. The owner's manual encourages a licensed contractor to review plans and participate in the installation. Use of a crane to install the tower is also recommended. However, the turbine does not require trained personnel for installation, maintenance, or servicing, so no warning of this nature is required on the manual's cover, per the Standard.

NREL checked the manual to determine if the safety instructions addressed requirements in the IEC small turbine design standard and found one issue, which is that the turbine has no provisions for securing the yaw mechanism.

Climbing

The user's manual recommends against climbing the tower. While there are ladder rungs on the Rohn SSV tower, they cannot provide access to the generator, which is mounted on an extension tube that places the generator 10 ft above the lattice tower.

Standing places, platforms, and floors

There are no standing places, platforms, or floors with this turbine.

Electrical grounding system

The owner's manual shows a schematic of the electrical system, including where to locate the inverter and disconnect it. The manual also directs the owner to a separate inverter manual. The owner's manual has details on sizing and wiring the electrical system and properly grounding the system.

Fire resistance and control

The inverter has a cooling fan and temperature faults; it is rated for normal operating temperatures from -20˚C to 45˚C.

Fire extinguisher

NREL provided a fire extinguisher in the building that housed the inverters. The manufacturer does not provide fire extinguishers or recommend that they be installed.

Emergency Stop Button

The turbine does not have an emergency stop button. It has an inverter stop button, which is shown in Figure 11. As noted previously, when the inverter is stopped, the rotor becomes unloaded, and its speed will increase to the governing speed of 240 to 260 rpm, in wind speeds greater than 7 m/s.

Lock-out / tag-out provisions

Ventera provided a lockable disconnect switch between the grid and the inverter. The electrical disconnect is shown in Figure 12.

Interlock on electrical cabinets

There is no interlock on the inverter enclosure.

Safety signs

1. There is a warning not to open the inverter “enclosure unless input and output switches are off,” see Figure 11.

2. NREL added labels indicating the voltage levels on all enclosures, electrical panels, and disconnects, see Figure 12.

Unauthorized changing of control settings

Although the inverter look-up table for loading the generator can be modified (by a trained person using appropriate software), there are no readily accessible ways to alter it or any other setting in the inverter.

Lighting Protection

The turbine does not have a lightning protection system. The tower was grounded at all three legs, as indicated by the owner’s manual, as a precaution against lightning.

During the test period, no direct or nearby lightning strikes were observed.

Presence of rotor and yaw lock

There is no rotor lock or yaw lock present on the turbine. The wind brake will prevent the rotor from spinning in winds, but does not lock the rotor completely stationary. The manual is vague on where to locate the wind brake. It states that the wind brake must be between the inverter and generator, but gives no indication of positioning the brake within sight of or in any proximity to the turbine or generator.

Documentation

NREL checked the manual to determine if the turbine met the documentation requirements in the IEC small turbine design standard and found the following issues:

- The manual does not make a recommendation for using a logbook.
- The inverter does not list its production date.
- The generator serial number is on a sticker on the plastic cover of the slip ring assembly, at the top of the generator. However, the turbine does not have other required information, such as a nameplate with manufacturer, model number, production date, or

electrical output limits. The inverter front panel shows that it is made for a VT10 and has Ventera Energy's contact information, but the inverter and generator are modular and have different serial numbers.

6.3. Dynamic Behavior

The operation was observed by NREL personnel for at least 5 minutes at wind speeds of approximately 5 m/s, 10 m/s, 15 m/s, and 20 m/s for a total observation period of at least 1 hour. NREL staff did not measure vibrations directly. Although there were noticeable vibrations in the tower, particularly at the junction of the lattice tower and the extension tube, which connects the generator to the tower, the vibrations were not deemed excessive. The turbine produced significantly more noise when the blades were governing by pitching the outer portion of the blade to control rotor speed. Rotor speed governing, through blade tip pitching, was witnessed in wind speeds greater than 13 m/s when the generator was loaded and above 7 m /s when the generator was unloaded. The turbine tracked the wind well in all wind speeds greater than 4.5 m/s. There were no noticeable yaw oscillations or other unusual behavior.

6.4. Graphs and Plots of Turbine Responses

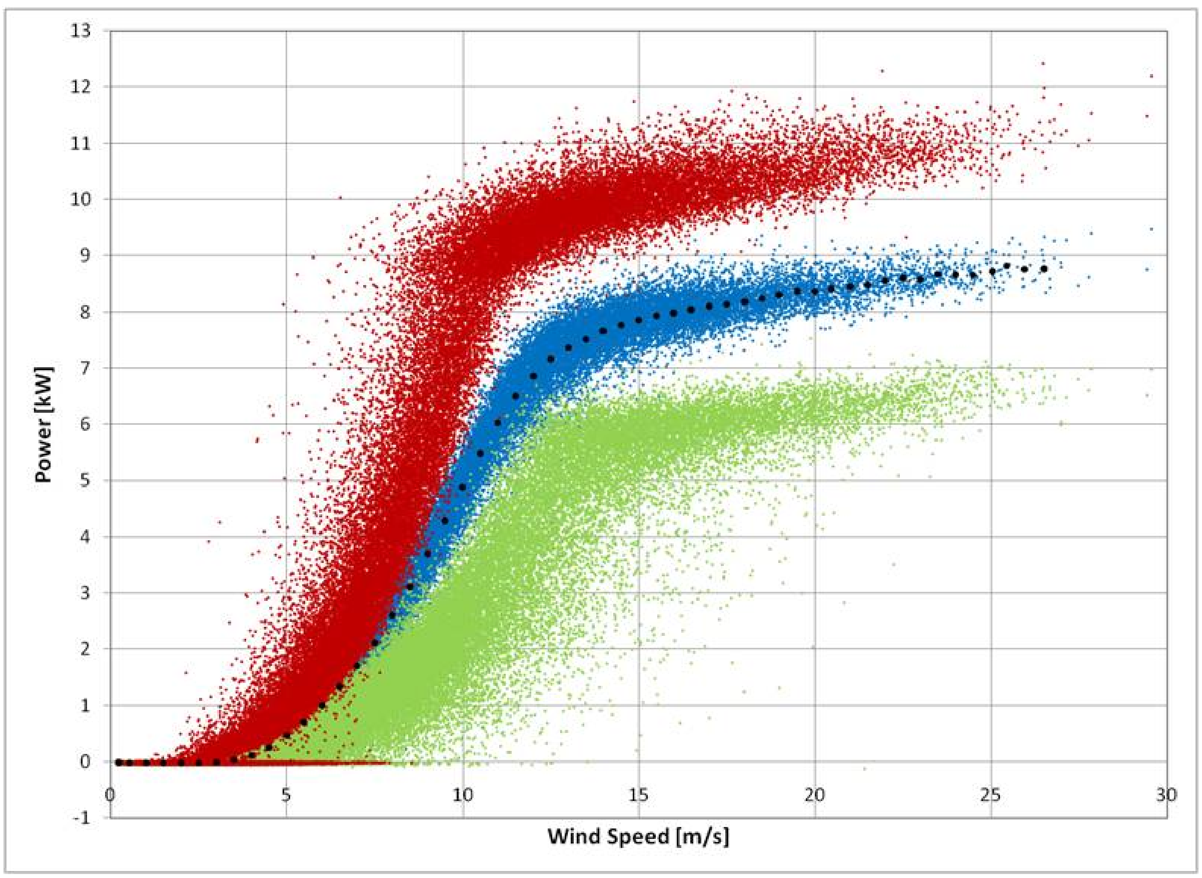

Figure 3. Power response to wind speed, 1-minute data
(Red–maxima, Green–minima, Blue–average, Black–bin average)

