Safety and Function Test Report for the Viryd CS8 Wind Turbine

J. Roadman, M. Murphy, and J. van Dam
National Renewable Energy Laboratory

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Technical Report
NREL/TP-5000-60060
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Contract No. DE-AC36-08GO28308

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Prepared under Task No. WE11.0206

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Safety and Function Test Report

for the

Viryd CS8 Wind Turbine

at the

National Wind Technology Center in

Boulder, Colorado

Conducted for

National Renewable Energy Laboratory

15013 Denver West Parkway

Golden, Colorado 80401

Conducted by

National Wind Technology Center

National Renewable Energy Laboratory

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Golden, Colorado 80401

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June 2013

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Approval By: [signature] 2 August 2013
Jeroen van Dam, NREL Test Engineer — Date

Review By: [signature] 5 August 2013
Arlinda Huskey, 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 of wind energy expansion by providing independent testing results for small turbines. Several turbines were selected for testing at the National Wind Technology Center (NWTC) at the National Renewable Energy Laboratory (NREL) as a part of the Small Wind Turbine Independent Testing project. Safety and function testing is one of up to five tests that may be performed on the turbines. Other tests include duration, power performance, acoustic noise, and power quality. Viryd Technologies, Inc. of Austin, Texas, was the recipient of the DOE grant and provided the turbine for testing.

The NWTC conducted this test in accordance with its quality system procedures to ensure that this final test report meets the full accreditation requirements by A2LA. NREL's quality system requires that the test meet all applicable requirements specified by A2LA and ISO/IEC 17025 or to note any exceptions in the test report.

2 Test Objective

The objective of this test is to:

- Verify that the test turbine displays the behavior predicted in the design
- Determine if provisions relating to personnel safety are properly implemented
- Characterize the dynamic behavior of the wind turbine at rated wind speed and above.

NREL does not limit the safety and function test to features described in the wind turbine documentation. NREL also inspects, possibly tests, and reports on features that are required by IEC 61400-2 that may not be described in the wind turbine documentation.

NREL conducted this test in accordance with Section 9.6 of the International Electrotechnical Commission (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, shown in Figure 1, is a three-bladed, upwind, passive yaw turbine with a rated power of 8 kW. It was commissioned on 12 October 2011 and decommissioned on 7 May 2013. Safety and function testing was conducted from 12 October 2011 through 13 February 2013. Table 1 lists the basic turbine configuration and operational data provided by the manufacturer. As part of Viryd's standard commissioning procedure, small shims were inserted between the hub plate and the blade root, thereby pitching the leading edge of the blades into the wind. The pitch angle of each blade with respect to the hub plate is fixed. The angle was measured and is provided in Table 2. Figure 2 shows the one-line diagram for the test turbine installation.

The following components were considered part of the test turbine system:

- A tower and foundation that were designed for installation at the NWTC test site 3.3a
- The wiring and components on the turbine side of the test shed's electrical panel, connecting the turbine to the electrical grid
- All control components including wiring between the up-tower components and the down-tower control panel.

Figure 1. Viryd CS8 test turbine at the NWTC
(*Photo by Mark Murphy, NREL 22258*)

Table 1. Test Turbine Configuration and Operational Data

Turbine Manufacturer and Address	Viryd Technologies, Inc. 9701 Metric Blvd. Suite 200 Austin, TX 78758
Model	Viryd CS8
Serial number	CS008100X
Rotor diameter (m)	8.5
Hub height (m)	25
Tower type	U.S. Tower, guyed, tilt-up lattice
Rated electrical power (kW)	8
Rated wind speed (m/s)	10
Small wind turbine class	II
Rotor speed range (rpm)	115–125
Fixed or variable pitch	Fixed
Power regulation (active or passive)	Passive
Number of blades	3
Blade pitch angle (deg)	See Table 2
Blade make, type, serial number	Viryd proprietary design, serial numbers not provided
Direction of rotation	Clockwise viewed from upwind
Description of control system (device and software version)	Proprietary – PCB
Tower make, type, height	U.S. Tower, tilt-up, guyed lattice, 24.4 m
Electrical output	240 VAC single phase

Table 2. Measured Blade Pitch Angle Relative to the Hub Plate

Blade	Pitch Angle
1	1.4°
2	1.1°
3	1.4°

The test configuration consisted of the turbine mounted on a lattice tower, the controller, the meteorological tower, associated wiring and junction boxes, and a data shed containing the data acquisition instrumentation. The turbine was installed on a guyed, tilt-up, 24.4-m lattice tower. The wire run from the base of the tower to the data shed is approximately 98 meters of #6 American Wire Gauge (AWG) wire. Inside the test shed, the turbine was connected to a 240-volt (V) panel, where 240/480-V and 0.480/13.2 kilovolt (kV) transformers allowed the turbine to connect to the site's 13.2-kV grid. Grid tolerances were 1% for frequency and 5% for voltage. This general electrical arrangement is shown in Figure 2.

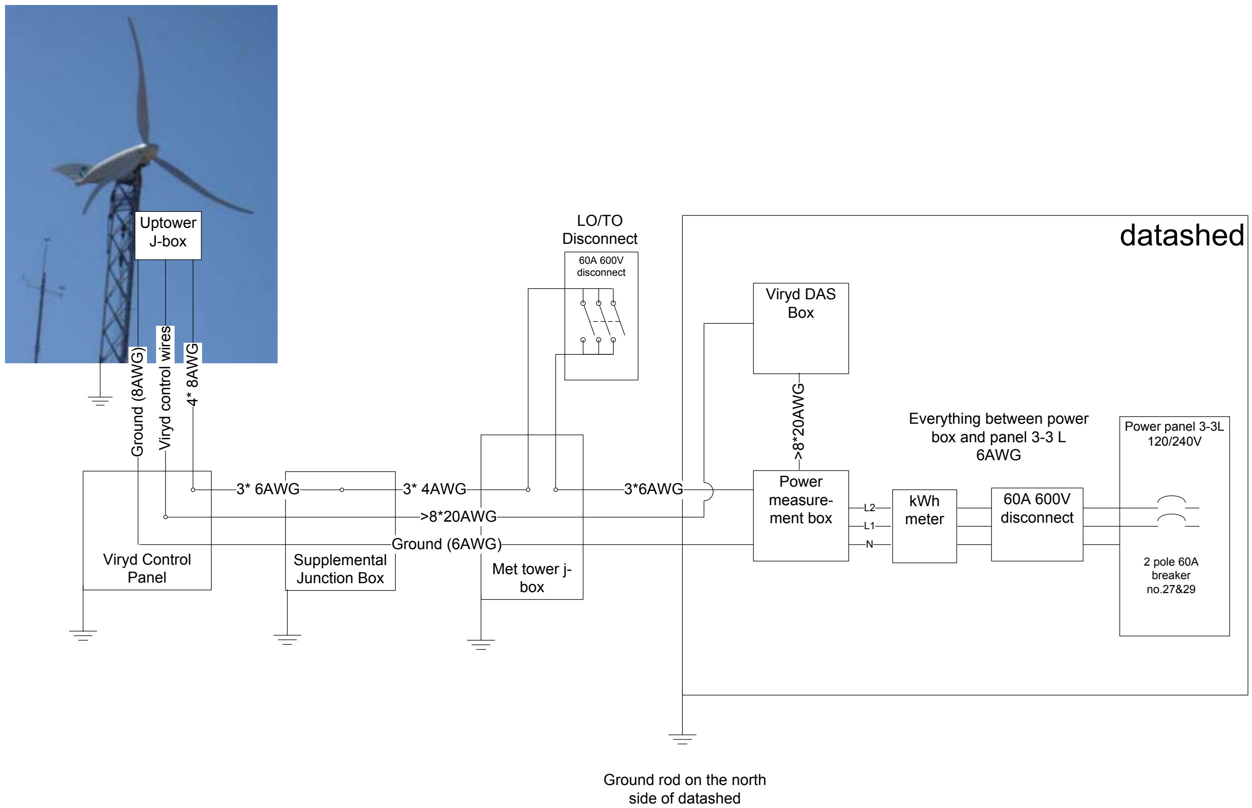

Figure 2. Electrical schematic of turbine installation
(Source: NREL 2012)

4 Test Site Description

The Viryd CS8 wind turbine was located at test site 3.3a of the NWTC, approximately 8 km south of Boulder, Colorado. The site consists of mostly flat terrain with short vegetation and prevailing winds bearing 292° relative to true north. Figure 3 and Figure 4 show the turbine and meteorological (met) tower locations, as well as nearby turbines. For measurements requiring accurate wind speed data, NREL personnel used data that was obtained when the wind direction was between 211° and 38° true. In this measurement sector, the influence of terrain and obstructions on the anemometer is small and meets the requirements in accordance with IEC 61400-12-1 without having to conduct a site calibration test.

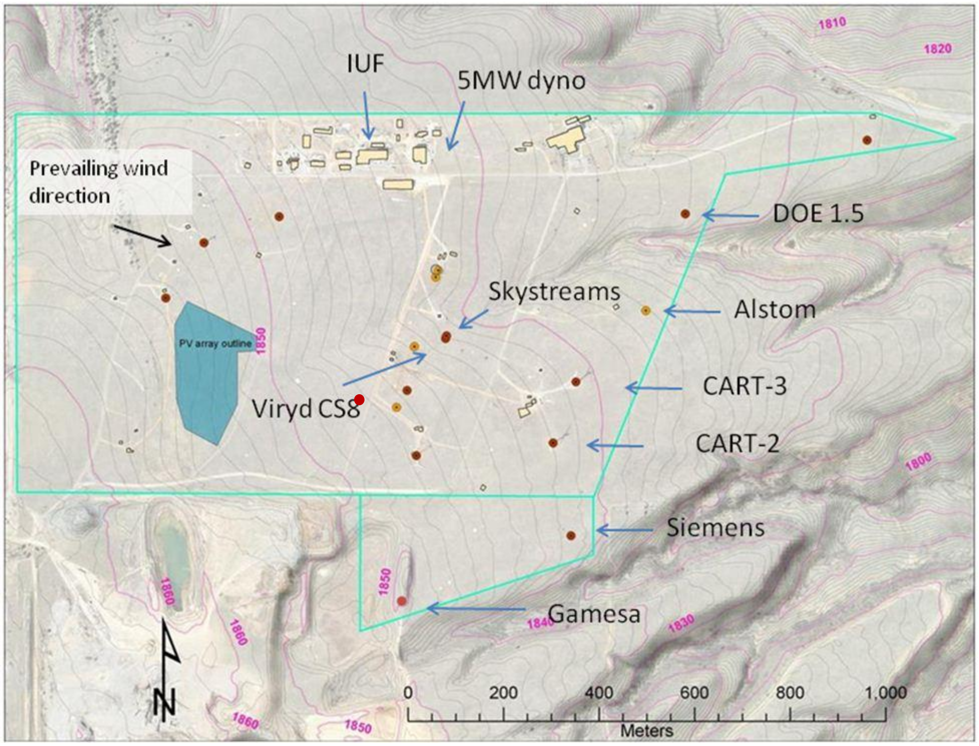

Figure 3. Map of the test site
(Source: NREL 2012)

