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Duration 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-5000-58970
June 2013

Contract No. DE-AC36-08GO28308

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Prepared under Task No. WE11.0206

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Duration 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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30 May 2013

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Approval By: Jeroen van Dam, NREL Test Engineer — 27 June 2013 — Date

Review By: Arlinda Huskey, NREL Test Engineer — 27 June 2013 — 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. Duration testing is one of up to five tests that may be performed on the turbines. Other tests include safety and function, 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.

Researchers at the NWTC conducted this test in accordance with its quality system procedures to ensure that this final test report meets the full accreditation requirements of 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 and Requirements

The objective of this test was to assess the following aspects of the Viryd CS8 wind turbine in accordance with Clause 9.4 of the International Electrotechnical Commission's (IEC) standard, *Wind Turbines - Part 2: Design Requirements for Small Wind Turbines*, IEC 61400-2 Ed. 2.0:2006-03 (hereafter referred to as the "Standard").

NREL tested the turbine's:

- Structural integrity and material degradation
- Quality of environmental protection
- Dynamic behavior.

The wind turbine will complete the duration test when it has achieved reliable operation for:

- At least 6 months of operation
- At least 2,500 hours of power production in winds of any velocity
- At least 250 hours of power production in winds of 1.2 V_{ave}, annual average wind speed at hub height, (10.2 m/s) and above
- At least 25 hours of power production in winds of 1.8 V_{ave} (15.3 m/s) and above.

Reliable operation means:

- An operational time fraction of at least 90%
- No major failure of the turbine or components in the turbine system
- No significant wear, corrosion, or damage to turbine components
- No significant degradation of produced power at comparable wind speeds.

Based on the parameters defined in the Standard for small wind turbine classes, Viryd identified the test turbine to be a class II. This corresponds to a V_{ave} of 8.5 m/s.

3 Description of Test Turbine

The test turbine, shown in Figure 1, is a three-bladed, upwind, passive yaw turbine with a rated power of 8 kW. 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 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, which connects the turbine system to the electrical grid at the test site
- 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, meteorological tower, associated wiring and junction boxes, and a data shed containing the data acquisition instrumentation. The turbine was installed on a guyed 24.4 m, tilt-up 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.

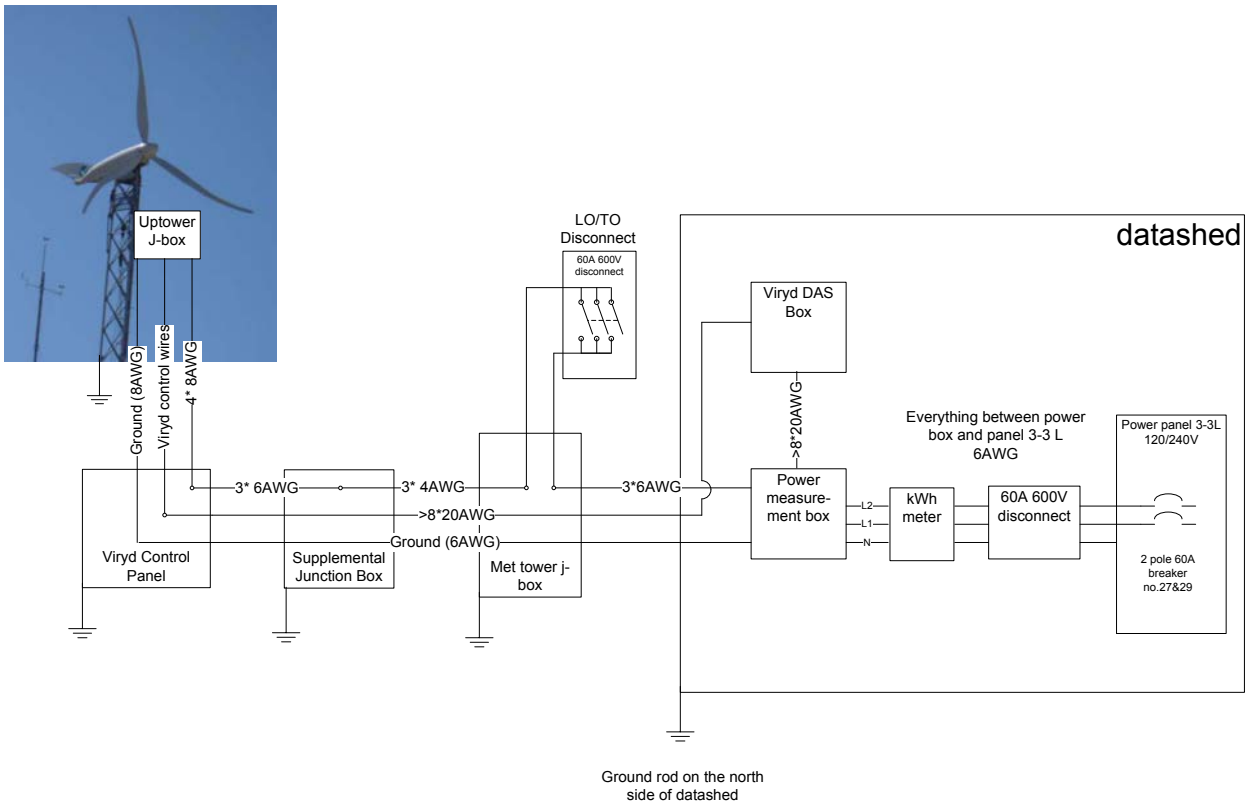


Figure 2. Electrical schematic of turbine installation

(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 tower locations, as well as nearby turbines. NREL engineers limited assessments of power degradation to data that were obtained when winds were within the measurement sector of 211° to 38°. In this measurement sector, the influence of terrain and obstructions on the anemometer is small and meets the requirements of IEC 61400-12-1 without having to conduct a site calibration test.

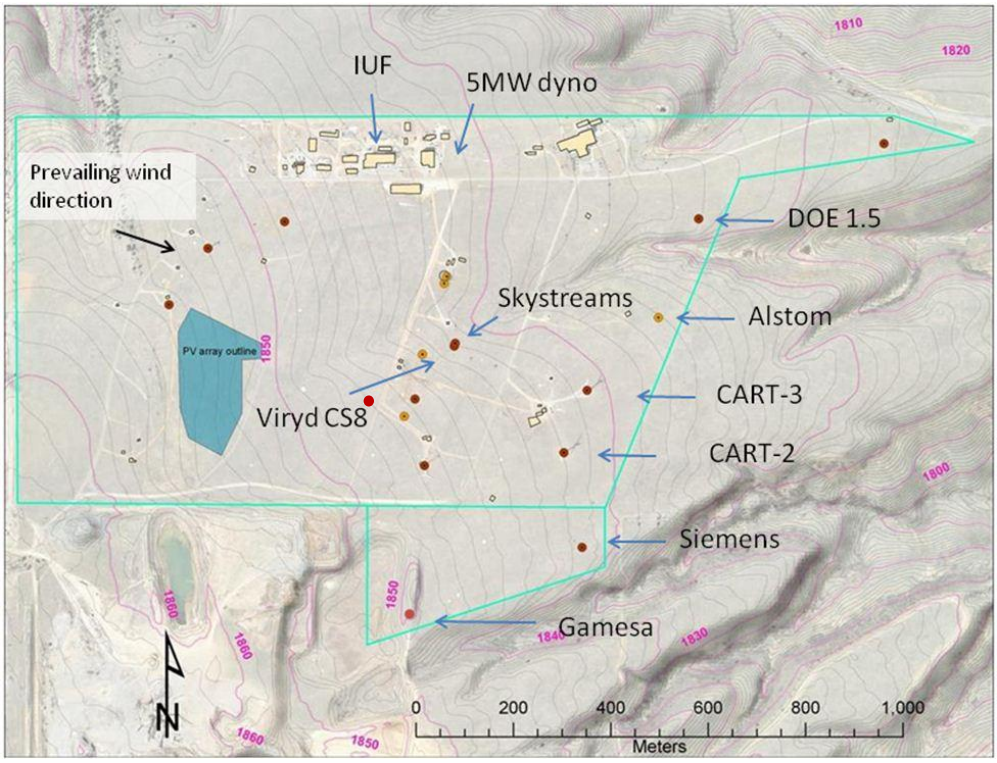


Figure 3. Map of the test site
(Source: NREL 2012)

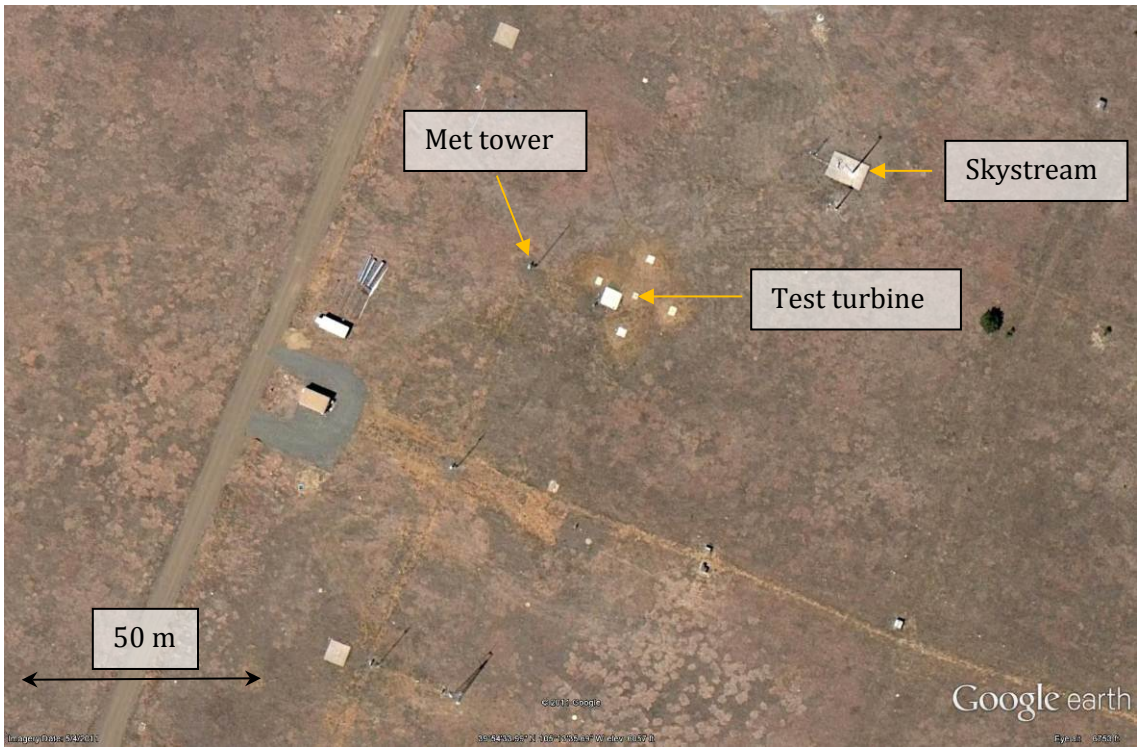


Figure 4. Close up of test site around the test turbine
(Source: Map data ©2012 Google earth)