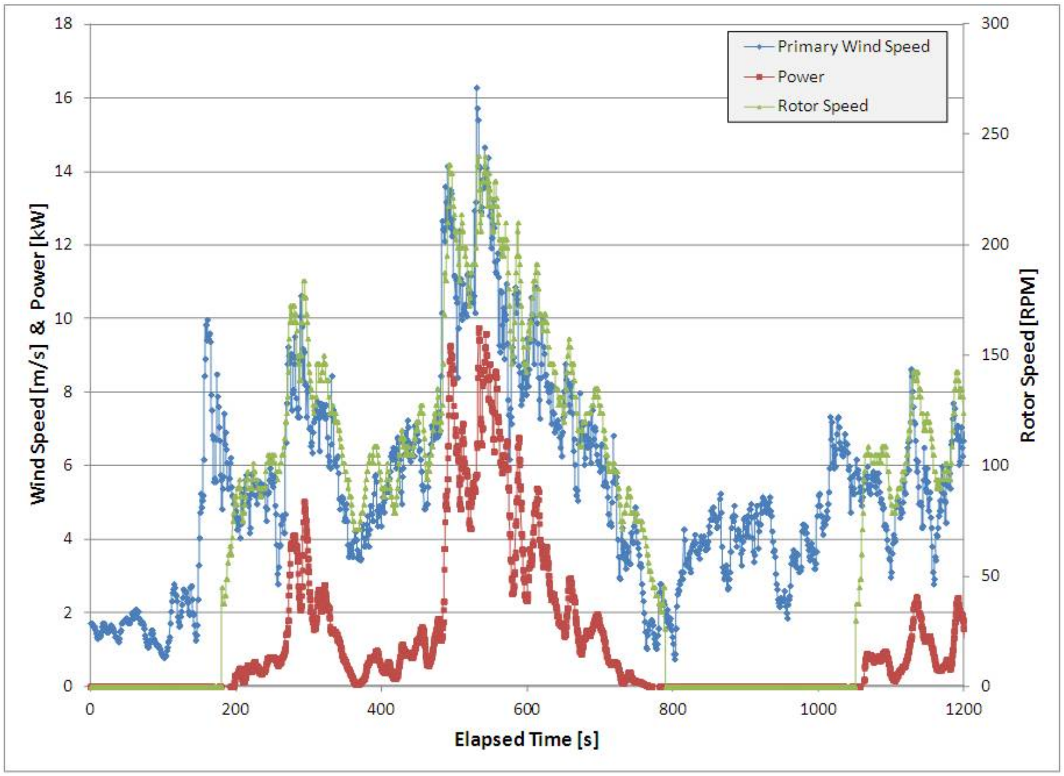

Figure 4. Normal operation including startup and shutdown, 10-Hz data

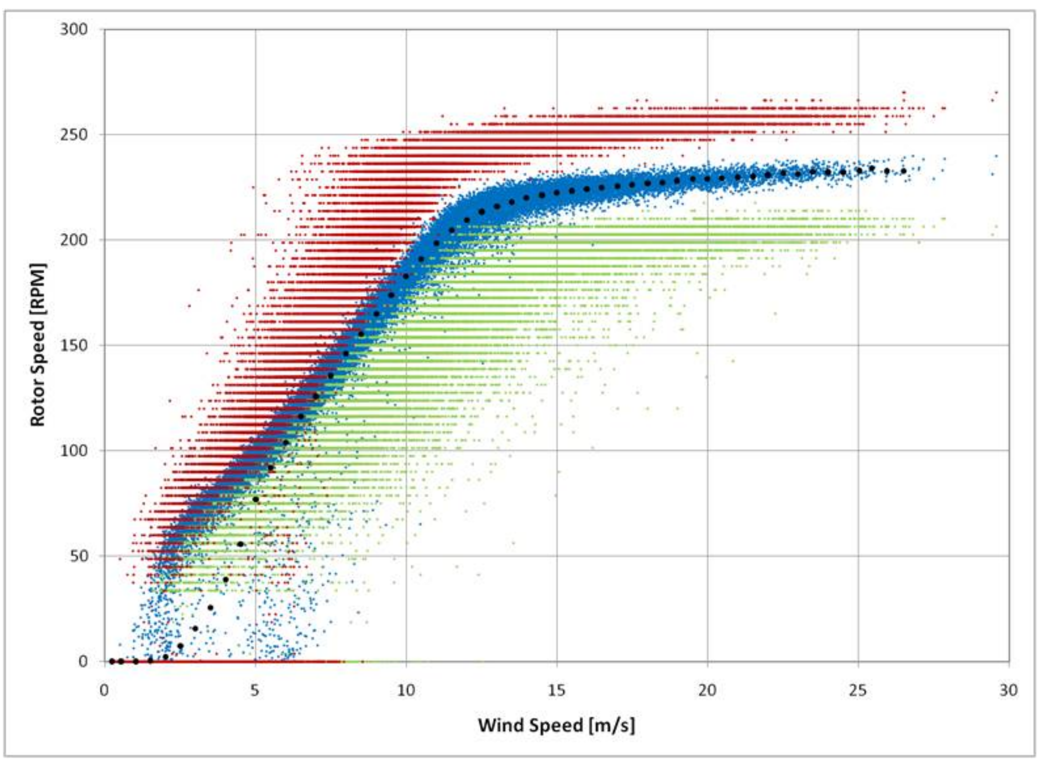

Figure 5. Rotor-speed response to wind speed, 1-minute data; (Red–maxima, Green–minima, Blue–average, Black–bin average)