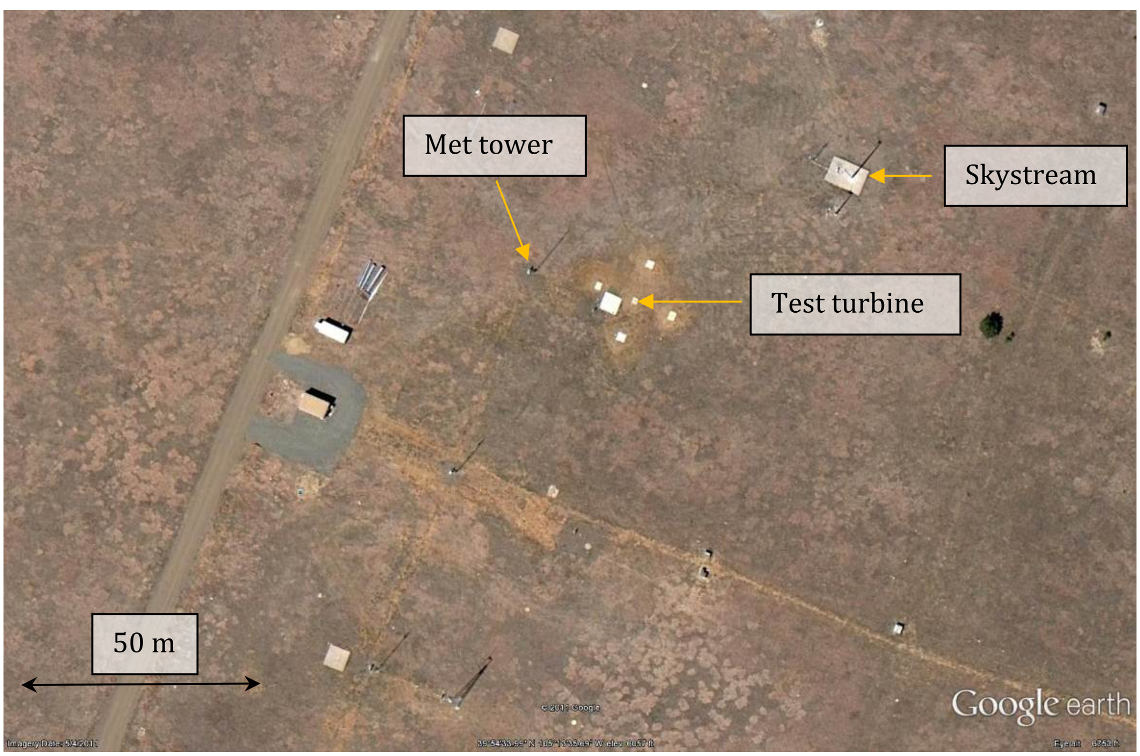

Figure 4. Close up of test site around the test turbine
(Source: Map data ©2012 Google earth)

5 Description of Instrumentation

In this test, the following parameters were measured: wind speed, electrical power, rotor speed, grid voltage, and turbine status. Additional parameters were logged for other tests.

For turbine status, NREL added voltage signals to monitor the status LEDs on the controller. The green LED indicates when the turbine is producing power; the blue LED indicates when the turbine is in standby, “waiting for wind” (solid), or experiencing a cut-out wind condition (blinking); and the red LED indicates when the turbine has faulted. This LED blinks various times at various duty cycles, based on whether the turbine is experiencing a recoverable fault, unrecoverable fault, or startup/shutdown sequences. However, Viryd informed NREL that the number of blinks alone was not sufficient to determine the cause of a fault. A computer running proprietary Viryd software was required to log into the controller and determine the exact cause; however, NREL personnel did not have the appropriate level of access to the turbine, therefore these diagnostics were beyond the scope of the test.

Rotor speed was measured by tapping into the Viryd CS8’s RPM signal being sent to the controller. NREL personnel used an optically isolated frequency to voltage converter for this purpose, which is detailed in Table 3.

Table 3. List of Channels and Measurement Instruments

Signal	Location	Sensor Make Model	Serial Number	Cal Due Date
Primary Wind Speed	24.9 m	Thies First Class	0707884 0609006	12 Sept. 2012 17 Sept. 2013
Reference Wind Speed	23 m	Met One, 010C	U2643	NA
Wind_Direction	23 m	Met One, 020	U1475 W5515	13 Sept. 2012 17 Sept. 2013
Air_Pressure	22.1 m	Vaisala, PTB101B	T0740016 C1040014	5 April 2012 13 Feb. 2013
Air_Temperature	22.4 m	Met One, T-200	0566229 0603-1	15 Sept. 2012 17 Sept. 2013
Precipitation	Data Shed	Campbell Scientific 237	NA	NA
Active_Power	Data Shed	Secondwind Phaser 5-4A20 with OSI pn. 12973 CT’s	01091 01091	15 Sept. 2012 15 Sept. 2013
Turbine Status	Turbine Controller	Turbine Controller Lights/ Brake Solenoid	NA	NA
Rotor Speed	Turbine Controller	Phoenix Contact MCR-f-UI-DC	67472901	3 Oct. 2012
Data Acquisition Modules	Data Shed	National Instruments NI 9229 National Instruments NI 9217 National Instruments NI 9205	13DEC38 12A2037 13FAE1C 12BFEE2 13E3D05 14DA726	24 June 2012 27 June 2013 24 June 2012 27 June 2013 24 June 2012 27 June 2013

Table 3 provides an equipment list that includes the specifications of the instruments used and Figure 5 provides the location of the met tower instruments. The first set of data acquisition modules were used beyond their calibration due date from 25 June 2012 through 26 July 2012. They were post-calibrated and found to be within tolerance. The pressure transducer was out of calibration from 6 Apr 2012 through 15 May 2012 and was post-calibrated. Residuals between the two calibrations were found to be at most 0.006 kPa, a negligible amount in the context of this test.

Calibration and post-calibration sheets are included in Appendix A.

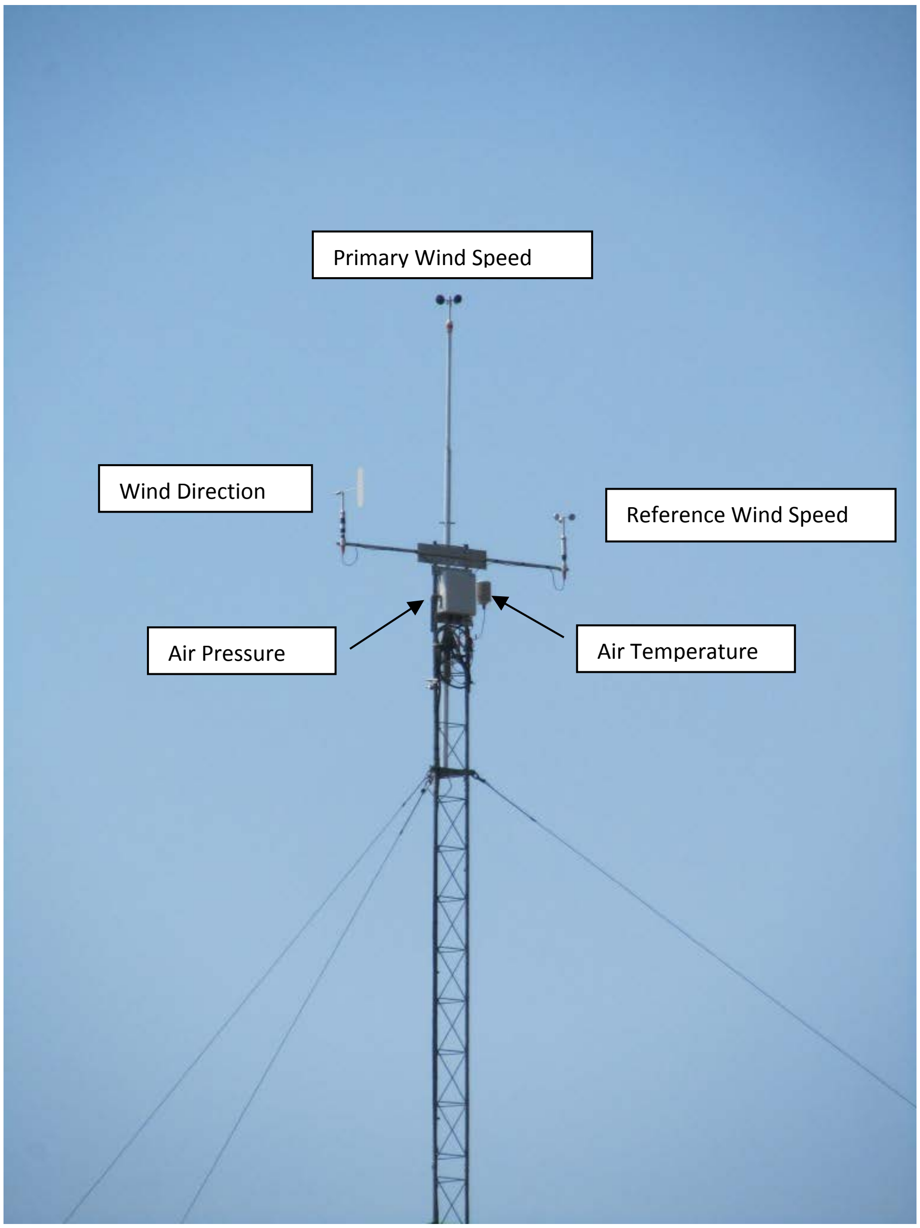

Figure 5. View of instruments on the met tower
(Source: NREL 2012)

6 Procedure

Safety and function testing can involve some risk to personnel and equipment. By incorporating appropriate controls into testing procedures, NREL staff worked to accomplish the tasks with minimal risk. This test report documents these controls in areas where they might have influenced the results. After installing the Viryd CS8 at NREL, Viryd's ability to directly support the turbine was significantly limited. As a result, not all of the required testing steps could be performed by NREL and are detailed throughout this report.

6.1 Control and Protection System Functions

Major turbine response categories for this type of testing include the following:

- Power control
- Rotor speed control
- Yaw orientation
- Startup, which was tested:
    - During normal operation (winds rising above cut-in)
    - After maintenance or fault clearance at the design wind speed or above
    - During maintenance of fault conditions at design wind speed or above
- Normal shutdown, which was tested:
    - During normal operation (wind speed decreasing to less than cut-in)
    - During normal operation (wind speed increasing to greater than cut-out)
- Emergency shutdown, which was tested during operation, and included:
    - Behavior upon excessive vibration[1]
    - Behavior upon loss of load
    - Turbine-specific checks[1]

NREL personnel observed the turbine response for each major response category: startup, normal shutdown, and emergency shutdown. In a normal test, faults or other actions that cause one of these major responses are simulated using the appropriate input and turbine response, and then verified by sensing the condition and indicating an appropriate response. For example, this procedure enables all of the emergency-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. However, because NREL personnel did not have sufficient access to the turbine to change any controller parameters or simulate these conditions, the results presented are limited to those observed over the course of normal turbine testing.

[1] NREL was unable to simulate some of these conditions.

6.2 Personnel Safety Provisions

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

- Safety instructions
- Climbing
- Standing place, platforms, and floors
- Electrical and grounding system
- Fire resistance and control
- Fire extinguisher
- Emergency stop buttons
- Lock-out/tag-out provisions
- Interlock on electrical cabinets
- Safety signs
- Unauthorized changing of control settings
- Lightning protection
- Presence and functioning of rotor and yaw lock.

6.3 Dynamic Behavior

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

7 Results

Test results reported here are based on tests conducted from 12 October 2011, when the turbine was commissioned, through 13 February 2013.

7.1 Control and Protection System Functions

The turbine controller appeared to operate as designed by Viryd. Cut-in appeared to miss some of the dynamic winds available on the NWTC's site. Viryd explained that the turbine controller utilizes a wind-speed-weighted algorithm to determine when to initiate a normal startup operation. Thus, a quick transition from low to strong winds will initiate a startup sooner than winds that are slowly increasing past cut-in. Cut-out appears to work well and as designed. Additionally, the turbine controller was able to sense downwind operation by monitoring wind speed measured by its tower-mounted anemometer and power.

Faults were observed throughout the test, but there was little to no indication of the causes of those faults. In all cases, the turbine shut down appropriately. Furthermore, NREL was limited in its ability to actively test single-fault failures and did not complete an exhaustive investigation or examine failures of "safe life" components. If a second fault were to occur during a critical event, severe results can be expected. NREL staff do 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.

NREL staff conducted the following tests and observations on the Viryd CS8.