5 Description of Instrumentation

Equipment used for duration testing differs only slightly from the equipment used for power performance testing. Normal power performance requires measurements of wind speed, wind direction, turbine power, air temperature, air pressure, precipitation, and overall turbine system availability. For duration testing, NREL added voltage signals to monitor the status light-emitting diodes (LEDs) on the controller. The green LED indicates when the turbine is producing power; the blue LED indicates when the turbine is on standby: "waiting for wind" (solid), or experiencing a cut-out wind condition (blinking); and the red LED indicates when the turbine has faulted. The red LED blinks various times at various duty cycles, based on whether the turbine is experiencing a recoverable or 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 was required to log into the controller and determine the exact cause. As a whole, this level of diagnostics was deemed beyond the scope of this test. Instead, NREL engineers set the threshold for examining whether the turbine was faulted based on the 10-minute average of the red LED signal being higher than 1% of its full-scale voltage when solidly lit. Every identified sequence was manually examined and classified as a fault or not based on additional signals and turbine behavior. For true faults, the NREL team worked under the guidance of Viryd to diagnose and fix the cause. Many of these faults are described below.

Figure 5 provides the location of the meteorological tower instruments and Table 3 provides the specifications for each of the instruments used. The first set of data acquisition modules were used beyond their calibration due date; they were post-calibrated and found to be within tolerance. The pressure transducer was out of calibration and was post-test calibrated. Residuals between the two calibrations were found to be 0.006 kPa at most, a negligible amount in the context of this test. No data was collected between 12 September 2012 and 17 September 2012 due to an instrumentation change. Post-test calibration sheets are provided in Appendix A.

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

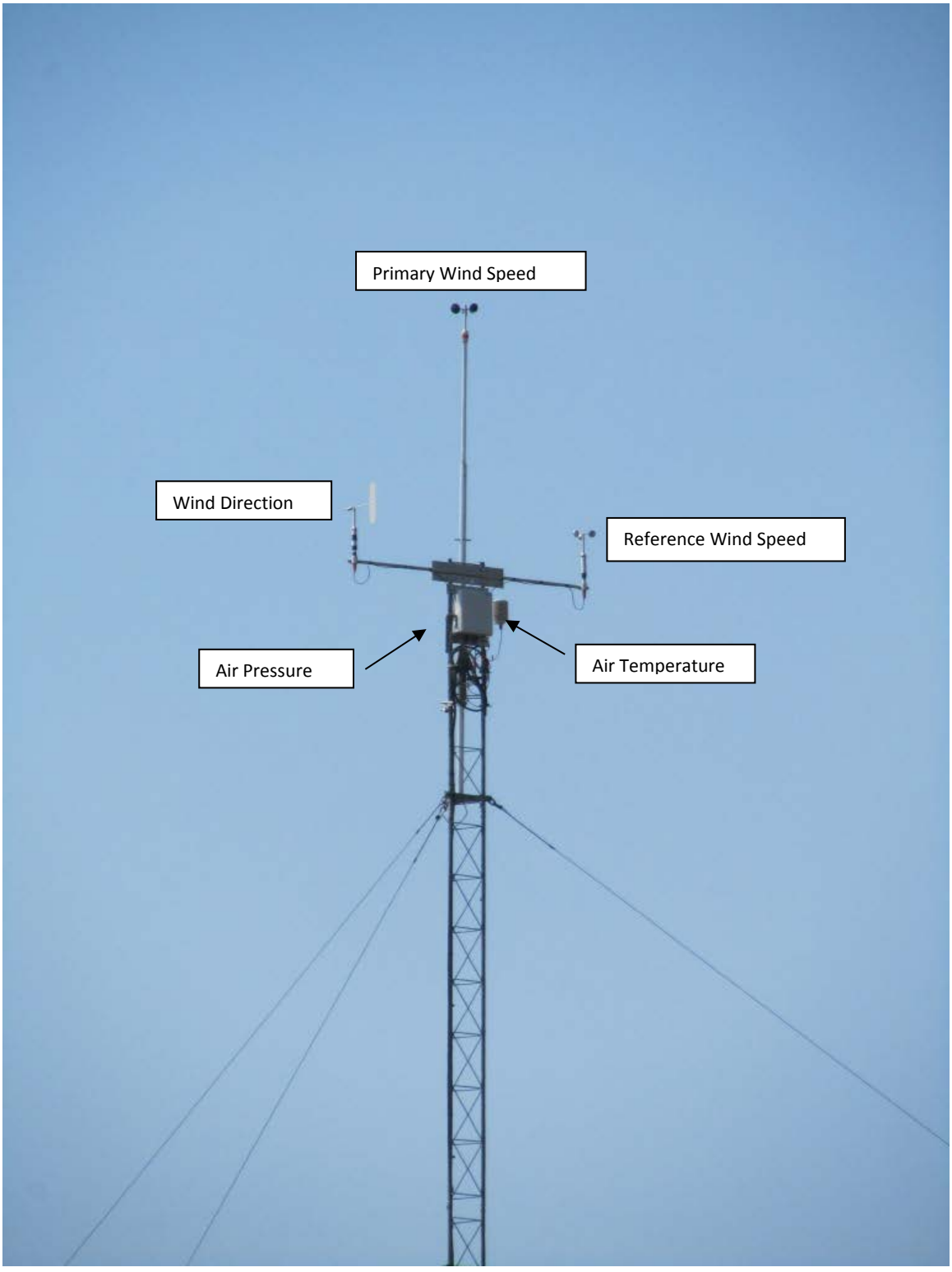


Figure 5. View of instruments on the meteorological tower
(Source: NREL 2012)

6 Results

6.1 Operation Time

The test turbine system was installed on 22 September 2011 (the commissioning checklist from the installation can be found in Appendix B). The turbine was ready for its initial shakedown period on 12 October 2011. The duration test began on 1 November 2011 and was terminated on 1 February 2013, after the turbine no longer produced power following a suspected and confirmed failure of the air compressor. Although the test period was more than 6 months, as required by the Standard, the turbine did not meet the Standard's criteria for reliable operation. NREL engineers analyzed operational time up until the last time the turbine produced power on 1 February 2013. The turbine was decommissioned on 7 May 2013.

6.2 Hours of Power Production

During the test, engineers recorded the following number of hours of power production:

- At any wind speed – 1,268.9 hours (2,500 hours required)
- Above 1.2*V_{ave} (10.2 m/s) – 442.7 hours (250 hours required)
- Above 1.8*V_{ave} (15.3 m/s) – 81.7 hours (25 hours required).

The turbine did not meet the requirement for hours of power production during the test. Table 4 shows the overall and monthly results of the duration test.

Table 4. Overall and Monthly Results of the Viryd CS8 Duration Test

Month	Hours of power			Environmental		Operational time fraction				
	0 m/s	10 m/s	15 m/s	max gust [m/s]	TI@15 m/s [%]	T_T	T_U	T_E	T_N	O [%]
Overall	***1268.9***	***442.7***	***81.7***	***47.7***	***18.3***	***11014.0***	***912.4***	***1067.9***	***1487.2***	***83.5%***
Min. Met?	**No**	**Yes**	**Yes**			**Yes**				**No**
Nov 2011	90.2	30.8	3.8	38.3	18.4	720	15.4	353.2	1.7	99.5
Dec	71.2	18.2	1.3	46.6	17.4	744	2	0.3	92.2	87.6
Jan 2012	0	0	0	46.2	17.9	744	172.5	146	425.5	0
Feb	79.5	32	14	47.7	23.3	696	71.2	15.8	431	29.2
Mar	156.7	67.3	26.5	41.9	19.5	744	12.8	1	29.2	96
Apr	96.7	33.8	4.3	30.1	17.3	720	136.8	12.2	42.3	92.6
May	78.8	27.2	0.8	28.2	19.6	744	3	12.7	10.3	98.6
Jun	129.7	36.3	1.2	25.2	15.1	720	0.8	0	0.2	100
Jul	54.5	16.8	0.2	34.1	14.6	744	94	1.5	48	92.6
Aug	83.3	20	0.8	30.3	11.9	744	157.8	0	0	100
Sep	38.7	7.8	0	21.1	16.9	720	200.3	0.5	0	100
Oct	82	31.3	5.7	34	19.3	744	45.6	202.7	29.5	94
Nov	75.5	17.8	1.3	35.2	18.2	720	0	116.7	82	86.4
Dec	100.8	39.5	6.5	33.2	19.2	744	0.1	167.8	145.3	74.8
Jan 2013	124.3	62.7	15.3	34.6	18.8	744	0	36.3	142.5	79.9
Feb	6.8	1.2	0	32.5	16.7	22	0.1	1.2	7.5	63.4

6.3 Operational Time Fraction

The operational time fraction is defined as follows:

$$O = \frac{T_T - T_N - T_U - T_E}{T_T - T_U - T_E} \times 100\%$$

where

T_T = the total time period under consideration
T_N = the time in which the turbine is known to be non-operational
T_U = the time in which the turbine status is unknown
T_E = the time that is excluded in the analysis.

