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Power Performance 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-5000-56500
December 2012

Contract No. DE-AC36-08GO28308

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Prepared under Task No. WE11.0206

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Power Performance Test Report

for the

Viryd CS8 Wind Turbine

at the
National Wind Technology Center

Golden, Colorado

Conducted by
National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, Colorado 80401
for
Wind Energy Program
DOE/NREL

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15 August 2012

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Approval By: _____ 1 November 2012
Jeroen van Dam, NREL Test Engineer — Date

Review By: _____ 1 November 2012
Arlinda Huskey, NREL Test Engineer — Date

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Test Objective

The objective of this test is to measure the power performance characteristics of the Viryd CS8 wind turbine in accordance with the International Electrotechnical Commission's (IEC) standard, *Wind Turbines – Part 12-1: Power Performance Measurements of Electricity Producing Wind Turbines; First Edition 2005-12* [1] and specifically Annex H of that standard related to small wind turbines. Hereafter, this document is referred to as "the standard."

In addition, the National Wind Technology Center (NWTC) at the National Renewable Energy Laboratory (NREL) conducted this test in accordance with its quality system procedures; so that the final test report will meet the full requirements for accreditation by A2LA. NREL's quality system requires that all applicable requirements specified by A2LA and ISO/IEC 17025 be met or to note any exceptions in the test report.

Test Summary

Figure 1 provides a summary of the power performance test results. These results are normalized to sea-level air density.

This test was begun on 12 October 2011, and ended on 4 February 2012. During that time, 741 hours of valid data were collected. The highest bin filled was the 19 meters per second (m/s) bin. According to the standard, enough data was collected to construct a complete power curve.

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Power Performance Test in compliance with IEC 61400-12-1
Viryd CS-8

Sea-Level Density Power Curve

Turbine Specifications:

Rated Power:	8	kW
Cut-in Wind Speed:	4.5	m/s
Cut-out Wind Speed:	25	m/s
Rated Wind Speed:	10	m/s
Rotor Diameter:	8.5	m
Control Type:	Stall	
Pitch Setting:	Fixed	

Site Conditions:

Measured Avg. Air Density:	1.026	kg/m^3
Measurement Sector:	211°-38°	

Test Statistics:

Start Date:	12-Oct-2011	
End Date:	4-Feb-2012	
Amount of Data Collected:	739.72	hours
Highest Bin Filled:	19.00	m/s
Test Completed?	Yes	

Bin Wind Speed (m/s)	Bin Power (kW)	Number Data Points	Cp	TI
0.54	-0.02	1,353	-2.87	0.15
1.02	-0.02	2,598	-0.47	0.12
1.51	-0.02	3,497	-0.14	0.10
2.00	-0.03	4,037	-0.09	0.09
2.50	-0.02	4,099	-0.05	0.08
3.00	-0.03	3,919	-0.03	0.08
3.49	-0.05	3,168	-0.03	0.08
4.00	-0.07	2,732	-0.03	0.09
4.49	-0.08	2,439	-0.03	0.09
4.99	-0.05	1,936	-0.01	0.10
5.49	0.11	1,738	0.02	0.11
6.00	0.49	1,475	0.07	0.11
6.50	1.17	1,318	0.12	0.12
7.00	2.12	1,203	0.18	0.12
7.50	2.96	1,135	0.20	0.12
7.99	3.88	1,073	0.22	0.12
8.49	4.68	1,009	0.22	0.12
8.99	5.59	833	0.22	0.12
9.50	6.28	786	0.21	0.12
9.99	6.80	621	0.20	0.12
10.49	7.07	545	0.18	0.13
10.99	7.58	487	0.16	0.13
11.50	7.50	413	0.14	0.12
12.00	7.39	355	0.12	0.12
12.48	7.52	296	0.11	0.13
12.98	7.17	261	0.09	0.12
13.50	6.74	218	0.08	0.13
14.00	6.56	176	0.07	0.13
14.50	6.24	166	0.06	0.13
14.99	5.96	119	0.05	0.13
15.50	5.75	94	0.04	0.13
15.99	5.69	91	0.04	0.13
16.51	5.43	54	0.03	0.13
16.96	5.34	54	0.03	0.13
17.53	4.80	32	0.03	0.12
18.02	4.88	21	0.02	0.12
18.51	4.88	18	0.02	0.10
19.00	4.94	14	0.02	0.13

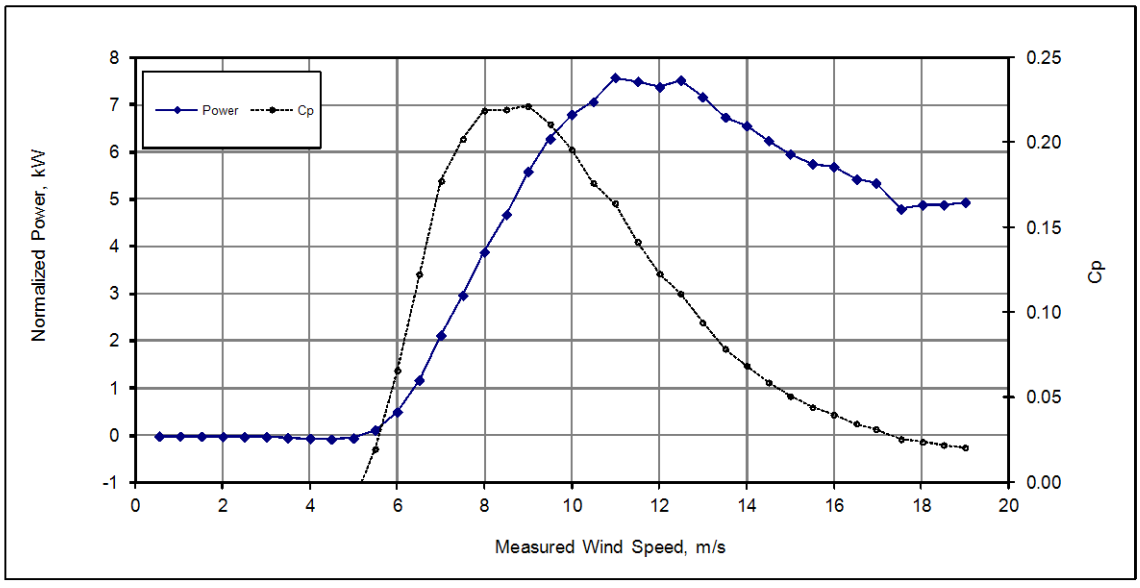

Figure 1. Power curve summary

Test Turbine Configuration

The test turbine was a horizontal-axis, three-bladed, upwind wind turbine. Table 1 provides the key details on the test turbine. Figure 2 shows the test turbine and Figure 3 shows an electrical schematic of the turbine installation.

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
Rotor speed range (rpm)	115–125
Fixed or variable pitch	Fixed
Number of blades	3
Blade pitch angle (deg)	See Table 2
Blade make, type, serial number	Viryd proprietary design, serial numbers not provided
Description of control system (device and software version)	Proprietary – PCB

NREL confirmed the rotor diameter by independent measurement. Small shims were inserted between the hub plate and the blade root, pitching the leading edge of the blades into the wind. The pitch angle of each blade with respect to the hub plate was measured and given below.