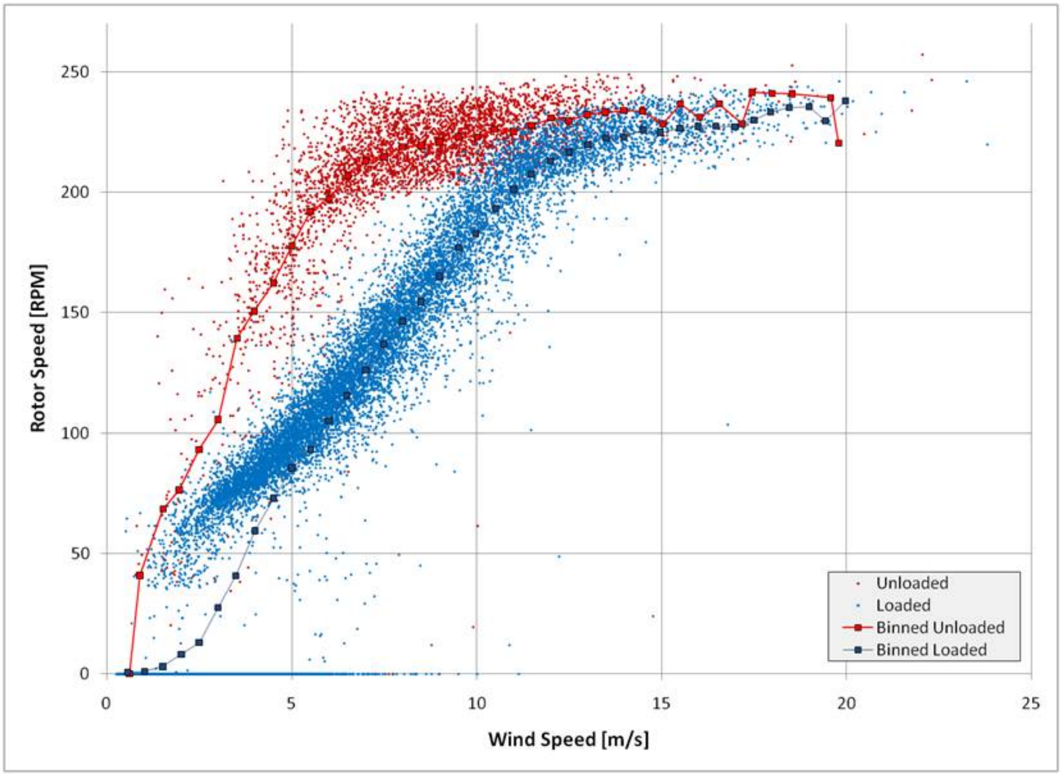

Figure 6. Rotor speed, loaded vs. unloaded, 5-second data

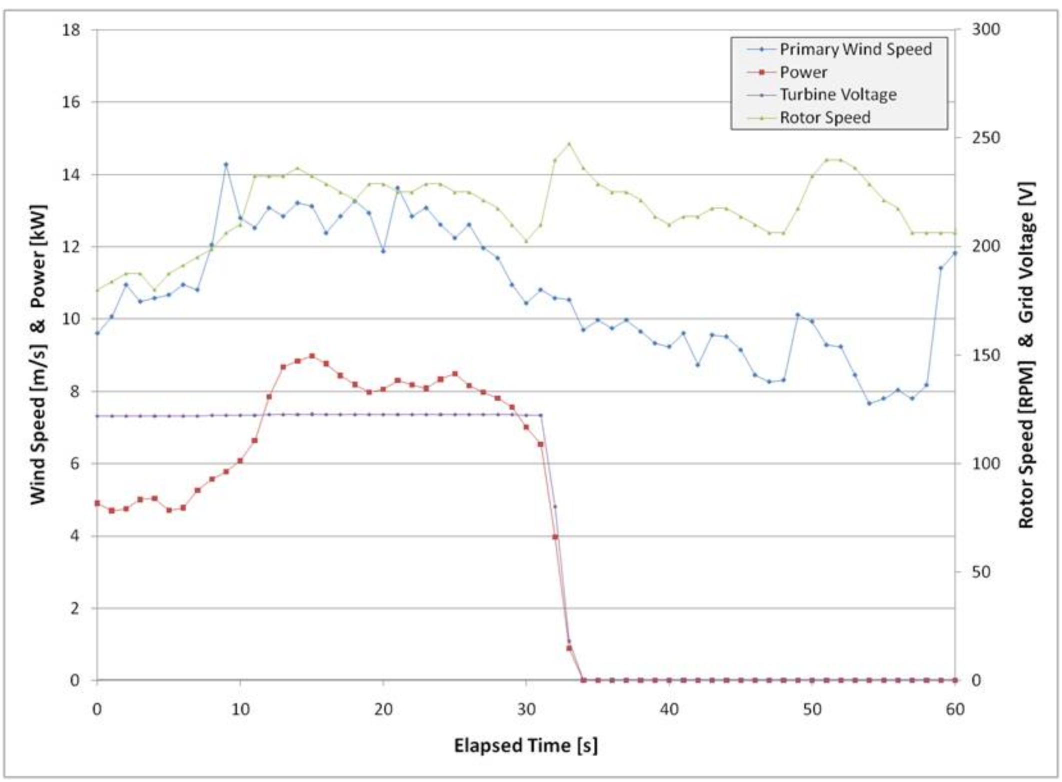

Figure 7. Grid outage, winds near 13 m/s; (Note: Voltage measurement is only for one leg of 240-Vac connection)

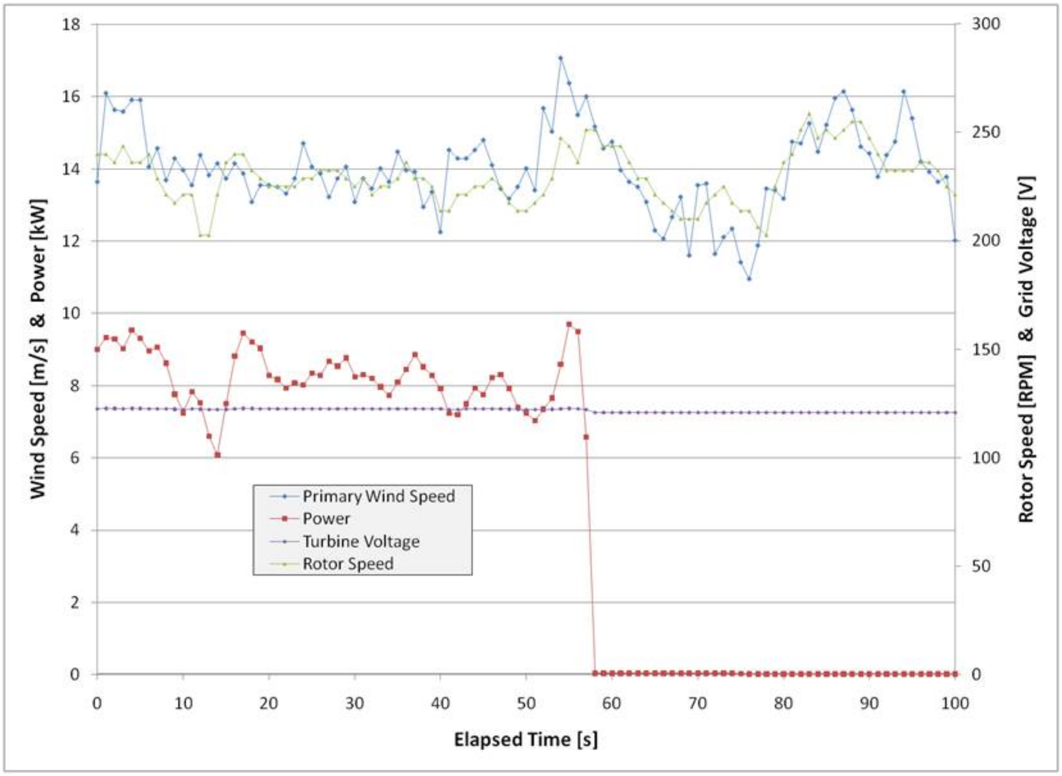

Figure 8. Inverter stop, wind above 13 m/s; rotor speed unchanged; (Note: No increase in rotor speed when the inverter goes offline since the rotor is already regulating)

