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Power Performance Test Report for the U.S. Department of Energy 1.5-Megawatt Wind Turbine

Ismael Mendoza, Jerry Hur, and Syhoune Thao
National Renewable Energy Laboratory

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Technical Report
NREL/TP-5000-63684
August 2015

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Prepared under Task No. WE15.1A02

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ACCREDITED
Acoustics and Vibration
CERT #1239.01

Power Performance Test Report

for the

DOE 1.5-MW Wind Turbine

in
Golden, Colorado, USA

Conducted for

U.S. Department of Energy Office of Energy Efficiency and Renewable Energy
Wind and Water Power Program
Forrestal Building
1000 Independence Avenue, SW
Washington, DC 20585

Conducted by

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

Ismael Mendoza, Amy Curtis, Jerry Hur, and Simon Thao

October 2014

Notice

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

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

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

Approval By: Ismael Mendoza — 23 April 2015
I. Mendoza, NREL Test Engineer — Date

Review By: Arlinda Huskey — 23 Apr 2015
A. Huskey, NREL Senior Engineer — Date

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1 Background

The U.S. Department of Energy (DOE) acquired and installed a 1.5-megawatt (MW) wind turbine at the National Wind Technology Center (NWTC) at the National Renewable Energy Laboratory (NREL). This turbine (hereafter referred to as the DOE 1.5) is envisioned to become an integral part of the research initiatives for the DOE Wind Program, such as Atmosphere to Electrons (A2e). A2e is a multiyear DOE research initiative targeting significant reductions in the cost of wind energy through an improved understanding of the complex physics governing wind flow into and through wind farms. For more information, visit http://energy.gov/eere/wind/atmosphere-electrons.

To validate new and existing high-fidelity simulations, A2e must deploy several experimental measurement campaigns across different scales. Proposed experiments include wind tunnel tests, scaled field tests, and large field measurement campaigns at operating wind plants. Data of interest includes long-term atmospheric data sets, wind plant inflow, intra-wind plant flows (e.g., wakes), and rotor loads measurements. It is expected that new, high-fidelity instrumentation will be required to successfully collect data at the resolutions required to validate the high-fidelity simulations.

The large-scale field measurement campaigns are expected to use the DOE 1.5 as it is of sufficient enough size to represent current technology, and turbines of this size are widely deployed in U.S. wind plants.

Expected future use of the DOE 1.5 at the NWTC may include the following (leading up to the large files measurement campaigns at operating plants):

- Deployment and validation of high-fidelity instrumentation prior to large-scale deployment at a wind plant
- Deployment of advanced controls algorithms
- Characterization of inflow, aerodynamics, turbine loads, and wake propagation on an unwaked turbine.

A series of tests were conducted to characterize the baseline properties and performance of the DOE 1.5 to enable research model development and quantify the effects of future turbine research modifications.

The tests included:

- Power performance per International Electrotechnical Commission (IEC) 61400-12-1
- Power quality per IEC 61400-21
- Acoustic noise per IEC 61400-11
- Mechanical loads per IEC 61400-13
- Modal testing.

The DOE 1.5 is built on the platform of GE's 1.5-MW SLE commercial wind turbine model. It was installed in a nonstandard configuration at the NWTC with the objective of supporting DOE Wind Program research initiatives such as A2e. Therefore, the test results may not represent the performance capabilities of other GE 1.5-MW SLE turbines.

The power performance test documented in this report is one of a series of tests carried out to establish a performance baseline for the DOE 1.5 in the NWTC inflow environment.

2 Test Requirements

NREL conducted this test in accordance with the International Electrotechnical Commission's (IEC) standard, Wind Turbine Generator Systems – Part 12-1: Wind turbines - Power performance measurements of electricity producing wind turbines, IEC 61400-12-1, Edition 1.0, 2005-12 [1]—hereafter referred to as the Standard.

Additionally, NREL conducted this test in accordance with its quality system procedures such that the final test report meets the full requirements of its accreditation by A2LA. NREL's quality system requires that all applicable requirements specified by A2LA and ISO/IEC 17025 are met and any exceptions in the test noted in the test report.