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

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

Figure 2. The Viryd CS8 test turbine at NREL (Source: NREL PIX 22258)

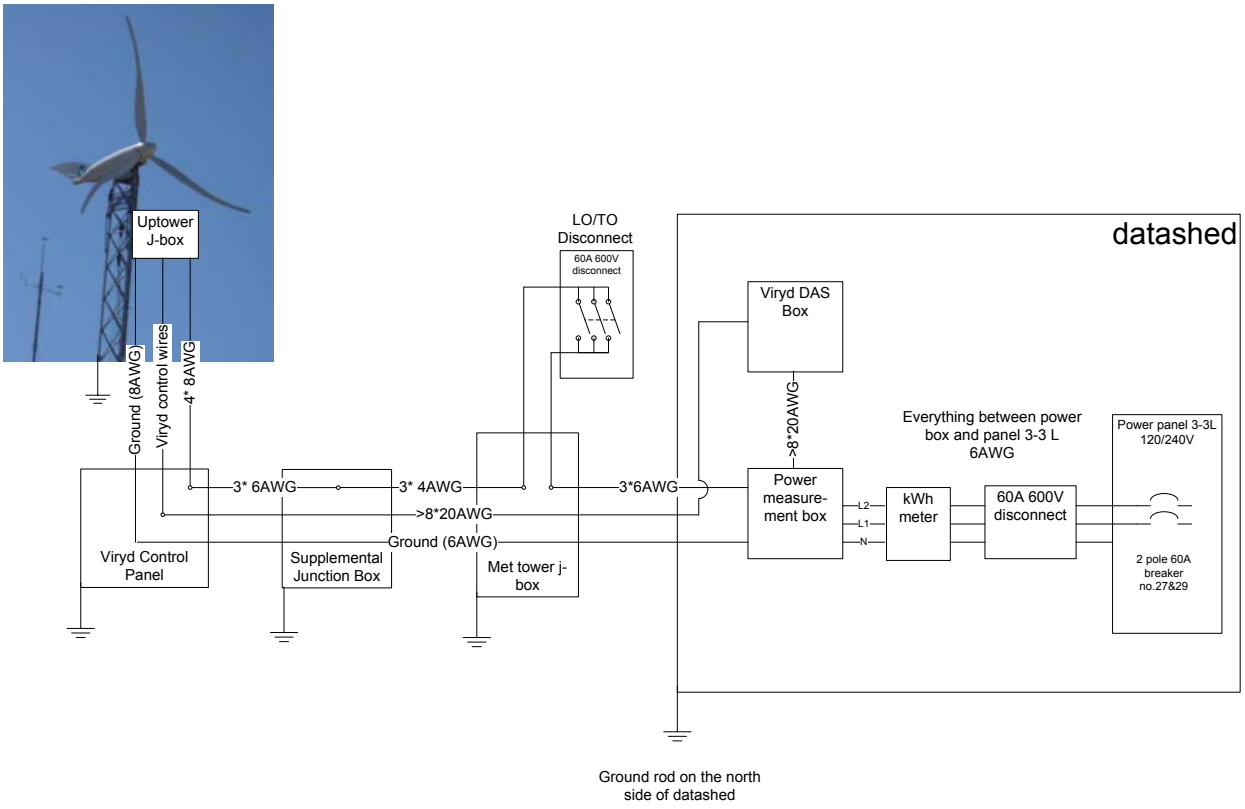

Figure 3. Electrical schematic of turbine installation

Test Site Description

The turbine is located at test site 3.3a of the NWTC, approximately 8 miles south of Boulder, Colorado. Figure 4 and Figure 5 show the turbine and meteorological (met) tower locations. These figures also show nearby obstructions and topographical features of the site.

Table 3 shows the terrain assessment completed according to Annex B of the standard. The terrain meets the requirements of the standard, thus, no site calibration was required. Figure 4 and Table 4 show the neighboring turbines and obstacles. Based on these criteria, the measurement sector for the power performance was determined to be 211–38°. Pictures of the test site taken from hub height are included in Appendix A.

The turbine is connected to a 240-volt (V) panel, where a 240–480-V and 480-V–13.2-kilovolt (kV) transformer is connected to a 13.2-kV grid. Grid tolerances are 1% for frequency and 5% for voltage.

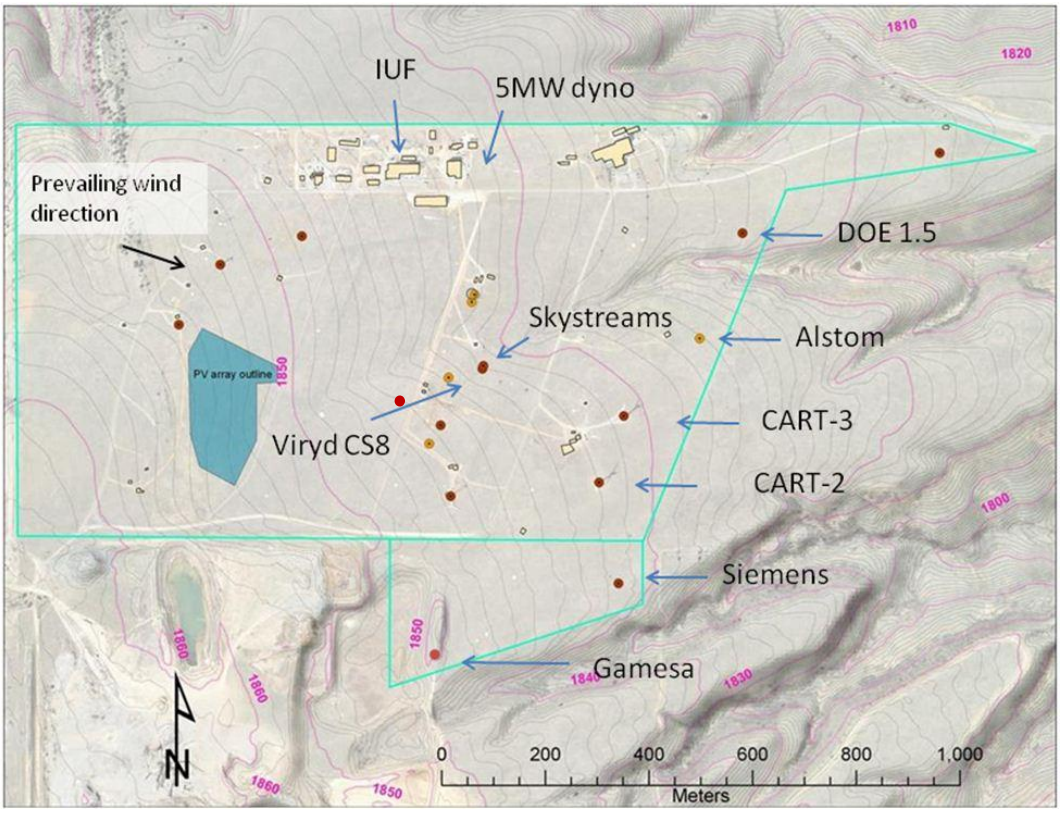

Figure 4. Map of the test site (Source: NREL 2012)