Power Control

Figure 6 and Figure 7 show that the power output of the turbine system was limited. Power limiting was achieved through stall control. Furthermore, the turbine draws a large inrush current during the motoring portion of the startup sequence. However, the power transducer rails at -24 kW during these events, so NREL analysts cannot comment on the magnitude of the inrush current.

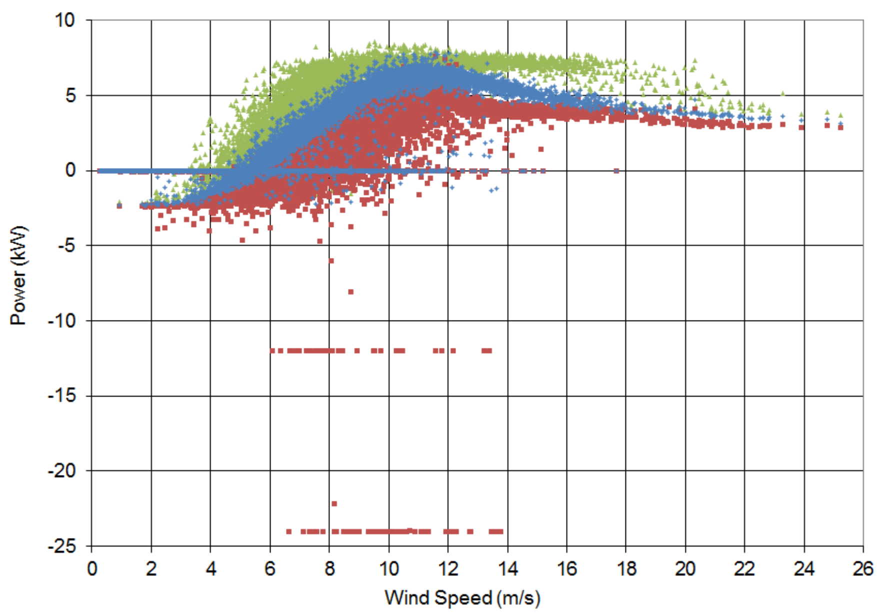

Figure 6. Power response to wind speed, 1-minute data[2]
(Green: maxima, Red: minima, Blue: average)

[2] The first power transducer installed during the test railed at -12 kW. Its range was adjusted, but the turbine railed it again at -24 kW. The power transducer was not adjusted further, as this would have represented an unacceptable loss of resolution. As such, no comment can be made about the magnitude of the minimum power during startup events.

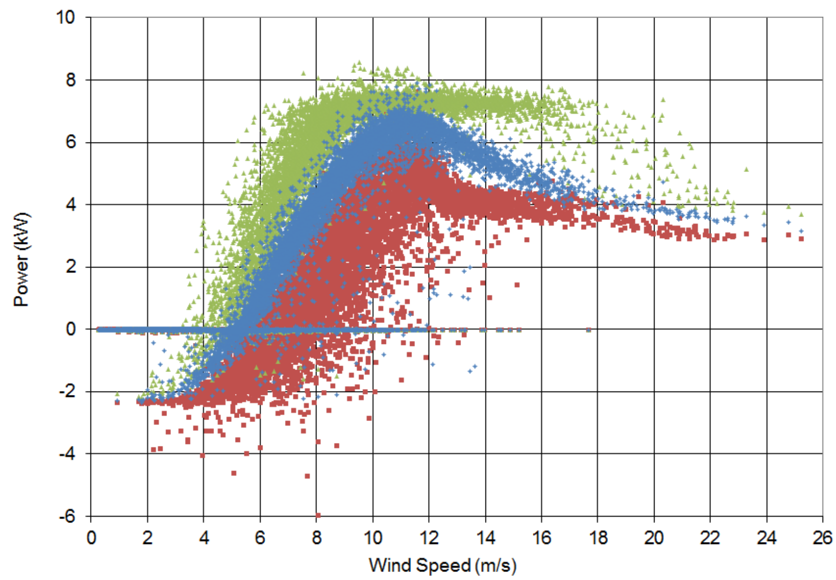

Figure 7. Power response to wind speed (close-up), 1-minute data[2]

Rotor Speed Control

During the test, the synchronous generator limited rotor RPM, as expected. Figure 8 shows both 1-minute average rotor speed data and maximum and minimum values in each 1-minute period, based on 40-Hz data. The increase of the RPM with wind speed was due to the generator slip.

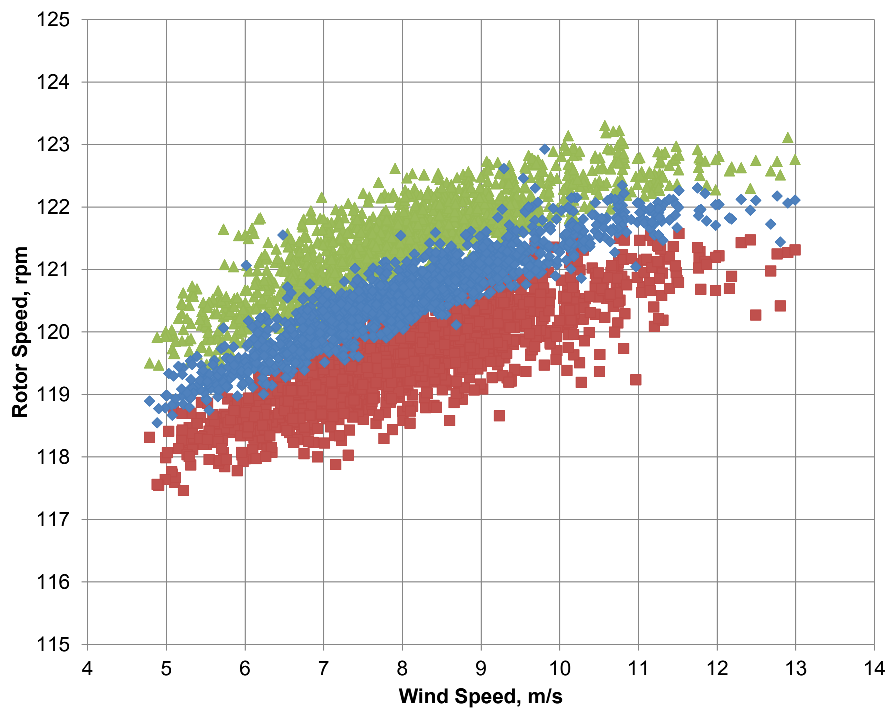

Figure 8. Rotor-speed response to wind speed, 1-minute data
(Red: maxima, Green: minima, Blue: average)

Yaw Orientation

NREL staff observed yaw behavior frequently during the test period and compared yaw position with the nearby wind-vane indication of wind direction. Normal behavior was observed under all wind conditions. At all wind speeds, the rotor operates roughly aligned with the prevailing wind direction. Any yaw error decreases as the wind speed increases.

Occasionally, the turbine was observed to run in a downwind condition. However, in all of these cases, the turbine controller sensed the condition, shut down the turbine, allowed the nacelle to passively yaw into the wind, and initiated a normal start procedure.

The Viryd turbine uses slip rings to transmit power to and from the nacelle to the tower cable. Therefore, droop cable over-twist is not an issue.

Startup

NREL staff observed large variations in the wind speed at which the turbine rotor initiates startup, ranging from 4 m/s to 8 m/s. As described above, Viryd's cut-in algorithm and the dynamic nature of the winds at the NWTC are thought to contribute to this variation. Once the winds are high enough for a long enough time period to satisfy the counter, the turbine controller responds by opening the brakes and motoring the turbine. Once wind speed and rotor speed are sufficiently high, the turbine begins to produce positive power. NREL staff observed the turbine starting up in a wide range of conditions, and did not notice any abnormal behavior during any of the startups. The staff also observed similar smooth cut-ins when the turbine was returned to service after a manual shutdown.

Normal Shutdown

The turbine manual identifies two types of shutdowns initiated by the controller: a normal, or controlled stop shutdown, and an emergency stop. When winds drop below cut-in, the rotor will motor for a period of time (again depending on the wind-speed-weighted counter). If winds remain low, the turbine will initiate a normal stop: engaging its brakes, disconnecting the generator, and bringing the rotor to a stop in approximately two rotations. Figure 9 shows a short time series of turbine operations including normal startup and shutdown. Figure 10 is a close-up of part of this time series and shows a normal shutdown initiated by the controller.

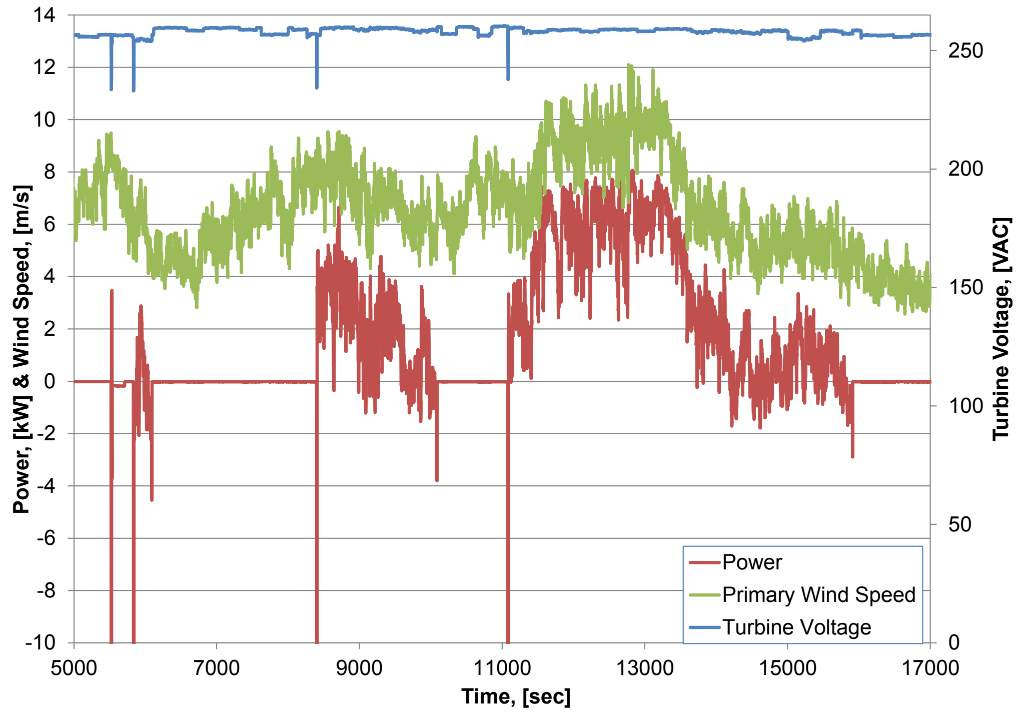

Figure 9. Normal operation including startup and shutdown, 1-Hz data

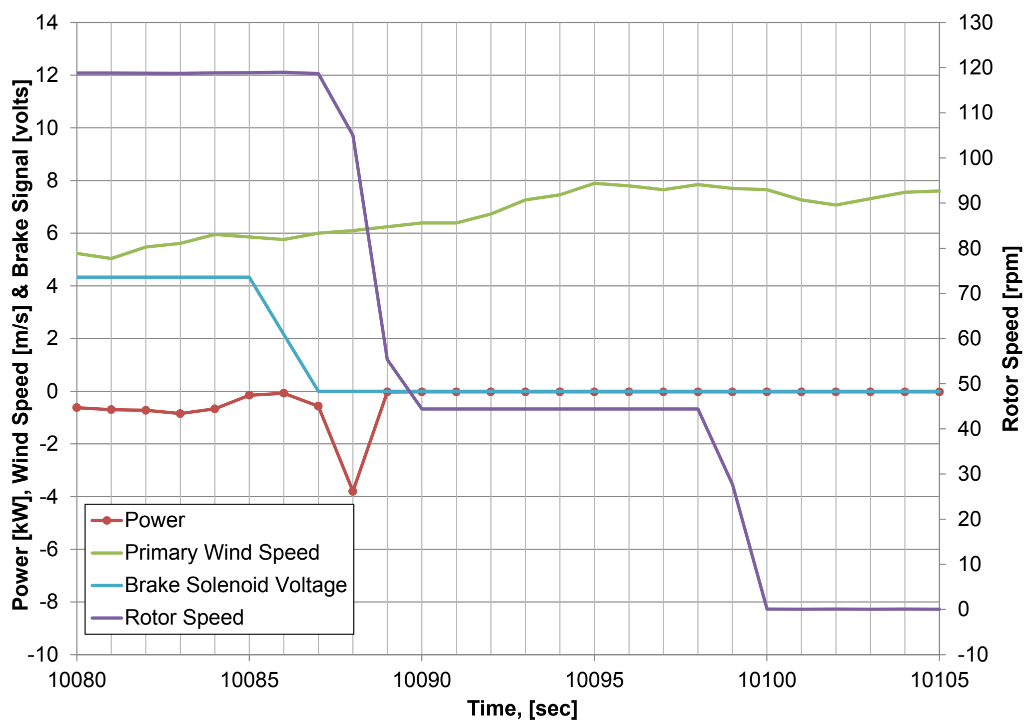

Figure 10. Normal shutdown (controller-initiated), 1-Hz data

If the turbine senses an instantaneous wind speed greater than 25 m/s, it engages the brake and stops the rotor. This will send the turbine into a recoverable fault state for 5 minutes. If, after this time period, the winds have dropped below 25 m/s, the turbine will motor and start up again. NREL personnel observed high-wind cut-out several times over the course of the test. An example is shown in Figure 11 and Figure 12.[3]