The overall operational time fraction of the combined wind turbine system—including the wind turbine, tower, and controller—in the total test period was 83.5%. Table 4 and Figure 6 show the operational time fraction per month.

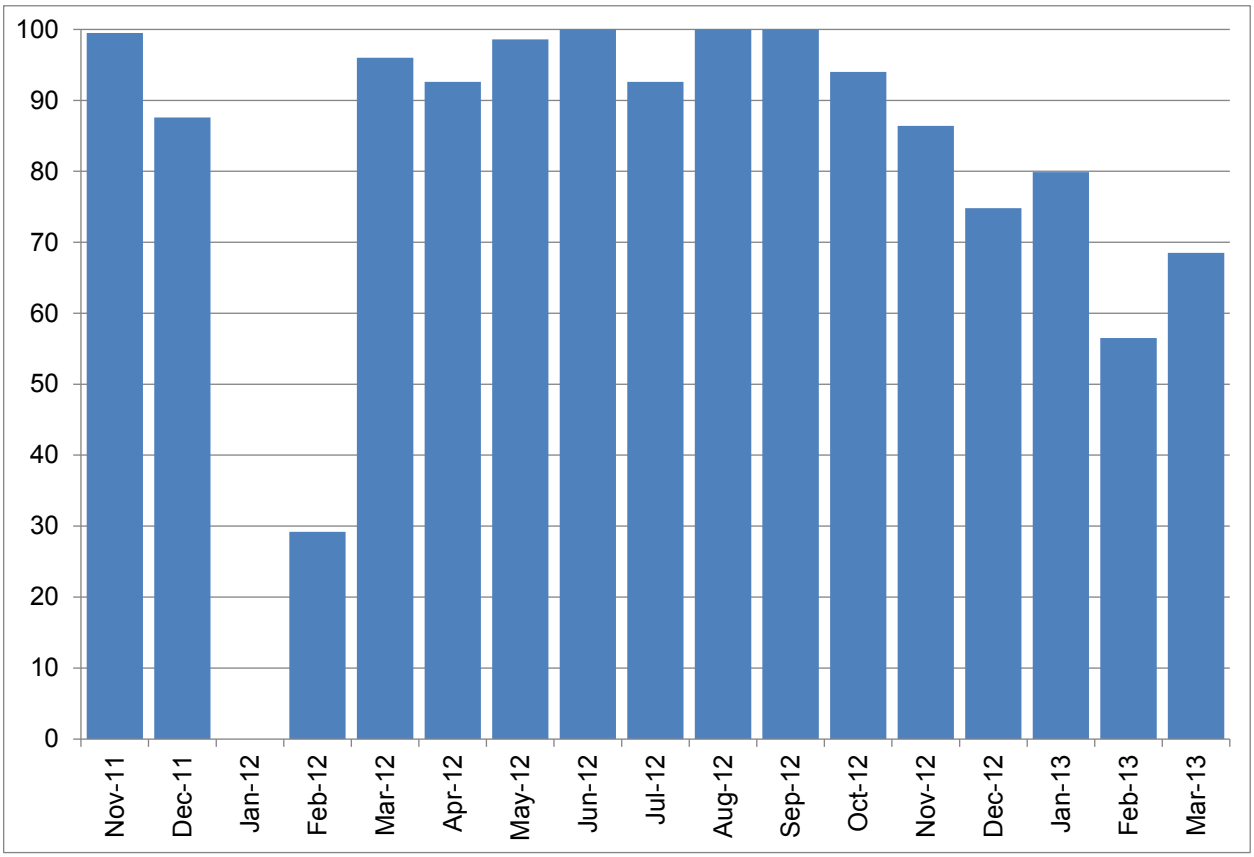


Figure 6. Operational time fraction for each month

System Downtime

The main reasons for wind turbine system downtime (T_N) during the test period were the failed anemometer, failed power supply, and failed compressor.

Failed Anemometer

On 31 December 2011, the turbine's anemometer failed. On 23 January 2012, a replacement anemometer from Viryd arrived and was installed on 31 January 2012. The downtime until the replacement anemometer arrived was classified as non-operational time (T_N), and the time between the arrival and installation of the anemometer was classified as excluded time (T_E), because the lack of available NREL personnel affected the timing of the installation.

Failed Power Supply

On 4 February 2012, the 24-VDC power supply for the controller failed. The controller was replaced on 21 February 2012 and downtime was classified as non-operational.

Failed Compressor

Analysis of the turbine duration data showed that the turbine produced power for the last time on 1 February 2013. After that, the turbine faulted every time the wind speed approached cut-in. During the post-test inspection, the pneumatic compressor for the brake system was found to be inoperative. The NREL team believes that this final series of faults may have been caused by the failed compressor.

Remaining T_N

Over the course of the test, the turbine experienced several faults of unknown origin. The NREL team was unable to log into the controller to determine the exact cause, but worked directly with Viryd to troubleshoot and reset the faults. The resulting downtime from the faults was classified as non-operational unless NREL engineers were unable to get to the issue in a timely manner, at which point excess faulted time was excluded.

Excluded Time T_E

The main reasons for excluding time (T_E) in the duration test were:

- Time during power outages that prevented the turbine from running
- Noise testing that required the turbine to be shut down
- Resetting of faults that took longer than normal because of personnel availability.

Unknown Time T_U

If no reliable measurements were available, the time was classified as unknown (T_U), because the turbine's status could not be explicitly determined.

6.4 Environmental Conditions

As an indication of the environmental conditions that the turbine experienced during the duration test, the highest instantaneous wind speed gust was 47.7 m/s (during February 2012) and the average turbulence intensity at 15 m/s was 18.3% based on 10-minute statistics.

6.5 Power Degradation Checks

A factor of reliable operation is that the turbine should experience no significant power degradation. Figure 7 shows a scatter plot of 10-minute averaged power versus wind speed over the course of the test. Figure 8 shows the power degradation plot, which provides the power level in individual wind speed bins for each month. These plots are then analyzed for any obvious trends in power production. Variations in the power levels from season to season are caused by air density variations. Stronger dips in power are present as a result of the known faulted conditions or excluded times (i.e., grid outages) being part of the data set, per the Standard. Thus, any unknown faults are hidden by the known time when the turbine is non-operational. The power degradation is more clearly observed Figure 9 than Figure 8, where the known offline turbine time is removed.

In Figure 7, two distinct power curves are observed, corresponding to a sharp decrease in power and power factor that was observed around 20 May 2012. It is worth noting that both run capacitors were found to be faulty during the post-test inspection (detailed in Appendix C). The NREL team suspect the failure of these capacitors caused the power degradation.

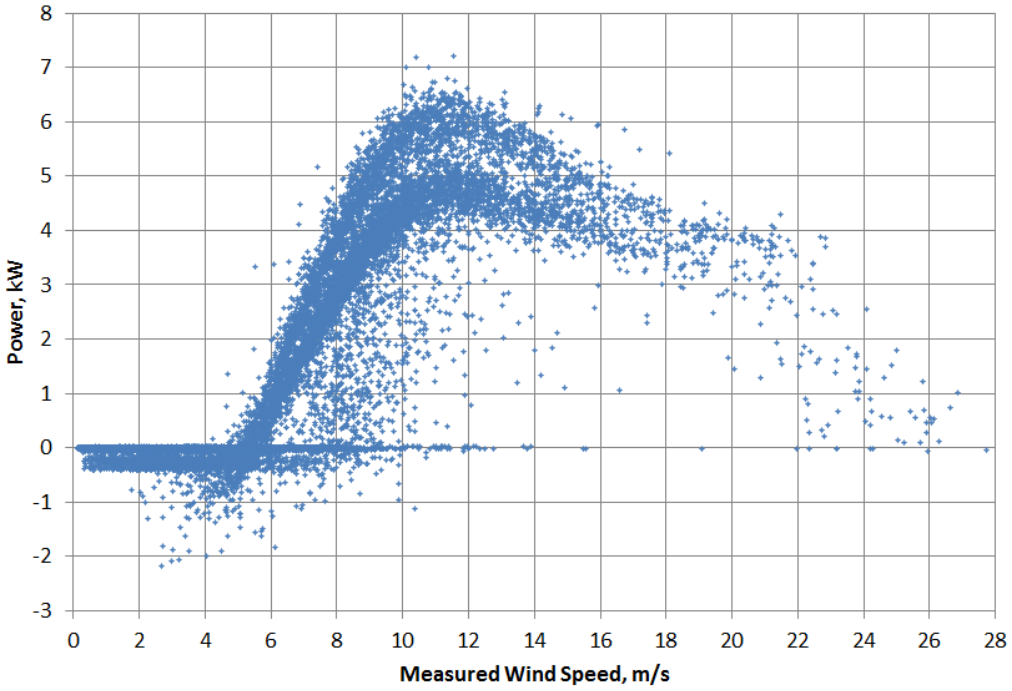


Figure 7. Scatter plot of power versus wind speed (10-minute averages)