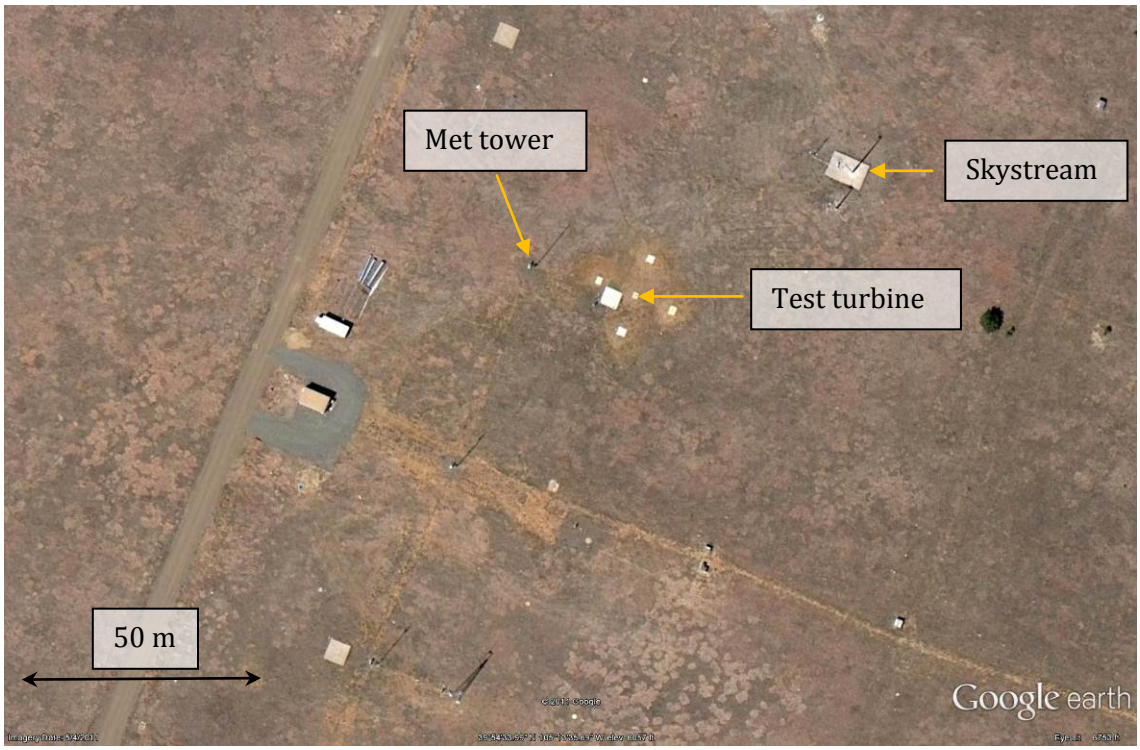

Figure 5. Close up of test site around the test turbine (Source: Google earth)

Table 3. Terrain Assessment

Viryd **Site: 3.3a**

Preliminary Measurement Sector: **211** to **38** deg True

Criteria for Test Site without Site Calibration Testing

Criterion	Description	Distance	Sector (deg)	*allowable*	Test Site Condition	Pass/Fail
1	Maximum slope of best fit plane < 3%	<2L	360	*3%*	2.8%	Pass
2	Maximum variation from best fit plane < 0.04 (H + D)	<2L	360	*+/-1.3m*	0.1	Pass
3	Maximum slope of best fit plane < 5%	2-4L	In	*5%*	2.7%	Pass
4	Maximum variation from best fit plane < 0.08 (H + D)	2-4L	In	*+/-2.7m*	0.4	Pass
5	Steepest slope maximum < 10%	2-4L	Out	*10%*	3.5%	Pass
6	Maximum slope of best fit plane < 10%	4-8L	In	*10%*	2.2%	Pass
7	Maximum variation from best fit plane < 0.13 (H + D)	4-8L	In	*+/-4.3m*	1.2	Pass
8	Steepest slope maximum < 10%	8-16L	In	*10%*	2.3%	Pass
9	No neighboring and operating turbines	$<2D_n$	360	*0*	0	Pass
10	No obstacles	$<2D_e$	360	*0*	0	Pass

Site Calibration Required? **no**

absolute value used for site condition

In = Inside Preliminary Measurement Sector

Out = Outside Preliminary Measurement Sector

Table 4. Neighboring Turbines and Obstacles

Obstacle or Turbine	Relative to:	Distance (m)	Bearing (deg T)	Obstructed Sector	
				Start (deg T)	End (deg T)
DOE 1.5	Test Turbine	620	63	39	80
Alstom	Test Turbine	474	80	49	102
CART-3	Test Turbine	322	102	72	115
CART-2	Test Turbine	332	126	97	139
Siemens	Test Turbine	501	142	109	164
Gamesa	Test Turbine	516	185	156	210
Industrial User Facility (IUF)	Test Turbine	420	345	334	4
5-MW dyno	Test Turbine	394	2	347	20
Viryd CS8 (test turbine)	Met Tower	21	106	79	150
DOE 1.5	Met Tower	636	64	41	82
Alstom	Met Tower	492	81	51	103
CART-3	Met Tower	343	102	74	116
CART-2	Met Tower	352	125	97	138
Siemens	Met Tower	518	140	109	162
Gamesa	Met Tower	520	183	154	207
IUF	Met Tower	410	348	336	6
5-MW dyno	Met Tower	390	5	350	23

Test Instrumentation

The data channels that were collected by the data acquisition system are listed in Table 5. For all sensors in-field, end-to-end checks were performed to verify proper installation.

Table 5. List of Channels and Measurement Instruments

Signal	Location	Sensor Make Model	Serial Number	Cal Due Date
WS_hub_height	24.9 m	Thies First Class	0707884	12 Sept. 2012
WS_Reference	23 m	Met One, 010C	U2643	NA
Wind_Direction	23 m	Met One, 020	U1475	13 Sept. 2012
Air_Pressure	22.1m	Vaisala, PTB101B	T0740016	5 April 2012
Air_Temperature	22.4 m	Met One, T-200	0566229	15 Sept. 2012
Precipitation	Data Shed	Campbell Scientific 237	NA	NA
Active_Power	Data Shed	Secondwind Phaser 5-4A20 with OSI pn. 12973 CT's	01091	15 Sept. 2012
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 13FAE1C 13E3D05	24 June 2012 24 June 2012 24 June 2012

Figure 6 shows a photograph of the met tower and the instruments used for the power performance test. The cross boom with the wind vane is approximately perpendicular to the predominant wind direction. Air temperature is measured in a radiation shield that is mounted off the met tower.

An in-situ comparison was performed on the anemometers. The results are given in Table 6 and show that the anemometer maintained its calibration over the test period as the maximum square sum of the systemic deviation and standard uncertainty is less than 0.1 m/s.

Table 6. In-Situ Comparison Results

	First 900 data points			Last 900 data points					
Wind speed bin m/s	Primary wind speed [m/s]	Ref. wind speed [m/s]	# Data points	Primary wind speed [m/s]	Ref. wind speed [m/s]	# Data points	Systemic deviation [m/s]	Standard uncert. [m/s]	In-situ comp. result [m/s]
6	5.99	5.87	201	5.87	5.70	124	-0.04	0.008	0.042
7	6.98	6.82	202	7.05	6.92	62	0.03	0.014	0.035
8	8.02	7.82	179	8.00	7.82	96	0.01	0.011	0.018
9	9.03	8.80	111	8.99	8.77	131	0.00	0.010	0.010
10	9.92	9.67	88	10.02	9.73	185	-0.04	0.008	0.037
11	10.96	10.67	62	10.96	10.65	150	-0.03	0.009	0.034
12	12.04	11.73	57	11.99	11.65	152	-0.03	0.009	0.034

Turbine status is monitored by measuring the voltage on the green (generating power), red (fault), and blue (wind status) light-emitting diodes (LEDs) on the controller cabinet as well as the brake solenoid voltage.