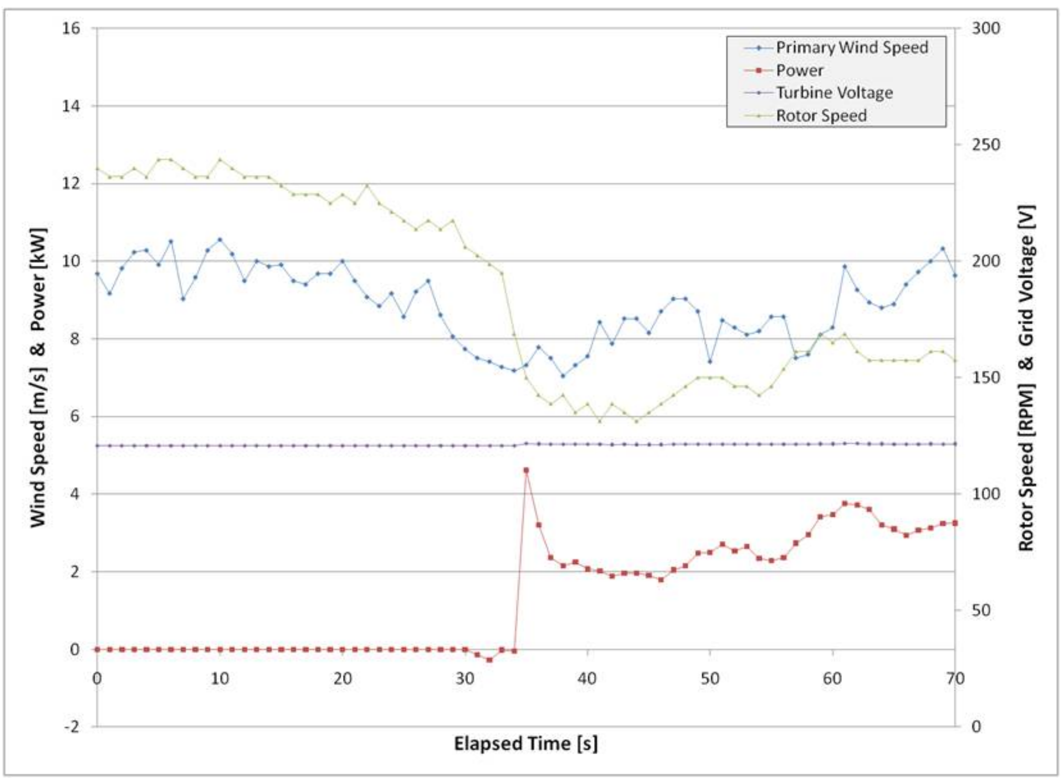

Figure 9. Inverter restart, wind below 13 m/s; rotor speed slows, 1-Hz data

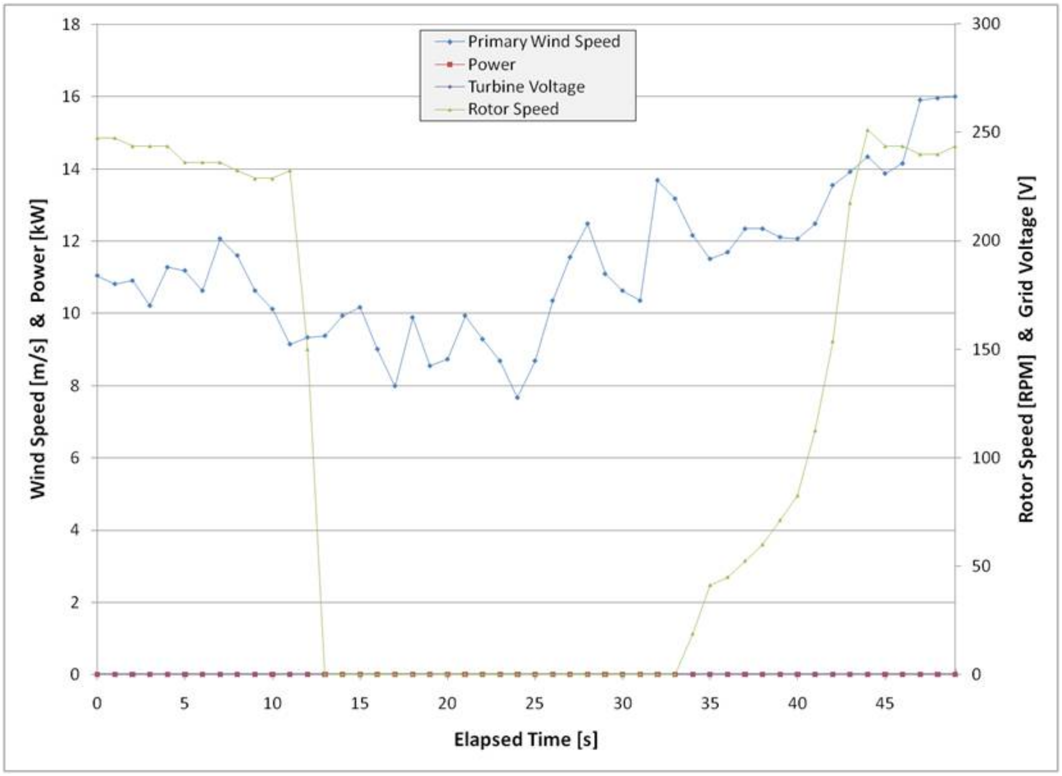

Figure 10. Wind brake for 15 seconds during grid outage in winds below 13 m/s, then released, 1-Hz data; (Note: The rpm signal is not available while the wind brake is applied, see section 6.1)

Figure 11. Inverter front panel, showing a “STOP" button on the touch screen display (PIX# 22252)

Figure 12. VT10 lockable disconnect switch and power meter, both provided by Ventera (PIX# 22253)

7. Exceptions

7.1. Exceptions to the Standard

None

7.2. Exceptions to NWTC Quality Assurance System

The primary anemometer and wind vane were used beyond their calibration due dates.

The anemometer was post-test calibrated and found to have held its calibration for the test period, within 0.02 m/s for the range of 6 to 12 m/s. The calibration sheets and analysis results are shown in Appendix A.

The wind vane was slightly damaged during high winds during the final days of October 2010; it was repaired on 1 November 2010. Comparisons with other wind vanes at the NWTC show that the vane's performance was consistent before and after damage and repair. Additional comparisons show that the repaired vane was consistent with a neighboring test site's measurements until the end of the test. Results of these in situ comparisons are in Appendix A.

The vane became due for calibration during the test. In lieu of a recalibration or a post-test calibration on the vane, these in situ comparisons were used to show that the vane's performance was consistent throughout the test.

A. Appendix - Equipment Calibration Sheets

A.1. Primary anemometer pre-test calibration sheet; installed on 21 January 2010, used until end of test

A.2. Primary anemometer post-test calibration sheet

A.3. Primary anemometer pre-test and post-test calibration comparison; the difference is less than 0.1 m/s for the range of 6 to 12 m/s

A.4. Power transducer calibration sheet; installed 18 February 2010, removed 13 September 2010

A.5. Power transducer calibration sheet; recalibrated and reinstalled 28 Sept10, used until end of test

A.6. Wind vane calibration sheet; installed 18 February 2010; used for entire test

A.7. Wind vane in situ comparison with NWTC site 1E1, August 2010. (+10.9° at 10m/s)

A.8. Wind vane in situ comparison with NWTC site 1E1, January 2011. (+10.1° at 10m/s)

A.9. Wind vane in situ comparison with NWTC site 3.1, January 2011. (-0.7° at 10m/s)

A.10. Wind vane in situ comparison with NWTC site 3.1, May 2011. (-0.7° at 10m/s)

A.11. Voltage Transducer calibration sheet, used for Rotor Speed measurement; installed 8 January 10, used until end of test

A.12. NI 9229 data acquisition module calibration; installed 26 July 2010, used until end of test

A.13. NI 9205 data acquisition module calibration; installed 26 July 2010, used until end of test

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WIND ENGINEERING
FLUID DYNAMICS

CERTIFICATE FOR CALIBRATION OF CUP ANEMOMETER

Certificate number: 09.02.3147 **Date of issue:** June 15, 2009

Type: Thies 4.3351.10.000 **Serial number:** 0609009

Manufacturer: ADOLF THIES GmbH & Co.KG, Hauptstrasse 76, 37083 Göttingen, Germany

Client: Sky Power Int'l LLC, 250 Sawdust Road, 29657-8521 Liberty SC, USA

Anemometer received: June 11, 2009 **Anemometer calibrated:** June 12, 2009

Calibrated by: mh **Calibration procedure:** IEC 61400-12-1, MEASNET

Certificate prepared and approved by: Calibration engineer, soh *Svend Ole Hansen*

Calibration equation obtained: v [m/s] = 0.04636 · f [Hz] + 0.22372

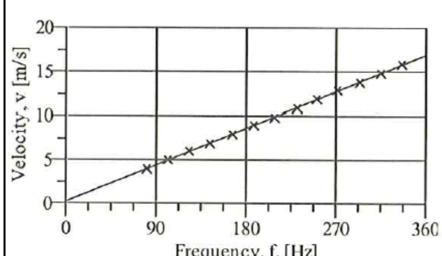
Standard uncertainty, slope: 0.00127 **Standard uncertainty, offset:** 0.05862