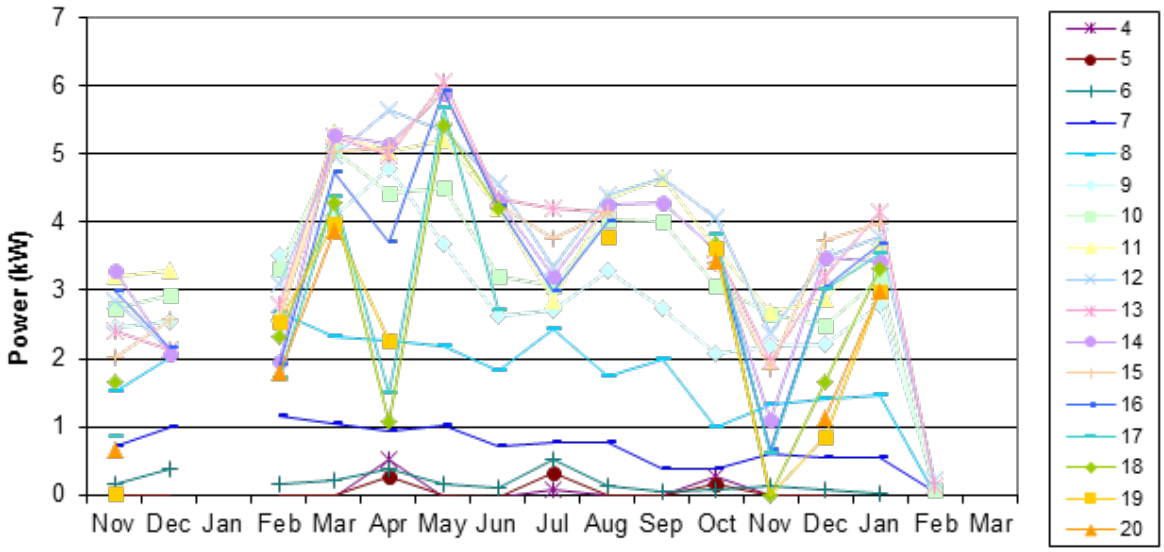


Figure 8. Power level in several wind speed bins (m/s) as a function of time

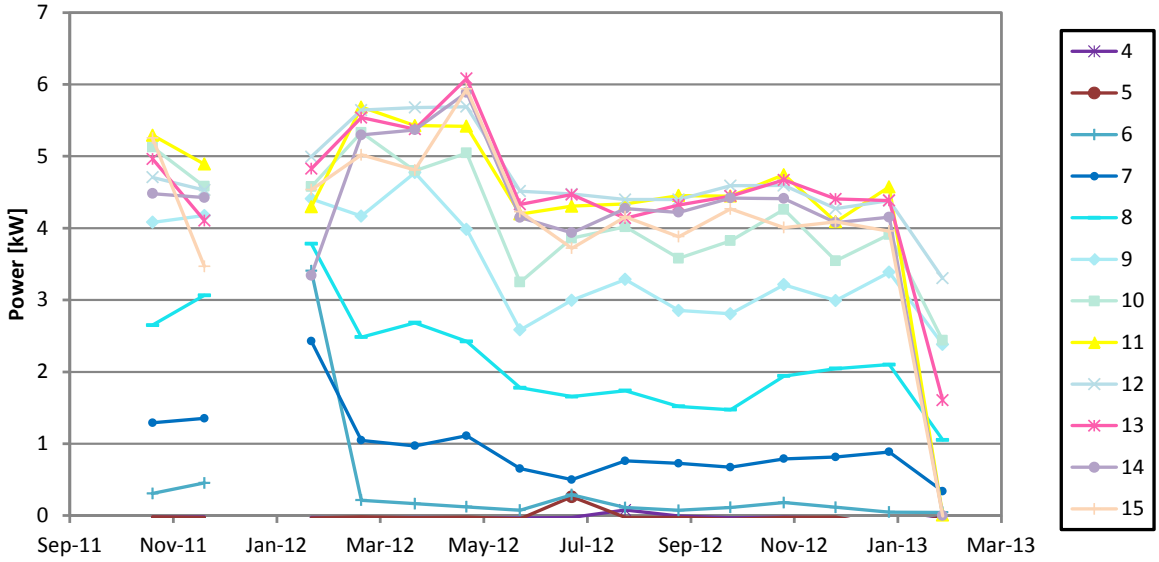


Figure 9. Power level in several wind speed bins (m/s) as a function of time with known non-operational time removed

6.6 Dynamic Behavior

The turbine's 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 over 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, as the turbine controller utilizes a wind-speed-weighted counter to determine when to start. The turbine passively tracked the wind well, both when running and parked with only minor vibration of the tail. Occasionally, the turbine would run downwind (detailed below). Running downwind always initiated a preprogrammed detection and 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. The following observation excerpts were recorded in the log book during the test.

21 February 2012 Wind Speed: 10-15 m/s Wind direction: WNW

"No defects noted. Operation is fine. Returned to run mode (after fault). Stand-by light illuminated. Awaiting normal operation.

Witnessed normal operation of turbine. Continued operation."

22 February 2012 Wind Speed: 10-25 m/s Wind direction: WNW

"Witnessed several shutdowns this morning. They've been accomplished by winds gusting greater than 25 m/s. The turbine stops and alternately flashes yellow and red LEDs. Blue LED also flashes.[1] After several minutes, the turbine enters standby and run modes."

6 June 2012 Wind Speed: 4-7 m/s Wind direction: NNE

"Observed the Viryd running downwind. Videos on my phone...heard it all the way from site 1.2. Ran for at least 10 minutes downwind, more likely 15. Observed the turbine go through its shutdown routine and yaw into the wind. After 5 minutes, it still is in standby/waiting for wind. Winds are low, not sure if it'll start up again."

"Turbine started back up at 19:47 MT."

18 October 2012 Wind Speed: 5-18 m/s Wind direction: WNW–NW

"Turbine running all day in high winds."

1 November 2012 Wind Speed: 3-5 m/s Wind direction: SE

"Reset turbine through manual reset and had turbine run through start up check. No odd noises or vibrations during check. Standby LED came back after check and fault LED went away."

12 November 2012 Wind Speed: 5-15 m/s Wind direction: W

"Ran turbine through startup check. Slight metallic noise, perhaps from tail fin, but might be worth checking before wind season picks up.[2] Standby LED is back on and fault LED cleared."

[1] This LED combination is in line with the manual's description of the turbine behavior during high-wind cut-out: a recoverable fault state with a 5-minute wait period accompanied by a flashing blue standby LED indicating the high wind event.

[2] Turbine was inspected and found to be in good working condition.

7 Uncertainty

NREL researchers estimated turbine uncertainty for the following parameters:

- Hours of power production
- Operational time fraction
- Highest instantaneous wind speed.

No uncertainty analysis was done for the power degradation results. These results were used only to find relative trends that might indicate hidden faults in the turbine.

7.1 Hours of Power Production

NREL researchers assumed that the turbine was producing power for the entire 10-minute period when the average power for that period was positive. This method overestimated the time for power production in wind speeds between 5 and 10 m/s. At these wind speeds, the turbine may have been producing power for about 90% of the time. At higher wind speeds, this method would produce less of an overestimate. NREL estimates that the reported time of power production in wind speeds greater than 0 m/s may be 5% less than calculated.

For the hours of power production above 10.2 m/s and 15.3 m/s, the uncertainty in the wind speed was assumed to be the dominant factor. Using the uncertainties in wind speed detailed below, uncertainty in wind speed at 15.6 m/s is 0.4 m/s. When considering this uncertainty, the hours of power production would at most reduce to 392.2 hours (above 10.6 m/s) and 71.7 hours (above 15.7 m/s), which still exceeds the 250 and 25 hours that the Standard requires.

7.2 Operational Time Fraction

The total test time was 11,014.0 hours. Even if the classification of T_N was off by 5% (which is a conservative assumption), the operational time fraction would be 84.4%.

7.3 Highest Instantaneous Wind Speed

The uncertainties in the wind speed measurements were 0.06 m/s calibration uncertainty, 0.03 m/s + 0.26% operational characteristics, 1% mounting effects, and 2% terrain effects. For the maximum instantaneous gust of 47.7 m/s, the uncertainty was 1.1 m/s.

8 Deviations and Exceptions

8.1 Deviations from the Standard

There were no deviations or exceptions to the Standard.

8.2 Deviations from Quality Assurance

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

In addition, the pressure transducer was used beyond its calibration due date (see Appendix A for the post-test calibration sheet). Residuals between the pre- and post-test calibrations were found to be 0.006 kPa at most, a negligible amount in the context of this test.

References

International Electrotechnical Commission (IEC). (2006). Wind Turbines – Part 2: Design requirements for small wind turbines, IEC 61400-2, Ed 2.0, Clause 9.4, 2006-03, Geneva, Switzerland.