2.1 Test Summary

The DOE 1.5 power performance test began on February 28, 2011, and ended on June 21, 2011. During that period, 262 hours of valid data were collected. The Standard requires at least three 10-minute wind speed averaged data points ranging from 1 m/s below cut-in up to 16 m/s in 0.5 m/s increments. When the data was binned by wind speed, more than three data points were recorded for each bin. According to the Standard, sufficient data was collected. The highest bin filled (with no wind speed normalization) was the 21.5 m/s bin.

Figure 1 is a summary of the results of the power performance test that NREL conducted on the DOE 1.5. These results are normalized to sea-level air density. Further details of these results are given in the Results section. Figure 2 shows a picture of the DOE 1.5 installed at the NWTC site.

NATIONAL RENEWABLE ENERGY LABORATORY

Power Performance Test
DOE/GE 1.5SLE

Sea-Level Density Power Curve

Turbine Specifications:

Serial Number:	TB059-3	
Rated Power:	1500	kW
Cut-in Wind Speed:	3.50	m/s
Cut-out Wind Speed:	25	m/s
Rated Wind Speed:	14.5	m/s
Rotor Diameter:	77	m
Control Type:	Active	
Pitch Setting:	Variable	

Site Conditions:

Location:	NWTC, Boulder, CO
Average Air Density:	0.99 kg/m^3
Measurement Sectors:	243-310 degrees true

Test Statistics:

Start Date:	28-Feb-2011
End Date:	21-Jun-2011
Amount of Data Collected:	262.33 hours
Highest Bin Filled:	21.50 m/s
Test Completed?	Yes

Bin Wind Speed (m/s)	Bin Power (kW)	Number Data Points	Cp
1.01	-4.92	11	-1.65
1.53	-5.44	25	-0.53
1.99	-5.78	34	-0.26
2.43	-5.56	34	-0.14
2.97	0.59	15	0.01
3.51	18.91	31	0.15
3.97	58.88	42	0.33
4.52	100.82	42	0.38
5.01	162.89	47	0.45
5.52	235.10	57	0.49
5.99	303.63	81	0.49
6.52	399.01	74	0.51
7.04	513.90	64	0.52
7.51	608.80	75	0.50
8.00	742.33	78	0.51
8.49	853.63	73	0.49
9.01	975.43	80	0.47
9.52	1,096.64	74	0.44
10.03	1,200.18	62	0.42
10.48	1,259.60	50	0.38
10.99	1,317.72	61	0.35
11.49	1,389.96	71	0.32
11.98	1,400.22	41	0.29
12.52	1,453.27	59	0.26
12.97	1,452.29	41	0.23
13.51	1,477.63	36	0.21
13.97	1,481.77	35	0.19
14.43	1,495.62	22	0.17
15.01	1,497.75	23	0.16
15.49	1,494.80	14	0.14
15.98	1,496.56	13	0.13
16.46	1,505.16	13	0.12
16.97	1,505.79	20	0.11
17.52	1,511.65	18	0.10
18.00	1,497.01	16	0.09
18.47	1,509.12	13	0.08
19.06	1,499.37	8	0.08
19.40	1,501.96	4	0.07
19.96	1,511.18	3	0.07
20.51	1,507.56	7	0.06
20.95	1,502.55	3	0.06
21.45	1,499.10	4	0.05