Covariance: -0.0000007 (m/s)²/Hz **Coefficient of correlation:** ρ = 0.999991

Absolute maximum deviation: -0.028 m/s at 10.883 m/s

Barometric pressure: 1004.2 hPa **Relative humidity:** 24.1%

Succession	Velocity pressure, q. [Pa]	Temperature in wind tunnel [°C]	Temperature in control room [°C]	Wind velocity, v. [m/s]	Frequency, f. [Hz]	Deviation, d. [m/s]	Uncertainty u_c (k=2) [m/s]
2	9.07	32.0	23.8	3.986	81.6316	-0.022	0.029
4	13.93	31.9	23.7	4.939	101.6035	0.004	0.033
6	20.26	31.8	23.7	5.955	123.2072	0.020	0.038
8	27.48	31.7	23.7	6.935	144.5096	0.012	0.044
10	35.79	31.6	23.7	7.914	165.9949	-0.006	0.049
12	45.23	31.5	23.7	8.895	187.0034	0.002	0.055
13-last	56.18	31.5	23.7	9.913	208.8310	0.007	0.061
11	67.70	31.5	23.7	10.883	230.5182	-0.028	0.067
9	80.29	31.6	23.7	11.853	250.5970	0.011	0.073
7	94.49	31.7	23.7	12.860	272.1574	0.019	0.080
5	109.40	31.8	23.7	13.840	294.2530	-0.026	0.086
3	125.69	31.9	23.8	14.838	315.2489	-0.001	0.092
1-first	143.07	32.2	23.8	15.838	336.5955	0.009	0.099



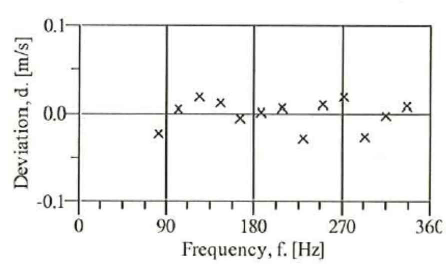


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Figure A.1. Primary anemometer pre-test calibration sheet; installed on 21 January 2010, used until end of test

Svend Ole Hansen ApS

SCT. JØRGENS ALLÉ 7 · DK-1615 KØBENHAVN V · DENMARK
TEL: (+45) 33 25 38 38 · FAX: (+45) 33 25 38 39 · WWW.SOHANSEN.DK

WIND ENGINEERING FLUID DYNAMICS

CERTIFICATE FOR CALIBRATION OF CUP ANEMOMETER

Certificate number: 11.02.4877
Date of issue: July 18, 2011
Type: Thies 4.3351.10.000
Serial number: 0609009
Manufacturer: ADOLF THIES GmbH & Co.KG, Hauptstrasse 76, 37083 Göttingen, Germany
Client: National Renewable Energy Lab, 1617 Cole Boulevard, Golden, Colorado 80401-3393, USA

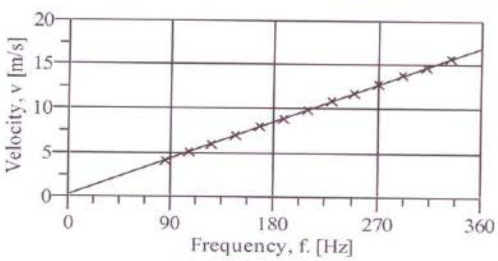
Anemometer received: June 30, 2011
Anemometer calibrated: July 17, 2011
Calibrated by: cn
Calibration procedure: IEC 61400-12-1, MEASNET
Certificate prepared by: jsa
Approved by: Calibration engineer, soh

Svend Ole Hansen

Calibration equation obtained: v [m/s] = 0.04670 · f [Hz] + 0.15965
Standard uncertainty, slope: 0.00081
Standard uncertainty, offset: 0.05257
Covariance: -0.0000003 (m/s)²/Hz
Coefficient of correlation: $\rho = 0.999996$
Absolute maximum deviation: -0.026 m/s at 11.811 m/s

Barometric pressure: 998.7 hPa
Relative humidity: 32.0%

Succession	Velocity pressure, q. [Pa]	Temperature in wind tunnel [°C]	Temperature in control room [°C]	Wind velocity, v. [m/s]	Frequency, f. [Hz]	Deviation, d. [m/s]	Uncertainty u_c (k=2) [m/s]
2	9.49	34.2	26.7	4.108	84.7680	-0.011	0.028
4	14.54	34.1	26.6	5.086	105.4851	-0.001	0.032
6	20.53	34.0	26.6	6.041	125.8334	0.005	0.037
8	27.57	33.9	26.6	6.999	146.1792	0.012	0.042
10	35.85	33.8	26.6	7.981	167.2917	0.008	0.047
12	45.14	33.8	26.6	8.954	188.4300	-0.006	0.053
13-last	55.37	33.7	26.6	9.917	208.8464	0.003	0.058
11	67.02	33.8	26.6	10.911	230.0220	0.008	0.064
9	78.51	33.9	26.6	11.811	250.0281	-0.026	0.069
7	92.42	34.0	26.6	12.816	271.0172	-0.001	0.075
5	106.62	34.0	26.6	13.768	291.2600	0.005	0.080
3	122.30	34.1	26.7	14.748	312.3682	-0.001	0.086
1-first	138.51	34.3	26.7	15.698	332.5736	0.006	0.092



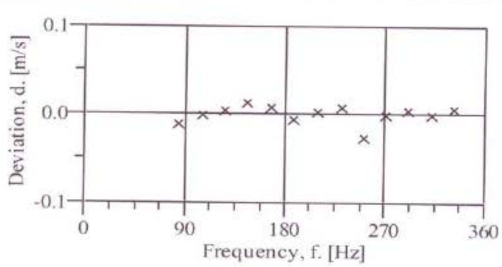


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Figure A.2. Primary anemometer post-test calibration sheet