Appendix A. Instrument Calibration Certificates

Svend Ole Hansen ApS
SCT. JORGENS 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: 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

Svend Ole Hansen

Calibration equation obtained: v [m/s] = 0.04839 · f [Hz] + 0.24584

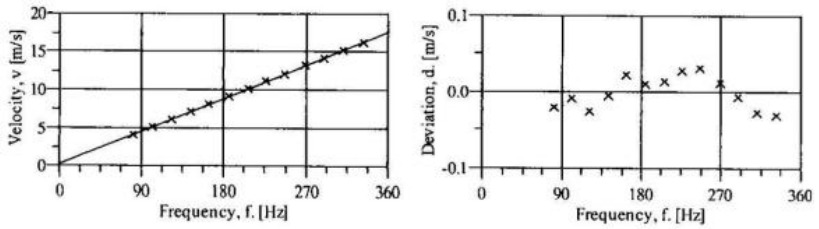
Standard uncertainty, slope: 0.00164 **Standard uncertainty, offset:** 0.07126

Covariance: -0.0000013 (m/s)²/Hz **Coefficient of correlation:** $\rho = 0.999985$

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



DANAK

Page 1 of 2

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

Svend Ole Hansen ApS
SCT. JØRGENS ALLÉ 7 · DK-1615 KØBENHAVN V · DENMARK
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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: $v\,[m/s] = 0.04654 \cdot f\,[Hz] + 0.15404$

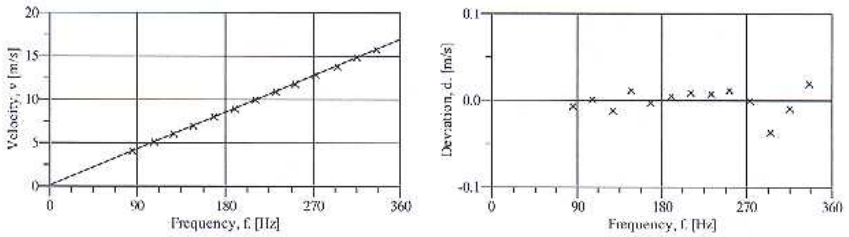
Standard uncertainty, slope: 0.00114 **Standard uncertainty, offset:** 0.07713

Covariance: -0.0000006 $(m/s)^2/Hz$ **Coefficient of correlation:** $\rho = 0.999993$

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

Page 1 of 2

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

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

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.

Item Calibrated:

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

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

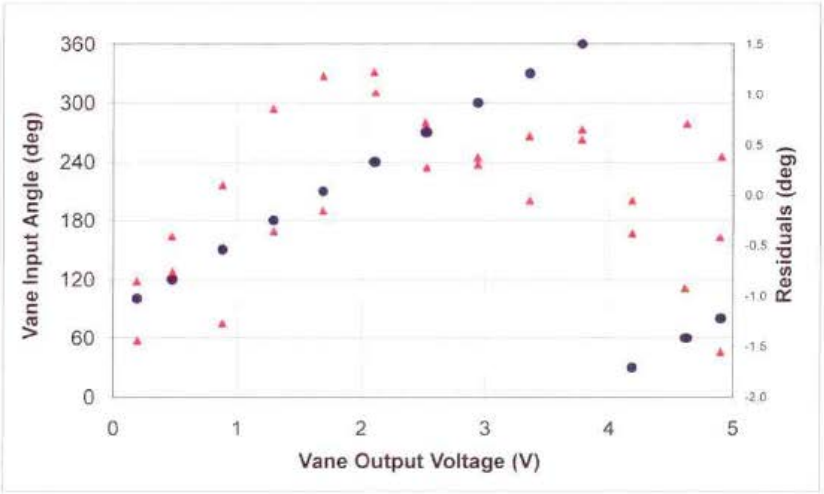


Figure A3. Calibration sheet for the wind vane used through 12 September 2012

Wind Vane Calibration Report

Calibration Laboratory:
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-12**

Report Number: W5515-120913

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

Page: 1 of 1

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

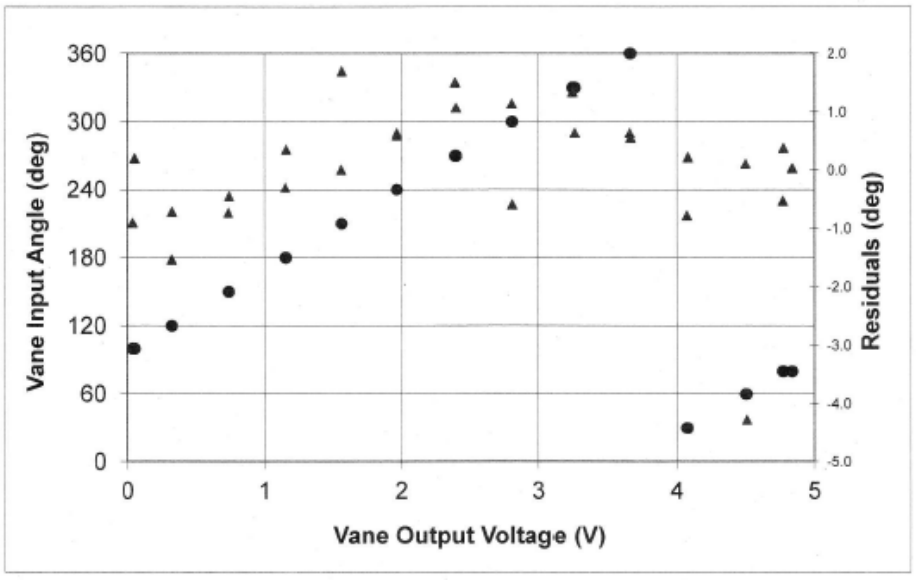


Figure A4. Calibration sheet for the wind vane used from 17 September 2012 on

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 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 power transducer calibration sheet used through 12 September 2012

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 power transducer calibration sheet used from 17 September 2012 on

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 from 15 May 2012 on

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-test 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 from 16 May 2012 on

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 Approved By: Reda

Date: 09/15/2011 Date: 09/15/2011

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

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 temperature sensor used from 17 September 2012 on

Tektronix
Service Solutions

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
Accuracy: Mfr Specifications

Model Number: NI 9229
Serial Number: 13DEC38

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 Appdx, 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.

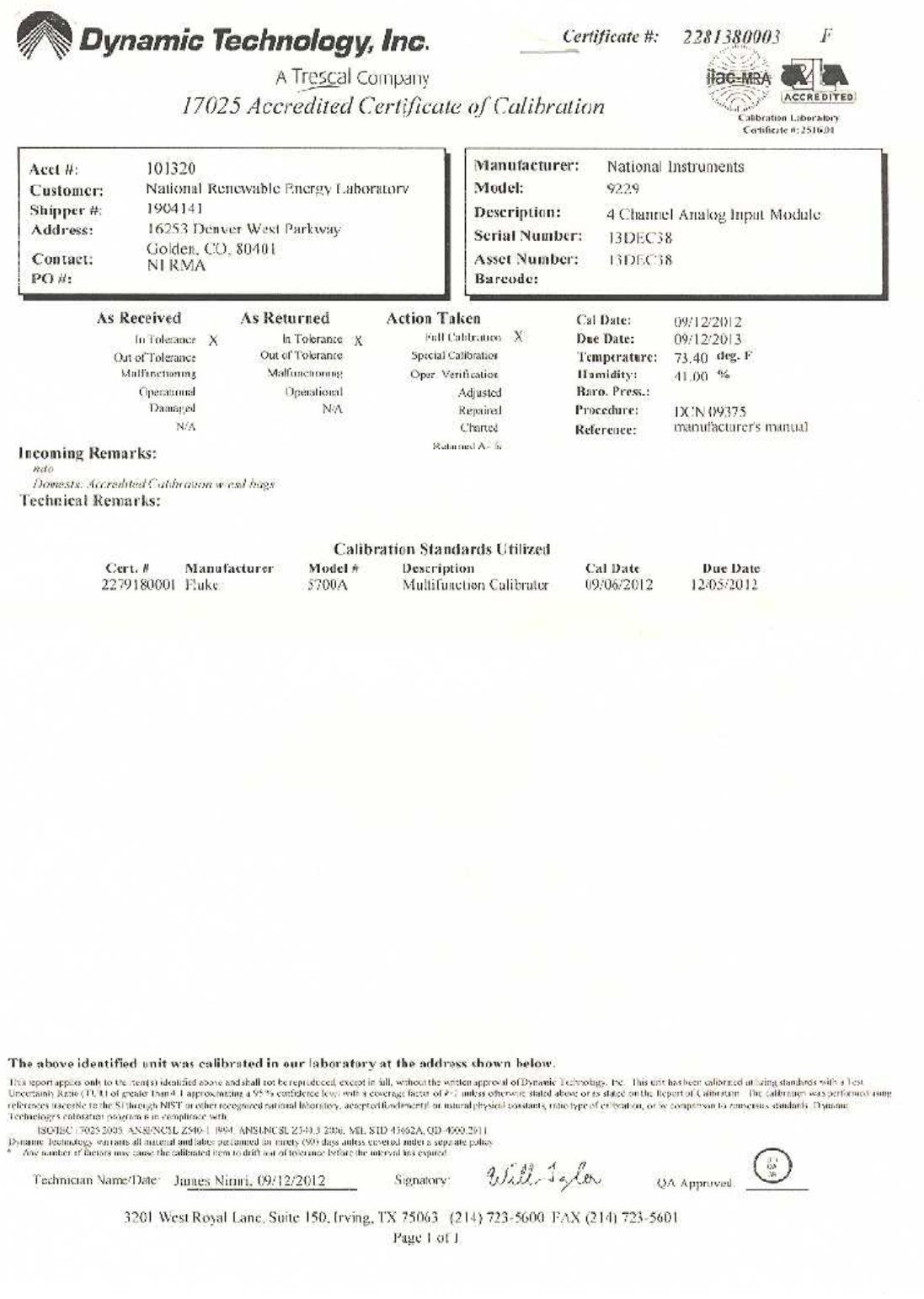
Approved By: COREY CLAXTON
Service Representative

Calibration Standards

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

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

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



Dynamic Technology, Inc.

A Trescal Company

17025 Accredited Certificate of Calibration

Certificate #: 2281380003 F

ACCREDITED

Calibration Laboratory
Certificate #: 2510.01

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 As-Is	

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

Incoming Remarks:

ndo

Domestic Accredited Calibration w/cal bags

Technical Remarks:

Calibration Standards Utilized

Cert. #	Manufacturer	Model #	Description	Cal Date	Due Date
2279180001	Fluke	5700A	Multifunction Calibrator	09/06/2012	12/03/2012

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 2:1 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 on this unit for (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: Bill Taylor QA Approved:

3201 West Royal Lane, Suite 150, Irving, TX 75063 (214) 723-5600 FAX (214) 723-5601

Page 1 of 1

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

Dynamic Technology, Inc.