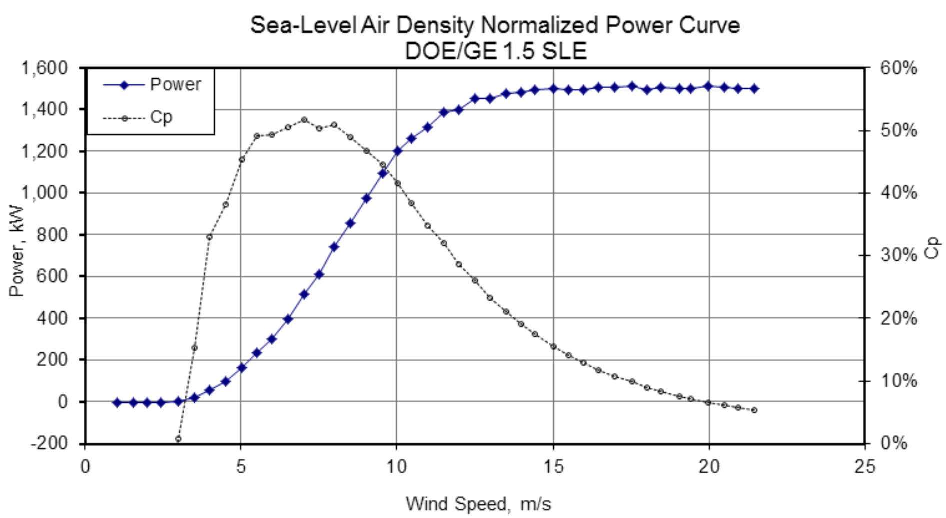


Figure 1. DOE 1.5 power performance summary sheet

Figure 2. DOE 1.5 at the NWTC. ***Photo by Jeroen van Dam, NREL***

3 Test Turbine Configuration

The turbine under test was a horizontal-axis, three-bladed, upwind machine with pitch control. Table 1 provides the key descriptive information of the test turbine.

Table 1. Test Turbine Configuration and Operational Data

Turbine manufacturer and address	GE Energy 300 Garlington Rd., P.O. Box 648 Greenville, SC 29602-0648
Model	GE 1.5 SLE
Serial number	TB059-3
Rotor diameter (m)	77
Hub height (m)	80
Tower type	Tubular
Rated electrical power (kW)	1,500
Rated wind speed (m/s)	14
Cut-out wind speed (m/s) (600 s average)	25
Rotor speed range (rpm)	10-20
Fixed or variable pitch	Variable
Number of blades	3
Blade pitch angle (deg)	Variable
Blade make, type, serial number	GE37c, S00028,S00029,S00030
Description of control system (device and software version)	ESS
Type class	IEC IIa

4 Test Site Description

The turbine was located at test site 4.0 of the NWTC, approximately 8 miles south of Boulder, Colorado. The terrain consists of mostly flat land with short vegetation (see Appendix A for photos of the test site). The site has prevailing winds bearing 292 degrees relative to true north. Figure 3 shows the turbine and meteorological (met) tower locations. This figure also shows nearby obstructions and topographical features of the site. To minimize the influence of obstructions and terrain during this test, NREL established a measurement sector from 243° to 310°. This measurement sector was derived according to the Standard's obstacles assessment criteria in Annex A. The obstructions are listed in Table 2 and are identified on the map in Figure 3. NREL limited it's assessments of power and energy production to data obtained when winds were within the measurement sector.