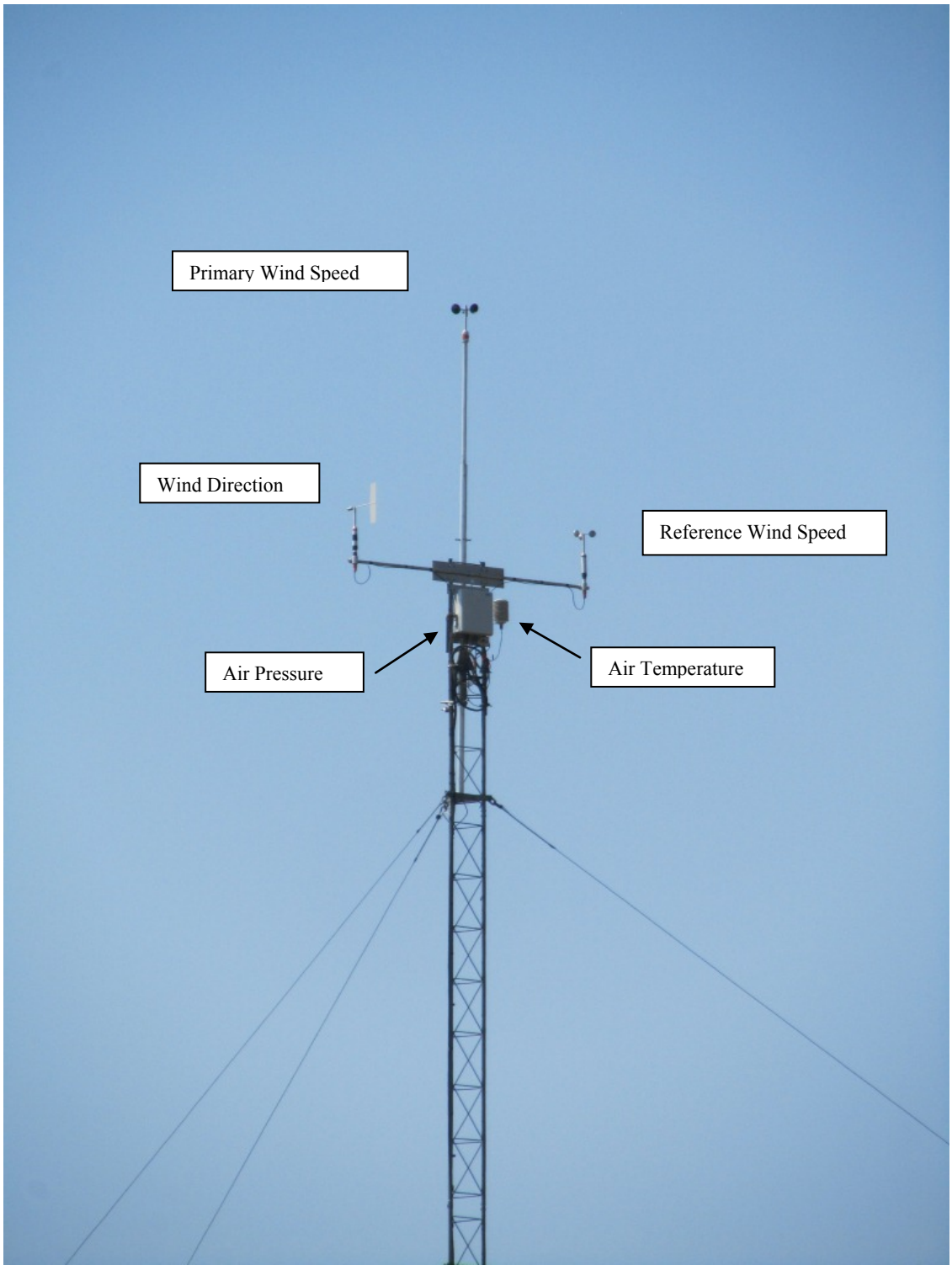

Figure 6. View of instruments on the met tower (Source: NREL 2012)

Measurement Procedure

One-minute statistics were stored for all channels.

Data was removed for:

1. Any obvious problems with the data acquisition system (DAS) (such as dropouts, flat lined, or maintenance)
2. Wind outside the measurement sector
3. Observations of icing on the blades or anemometer impacted by icing
4. The 1-minute maximum of the turbine fault LED voltage being at or above 5% of its high (faulted) value. This criterion was chosen because the LED blinks in different patterns and duty cycles during various fault conditions.
5. Known faults within turbine hardware including an inoperable control system power supply and a broken turbine anemometer.

NREL kept a logbook; a copy is available upon request. No special maintenance activities that could impact the power performance test (such as blade washing) were observed by or reported to NREL.

Results

This test began on October 12, 2011, and ended on February 4, 2012. During that time, 741 hours of available data was collected. The highest bin filled was the 19 m/s bin. According to the standard, enough data was collected to construct a complete power curve. Because no cut-out hysteresis was observed, only database A was reported.

Tabular Results of Power Performance Test

The tabular results are provided below for sea-level and site-average densities. The measured average air density was 1.026 kg/m^3, which, when rounded to the nearest 0.05 kg/m^3, is 1.05kg/m^3.

Table 7. Performance at Sea-Level Air Density, 1.225 kg/m^3, Database A

Bin	Normalized wind speed (m/s)	Power output (kW)	Power coefficient	Number of 1-minute data sets	Category A uncertainty (kW)	Category B uncertainty (kW)	Combined uncertainty (kW)
1	0.54	0.0	-2.87	1353	0.0	0.1	0.1
2	1.02	0.0	-0.47	2598	0.0	0.1	0.1
3	1.51	0.0	-0.14	3497	0.0	0.1	0.1
4	2.00	0.0	-0.09	4037	0.0	0.1	0.1
5	2.50	0.0	-0.05	4099	0.0	0.1	0.1
6	3.00	0.0	-0.03	3919	0.0	0.1	0.1
7	3.49	0.0	-0.03	3168	0.0	0.1	0.1
8	4.00	-0.1	-0.03	2732	0.0	0.1	0.1
9	4.49	-0.1	-0.03	2439	0.0	0.1	0.1
10	4.99	-0.1	-0.01	1936	0.0	0.1	0.1
11	5.49	0.1	0.02	1738	0.0	0.1	0.1
12	6.00	0.5	0.07	1475	0.0	0.2	0.2
13	6.50	1.2	0.12	1318	0.0	0.2	0.2
14	7.00	2.1	0.18	1203	0.0	0.3	0.3
15	7.50	3.0	0.20	1135	0.1	0.3	0.3
16	7.99	3.9	0.22	1073	0.1	0.4	0.4
17	8.49	4.7	0.22	1009	0.1	0.3	0.3
18	8.99	5.6	0.22	833	0.1	0.4	0.4
19	9.50	6.3	0.21	786	0.1	0.3	0.3
20	9.99	6.8	0.20	621	0.1	0.3	0.3
21	10.49	7.1	0.18	545	0.1	0.2	0.2
22	10.99	7.6	0.16	487	0.1	0.3	0.3
23	11.50	7.5	0.14	413	0.1	0.1	0.2
24	12.00	7.4	0.12	355	0.1	0.1	0.2
25	12.48	7.5	0.11	296	0.1	0.1	0.2
26	12.98	7.2	0.09	261	0.1	0.2	0.2
27	13.50	6.7	0.08	218	0.1	0.3	0.3
28	14.00	6.6	0.07	176	0.1	0.2	0.2
29	14.50	6.2	0.06	166	0.1	0.2	0.2
30	14.99	6.0	0.05	119	0.1	0.2	0.2
31	15.50	5.8	0.04	94	0.1	0.2	0.2
32	15.99	5.7	0.04	91	0.0	0.1	0.1
33	16.51	5.4	0.03	54	0.1	0.2	0.2
34	16.96	5.3	0.03	54	0.1	0.1	0.2
35	17.53	4.8	0.03	32	0.2	0.4	0.4
36	18.02	4.9	0.02	21	0.1	0.1	0.2
37	18.51	4.9	0.02	18	0.1	0.1	0.2
38	19.00	4.9	0.02	14	0.1	0.1	0.1