A Trescal Company

17025 Accredited Certificate of Calibration

Certificate #: *2225020001* *F*

DOE# 03892C

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: 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: QA Approved:

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Page 1 of 1

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

Tektronix
Service Solutions

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
Accuracy: Mfr. Specifications

Model Number: NI 9217
Serial Number: 13FAE1C

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

Technician: COREY CLAXTON
Cal Date 24Jun2011
Cal Due Date: 24Jun2012
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.

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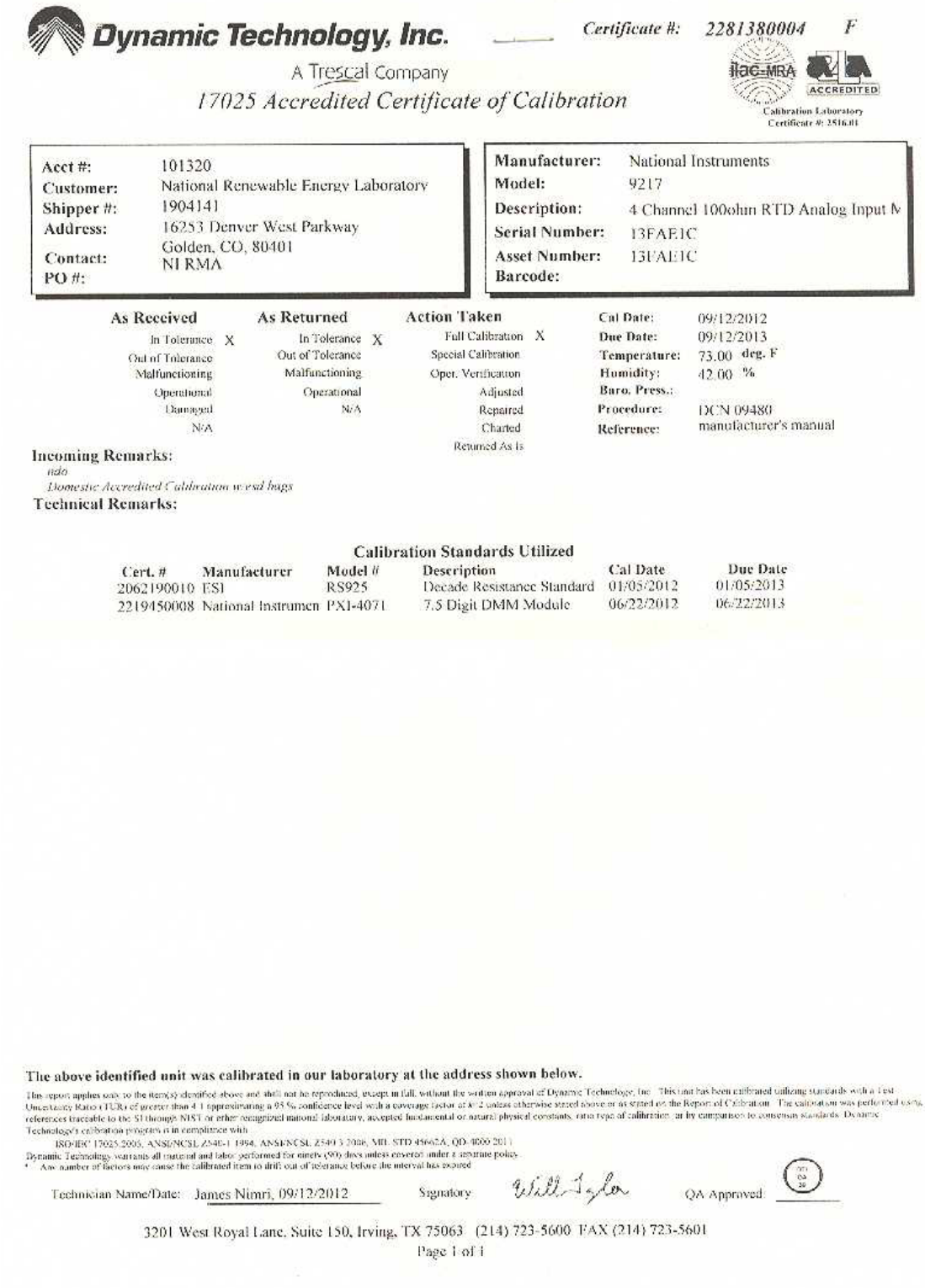
Figure A16. Calibration sheet for signal conditioning module 13FAE1C used through 26 July 2012



Dynamic Technology, Inc.

A Trescal Company

Certificate #: 2281380004 F

17025 Accredited Certificate of Calibration

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:

nido

Domestic Accredited Calibration w/seal 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-9000:2011

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: Will Taylor QA Approved:

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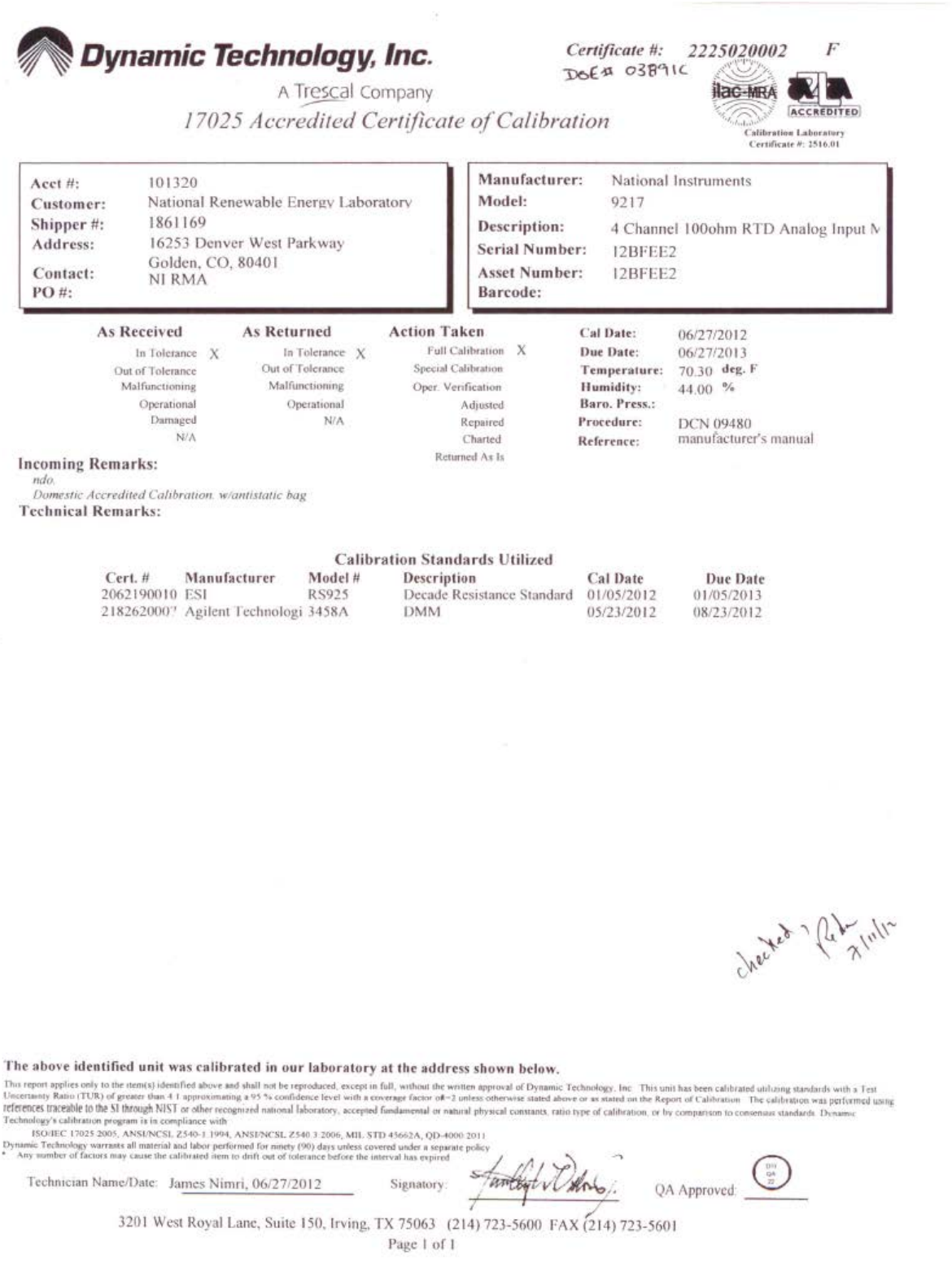
Page 1 of 1

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



Dynamic Technology, Inc.

A Trescal Company

17025 Accredited Certificate of Calibration

Certificate #: 2225020002 F

DOE# 038910

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 - Rob 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: QA Approved:

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Page 1 of 1

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

Tektronix
Service Solutions

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

Technician: COREY CLAXTON
Cal Date 24Jun2011
Cal Due Date: 24Jun2012
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.