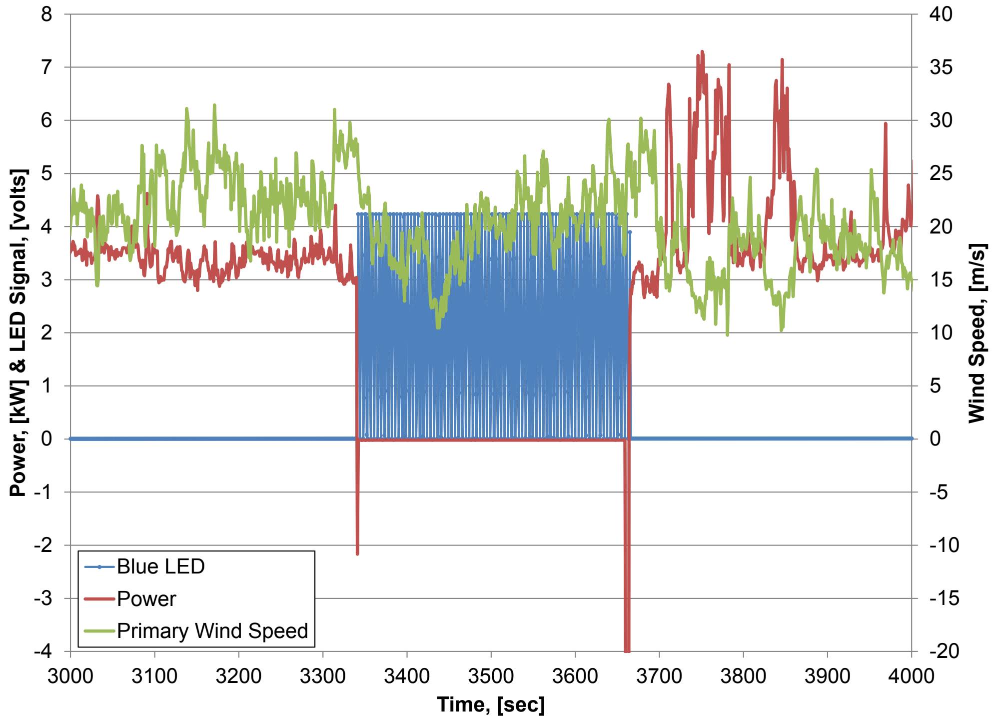

Figure 11. High wind shutdown and startup

[3] The turbine monitors wind speed with an anemometer mounted on the turbine tower below hub height. This signal was not recorded by NREL's data acquisition system. However, the primary wind speed signal is shown on the plot.

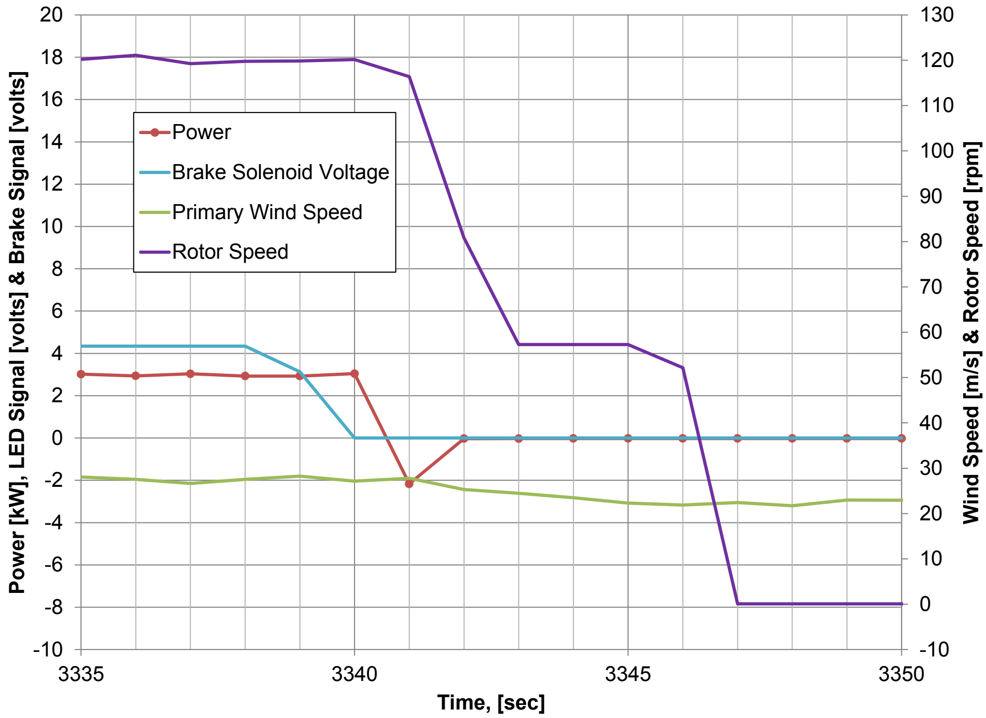

Figure 12. High wind shutdown (controller-initiated)

Emergency Shutdown during Operation from Any Operating Condition

As NREL staff did not have access to the controller software interface, the only means of stopping the turbine during the test was by using the grid disconnect (recommended by Viryd). As such, normal and emergency stops initiated by the end user were identical.

According to the manual, emergency stops will be initiated by the controller when the following conditions are sensed:

- A transmission speed ratio error[4]
- Rotor over-speed
- Delayed controlled shutdown
- Excessive start-up power draw.

To NREL's knowledge, the turbine never initiated an emergency stop for these conditions.

A user-initiated emergency stop is the same as a normal stop: disconnecting the grid. During the test, shutdown behavior was consistent with the manual: the turbine applied the brakes and

[4] The constant speed (CS) model is instrumented with a single RPM sensor on the low-speed shaft. Therefore , it cannot sense a transmission speed ratio error.

brought the rotor to a stop. NREL staff performed these types of shutdowns in addition to the automatic shutdowns observed. An example time series is shown in Figure 13 and Figure 14. The turbine safely brought the rotor to a stop any time this test was performed.

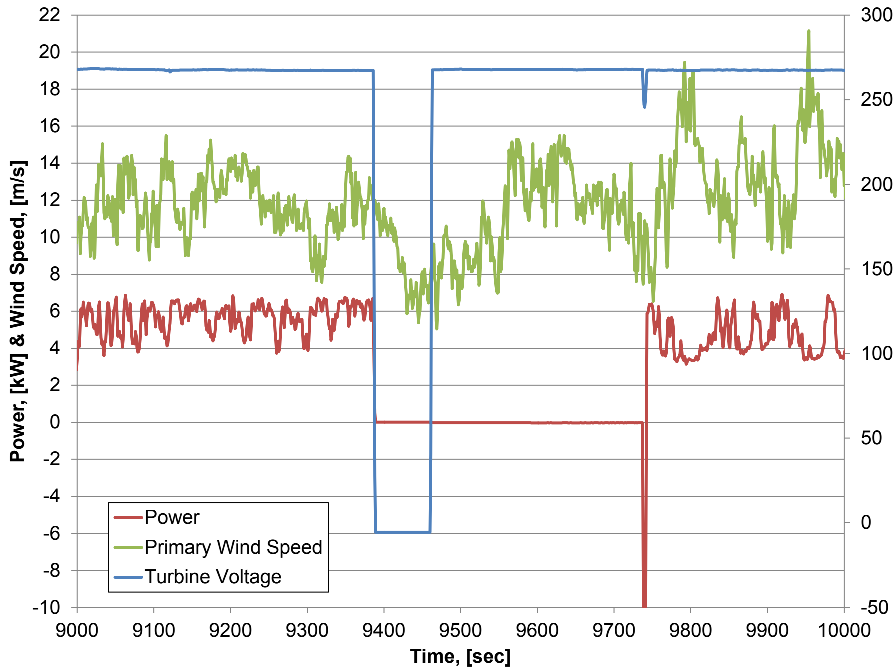

Figure 13. Manual stop (grid disconnect) and normal restart with winds between 10 and 15 m/s

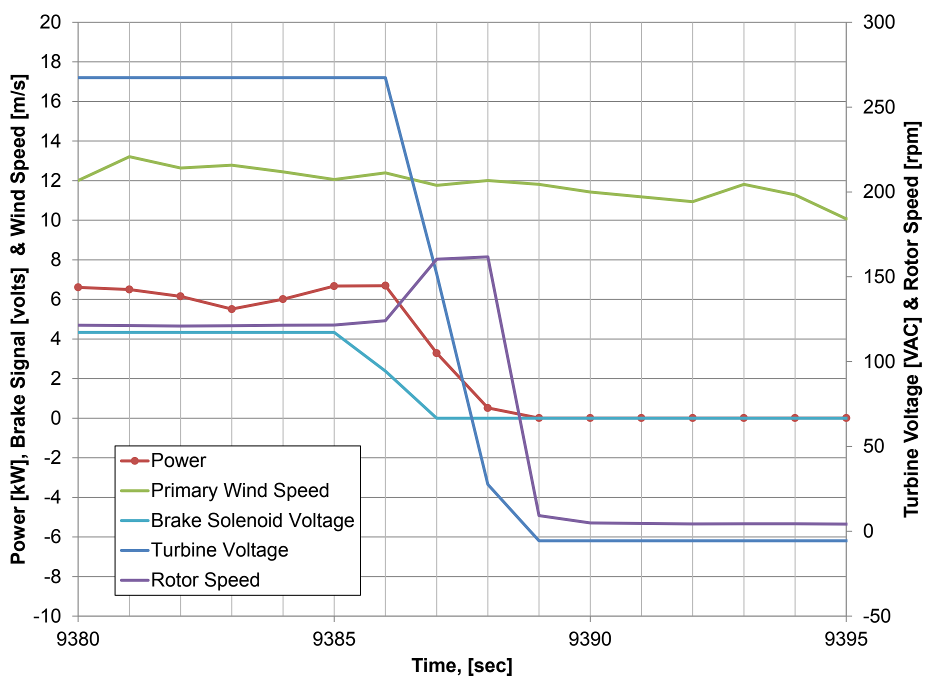

Figure 14. Manual stop (grid disconnect)

Behavior upon Excessive Vibration

To NREL's knowledge, the turbine has no means of sensing excessive vibration. The IEC turbine design standards require such sensors on large turbines, but not on turbines smaller than 200 m^2.