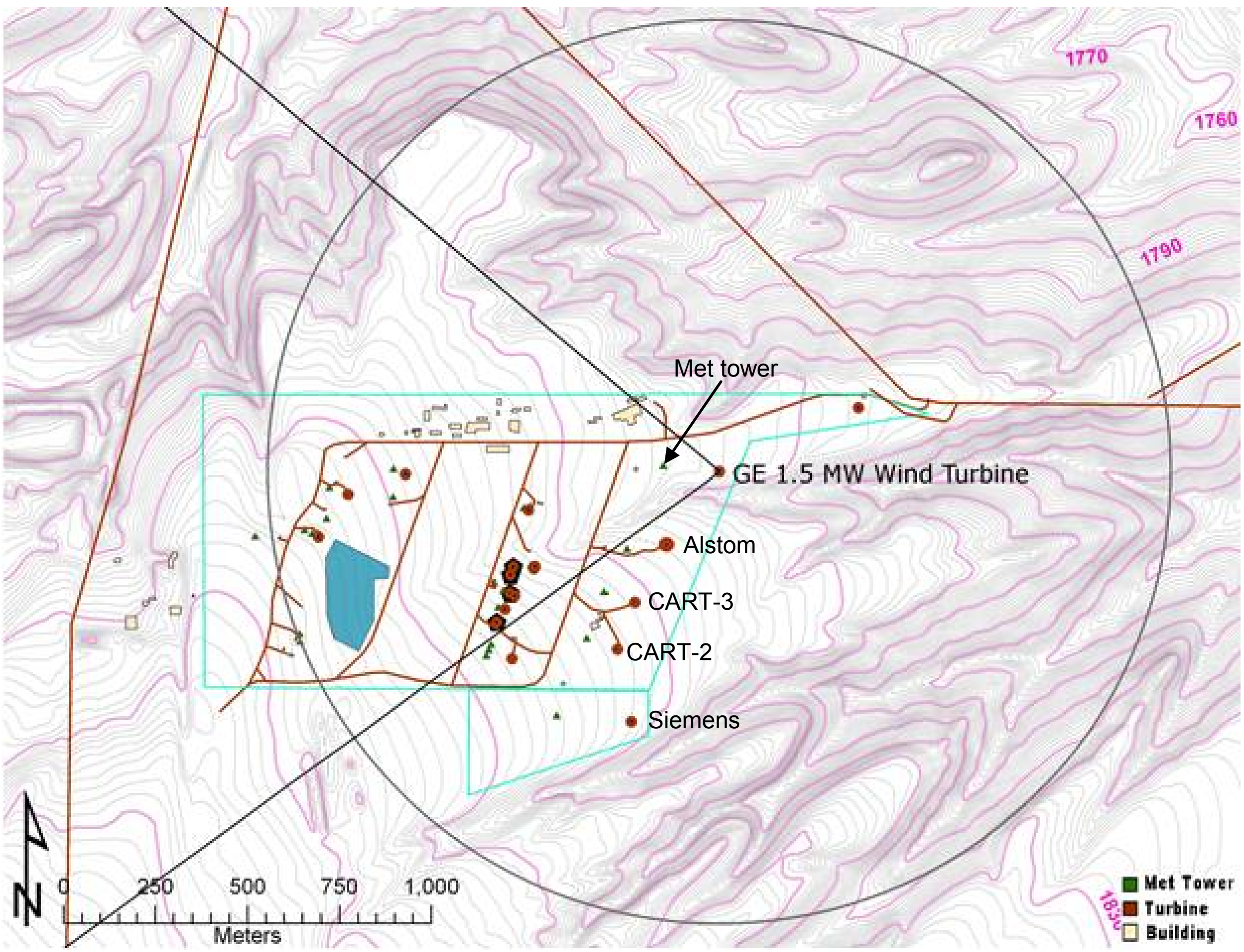


Figure 3. Map of test site

Table 2. Neighboring Turbines and Obstacles

Obstacle or Turbine	Relative to:	Distance (m)	Bearing (deg T)	Equiv. Dia. (m)	Obstructed Sector Start (deg T)	Obstructed Sector End (deg T)
Alstom	Test Turbine	219	204	101	124	242
CART-2	Test Turbine	557	211	40	172	233
CART-3	Test Turbine	422	214	43	177	227
Siemens	Test Turbine	718	200	101	165	222
Test Turbine	Met Tower	153.43	100	N/A	46	146

NREL completed the site assessment requirements of Annex B of the Standard. Table 3 shows the results from the site assessment, which indicates that a site calibration is required because of the terrain variation; however, the client and NREL agreed not to perform a site calibration and instead increased the uncertainty in the analysis for flow distortion as a result of the terrain. This was noted as a deviation of the Standard.

Table 3. Test Site Terrain Assessment

DOE 1.5 **Site: 4.0**

Measurement Sector: **243** to **310** 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%*	2.4%	Pass
2	Maximum variation from best fit plane < 0.04 (H + D	<2L	360	*+/-5.9m*	15.7	Fail
3	Maximum slope of best fit plane < 5%	2-4L	In	*5%*	1.5%	Pass
4	Maximum variation from best fit plane < 0.08 (H + D	2-4L	In	*+/-11.8m*	2.6	Pass
5	Steepest slope maximum < 10%	2-4L	Out	*10%*	1.7%	Pass
6	Maximum slope of best fit plane < 10%	4-8L	In	*10%*	2.1%	Pass
7	Maximum variation from best fit plane < 0.13 (H + D	4-8L	In	*+/-19.2m*	19.2	Pass
8	No neighboring and operating turbines	<$2D_n$	360	*0*	0	Pass
9	No obstacles	<$2D_e$	360	*0*	0	Pass

Site Calibration Required? **yes**

absolute value used for site condition
In = Inside Preliminary Measurement Sector
Out = Outside Preliminary Measurement Sector