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 Appdx, 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
511/717	15-0048	MULTIFUNCTION CALIBRATOR	FLUKE	5700A	05May2011	03Aug2011

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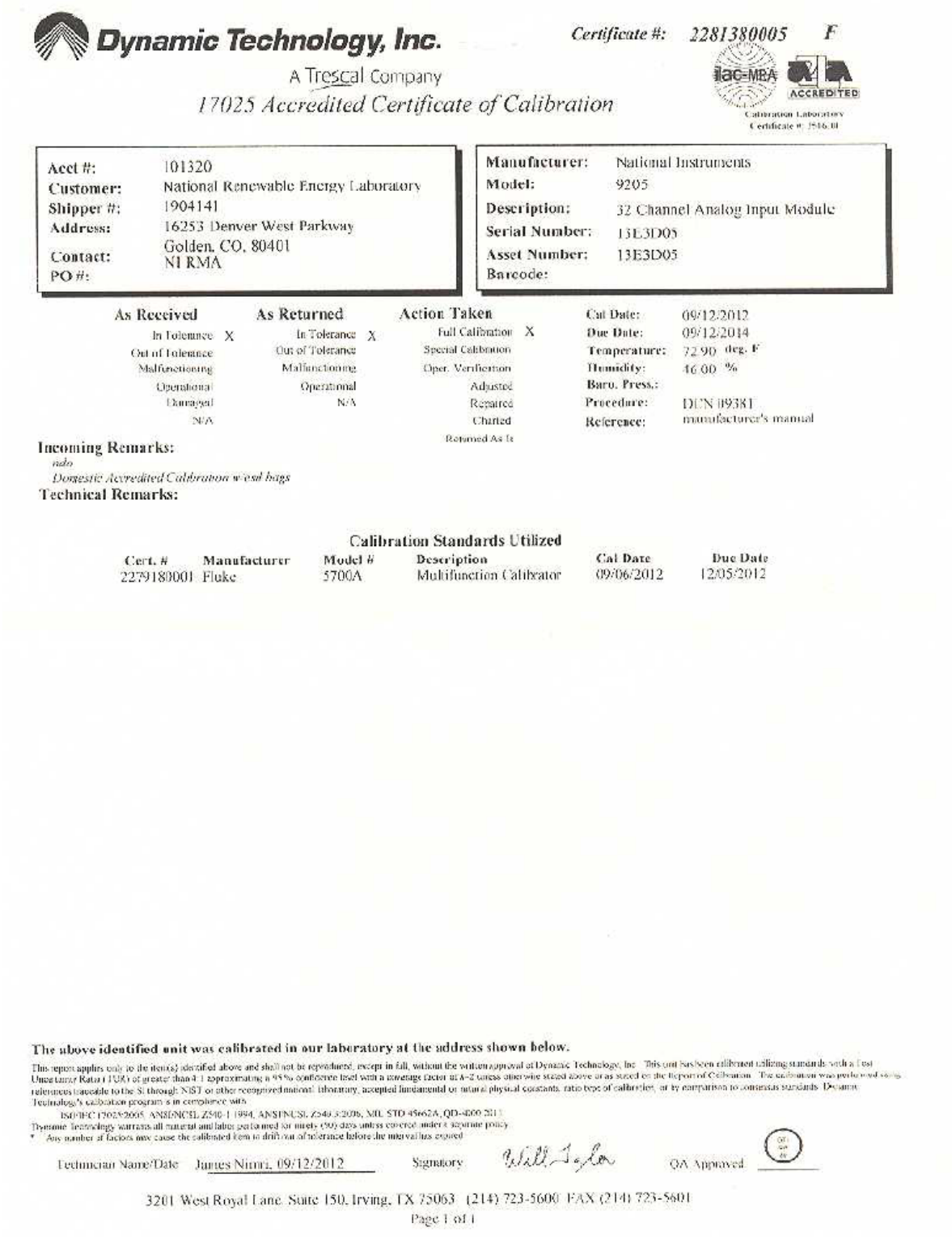
Figure A19. Calibration sheet for signal conditioning module 13E3D05 used through 26 July 2012



Dynamic Technology, Inc.

A Trescal Company

17025 Accredited Certificate of Calibration

Certificate #: *2281380005* *F*

ilac-MRA ACCREDITED

Calibration Laboratory
Certificate #: 3516.01

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	**Cal Date:**	09/12/2012
Out of Tolerance		Out of Tolerance		Special Calibration		**Due Date:**	09/12/2014
Malfunctioning		Malfunctioning		Oper. Verification		**Temperature:**	72.90 deg. F
Operational		Operational		Adjusted		**Humidity:**	46.00 %
Damaged		N/A		Repaired		**Baro. Press.:**	
N/A				Charted		**Procedure:**	DCN 09381
				Returned As Is		**Reference:**	manufacturer's manual

Incoming Remarks:

ndo

Domestic Accredited Calibration w/cal 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 noted 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-4600 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 Nimni, 09/12/2012 Signatory: Will Taylor QA Approved:

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Page 1 of 1

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

Dynamic Technology, Inc.

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Certificate #: 2225020003 F

DOE# 04373C

17025 Accredited Certificate of Calibration

ilac-MRA A2LA 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, Rich 7/27/12

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: QA Approved:

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Page 1 of 1

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

Appendix B. Turbine Commissioning Checklist

Commissioning Procedure for Vyrid CS8 Wind Turbine Generator at Site 3.3a
26 September 2011

1.0 Introduction

NREL will perform an acceptance test for the Vyrid CS8 to ensure proper installation and operation of the system prior to certification testing. This test will include, but not be limited to, an inspection of the wind generator installation, the tower, all electrical connections and fusing, the inverters for the system, the electrical connections throughout the system, and a safety inspection of the system. NREL staff will not do anything that will alter the long-term reliability or performance of the system during the acceptance test. NREL staff will not change any system set points without direct involvement of Viryd.

2.0 Documentation Review

NREL will review the Owner's Manual for the project to ensure adequacy. The manual should include a complete set of schematics, technical specifications, operating instructions, emergency procedures, maintenance procedures, and warranty information.

A final set of as-built drawings must be provided. These shall include electrical, mechanical, and physical drawings.

3.0 Visual Inspection

The system will be visually inspected for safety and compliance with accepted installation practices. Any deviation from the as-built will be noted. All fuses, circuit breakers, disconnect switches and wires will be inspected and their current ratings and type will be verified and compared to the one-line electrical diagram. The grounding system will be inspected. The turbine mounting and all turbine fasteners will be inspected.

Commissioning Checklist

Task	Date	Notes/Conducted by:
Viryd & electrical inspection		
Viryd commissioning procedure	10/6	JVR, NB
Electrical Inspection Completed	9/26	Wilde, confirmed via email
Inspection (tower & wiring)		
Visually inspect turbine components for any damage or deviations from normal	9/22	JVR, Mark, Nick Baker
Review final as-built drawings for system installation and verify that drawings and installation are in agreement	10/20	JVR Im
Verify all wire sized per manufacturer drawing and one-line drawing	9/26	JVR, Mark, Wilde
Verify 60 amp breaker size in power panel 3.3	10/6	Breaker #s: J7 + J9 JVR
Verify conductor sizing	9/22	JVR, Mark, Nick
Inspect tower, control box, supplemental box and met box grounding	9/26	Wilde, Roadman, Mark
Verify tower alignment & plumb	9/22	Nick Baker, Mark Murphy, Scott Wilde
Inverter performance		
List ways to shut down turbine, verify all - disconnect power (safest) - reset button in panel (not suggested)	10/6	JVR, Nick
Verify turbine and inverter shut off with grid disconnect at turbine specific disconnect	10/4	JVR Nick Jeroen Mark
Verify turbine and inverter shut off with grid disconnect at turbine breaker in power panel 3.3	10/5	JVR ND
Verify turbine restarts after grid loss was simulated and reset	10/4	JVR Nick
Second disconnect in test shed	10/6	JVR, Nick, Jeroen, Mark

* wireless off not working.
⇒ Zigbee download only

Figure B1. Viryd CS8 commissioning checklist, page 1

Performance in winds > cut-in wind speed		
Verify that turbine blades spin freely at 4.5 m/s or above	9/22	N/A, must motor to start
Verify freedom from excessive vibration	10/6	* JMR, NB, JvD, mm
Verify absence of unusual & excessive noise	10/6	
Verify power generation to manufacturer's power curve	10/20	JvD JMR
Verify RPM signal from controller	10/4	JMR, Mick, Mark
Verify "turbine status" signal from controller	10/4	JMR, Mick, Mark
Measure the frequency under load L2L 60Hz L2N 60Hz	10/6	JMR, NB
Measure the current under load	10/11	JMR, mm, Im
Measure the voltage under load L2N 122V L2L 244V	10/6	JMR, NB
Transfer to NREL L2N2 122V		
At least one NREL employee trained	10/11	JMR, NB, mm
⇒ Mark knows board/DIP switches		
⇒ Jason knows mechanical		

OK JMR NB

4.0 Acceptance of Commissioning Procedures

The installation of the Viryd Wind Turbine Generator at Site 3.3a has been reviewed and is in conformance with the commissioning procedures above. As a result, we hereby agree that this installation has been completed satisfactorily and approve that the turbine system is ready for NREL's Readiness Verification (i.e. safety review necessary for unattended operation) and Independent Testing (i.e. field testing to IEC standards).

Nicholas Baker, Viryd Technologies — 10/11/11 — Date **

Jason Roadman, NREL — 11/20/11 — Date

Seroen van Dam, NREL — 11/21/11 — DATE

*: guy wires too loose 10/4/11 NB JMR ⇒ retensioned before 10/6
tail vibration normal 10/4/11 JMR NB

**: Mark knows what to do w/ capacitor, but OK if doesn't go in

Figure B2. Viryd CS8 commissioning checklist, page 2

Appendix C. Post-Test Tear Down Inspection

The Viryd CS8 turbine was taken down from site 3.3a on 07 May 2013 after NREL engineers completed all testing activities as part of the U.S. DOE's Independent Testing project. A tear down inspection was performed as part of the duration test, and the report included the following observations.

Nose cone

The nose cone did not show any signs of wear. No cracks were found near any of the bolt holes.

Nacelle cover

The nacelle cover was found to be in good condition. Minor cracking could be seen in some of the gel coat, but no structural cracking was observed. Minor scrapes in the paint (Figure C1) were also found, caused by the turbine yawing with the covers lowered during the up-tower inspections.