Behavior upon Loss of Load

For the Viryd CS8 turbine, loss of load is identical to a normal shutdown. The brakes are applied and the rotor is brought to a stop. To assess this capability, NREL personnel conducted manual grid outages several times during the test. Additionally, the turbine experienced several grid outages when NREL lost power over the course of the test. In all cases, the rotor was brought to a stop and the turbine returned to normal operation after power was restored. In one case, the turbine entered a faulted state after power was restored, but the exact cause could not be determined because the controller does not convey the nature of certain types of faults to the end user. However, a manual fault reset performed by NREL at Viryd's request brought the turbine back to normal operation. Figure 13 and Figure 14 show plots of the rotor coming to a stop during a manual stop (disconnecting grid power) and restarting after grid power is restored and the wind speed counter is satisfied.

Turbine-Specific Checks

There were several tests that did not occur during the testing campaign, as they would have required a temporary change of controller setpoints, and Viryd was unable to support this level of testing. These turbine-specific checks include:

- Grid under- and over-frequency
- Grid under- and over-voltage
- Over-speed condition
- Temperature fault
- Pressure fault
- Generator over power
- Transmission ratio error (may not apply to the constant speed (CS) model).

There may be more cases that the controller is designed to sense and act upon but Viryd was not available to help perform a complete inventory of those cases.

7.2 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, but does not list this requirement on the manual's cover, as required by the IEC standard. Use of a forklift or telehandler is required to attach the nacelle to the tower. The maintenance is split into maintenance that must be done by the owner and maintenance that must be performed by the installer. The owner-completed maintenance includes only simple tasks with minimal safety implications. The annual maintenance must be conducted by an installer or trained service technician only. NREL personnel checked the manual to determine if the safety instructions addressed requirements in the IEC small turbine design standard and found one additional issue: the turbine has no provisions for securing the yaw mechanism.

Climbing

Although the tower is a lattice-type that can be climbed, opening the nacelle covers could present a potentially dangerous situation while climbing. The manual recommends tilting the tower down whenever work must be performed on the turbine or using a man-lift to access the turbine without tilting the tower down. During the test, NREL staff used man-lifts to access the turbine.

Standing Places, Platforms, and Floors

There are no standing places, platforms, or floors on the turbine.

Electrical Grounding System

The owner's manual shows a schematic of the electrical system and provides information on how to size, wire, and properly ground the electrical system. The manual recommends that a licensed electrician be part of the installation crew.

Fire Resistance and Control/Fire Extinguisher

The turbine generator has a cooling fan and is rated for normal operating temperatures of up to 40˚C. NREL provided a fire extinguisher in the test shed near the turbine. The manufacturer does not provide fire extinguishers or recommend that they be installed. However, for a turbine of this size, this is what can be reasonably expected.

Lock-Out/Tag-Out Provisions

Viryd provided a lockable disconnect switch between the grid and the turbine (shown in Figure 15).

Figure 15. Viryd CS8 lockable disconnect switch and power meter
(*Photo by Mark Murphy, NREL*)

Emergency Stop Button

The turbine does not have an emergency stop button, only a disconnect switch. The turbine manual recommends only engaging the disconnect switch in dangerous situations. However, during installation, Viryd personnel instructed NREL staff to use the disconnect switch for stopping the turbine. The disconnect switch was the only provided means of stopping the turbine.

Interlock on Electrical Cabinets

There is no interlock on the controller enclosure.

Safety Signs

There is one safety sign on the turbine that states: "Hazardous voltages, disconnect power before opening. Contact causes severe electrical shock." See Figure 16.

NREL staff added labels indicating the voltage levels on all enclosures, electrical panels, and disconnect switches (see Figure 15 and Figure 16).

Figure 16. Viryd CS8 controller enclosure, showing a voltage warning and additional voltage labeling added by NREL
(*Photo by Jason Roadman, NREL*)

Unauthorized Changing of Control Settings

There is no easy way for an unauthorized user to change any of the control settings, as this would require intimate knowledge of the controller communication protocol.

Lightning Protection

The turbine does not have a dedicated lightning protection system, but the tower was grounded (as indicated by the owner's manual).

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

Presence of Rotor and Yaw Lock

The brake system serves as the rotor lock on this turbine. The brake calipers are pneumatically actuated against an internal mechanical spring and are of the fail-closed type. The brake will prevent the rotor from spinning in windy conditions, and was found to lock the rotor so it was completely stationary for any maintenance performed over the course of the test.

There is no yaw lock present on this turbine, nor is disabling the yaw motion described as part of the maintenance procedures. During the course of the test, NREL staff would approach the turbine in the man-lift, grab the tail, and position the man-lift basket to limit the yaw motion.

Documentation

NREL personnel 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 cover does not display the statement : "Maintenance and repairs to be performed by trained personnel only"
- The manual was not updated from the continuously variable transmission to the constant speed model installed
- The manual is of a generic type and does not provide specific serial numbers of major components for the turbine installation
- There is no turbine nameplate, as referred to in the standards. Individual components such as the generator, gearbox, and blades have individual nameplates, but they did not cover the range of information required by the standard for the turbine nameplate.

7.3 Dynamic Behavior

Turbine operation was observed by NWTC personnel for several minutes on a weekly basis over the course of the test. Observed wind speeds ranged from less than 5 m/s (below cut-in) to more than 26 m/s. Total observation time was well in excess of 1 hour. The turbine was observed to cut-in between 4 and 8 m/s, smoothly motoring up and switching to producing power. The exact wind speed for cut-in varied based on the wind-speed-weighted counter mentioned earlier. The turbine was observed to passively track the wind well, both when running and parked with only minor vibration of the tail. Occasionally, the turbine was observed to run downwind (detailed above). Running downwind was always detected by the controller and initiated a shutdown algorithm, followed by the tail passively turning the turbine back into the wind, thereby allowing the turbine to start back up. No excessive vibration of any components was observed throughout the test.

8 Deviations and Exceptions

8.1 Deviations from the Standard

The initial power transducer used during the test railed at -12 kW and was re-configured and re-calibrated, but railed at -24 kW when the turbine motored the rotor upon start up. High-speed data showed no significant impact on the 1-minute averages, but no statement can be made about the absolute magnitude of the inrush current during turbine startup.

Not all tests could be performed because of the lack of support from the manufacturer.

8.2 Deviations from Quality Assurance

The first set of data acquisition modules were used beyond their calibration due date; they were post-calibrated and found to be within tolerance. Appendix A includes post-calibration sheets.

The pressure transducer was out of calibration from 6 Apr 2012 through 15 May 2012. Residuals between the calibration and post-test calibration were found to be 0.006 kPa at most, a negligible amount in the context of this test.

Appendix A. Instrument Calibration Certificates

Figures A1 through A21 show the calibration sheets for the instruments used during the Viryd CS8 safety and function tests.

Svend Ole Hansen ApS

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WIND ENGINEERING FLUID DYNAMICS

CERTIFICATE FOR CALIBRATION OF CUP ANEMOMETER

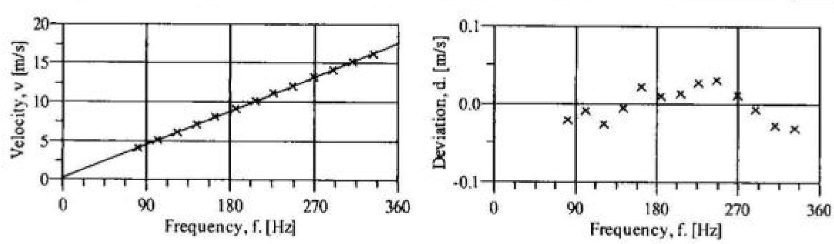
Certificate number: 10.02.6374 **Date of issue:** October 25, 2010
Type: Thies 4.3350.00.000 **Serial number:** 0707884
Manufacturer: ADOLF THIES GmbH & Co.KG, Hauptstrasse 76, 37083 Göttingen, Germany
Client: NREL Meterology and Calibration Laboratory, 1617 Cole Blvd, Golden, CO 80401 USA

Anemometer received: October 21, 2010 **Anemometer calibrated:** October 24, 2010
Calibrated by: as **Calibration procedure:** IEC 61400-12-1, MEASNET
Certificate prepared by: jsa **Approved by:** Calibration engineer, soh

Calibration equation obtained: v [m/s] = 0.04839 · f [Hz] + 0.24584
Standard uncertainty, slope: 0.00164 **Standard uncertainty, offset:** 0.07126
Covariance: -0.0000013 (m/s)²/Hz **Coefficient of correlation:** ρ = 0.999985
Absolute maximum deviation: 0.032 m/s at 12.219 m/s

Barometric pressure: 993.9 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	9.70	31.2	22.8	4.137	80.8256	-0.020	0.028
4	14.88	31.0	22.8	5.123	100.9651	-0.008	0.032
6	21.30	30.9	22.8	6.129	122.0926	-0.025	0.037
8	29.13	30.8	22.7	7.166	143.0869	-0.004	0.043
10	37.89	30.7	22.7	8.172	163.3293	0.022	0.048
12	47.90	30.7	22.7	9.188	184.5738	0.010	0.054
13-last	59.22	30.6	22.7	10.215	205.7189	0.014	0.060
11	71.27	30.7	22.7	11.207	225.9264	0.029	0.066
9	84.70	30.8	22.7	12.219	246.7675	0.032	0.072
7	99.66	30.9	22.8	13.256	268.6190	0.012	0.078
5	115.27	31.0	22.8	14.259	289.7302	-0.006	0.084
3	132.29	31.1	22.8	15.278	311.2080	-0.027	0.090
1-first	150.67	31.3	22.9	16.311	332.6236	-0.030	0.096



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Page 1 of 2

Figure A1. Calibration sheet for the primary anemometer used through 12 September 2012

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WIND ENGINEERING FLUID DYNAMICS

CERTIFICATE FOR CALIBRATION OF CUP ANEMOMETER

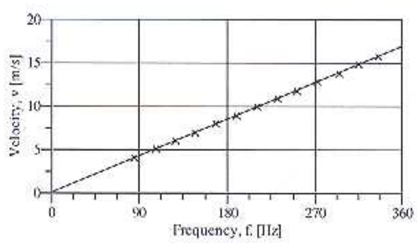
Certificate number: 12.02.6727 **Date of issue:** August 24, 2012
Type: Thies 4.3351.10.000 **Serial number:** 0609006
Manufacturer: ADOLF THIES GmbH & Co.KG, Hauptstrasse 76, 37083 Göttingen, Germany
Client: National Renewable Energy Lab, 1617 Cole Boulevard, Golden, Colorado 80401-3393, USA

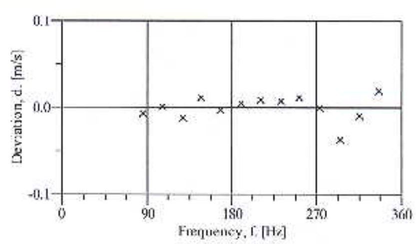
Anemometer received: August 13, 2012 **Anemometer calibrated:** August 23, 2012
Calibrated by: asj **Calibration procedure:** IEC 61400-12-1, MEASNET
Certificate prepared by: ca **Approved by:** Calibration engineer, ml

Calibration equation obtained: v [m/s] = 0.04654 · f [Hz] + 0.15404
Standard uncertainty, slope: 0.00114 **Standard uncertainty, offset:** 0.07713
Covariance: -0.0000006 (m/s)²/Hz **Coefficient of correlation:** ρ = 0.999993
Absolute maximum deviation: -0.036 m/s at 13.844 m/s

Barometric pressure: 1009.3 hPa **Relative humidity:** 27.6%

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	9.65	33.4	25.5	4.112	85.1908	-0.007	0.021
4	14.95	33.3	25.5	5.119	106.6331	0.002	0.025
6	21.07	33.1	25.4	6.075	127.4800	-0.012	0.029
8	28.26	33.1	25.4	7.035	147.5747	0.012	0.033
10	36.34	33.0	25.4	7.977	168.1495	-0.003	0.037
12	45.88	33.0	25.4	8.962	189.1365	0.005	0.042
13-last	56.70	32.9	25.4	9.963	210.5526	0.009	0.046
11	68.46	33.0	25.4	10.948	231.7626	0.007	0.051
9	80.56	33.1	25.4	11.878	251.6408	0.012	0.055
7	94.56	33.1	25.4	12.870	273.2038	0.000	0.059
5	109.38	33.2	25.4	13.844	294.9135	-0.036	0.064
3	125.53	33.4	25.5	14.833	315.5930	-0.009	0.068
1-first	141.94	33.6	25.5	15.780	335.3141	0.020	0.073





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CAL Reg.nr. 452
Accreditation to ISO 17025

Figure A2. Calibration sheet for the primary anemometer used from 17 September 2012 onward

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
Cert Lab

Calibration Date: **13-Sep-11**

Report Number: U1475-110913

Page: 1 of 1

Procedure:
NWTC-CT: C104 Calibrate Wind Vane_091209.docx

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	020C
Serial Number	U1475
Vane Material	Aluminum
Condition	Refurbished

Deviations from procedure:
Output of Wind vane was set for 5 Volts.Inclinometer out of calibration by 11 days.Inclinometer was sent out for a post cal.