5 Description of Test Equipment

Table 4 shows the equipment used and calibration due dates. Appendix B of this report contains the calibration sheets. Figure 4 depicts the placement of the meteorological instruments on the tower. An additional exception to the Standard was taken because of the deviation of the recommended anemometer mounting. Additional uncertainty was included in the analysis regarding the mounting effects. At the end of the test, an *in situ* comparison was performed on the primary anemometer with the reference anemometer as prescribed in the Standard to verify that the primary anemometer did not change its calibration during the measurement period. The results showed a difference of less than 0.1 m/s for the range of 6–12 m/s and within the tolerances allowed by the Standard.

Table 4. Equipment Used in the Power Performance Test

Instrument	Make, Model	Serial Number	Calibration Due Date
Power transducer	Ohio Semitronics DWV-008D	09070337	January 7, 2012
Primary anemometer	Thies, First Class	0909219	December 20, 2011
Reference anemometer	Met One, SS-201	K16684	in situ
Wind vane	Met One, SD-201 with aluminum vane	K16689	January 5, 2012
Pressure sensor	Vaisala, PTB101B	B2130018	December 22, 2011
Temperature sensor	Met One, T-200	0673552	December 22, 2011
Precipitation sensor	Campbell Scientific, 237	None	*in situ*
Data acquisition system	Compact DAQ w/LabView-based data acquisition cDAQ-9172 NI 9229 NI 9217 NI 9205	 1361570 12B6DD2 12BD192 12E9CD3	 August 21, 2011 August 21, 2011 August 21, 2011