Table 8. Performance at Site-Average Density, 1.05 kg/m^3, Database A

Bin	Normalized wind speed (m/s)	Power output (kW)	Power coefficient	Number of 1-minute data sets	Category A uncertainty (kW)	Category B uncertainty (kW)	Combined uncertainty (kW)
1	0.54	0.0	-2.87	1353	0.0	0.1	0.1
2	1.02	0.0	-0.47	2598	0.0	0.1	0.1
3	1.51	0.0	-0.14	3497	0.0	0.1	0.1
4	2.00	0.0	-0.09	4037	0.0	0.1	0.1
5	2.50	0.0	-0.05	4099	0.0	0.1	0.1
6	3.00	0.0	-0.03	3919	0.0	0.1	0.1
7	3.49	0.0	-0.03	3168	0.0	0.1	0.1
8	4.00	-0.1	-0.03	2732	0.0	0.1	0.1
9	4.49	-0.1	-0.03	2439	0.0	0.1	0.1
10	4.99	0.0	-0.01	1936	0.0	0.1	0.1
11	5.49	0.1	0.02	1738	0.0	0.1	0.1
12	6.00	0.4	0.07	1475	0.0	0.1	0.1
13	6.50	1.0	0.12	1318	0.0	0.2	0.2
14	7.00	1.8	0.18	1203	0.0	0.3	0.3
15	7.50	2.5	0.20	1135	0.0	0.3	0.3
16	7.99	3.3	0.22	1073	0.1	0.3	0.3
17	8.49	4.0	0.22	1009	0.1	0.3	0.3
18	8.99	4.8	0.22	833	0.1	0.4	0.4
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22	10.99	6.5	0.16	487	0.1	0.3	0.3
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27	13.50	5.8	0.08	218	0.1	0.2	0.3
28	14.00	5.6	0.07	176	0.1	0.2	0.2
29	14.50	5.4	0.06	166	0.1	0.2	0.2
30	14.99	5.1	0.05	119	0.1	0.2	0.2
31	15.50	4.9	0.04	94	0.0	0.2	0.2
32	15.99	4.9	0.04	91	0.0	0.1	0.1
33	16.51	4.7	0.03	54	0.1	0.2	0.2
34	16.96	4.6	0.03	54	0.1	0.1	0.1
35	17.53	4.1	0.03	32	0.2	0.3	0.4
36	18.02	4.2	0.02	21	0.1	0.1	0.2
37	18.51	4.2	0.02	18	0.1	0.1	0.2
38	19.00	4.2	0.02	14	0.1	0.1	0.1

Table 9. Annual Energy Production at Sea-Level Density, 1.225 kg/m^3; Database A

Estimated Annual Energy Production (AEP), Database A (All Valid Data)					
Reference air density:		1.225	kg/m^3		
Cut-out wind speed:		25.00	m/s		
Hub Height Annual Average Wind Speed (Rayleigh)	**AEP-Measured**	**Standard Uncertainty in AEP-Measured**		**AEP-Extrapolated**	**Complete if AEP Measured is at Least 95% of AEP Extrapolated**
m/s	**kWh**	**kWh**	**%**	**kWh**	
4	4,045	1,279	32%	4,045	Complete
5	10,132	1,533	15%	10,132	Complete
6	17,011	1,709	10%	17,028	Complete
7	23,211	1,806	8%	23,342	Complete
8	27,991	1,841	7%	28,487	Complete
9	31,166	1,829	6%	32,372	Complete
10	32,881	1,784	5%	35,103	Incomplete
11	33,425	1,714	5%	36,833	Incomplete
AEP measured assumes zero power between highest bin and cut-out					
AEP extrapolated assumes power in last bin between last bin and cut-out					

Table 10. Annual Energy Production at Site-Average Density, 1.05 kg/m^3; Database A

Estimated Annual Energy Production (AEP), Database A (All Valid Data)					
Reference air density:		1.05	kg/m^3		
Cut-out wind speed:		25.00	m/s		
Hub Height Annual Average Wind Speed (Rayleigh)	**AEP-Measured**	**Standard Uncertainty in AEP-Measured**		**AEP-Extrapolated**	**Complete if AEP Measured is at Least 95% of AEP Extrapolated**
m/s	**kWh**	**kWh**	**%**	**kWh**	
4	3,467	1,216	35%	3,467	Complete
5	8,684	1,421	16%	8,685	Complete
6	14,581	1,563	11%	14,595	Complete
7	19,895	1,640	8%	20,008	Complete
8	23,992	1,666	7%	24,417	Complete
9	26,714	1,653	6%	27,748	Complete
10	28,183	1,611	6%	30,088	Incomplete
11	28,650	1,547	5%	31,571	Incomplete
AEP measured assumes zero power between highest bin and cut-out					
AEP extrapolated assumes power in last bin between last bin and cut-out					

Graphical Results

Graphical results for power curve, power coefficient, and turbulence intensity are given below.