Results:

Slope:	**72.32**	**deg/V**
Offset to boom:	**86.71**	**deg**
Max error:	1.23	deg

Estimated Uncertainty:

Inclinometer Uncertainty (deg)	Total Uncertainty (deg)
0.10	0.82

Traceability:

	Mfg & Model	Serial Number	Cal Date
Inclinometer:	Spi-Tronic	31-038-3	2-Sep-10
Voltmeter:	Fluke 289	97380111	6-Jan-11

Calibration by: Mark Murphy

13-Sep-11
Date

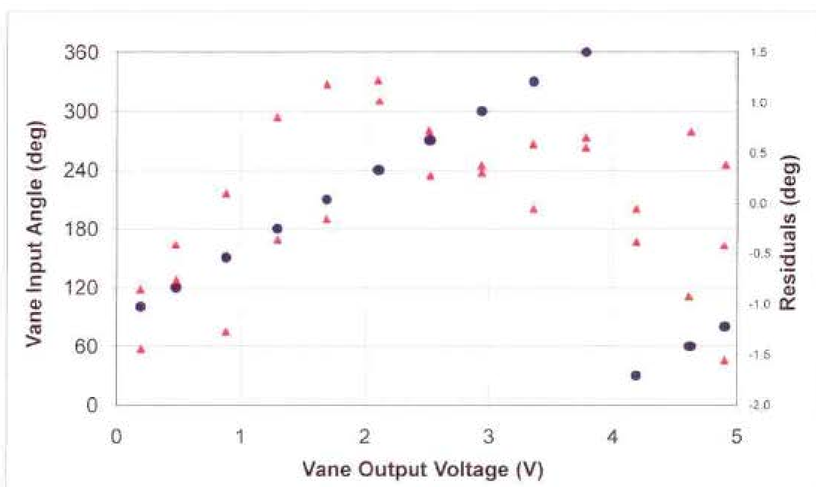

Figure A3. Calibration sheet for the wind vane used through 12 September 2012

Wind Vane Calibration Report

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

Calibration Location:
National Wind Technology Center
Cert Lab

Calibration Date: **13-Sep-12**

Report Number: W5515-120913

Page: 1 of 1

Procedure:
NWTC-CT: C104 Calibrate Wind Vane_091209.docx

Deviations from procedure:
Output of Wind vane was set for 5 Volts.

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	020C
Serial Number	**W5515**
Vane Material	Aluminum
Condition	Refurbished

Results:

Slope:	**71.63**	**deg/V**
Offset to boom:	**97.81**	**deg**
Max error:	1.70	deg

Estimated Uncertainty:

Inclinometer Uncertainty (deg)	Total Uncertainty (deg)
0.10	1.22

Traceability:

	Mfg & Model	Serial Number	Cal Date
Inclinometer:	Spi-Tronic	31-038-3	5-Oct-11
Voltmeter:	HP 3458A	2823A05145	15-Sep-11

Calibration by: Mark Murphy — 13-Sep-12 (Date)

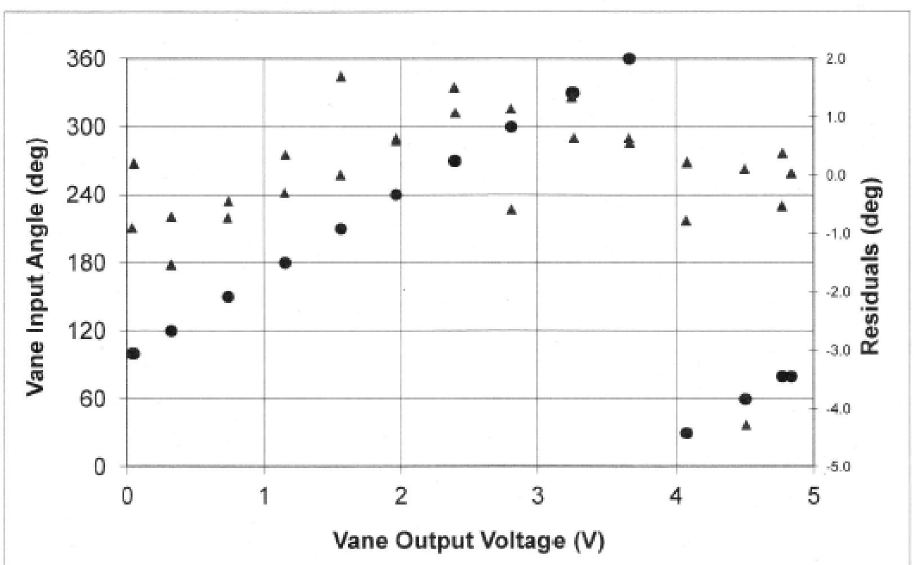

Figure A4. Calibration sheet for the wind vane used from 17 September 2012 onward

Branch #: 5000

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Phaser Power Transducer & 2-CTs

DOE #: 04195C

Model # : Phaser

S/N : 01091

Calibration Date: 09/15/2011

Due Date: 09/15/2013

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, i.e. actual power = the listed input power in the table times two.
A.3. Analog Output-1 is measured across precision resistor = 250 Ω.
A.4. Phaser Full Scale setting = -12 KW to 12 KW.

Input Current (AAC)	Input Power (KW)	Analog Output-1 (VDC)
50	12	4.999
25	6	3.999
0	0	2.999
-25	-6	2.003
-50	-12	1.005

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)
6	1.0	4.998
"	0.8	4.155
"	0.6	3.342
"	0.4	2.534
"	0.2	1.731
"	0	1.068

Page 1 of 2

Figure A5. Page 1 of the power transducer calibration sheet used through 12 September 2012

C. Set-Up for Current THD-A Calibration:
C.1. Current is applied to Line A Current Transformer.
C.2. Analog Output-3 is set for THD, and is measured across precision resistors = 250 Ω.

Current (AAC)	THD (%)	Analog Output-4 (VDC)
50	0	1.005
"	H1 = 5	1.199
"	H1 = 10	1.396
"	H2 = 15	1.594
"	H2 = 20	1.787
"	H2 = 25	1.974
"	H2 = 30	2.153

D. Set-Up for Line A-B Voltage Calibration:
D.1. Voltage is applied between Line A & B.
D.2. Analog Output-4 is set to measure from 0 VAC to 259.8 VAC, and is measured across precision resistor = 250 Ω.

	Input Voltage (V)	Analog Output-3 (VDC)
	240	4.220
	160	3.459
	80	2.229
	0	0.998

D. Set-Up for Total Harmonic Distortion (THD/F) Calibration:
D.1. Voltage is applied between Lines A&B.
D.2. Analog Output-4 is set for THD, and is measured across precision resistors = 250 Ω.

Notes:
- Calibration was performed using instruments that are traceable to NIST, DOE# 126410 and 01889C.
- Calibration was performed at temperature = 23°C, ± 1 °C, and relative humidity = 39%, ± 10%.
- Uncertainty of nominal values is ± 0.15% of reading.
- H1&H2 are the first and second harmonics. When a harmonic amplitude is set to a value>0, all other harmonics are set to zero.

Calibrated By: Reda

Date : 09/15/2011

Q.A By : Bev

Date : 09/15/2011

Page 2 of 2

Figure A6. Page 2 of the power transducer calibration sheet used through 12 September 2012

Branch #: 5000 Page 1 of 4

NREL METROLOGY LABORATORY

TEST REPORT

Test Instrument:	Phaser Power Transducer	DOE #:	04195C
Model #:	Phaser-5-485-4A20	S/N:	01091
Calibration Date:	9/13/2012	Date Due:	9/13/2014

Test No.	Function Tested	Nominal Input	Measured Output at 250 Ohm (DCV)		( ) Mfr Specs (X)Data Only
			As Found	As Left	
1.	Analog Output 1: Power in Watt applied to Phase A&B with 120V @ 60 Hz				
		-24000	1.008		
		-12000	2.004		
		0	2.999		
		12000	3.996		
		24000	4.993		
2.	Analog Output 2: Power Factor at 1200 W @ A&B with 120V @ 60 Hz				
		1	5.000		
		0.8	4.155		
		0.6	3.342		
		0.4	2.534		
		0.2	1.731		
		0	1.068		
3.	Analog Output 3: THD for current in % at 100A @ A&B with 120V @ 60 Hz				
		0	1.004		
		5	1.198		
		10	1.397		
		15	1.595		
		20	1.786		
		25	1.975		
		30	2.152		
4.	Analog Output 4: Voltage in volts between A&B @ 60 Hz				
		0	2.998		
		80	3.613		
		160	4.229		
		240	4.607		

Notes:

Figure A7. Page 1 of the power transducer calibration sheet used from 17 September 2012 onward

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Pressure Transmitter DOE #: 02844C

Model # : PTB101B S/N : T0740016

Calibration Date: 04/05/2011 Due Date: 04/05/2012

No	Function Tested	Nominal Value (kPa)	Measured Output Voltage (VDC)		( )Mfr. Specs. OR (X)Data only (mb)
			As Found	As Left	
*	Absolute Pressure				
		65	0.273		
		70	0.545		
		75	0.817		
		80	1.088		
		85	1.360		
		90	1.631		
		95	1.903		
		100	2.175		

Notes:
1. Expanded Uncertainty of the nominal value is ± 0.2 kPa, with k = 2.
2. Calibration was performed at 23°C and 37% RH.
3. Calibration was performed using standards that are traceable to NIST. DOE #'s 128120, 02301C.

Calibrated By: P. Morse
Date: 04/05/2011

Approved By: Reda
Date: 04/05/2011

Figure A8. Calibration sheet for the pressure transducer used 15 May 2012

NREL METROLOGY LABORATORY

TEST REPORT

Test Instrument: Pressure Transmitter — DOE #: 02844C

Model #: PTB101B — S/N: T0740016

Calibration Date: 5/23/2012 — Date Due: 5/23/2013

Test No.	Function Tested	Nominal Input (kPa)	Measured Output (DCV)		( ) Mfr Specs (X)Data Only
			As Found	As Left	
1.	Absolute Pressure				
		65	0.2755		
		70	0.5474		
		75	0.8191		
		80	1.0906		
		85	1.3622		
		90	1.6337		
		95	1.9055		
		100	2.1777		

Notes:

- Calibration was performed using instruments that are traceable to NIST: DOE# 128120 and 02301C
- Calibration was performed at a temperature of 22°C and Relative Humidity of 41%
- Expanded uncertainity of the nominal value is ± 0.2 kPa, with k=2

Calibrated By: P. Morse
Date: 5/23/2012

Approved By: Reda
Date: 5/23/2012

Figure A9. Post-calibration sheet for the pressure transducer used through 15 May 2012

Branch #: 5000 | Sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Pressure Transmitter | DOE #: 03510C

Model # : PTB101B | S/N : C1040014

Calibration Date: 02/13/2012 | Due Date: 02/13/2013

No	Function Tested	Nominal Value (kPa)	Measured Output Voltage (VDC)		( )Mfr. Specs. OR (X)Data only (mb)
			As Found	As Left	
*	Absolute Pressure				
		65	0.2704	Same	
		70	0.5427	"	
		75	0.8146	"	
		80	1.0862	"	
		85	1.3577	"	
		90	1.6291	"	
		95	1.9005	"	
		100	2.1722	"	

Notes:
1. Expanded Uncertainty of the nominal value is ± 0.2 kPa, with k = 2.
2. Calibration was performed at 24°C and 43% RH.
3. Calibration was performed using standards that are traceable to NIST. DOE Numbers: 128120 and 02301C.