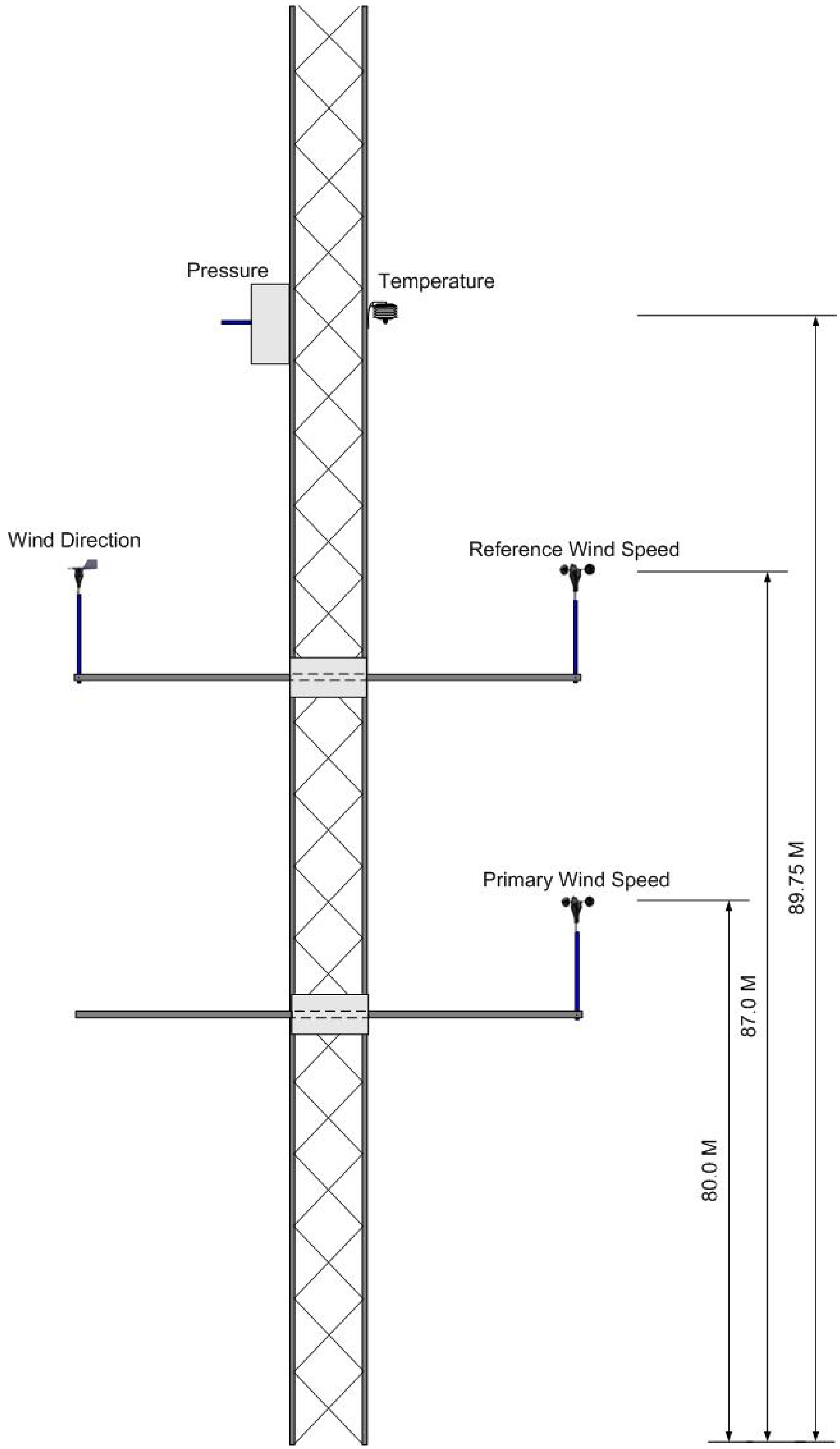


Figure 4. Meteorological (met) tower with instrument configuration.
Illustration by Ismael Mendoza, NREL

To ensure that only data obtained during normal operation of the turbine are used in the analysis, and to ensure that data are not corrupted, NREL excluded data sets from the database under the following circumstances:

- External conditions other than wind speed are out of the normal range for turbine operation.
- The turbine cannot operate because of a turbine fault condition.
- The turbine is manually shut down or in a test or maintenance operating mode.
- There is failure or maintenance of the data acquisition system

Two methods were used to track when any of these conditions occur during the test. In the first method, the logbook was checked for such events. The turbine supervisory control and data acquisition (SCADA) provided status signals to the data acquisition system that indicated when the turbine was available, braked, or faulted. In the second method, the status signal was checked in the data file during analysis.

6 Description of Test Procedure

NREL conducted the test according to the procedures in the Standard. The sampling rate was 10 kHz, which was decimated to 40 Hz and then averaged over a 10-minute period. NREL also collected standard deviation, minimum, and maximum statistics for each averaging period.

Only database A is reported because the turbine did not reach cut-out wind speeds during the test period.

Table 5 gives the uncertainty sources and values used in the analysis. 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 flow distortion. The Type A and Type B uncertainties are combined to get the combined standard uncertainty.

Table 5. Uncertainty Values used in the Analysis

Component	Uncertainty	Source
Power		
Power Transducer[a]	0.869%	Calibration sheet
Data Acquisition	5.4 kW +0.075%	Specifications
Wind Speed		
Calibration	0.0265 m/s	Calibration sheet
Operational Characteristics	0.052 m/s + 0.52%	IEC equation (I.2)
Mounting Effects	2.50%	Assumption due to side-mounting
Terrain Effects	3.00%	Assumption due to no site calibration
Data Acquisition	0.002 m/s	Assumption
Temperature		
Temperature Sensor	0.150 ˚C	Calibration sheet
Radiation Shielding	0.200 ˚C	Assumption
Mounting Effects	0.138 ˚C	IEC method
Data Acquisition	0.200 ˚C	Specifications
Air Pressure		
Pressure Sensor	0.100 kPa	Specifications
Mounting Effects	0.007 kPa	IEC method
Data Acquisition	0.034 kPa	Specifications

[a]Power transducer calibrated as single system.

7 Test Results

7.1 Tabular Results of Power Performance Test

Table 6 through Table 9 provide the power performance test results in tabular format.