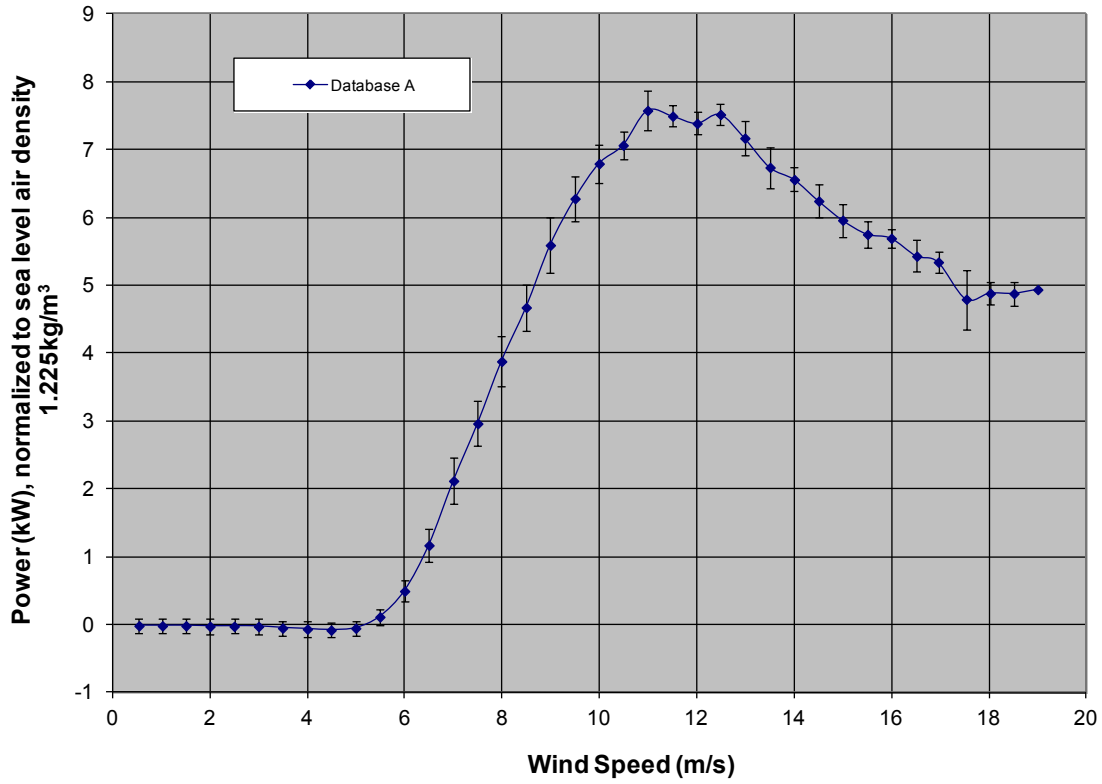


Figure 7. Power curve at sea-level density, 1.225 kg/m^3, database A

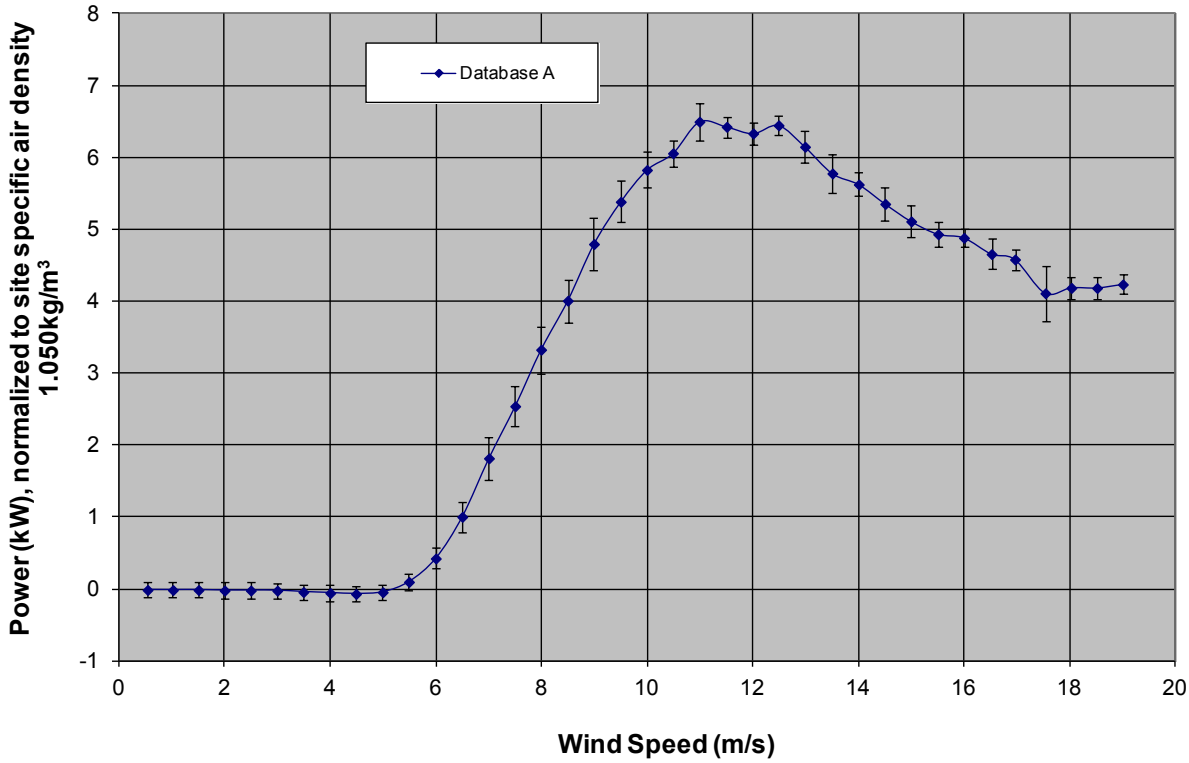


Figure 8. Power curve at site-specific density, 1.05 kg/m^3, database A

The scatter plot below shows the mean, standard deviation, minimum, and maximum power for the 1-minute data points for database A. The large negative values for the minima are caused by the turbine motoring the rotor upon start up. Initially the power transducer was set up for a minimum power level of -12 kilowatts (kW). As the power transducer railed, the setting was changed to allow a minimum power reading of -24 kW. After this change, the power transducer still railed. High-speed measurements showed that the power draw peak was very short in duration and there was a negligible effect on the 1-minute average power values and thus the power curve and AEP calculations. The power transducer limits were left unchanged to avoid sacrificing resolution.

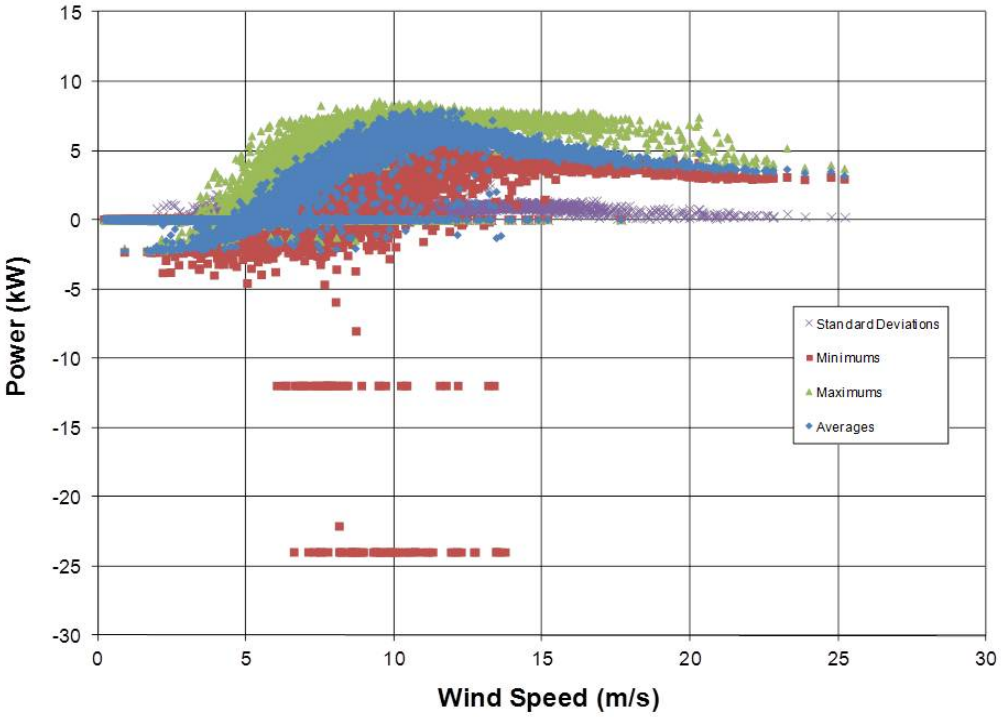


Figure 9. Scatter plot of mean, standard deviation, minimum, and maximum power, database A

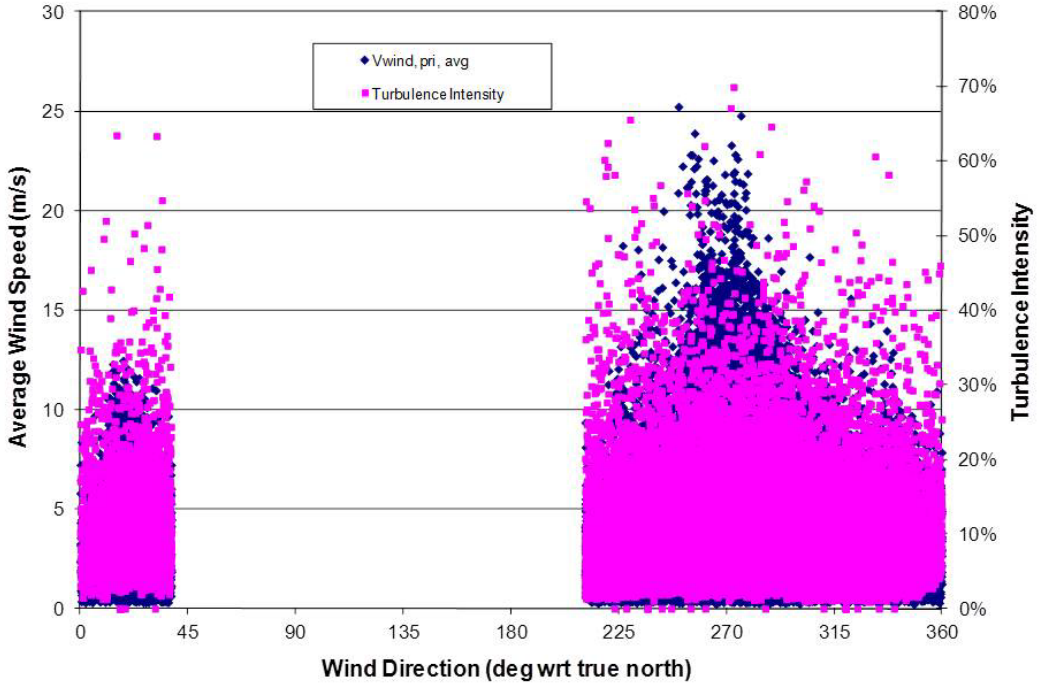


Figure 10. Wind speed and turbulence intensity as a function of wind direction (one-minute values based on a 1-Hz sample rate)