Calibrated By: P. Morse
Date: 02/13/2012

Approved By: Reda
Date: 02/13/2012

Figure A10. Calibration sheet for the pressure transducer used 16 May 2012 onward

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: RTD-Probe DOE #: 02952C

Model #: 8N01N S/N : 0566229

Calibration Date: 09/15/2011 Due Date: 09/15/2012

No	Function Tested	Nominal Value (°C)	Measured Values (Ω)		( )Mfr. Specs. OR (X)Data only
			AS Found	AS Left	
*	Temperature:	-15	94.130	Same	
		0	99.994	"	
		15	105.832	"	
		30	111.643	"	
	Notes: - Calibration was performed using instruments that are traceable to NIST. DOE#s 124272, 108603, and 108604. - Calibration was performed at temperature = 23 °C and relative humidity = 40%. - Uncertainty of Nominal Values = ± 0.03 °C, k = 2.				

Calibrated By: P. Morse
Date: 09/15/2011

Approved By: Reda
Date: 09/15/2011

Figure A11. Calibration sheet for the temperature sensor used through 12 September 2012

Branch #: 5000 Page 1 of 1

NREL METROLOGY LABORATORY

TEST REPORT

Test Instrument: RTD DOE #: 03465C

Model #: T200A S/N: 0603-1

Calibration Date: 7/20/2012 Date Due: 7/20/2013

Test No.	Function Tested	Applied Value (°C)	Measured Values (Ω)		( ) Mfr Specs (X)Data Only
			As Found	As Left	
1.					
	Temperature	-15	94.126		
		0	100.025		
		15	105.892		
		30	111.724		

Notes:

- Calibration was performed using instruments that are traceable to NIST. DOE# 124272, 108603, 108604.
- Calibration was performed at a temperature of 23°C and Relative Humidity of 41%
- Uncertainty of Nominal Values = ± 0.02°C, k = 2.

Calibrated By: Reda
Date: 7/20/2012

Approved By: Preston
Date: 7/20/2012

Figure A12. Calibration sheet for the temperature sensor used 17 September 2012 onward

Tektronix
Service Solutions

ACLASS ACCREDITED CALIBRATION

Certificate of Calibration

5258254

Certificate Page 1 of 1

Instrument Identification

Company ID: 120205
NATIONAL RENEWABLE ENERGY LAB
BEV KAY/SRRL
16253 DENVER WEST PARKWAY
GOLDEN, CO 80401

PO Number: CC-BEVERLY KAY

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 INSTRUMENTS CAL EXECUTIVE 3.4.1

Technician: COREY CLAXTON
Cal Date 24Jun2011
Cal Due Date: 24Jun2012
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 39.0 %

Remarks: *CALIBRATED WITH DATA, REFER TO ATTACHED DATA FOR BEFORE AND AFTER READINGS.*

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.

Tektronix Service Solutions is registered to ISO 9001:2008. Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994 (R2002), ISO 10012:2003, 10CFR50 AppB, and 10CFR21.

ISO/IEC 17025-2005 accredited calibrations are per ACLASS certificate # AC-1187 within the scope for which the lab is accredited.
When uncertainty measurement calculations have been calculated per customer request, reported condition statements do not take into account uncertainty of measurement.
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: COREY CLAXTON
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Manufacturer	Model	Cal Date	Date Due
5112717	15-0048	MULTIFUNCTION CALIBRATOR	FLUKE	5700A	05May2011	03Aug2011

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

Figure A13. Calibration sheet for the signal conditioning module 13DEC38 used through 26 July 2012

Dynamic Technology, Inc.

A Trescal Company

17025 Accredited Certificate of Calibration

Certificate #: 2281380003 F

ilac-MRA ACCREDITED
Calibration Laboratory
Certificate #: 2516.01

Acct #:	101320
Customer:	National Renewable Energy Laboratory
Shipper #:	1904141
Address:	16253 Denver West Parkway Golden, CO, 80401
Contact:	NI RMA
PO #:	

Manufacturer:	National Instruments
Model:	9229
Description:	4 Channel Analog Input Module
Serial Number:	13DEC38
Asset Number:	13DEC38
Barcode:	

As Received		**As Returned**		**Action Taken**	
In Tolerance	X	In Tolerance	X	Full Calibration	X
Out of Tolerance		Out of Tolerance		Special Calibration	
Malfunctioning		Malfunctioning		Oper. Verification	
Operational		Operational		Adjusted	
Damaged		N/A		Repaired	
N/A				Charted	
				Returned A-6	

Cal Date:	09/12/2012
Due Date:	09/12/2013
Temperature:	73.40 deg. F
Humidity:	41.00 %
Baro. Press.:	
Procedure:	DCN 09375
Reference:	manufacturer's manual

Incoming Remarks:

n/a

Domestic Accredited Calibration w/ end bags

Technical Remarks:

Calibration Standards Utilized

Cert. #	Manufacturer	Model #	Description	Cal Date	Due Date
2279180001	Fluke	5700A	Multifunction Calibrator	09/06/2012	12/05/2012

The above identified unit was calibrated in our laboratory at the address shown below.

This report applies only to the item(s) identified above and shall not be reproduced, except in full, without the written approval of Dynamic Technology, Inc. This unit has been calibrated utilizing standards with a Test Uncertainty Ratio (TUR) of greater than 4:1 approximating a 95 % confidence level with a coverage factor of k=2 unless otherwise stated above or as stated on the Report of Calibration. The calibration was performed using references traceable to the SI through NIST or other recognized national laboratory, accepted fundamental or natural physical constants, ratio type of calibration, or by comparison to consensus standards. Dynamic Technology's calibration program is in compliance with:

ISO/IEC 17025:2005, ANSI/NCSL Z540-1 1994, ANSI/NCSL Z540.3 2006, MIL STD 45662A, QD 4000.2011

Dynamic Technology warrants all material and labor performed for ninety (90) days unless covered under a separate policy.

* Any number of factors may cause the calibrated item to drift out of tolerance before the interval has expired.

Technician Name/Date: James Nimri, 09/12/2012 Signatory: [signature] QA Approved: [stamp]

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Figure A14. Post-calibration sheet for the signal conditioning module 13DEC38 used through 26 July 2012

Dynamic Technology, Inc.

A Trescal Company

17025 Accredited Certificate of Calibration

Certificate #: 2225020001 F

DOE# 038920

ilac-MRA ACCREDITED

Calibration Laboratory Certificate #: 2516.01

Acct #:	101320
Customer:	National Renewable Energy Laboratory
Shipper #:	1861169
Address:	16253 Denver West Parkway Golden, CO, 80401
Contact:	NI RMA
PO #:	

Manufacturer:	National Instruments
Model:	9229
Description:	4 Channel Analog Input Module
Serial Number:	12A2037
Asset Number:	12A2037
Barcode:	

As Received		As Returned		Action Taken	
In Tolerance	X	In Tolerance	X	Full Calibration	X
Out of Tolerance		Out of Tolerance		Special Calibration	
Malfunctioning		Malfunctioning		Oper. Verification	
Operational		Operational		Adjusted	
Damaged		N/A		Repaired	
N/A				Charted	
				Returned As Is	

Cal Date:	06/27/2012
Due Date:	06/27/2013
Temperature:	70.00 deg. F
Humidity:	44.00 %
Baro. Press.:	
Procedure:	DCN 09375
Reference:	manufacturer's manual

Incoming Remarks:

ndo.

Domestic Accredited Calibration. w/antistatic bag

Technical Remarks:

Calibration Standards Utilized

Cert. #	Manufacturer	Model #	Description	Cal Date	Due Date
2182620002	Fluke	5700A	Multifunction Calibrator	05/09/2012	08/07/2012

Checked: [signature] 7/11/12

The above identified unit was calibrated in our laboratory at the address shown below.

This report applies only to the item(s) identified above and shall not be reproduced, except in full, without the written approval of Dynamic Technology, Inc. This unit has been calibrated utilizing standards with a Test Uncertainty Ratio (TUR) of greater than 4:1 approximating a 95 % confidence level with a coverage factor of=2 unless otherwise stated above or as stated on the Report of Calibration. The calibration was performed using references traceable to the SI through NIST or other recognized national laboratory, accepted fundamental or natural physical constants, ratio type of calibration, or by comparison to consensus standards. Dynamic Technology's calibration program is in compliance with:

ISO/IEC 17025:2005, ANSI/NCSL Z540-1:1994, ANSI/NCSL Z540.3:2006, MIL STD 45662A, QD-4000:2011

Dynamic Technology warrants all material and labor performed for ninety (90) days unless covered under a separate policy

* Any number of factors may cause the calibrated item to drift out of tolerance before the interval has expired

Technician Name/Date: James Nimri, 06/27/2012 Signatory: [signature] QA Approved: DTI QA 22

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Figure A15. Calibration sheet for the signal conditioning module 12A2037 used from 26 July 2012 onward

Tektronix
Service Solutions

ACLASS ACCREDITED CALIBRATION

Certificate of Calibration

5258250

Certificate Page 1 of 1

Instrument Identification

Company ID: 120205
NATIONAL RENEWABLE ENERGY LAB
BEV KAY/SRRL
16253 DENVER WEST PARKWAY
GOLDEN, CO 80401

PO Number: CC-BEVERLY KAY

Instrument ID: **04036C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CH 100 OHM 24-BIT RTD ANALOG INPUT

Model Number: NI 9217
Serial Number: 13FAE1C

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 INSTRUMENTS CAL EXECUTIVE 3.4.1

Technician: COREY CLAXTON
Cal Date 24Jun2011
Cal Due Date: 24Jun2012
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 39.0 %

Remarks: *CALIBRATED WITH DATA, REFER TO ATTACHED DATA FOR BEFORE AND AFTER READINGS.*

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.

Tektronix Service Solutions is registered to ISO 9001:2008. Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994 (R2002), 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.
When uncertainty measurement calculations have been calculated per customer request, reported condition statements do not take into account uncertainty of measurement.
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 Tektronix Service Solutions.

Approved By: COREY CLAXTON
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Manufacturer	Model	Cal Date	Date Due
4647338	15-0064	DIGITAL MULTIMETER	HEWLETT PACKARD	3458A	08Feb2011	08Feb2012

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Figure A16. Calibration sheet for the signal conditioning module 13FAE1C used through 26 July 2012

Dynamic Technology, Inc.
A Trescal Company

17025 Accredited Certificate of Calibration

Certificate #: 2281380004 F

ilac-MRA A2LA ACCREDITED
Calibration Laboratory
Certificate #: 2516.01

Acct #:	101320
Customer:	National Renewable Energy Laboratory
Shipper #:	1904141
Address:	16253 Denver West Parkway Golden, CO, 80401
Contact:	NI RMA
PO #:	

Manufacturer:	National Instruments
Model:	9217
Description:	4 Channel 100ohm RTD Analog Input M
Serial Number:	13FAE1C
Asset Number:	13FAE1C
Barcode:	

As Received		As Returned		Action Taken	
In Tolerance	X	In Tolerance	X	Full Calibration	X
Out of Tolerance		Out of Tolerance		Special Calibration	
Malfunctioning		Malfunctioning		Oper. Verification	
Operational		Operational		Adjusted	
Damaged		N/A		Repaired	
N/A				Charted	
				Returned As Is	

Cal Date:	09/12/2012
Due Date:	09/12/2013
Temperature:	73.00 deg. F
Humidity:	42.00 %
Baro. Press.:	
Procedure:	DCN 09480
Reference:	manufacturer's manual

Incoming Remarks:
ndo
Domestic Accredited Calibration w/esd bags

Technical Remarks:

Calibration Standards Utilized

Cert. #	Manufacturer	Model #	Description	Cal Date	Due Date
2062190010	ESI	RS925	Decade Resistance Standard	01/05/2012	01/05/2013
2219450008	National Instrumen	PXI-4071	7.5 Digit DMM Module	06/22/2012	06/22/2013

The above identified unit was calibrated in our laboratory at the address shown below.