Blades

The turbine blades were found to be in good shape. A small chip was observed on the leading edge of one of the blades (Figure C2). All blade roots showed signs of light rubbing on the hub clamping brackets (Figure C3).

Brake system

The brake system consists of two normally closed, pneumatically actuated brake calipers. The brake disk showed no signs of significant wear. The guide pins appeared in good condition, however, one was found to have loosened several turns (Figure C4). Although this loosening had not yet caused any wear or problems, it easily could have if it had continued to operate unchecked. All air hoses appeared in good condition. Brake pad thickness was measured to be 0.31" for both pads on the rotor side. Brake pad thickness was measured to be 0.31" and 0.31" on the downwind side. The compressor was supplied with 24 VDC during the inspection and was found to be inoperative. NREL engineers believe that the failure of the compressor led to the turbine's inability to produce power after 1 February 2013 and the subsequent termination of the test.

Gearbox

The gearbox and oil were visually inspected. No cracking, chipping, or excessive wear were observed on any of the gearbox components. Minor amounts of grease were found inside the gearbox (Figure C5); however, the oil was in good condition.

Yaw system

All welds on the yaw head were visually inspected and no cracks were found. The yaw bearing rotated smoothly and showed no signs of excessive play.

Generator

The generator was not disassembled to the point where the windings could be inspected. The outside of the housing and cooling fan appeared in good condition.

Tail assembly

The tail vane was inspected visually, and no cracks were found. The tail boom did not have any cracks or signs of wear. The fasteners attaching the tail were rusted (Figure C6).

Up-tower electrical components

The up-tower electrical components included:

- Start and run capacitors. The start and (one of two) run capacitors appeared in good shape. The second run capacitor, shown in Figure C7, had a hole in the can that was close to where the mechanical retaining strap contacted the case. Electrolyte leakage was observed inside the junction box containing the capacitors. Tests of the capacitors showed that both run capacitors had failed.
- Slipring assembly. The slipring assembly did not show any unexpected wear, signs of arcing, or overheating.
- Terminal blocks. The terminal blocks were intact with all connections tight.
- General wiring. All wiring appeared in good condition, with no signs of wear or overheating on any of the loom or insulation.[3]

Tower

The tower was visually inspected, and no cracked welds were found. All fasteners and locknuts were present. During the test, following strong rain storms, water was found in the loop at the bottom of the down tower conduit. Improved waterproofing of the control anemometer junction box was conducted at Viryd's request, thereby alleviating ingress of water.

The winch, gin-pole, and associated rigging were all found to be in good condition at the end of the test. The system was used to lower the turbine during decommissioning and performed as expected.

Foundation

The foundation and guy wire attachment plates were visually inspected. The concrete was in good condition, with no cracking or excessive corrosion, and all fasteners were still tight.

Controller

The controller was visually inspected. All wires were in good condition, with no signs of wear or overheating. Connections showed no evidence of damage caused by the elements.

[3] The condition of the wiring inside the generator was not inspected.

Figure C1. Scratches on Viryd nacelle cover

Figure C2. Chip discovered on leading edge of blade

Figure C3. Blade root

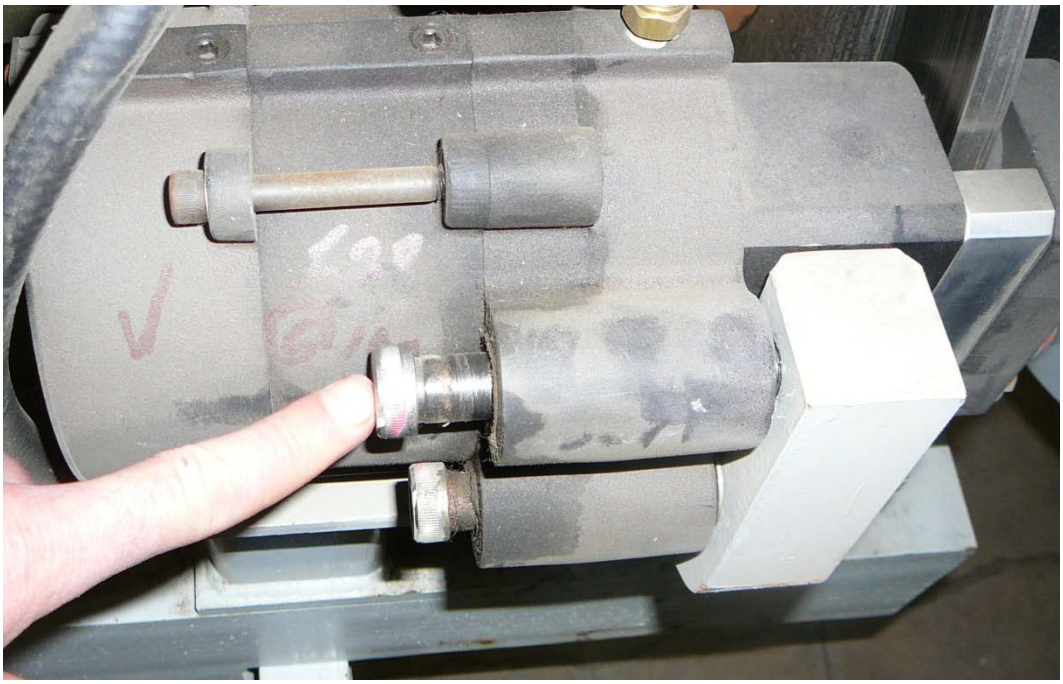

Figure C4. Loosened brake caliper bolt

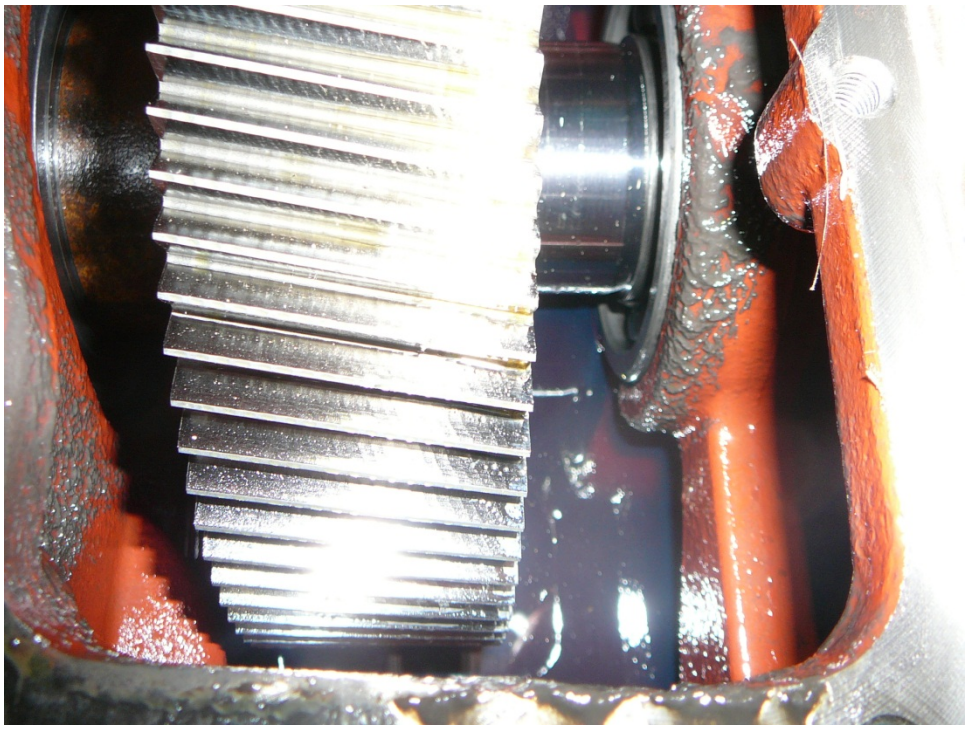

Figure C5. Inspection inside gearbox

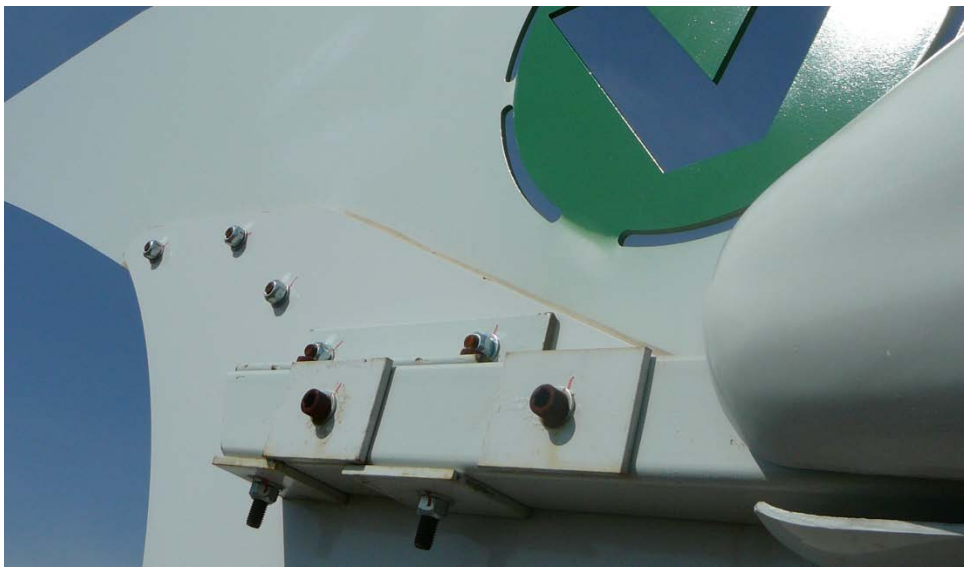

Figure C6. Rusty fasteners on tail

Figure C7. Failed run capacitor