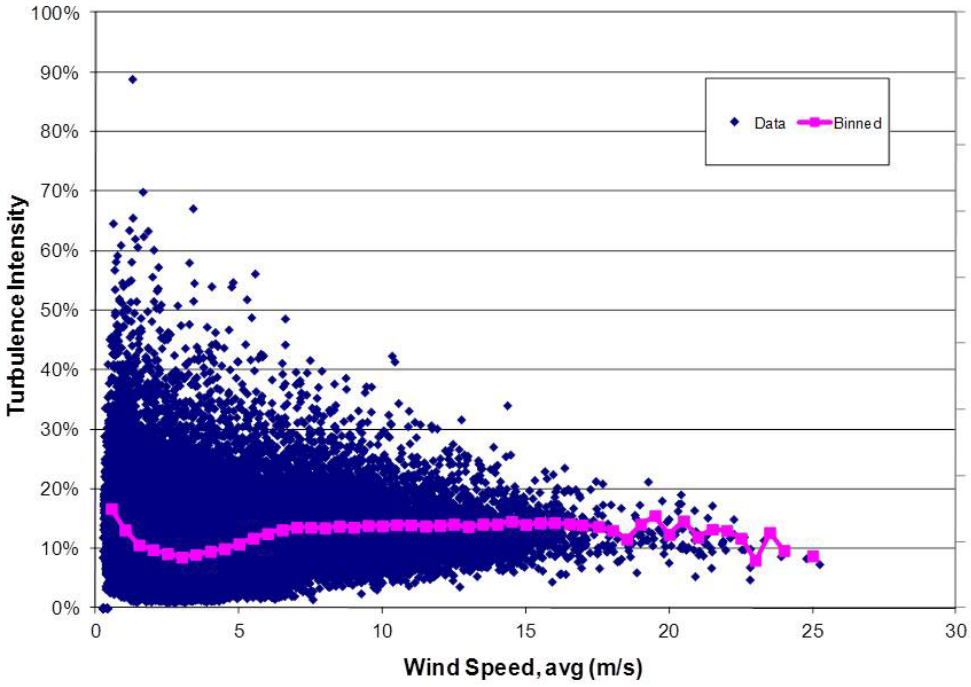


Figure 11. One-minute average (based on 1 Hz) and bin average values of turbulence intensity as a function of measured wind speed

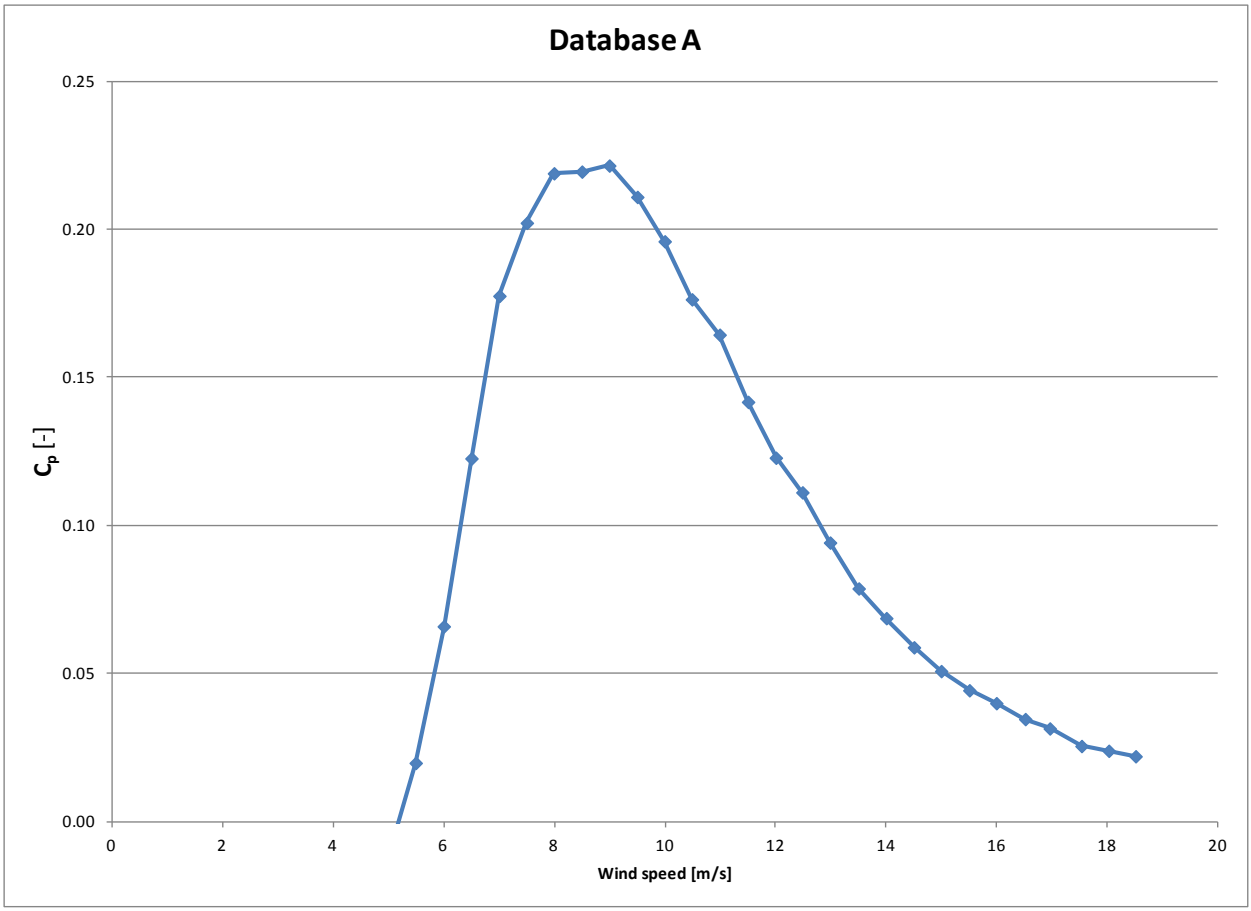


Figure 12. Power coefficient C_p for sea-level average density, 1.225 kg/m^3; database A, with turbine rotor swept area = 56.7m^2

Uncertainty

The uncertainty analysis was performed in accordance with the standard. The Type A uncertainty in each wind speed bin is based on the standard deviation of the power values in the bin (Section E.4 of the Standard). The Type B uncertainties are related to the uncertainties in the instrumentation and terrain. The Type B uncertainty reported above was based on the values listed in Table 11. The Type A and Type B uncertainty are combined to get the combined standard uncertainty.

Table 11. Uncertainty Values Used in the Analysis

Component	Uncertainty, Fixed	Uncertainty, % Reading	Source
Power (kW)	0.11	0.53%	
Current transformers		0.52%	Instrument specifications
Power transducer	0.01		Instrument specifications
Data acquisition	0.11	0.08%	Instrument specifications
Wind Speed (m/s)	0.06	2.25%	
Calibration	0.05		Cal sheet
Operational char.	0.03	0.26%	IEC eq I.2
Mounting effects		1.00%	Assumption-based on standard
Terrain effects		2.00%	Standard
Data acquisition	0.00		Algorithm
Temperature (K)	0.72	0.00%	
Temperature sensor	0.15		Instrument specifications
Radiation shielding	0.60		Assumption
Mounting effects	0.09		Assumption
Data acquisition	0.35		Instrument specifications
Air Pressure (kPa)	0.24	0.00%	
Pressure sensor	0.23		Instrument specifications
Mounting effects	0.00		10% of average correction
Data acquisition	0.06		Instrument specifications

Exceptions

Exceptions to Standard

The power transducer rails at -24 kW when the turbine motors the rotor upon start up. High-speed data showed no significant impact on the 1-minute average values.