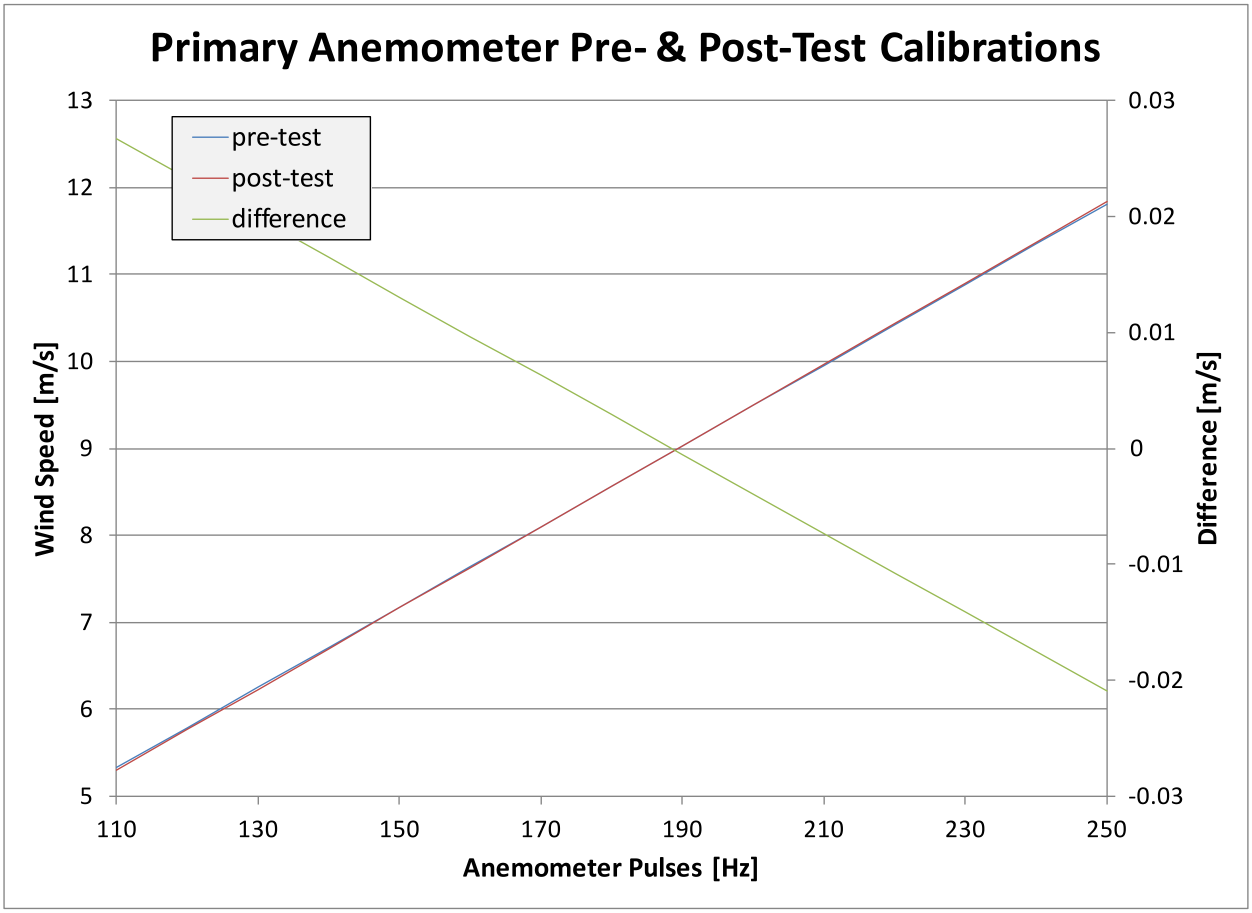


Figure A.3. Primary anemometer pre-test and post-test calibration comparison; the difference is less than 0.1 m/s for the range of 6 to 12 m/s

Branch #: 5000

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Phaser Power Transducer & 2-CTs DOE #: 02825C

Model # : Phaser-5-4A 20 S/N : 02061

Calibration Date: 09/09/2009 Due Date: 09/09/2011

A. Set-Up for Total Real Power Calibration:
A.1. Voltage is applied between phases A&B and N = 120 V @ 60 Hz.
A.2. Current is applied to n = 2 TURNS through the two current transformer that are connected to phases A&B. Please note that the number of turns are not included in calculating the input power.
A.3. Analog Output-1 is measured across precision resistor = 250 Ω.
A.4. Phaser Full Scale setting = -18 KW to 18 KW.

Input Current (AAC)	Input Power (KW)	Analog Output-1 (VDC)
75	18	4.991
50	12	4.327
25	6	3.661
0	0	3.021
-25	-6	2.331
-50	-12	1.665
-75	-18	1.000

B. Set-Up for Power Factor Calibration:
B.1. Voltage & Current are applied as A.1 & A.2.
B.2. Analog Output-2 is measured across precision resistor = 250 Ω.

Power (KW)	Power Factor	Analog Output-2 (VDC)
18	1.0	4.988
"	0.8	4.179
"	0.6	3.376
"	0.4	2.577

Figure A.4. Power transducer calibration sheet; installed 18 February 2010, removed 13 September 2010

Branch #: 5000

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Phaser Power Transducer & 2-CTs   DOE #: 02825C

Model # : Phaser-5-4A 20   S/N : 02061

Calibration Date: 09/22/2010   Due Date: 09/22/2012

A. Set-Up for Total Real Power Calibration:
A.1. Voltage is applied between phases A&B and N = 120 V @ 60 Hz.
A.2. Current is applied to n = 2 TURNS through the two current transformer that are connected to phases A&B. Please note that the number of turns are not included in calculating the input power.
A.3. Analog Output-1 is measured across precision resistor = 250 Ω.
A.4. Phaser Full Scale setting = -18 KW to 18 KW.

Input Current (AAC)	Input Power (KW)	Analog Output-1 (VDC)
75	18	4.991
50	12	4.325
25	6	3.658
0	0	2.996
-25	-6	2.331
-50	-12	1.667
-75	-18	1.002

B. Set-Up for Power Factor Calibration:
B.1. Voltage & Current are applied as A.1 & A.2.
B.2. Analog Output-2 is measured across precision resistor = 250 Ω.

Power (KW)	Power Factor	Analog Output-2 (VDC)
18	1.0	4.988
"	0.8	4.172
"	0.6	3.370
"	0.4	2.567

Page 1 of 2

Figure A.5. Power transducer calibration sheet; recalibrated and reinstalled 28 September 2010, used until end of test

NREL National Renewable Energy Laboratory

NWTC Testing Group

Wind Vane Calibration Report

Calibration Laboratory:
National Wind Technology Center - Cert. Team
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401

Customer:
National Wind Technology Center - Certification Team
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401

Calibration Location:
National Wind Technology Center
Room 101, NWTC Bldg 256

Calibration Date: **30-Dec-09**

Report Number: G4707-091230

Page: 1 of 1

Procedure:
NWTC-CT: CI04 Calibrate Wind Vane_091209.pdf

Deviations from procedure: Calibrated on 5V Range
Calibrated in Volts (not mV)

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	020C
Serial Number	G4707
Vane Material	Aluminum
Condition	Refurbished

Results:

Slope:	72.7001	deg/V
Offset to boom:	94.6	deg
Max error:	0.4	deg

Estimated Uncertainty:

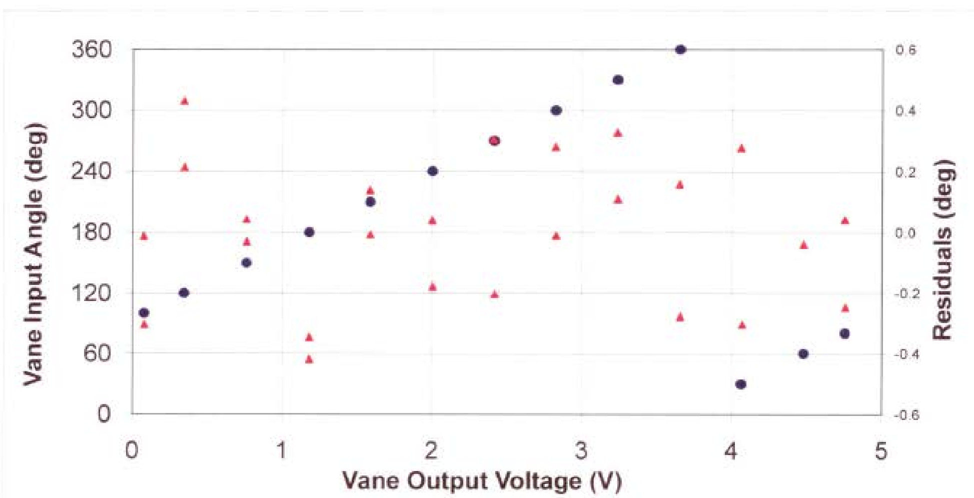
Inclinometer Uncertainty (deg)	Total Uncertainty (deg)
0.10	0.25

Traceability:

	Mfg & Model	Serial Number	Cal Date
Inclinometer:	SPI Tronic Pro360	31-038-3	19-May-09
Voltmeter:	HP 3458A	2823A05145	5-May-09

Calibration by: David Jager

Date: 4 Jan 10



Vane Cal G4707 091230.xls

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Page 1 of 1

Figure A.6. Wind vane calibration sheet; installed 18 February 2010; used for entire test