This report applies only to the item(s) identified above and shall not be reproduced, except in full, without the written approval of Dynamic Technology, Inc. This unit has been calibrated utilizing standards with a Test Uncertainty Ratio (TUR) of greater than 4:1 approximating a 95 % confidence level with a coverage factor of k=2 unless otherwise stated above or as stated on the Report of Calibration. The calibration was performed using references traceable to the SI through NIST or other recognized national laboratory, accepted fundamental or natural physical constants, ratio type of calibration, or by comparison to consensus standards. Dynamic Technology's calibration program is in compliance with:

ISO/IEC 17025:2005, ANSI/NCSL Z540-1 1994, ANSI/NCSL Z540 3 2006, MIL STD 45662A, QD 4000 2011

Dynamic Technology warrants all material and labor performed for ninety (90) days unless covered under a separate policy.

* Any number of factors may cause the calibrated item to drift out of tolerance before the interval has expired

Technician Name/Date: James Nimri, 09/12/2012 Signatory: [signature] QA Approved: [stamp]

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Page 1 of 1

Figure A17. Post-calibration sheet for the signal conditioning module 13FAE1C used through 26 July 2012

Dynamic Technology, Inc.

A Trescal Company

17025 Accredited Certificate of Calibration

Certificate #: *2225020002* *F*

DOE# 03891C

ilac-MRA ACCREDITED

Calibration Laboratory
Certificate #: 2516.01

Acct #:	101320
Customer:	National Renewable Energy Laboratory
Shipper #:	1861169
Address:	16253 Denver West Parkway Golden, CO, 80401
Contact:	NI RMA
PO #:	

Manufacturer:	National Instruments
Model:	9217
Description:	4 Channel 100ohm RTD Analog Input M
Serial Number:	12BFEE2
Asset Number:	12BFEE2
Barcode:	

As Received		**As Returned**		**Action Taken**	
In Tolerance	X	In Tolerance	X	Full Calibration	X
Out of Tolerance		Out of Tolerance		Special Calibration	
Malfunctioning		Malfunctioning		Oper. Verification	
Operational		Operational		Adjusted	
Damaged		N/A		Repaired	
N/A				Charted	
				Returned As Is	

Cal Date:	06/27/2012
Due Date:	06/27/2013
Temperature:	70.30 deg. F
Humidity:	44.00 %
Baro. Press.:	
Procedure:	DCN 09480
Reference:	manufacturer's manual

Incoming Remarks:

ndo.

Domestic Accredited Calibration. w/antistatic bag

Technical Remarks:

Calibration Standards Utilized

Cert. #	Manufacturer	Model #	Description	Cal Date	Due Date
2062190010	ESI	RS925	Decade Resistance Standard	01/05/2012	01/05/2013
218262000?	Agilent Technologi	3458A	DMM	05/23/2012	08/23/2012

checked, Pedro 7/11/12

The above identified unit was calibrated in our laboratory at the address shown below.

This report applies only to the item(s) identified above and shall not be reproduced, except in full, without the written approval of Dynamic Technology, Inc. This unit has been calibrated utilizing standards with a Test Uncertainty Ratio (TUR) of greater than 4:1 approximating a 95 % confidence level with a coverage factor of k=2 unless otherwise stated above or as stated on the Report of Calibration. The calibration was performed using references traceable to the SI through NIST or other recognized national laboratory, accepted fundamental or natural physical constants, ratio type of calibration, or by comparison to consensus standards. Dynamic Technology's calibration program is in compliance with

ISO/IEC 17025:2005, ANSI/NCSL Z540-1:1994, ANSI/NCSL Z540.3:2006, MIL STD 45662A, QD-4000:2011

Dynamic Technology warrants all material and labor performed for ninety (90) days unless covered under a separate policy

* Any number of factors may cause the calibrated item to drift out of tolerance before the interval has expired

Technician Name/Date: James Nimri, 06/27/2012 Signatory: QA Approved:

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Page 1 of 1

Figure A18. Calibration sheet for the signal conditioning module 12BFEE2 used from 26 July 2012 onward

Tektronix
Service Solutions

ACLASS ACCREDITED CALIBRATION

Certificate of Calibration

5258252

Certificate Page 1 of 1

Instrument Identification

Company ID: 120205
NATIONAL RENEWABLE ENERGY LAB
BEV KAY/SRRL
16253 DENVER WEST PARKWAY
GOLDEN, CO 80401

PO Number: CC-BEVERLY KAY

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

Model Number: NI 9205
Serial Number: 13E3D05

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 INSTRUMENTS CAL EXECUTIVE 3.4.1

Technician: COREY CLAXTON
Cal Date 24Jun2011
Cal Due Date: 24Jun2012
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 39.0 %

Remarks: *CALIBRATED WITH DATA, REFER TO ATTACHED DATA FOR BEFORE AND AFTER READINGS.*

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.

Tektronix Service Solutions is registered to ISO 9001:2008. Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994 (R2002), 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.
When uncertainty measurement calculations have been calculated per customer request, reported condition statements do not take into account uncertainty of measurement.
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 Tektronix Service Solutions.

Approved By: COREY CLAXTON
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Manufacturer	Model	Cal Date	Date Due
5112717	15-0048	MULTIFUNCTION CALIBRATOR	FLUKE	5700A	05May2011	03Aug2011

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Figure A19. Calibration sheet for the signal conditioning module 13E3D05 used through 26 July 2012

Dynamic Technology, Inc.

A Trescal Company

17025 Accredited Certificate of Calibration

Certificate #: 2281380005 F

ilac-MRA ACCREDITED Calibration Laboratory Certificate #: 1516.01

Acct #:	101320
Customer:	National Renewable Energy Laboratory
Shipper #:	1904141
Address:	16253 Denver West Parkway Golden, CO, 80401
Contact:	NI RMA
PO #:	

Manufacturer:	National Instruments
Model:	9205
Description:	32 Channel Analog Input Module
Serial Number:	13E3D05
Asset Number:	13E3D05
Barcode:	

As Received		As Returned		Action Taken	
In Tolerance	X	In Tolerance	X	Full Calibration	X
Out of Tolerance		Out of Tolerance		Special Calibration	
Malfunctioning		Malfunctioning		Oper. Verification	
Operational		Operational		Adjusted	
Damaged		N/A		Repaired	
N/A				Charted	
				Returned As Is	

Cal Date:	09/12/2012
Due Date:	09/12/2014
Temperature:	72.90 deg. F
Humidity:	46.00 %
Baro. Press.:	
Procedure:	DCN 09381
Reference:	manufacturer's manual

Incoming Remarks:

n/a

Domestic Accredited Calibration w/esd bags

Technical Remarks:

Calibration Standards Utilized

Cert. #	Manufacturer	Model #	Description	Cal Date	Due Date
2279180001	Fluke	5700A	Multifunction Calibrator	09/06/2012	12/05/2012

The above identified unit was calibrated in our laboratory at the address shown below.

This report applies only to the item(s) identified above and shall not be reproduced, except in full, without the written approval of Dynamic Technology, Inc. This unit has been calibrated utilizing standards with a Test Uncertainty Ratio (TUR) of greater than 4:1 approximating a 95% confidence level with a coverage factor of k=2 unless otherwise stated above or as stated on the Report of Calibration. The calibration was performed using references traceable to the SI through NIST or other recognized national laboratory, accepted fundamental or natural physical constants, ratio type of calibration, or by comparison to consensus standards. Dynamic Technology's calibration program is in compliance with:

ISO/IEC 17025:2005, ANSI/NCSL Z540-1 1994, ANSI/NCSL Z540.3:2006, MIL STD 45662A, QD-4000 2011

Dynamic Technology warrants all material and labor performed for ninety (90) days unless covered under a separate policy.

* Any number of factors may cause the calibrated item to drift out of tolerance before the interval has expired.

Technician Name/Date: James Nimri, 09/12/2012 Signatory: [signature] QA Approved: [stamp]

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Figure A20. Post-calibration sheet for the signal conditioning module 13E3D05 used through 26 July 2012

Dynamic Technology, Inc.

A Trescal Company

17025 Accredited Certificate of Calibration

Certificate #: 2225020003 F

DOE# 04373C

ilac-MRA ACCREDITED

Calibration Laboratory Certificate #: 2516.01

Acct #:	101320
Customer:	National Renewable Energy Laboratory
Shipper #:	1861169
Address:	16253 Denver West Parkway Golden, CO, 80401
Contact:	NI RMA
PO #:	

Manufacturer:	National Instruments
Model:	9205
Description:	32 Channel Analog Input Module
Serial Number:	14DA726
Asset Number:	14DA726
Barcode:	

As Received		As Returned		Action Taken	
In Tolerance	X	In Tolerance	X	Full Calibration	X
Out of Tolerance		Out of Tolerance		Special Calibration	
Malfunctioning		Malfunctioning		Oper. Verification	
Operational		Operational		Adjusted	X
Damaged		N/A		Repaired	
N/A				Charted	
				Returned As Is	

Cal Date:	06/27/2012
Due Date:	06/27/2014
Temperature:	70.30 deg. F
Humidity:	44.00 %
Baro. Press.:	
Procedure:	DCN 09381
Reference:	manufacturer's manual

Incoming Remarks:

ndo

Domestic Accredited Calibration. w/antistatic bag

Technical Remarks:

Calibration Standards Utilized

Cert. #	Manufacturer	Model #	Description	Cal Date	Due Date
2182620002	Fluke	5700A	Multifunction Calibrator	05/09/2012	08/07/2012

Checked, Red 7/12/12

The above identified unit was calibrated in our laboratory at the address shown below.

This report applies only to the item(s) identified above and shall not be reproduced, except in full, without the written approval of Dynamic Technology, Inc. This unit has been calibrated utilizing standards with a Test Uncertainty Ratio (TUR) of greater than 4:1 approximating a 95 % confidence level with a coverage factor of k=2 unless otherwise stated above or as stated on the Report of Calibration. The calibration was performed using references traceable to the SI through NIST or other recognized national laboratory, accepted fundamental or natural physical constants, ratio type of calibration, or by comparison to consensus standards. Dynamic Technology's calibration program is in compliance with:

ISO/IEC 17025:2005, ANSI/NCSL Z540-1:1994, ANSI/NCSL Z540.3:2006, MIL STD 45662A, QD-4000 2011

Dynamic Technology warrants all material and labor performed for ninety (90) days unless covered under a separate policy.

* Any number of factors may cause the calibrated item to drift out of tolerance before the interval has expired.

Technician Name/Date: James Nimri, 06/27/2012 Signatory: [signature] QA Approved: [stamp: DTI QA 22]

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Figure A21. Calibration sheet for the signal conditioning module 14DA726 used from 26 July 2012 onward

References

International Electrotechnical Commission (IEC). (2006). Wind Turbines – Part 2: Design requirements for small wind turbines, IEC 61400-2, Ed 2.0, Clause 9.6, 2006-03, Geneva, Switzerland.