Exceptions to NWTC Quality Assurance System

None

References

[1] “Wind Turbines - Power performance measurements of electricity producing wind turbines,” IEC 61400-12-1 First edition, 2005-12.

[2] “Wind Turbine Generator System Power Performance Test Plan for the Viryd CS-8 Wind Turbine,” J. Roadman, M. Murphy, J. van Dam, November 2011.

Appendix A: Pictures of Test Site

Figure 13. View towards the southwest (Source: NREL 2012)

Figure 14. View towards the west (Source: NREL 2012)

Figure 15. View towards the northwest (Source: NREL 2012)

Figure 16. View towards the north (Source: NREL 2012)

Figure 17. View towards the northeast (Source: NREL 2012)

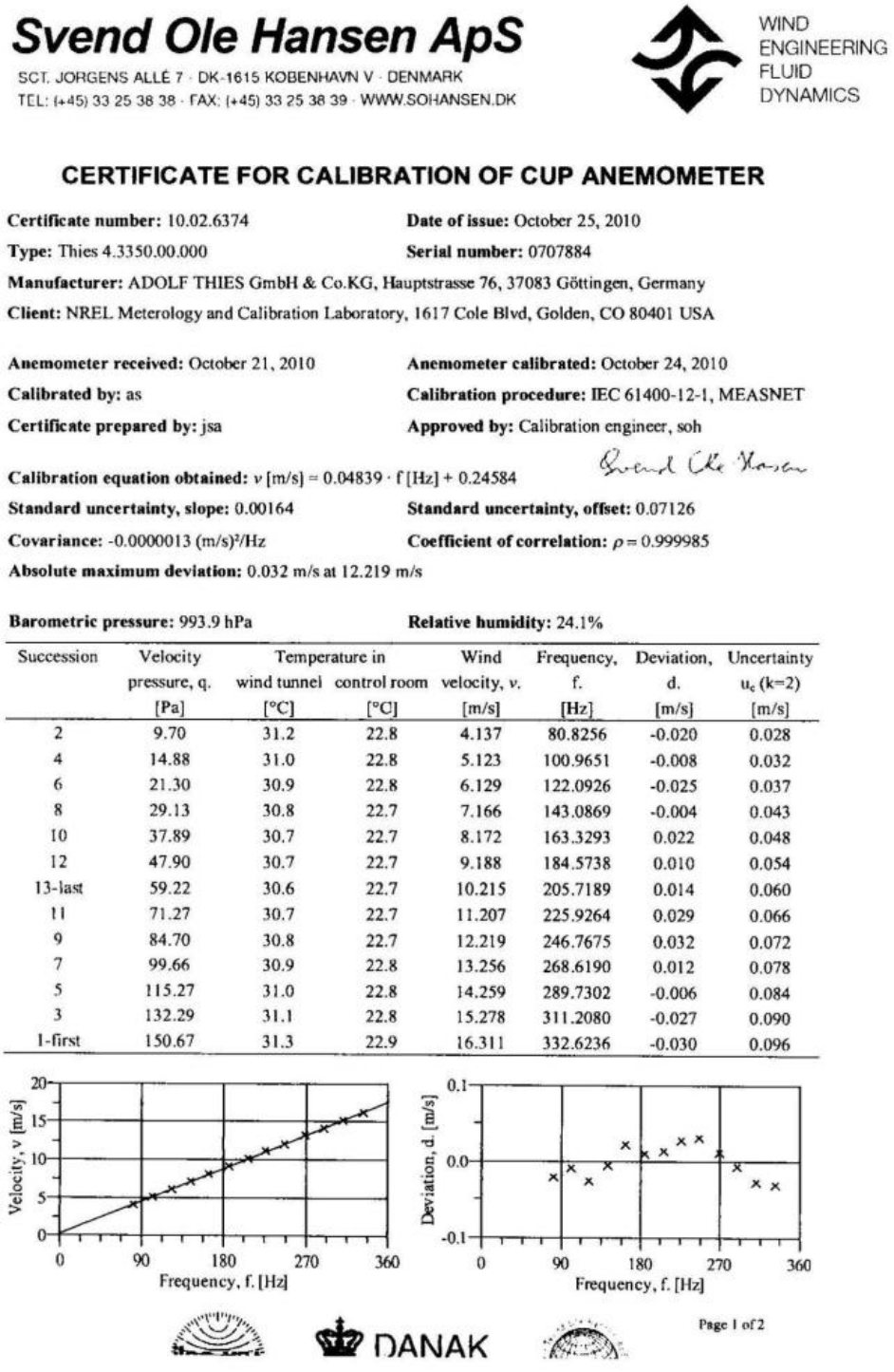
Figure 18. View towards the east/northeast (Source: NREL 2012)

Figure 19. View towards the east (Source: NREL 2012)

Figure 20. View towards the southeast (Source: NREL 2012)

Figure 21. View towards the south (Source: NREL 2012)

Appendix B: Instrument Calibration Sheets



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

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 22. Calibration sheet for primary anemometer

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 23. Page 1 of power transducer calibration sheet

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 24. Page 2 of power transducer calibration sheet

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 25. Calibration sheet for the pressure transducer

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 26. Calibration sheet for temperature sensor

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

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.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 — Date: 13-Sep-11

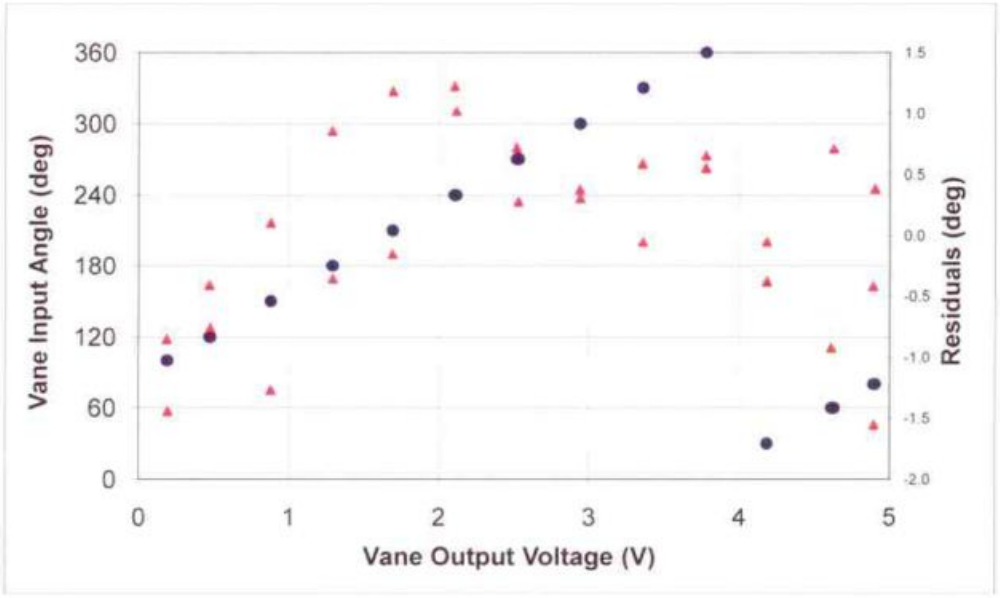


Figure 27. Calibration sheet for frequency to voltage converter used for primary wind speed

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
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
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 Appdl, 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 28. Calibration sheet for signal conditioning module 13DEC38

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

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

Figure 29. Calibration sheet for signal conditioning module 13FAE1C

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.

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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.
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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 30. Calibration sheet for signal conditioning module 13E3D05