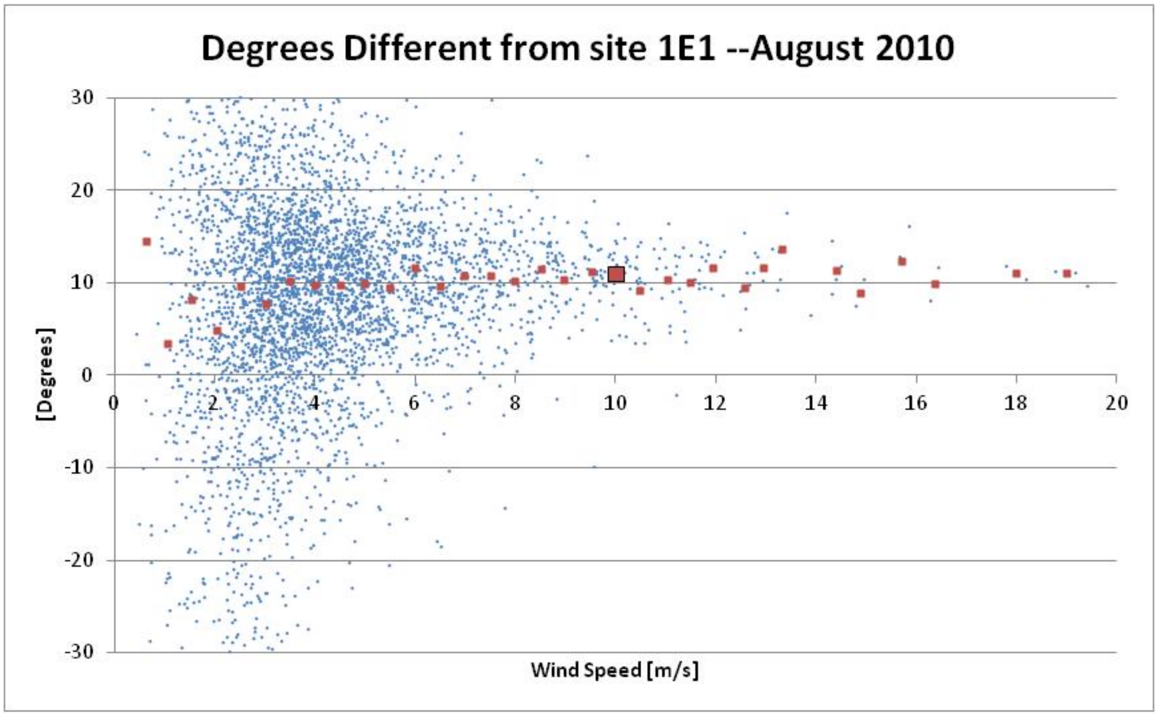

Figure A.7. Wind vane in situ comparison with NWTC site 1E1, August 2010. (+10.9° at 10m/s)

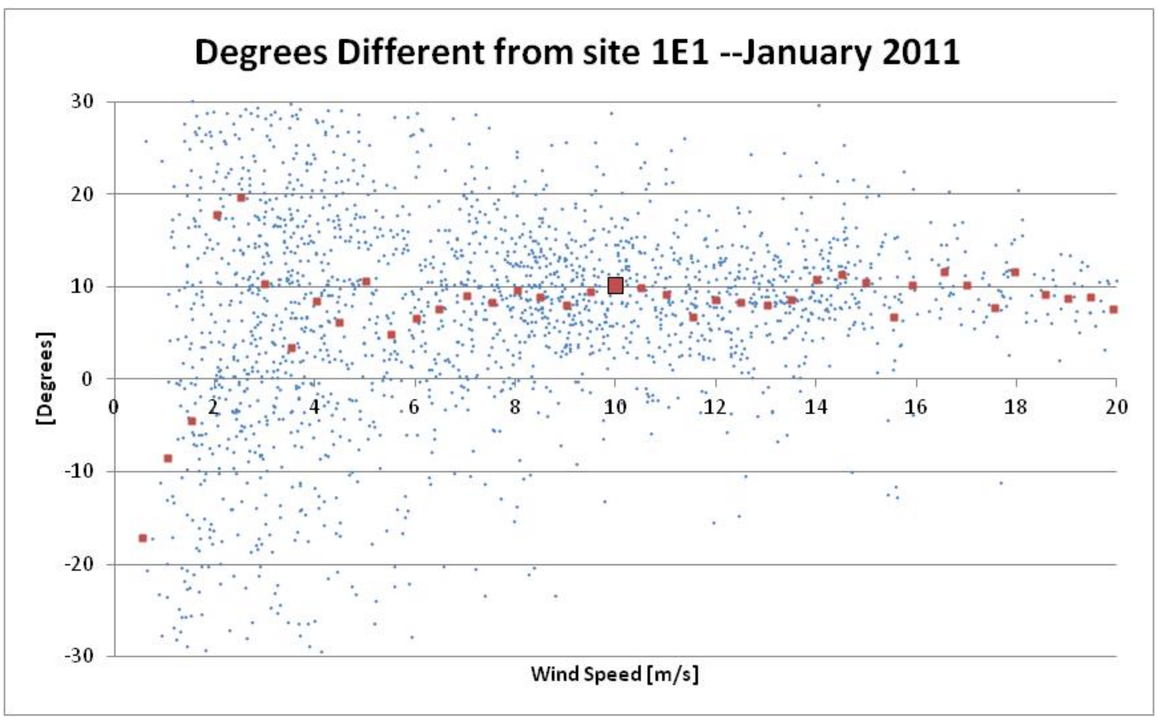

Figure A.8. Wind vane in situ comparison with NWTC site 1E1, January 2011. (+10.1° at 10m/s)

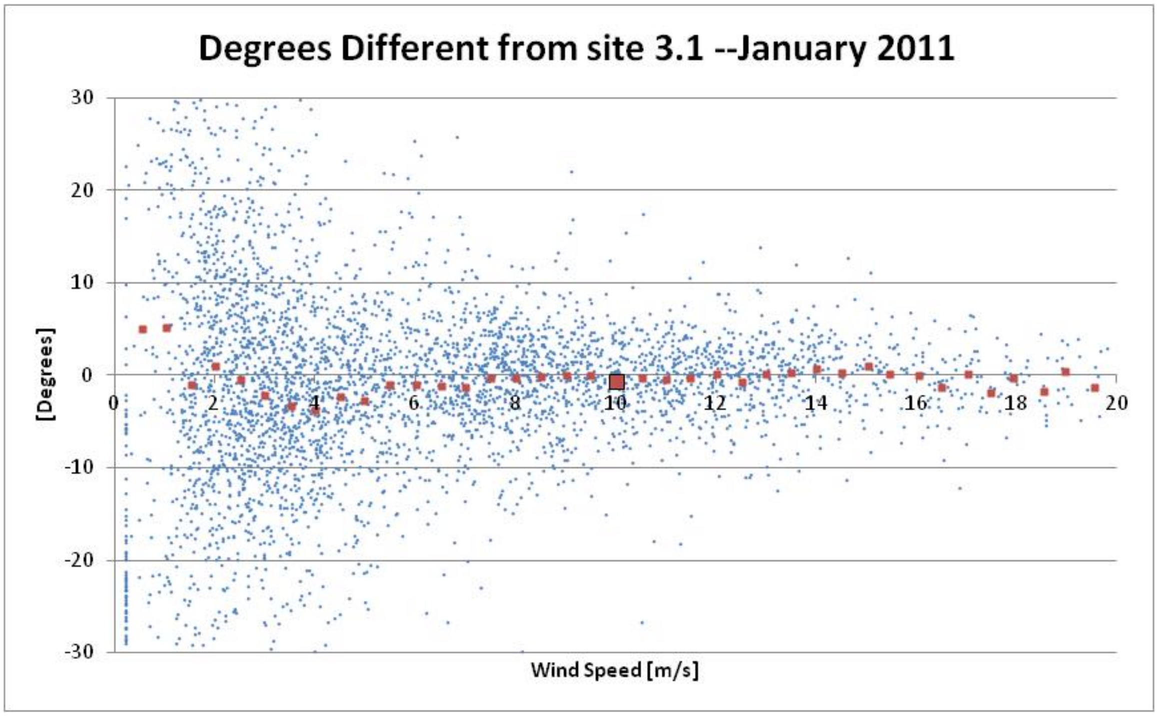

Figure A.9. Wind vane in situ comparison with NWTC site 3.1, January 2011. (-0.7° at 10m/s)

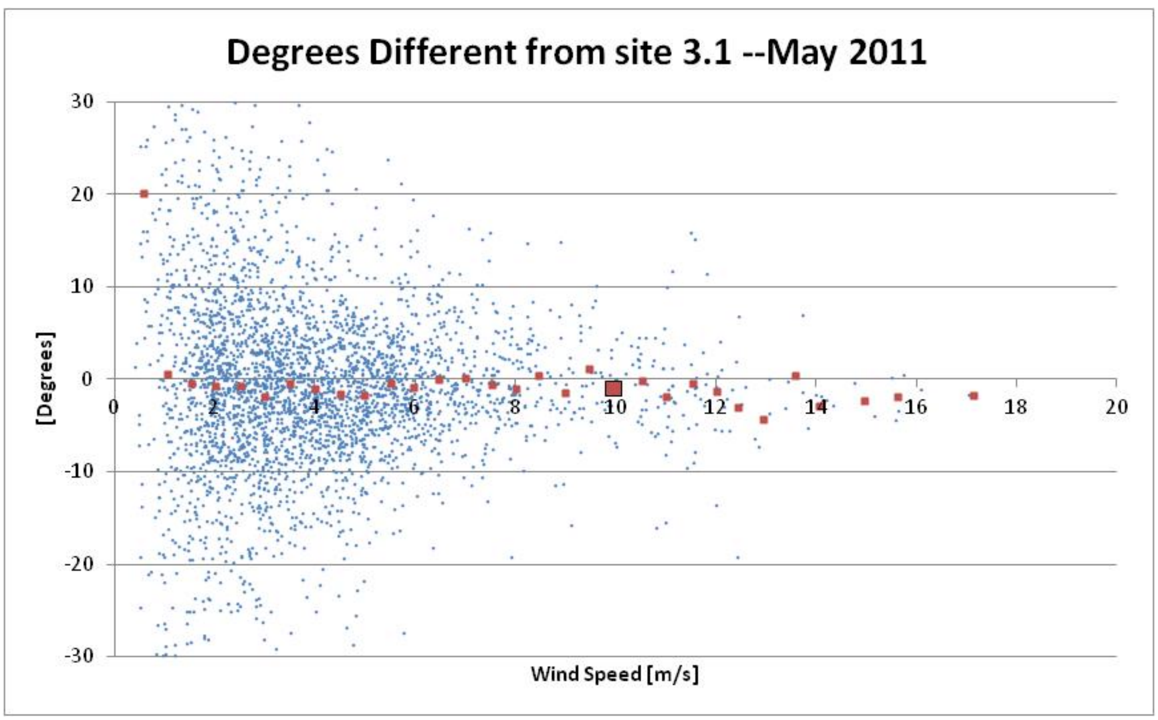

Figure A.10. Wind vane in situ comparison with NWTC site 3.1, May 2011. (-1.0° at 10m/s)

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Voltage Transducer DOE #: 03622C

Model # : VT7-010E S/N : 08010700

Calibration Date: 01/11/2010 Due Date: 01/11/2012

No	Function Tested	Nominal Input	Measured Output AS Found	Measured Output AS Left	( )Mfr. Specs. OR (X)Data only
*	Input Voltage	VDC	mADC	mADC	
		0	3.989	Same	
		100	6.673	"	
		200	9.347	"	
		300	12.015	"	
		400	14.682	"	
		500	17.347	"	
		600	20.011	"	

Notes:
- Calibration was performed using instruments that are traceable to NIST, DOE# 126410 and 01888C.
- Calibration was performed at temperature = 23 °C and relative humidity = 40%.
- Uncertainty of nominal values is ± 0.15% of reading.

Calibrated By: Reda QA By : Bev

Date : 01/11/2010 Date : 01/11/2010

Figure A.11. Voltage transducer calibration sheet, used for rotor speed measurement; installed 8 January 2010, used until end of test

Davis Calibration

ACLASS ACCREDITED CALIBRATION

Certificate of Calibration

3913562

Certificate Page 1 of 1

Instrument Identification

Company ID: 120205

NREL
BEV KAY
16253 DENVER WEST PARKWAY
GOLDEN, CO, 80401

PO Number: CC- TBA

Instrument ID: **04037C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CHANNEL, ±60 V, 24-BIT SIMULTANEOUS ANALOG INPUT

Model Number: NI 9229
Serial Number: 13DEC38

Accuracy: Mfr Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025 WITH UNCERTAINTIES
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: NATIONAL INSTRUMENTS3.4 CAL EXECUTIVE REV 3.4
Remarks: *Reference attached Calibration Data w/uncertainties.*

Technician: WAYNE GETCHELL
Cal Date 22Feb2010
Cal Due Date: 22Feb2011
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 39.0 %

The instrument on this certification has been calibrated against standards traceable to the National Institute of Standards and Technology (NIST) or other recognized national metrology institutes, derived from ratio type measurements, or compared to nationally or internationally recognized consensus standards.

A test uncertainty ratio (T.U.R.) of 4:1 [K=2, approx. 95% Confidence Level] was maintained unless otherwise stated.

Davis Calibration Laboratory is certified to ISO 9001:2008 by Eagle Registrations (certificate # 3046). Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994, ISO 10012:2003, 10CFR50 AppxB, and 10CFR21.

ISO/IEC 17025-2005 accredited calibrations are per ACLASS certificate # AC-1187 within the scope for which the lab is accredited. All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.

This certificate shall not be reproduced except in full, without written consent of Davis Calibration Laboratory.

Approved By: WAYNE GETCHELL
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
3768091	15-0048	MULTIFUNCTION CALIBRATOR	5700A	29Dec2009	29Mar2010

Davis Calibration • 2324 Ridgepoint Drive, Suite D • Austin, TX 78754 • Phone: 800-365-0147 • Fax: 512-926-8450

Figure A.12. NI 9229 data acquisition module calibration; installed 26 July 2010, used until end of test

Davis Calibration ACLASS ACCREDITED CALIBRATION

Certificate of Calibration

3930692

Certificate Page 1 of 1

Instrument Identification

Company ID: 120205
PO Number: CC- TBA

NREL
BEV KAY
16253 DENVER WEST PARKWAY
GOLDEN, CO, 80401

Instrument ID: **04035C**
Model Number: NI 9205
Manufacturer: NATIONAL INSTRUMENTS
Serial Number: 13E3D05
Description: 32-CH ±200 MV TO ±10 V, 16-BIT, 250 KS/S ANALOG INPUT MODULE

Accuracy: Mfr Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025 WITH UNCERTAINTIES
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: NATIONAL INSTRUMENTS3.4 CAL EXECUTIVE REV 3.4

Technician: WAYNE GETCHELL
Cal Date 22Feb2010
Cal Due Date: 22Feb2011
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 39.0 %

Remarks: *Reference attached Calibration Data w/uncertainties.*

The instrument on this certification has been calibrated against standards traceable to the National Institute of Standards and Technology (NIST) or other recognized national metrology institutes, derived from ratio type measurements, or compared to nationally or internationally recognized consensus standards.

A test uncertainty ratio (T.U.R.) of 4:1 [K=2, approx. 95% Confidence Level] was maintained unless otherwise stated.

Davis Calibration Laboratory is certified to ISO 9001:2008 by Eagle Registrations (certificate # 3046). Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994, ISO 10012:2003, 10CFR50 AppxB, and 10CFR21.

ISO/IEC 17025-2005 accredited calibrations are per ACLASS certificate # AC-1187 within the scope for which the lab is accredited. All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.

Approved By: GALEN WASHBURN
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
3768091	15-0048	MULTIFUNCTION CALIBRATOR	5700A	29Dec2009	29Mar2010

Davis Calibration • 2324 Ridgepoint Drive, Suite D • Austin, TX 78754 • Phone: 800-365-0147 • Fax: 512-926-8450

Figure A.13. NI 9205 data acquisition module calibration; installed 26 July 2010, used until end of test