Table 6. Performance at Sea-Level Air Density, 1.225 kg/m3

Measured Power Curve (Database A)							
Reference air density:		1.225	kg/m^3				
Bin Number	Normalized Wind Speed (m/s)	Power Output (kW)	Cp	Number of 10-Minute Data Sets	Category A Standard Uncertainty (kW)	Category B Standard Uncertainty (kW)	Combined Standard Uncertainty (kW)
1	1.01	-4.92	-1.65	11	0.08	5.41	5.41
2	1.53	-5.44	-0.53	25	0.19	5.40	5.40
3	1.99	-5.78	-0.26	34	0.17	5.40	5.40
4	2.43	-5.56	-0.14	34	0.50	5.40	5.42
5	2.97	0.59	0.01	15	3.59	5.60	6.65
6	3.51	18.91	0.15	31	3.46	7.43	8.20
7	3.97	58.88	0.33	42	4.37	15.60	16.20
8	4.52	100.82	0.38	42	7.15	15.20	16.80
9	5.01	162.89	0.45	47	7.04	26.75	27.66
10	5.52	235.10	0.49	57	6.68	32.83	33.50
11	5.99	303.63	0.49	81	5.82	35.27	35.75
12	6.52	399.01	0.51	74	6.45	48.48	48.90
13	7.04	513.90	0.52	64	5.87	63.23	63.50
14	7.51	608.80	0.50	75	10.55	60.29	61.20
15	8.00	742.33	0.51	78	8.37	88.46	88.85
16	8.49	853.63	0.49	73	13.68	78.01	79.20
17	9.01	975.43	0.47	80	13.18	85.13	86.15
18	9.52	1,096.64	0.44	74	14.76	89.54	90.75
19	10.03	1,200.18	0.42	62	9.53	82.13	82.68
20	10.48	1,259.60	0.38	50	10.78	57.41	58.42
21	10.99	1,317.72	0.35	61	10.90	50.87	52.02
22	11.49	1,389.96	0.32	71	6.70	67.10	67.44
23	11.98	1,400.22	0.29	41	19.78	16.81	25.96
24	12.52	1,453.27	0.26	59	5.39	50.58	50.87
25	12.97	1,452.29	0.23	41	7.53	13.94	15.84
26	13.51	1,477.63	0.21	36	4.53	28.54	28.90
27	13.97	1,481.77	0.19	35	7.93	15.01	16.97
28	14.43	1,495.62	0.17	22	4.82	22.34	22.85
29	15.01	1,497.75	0.16	23	4.58	14.43	15.13
30	15.49	1,494.80	0.14	14	3.95	14.73	15.25
31	15.98	1,496.56	0.13	13	4.74	14.43	15.19
32	16.46	1,505.16	0.12	13	5.06	18.48	19.16
33	16.97	1,505.79	0.11	20	2.86	14.35	14.63
34	17.52	1,511.65	0.10	18	4.22	16.19	16.73
35	18.00	1,497.01	0.09	16	6.82	25.98	26.86
36	18.47	1,509.12	0.08	13	3.41	23.60	23.85
37	19.06	1,499.37	0.08	8	6.16	18.92	19.90
38	19.40	1,501.96	0.07	4	6.00	15.46	16.58
39	19.96	1,511.18	0.07	3	6.30	19.32	20.32
40	20.51	1,507.56	0.06	7	3.80	15.29	15.75
41	20.95	1,502.55	0.06	3	6.54	17.18	18.38
42	21.45	1,499.10	0.05	4	8.33	15.42	17.52

Table 7. Performance at Site Average Density, 1.00 kg/m3

Measured Power Curve (Database A)							
Reference air density:	**1.00**	**kg/m^3**					
Bin Number	**Normalized Wind Speed** (m/s)	**Power Output** (kW)	**Cp**	**Number of 10-Minute Data Sets**	**Category A Standard Uncertainty** (kW)	**Category B Standard Uncertainty** (kW)	**Combined Standard Uncertainty** (kW)
1	1.06	-4.92	-1.77	10	0.09	5.41	5.41
2	1.50	-5.22	-0.66	15	0.19	5.40	5.40
3	1.97	-5.78	-0.32	35	0.18	5.40	5.40
4	2.49	-5.74	-0.16	38	0.43	5.40	5.42
5	3.01	0.38	0.01	17	3.14	5.62	6.44
6	3.60	7.91	0.07	19	3.90	5.75	6.95
7	4.02	41.48	0.27	39	4.21	14.52	15.11
8	4.49	72.51	0.34	32	6.50	13.32	14.82
9	5.01	120.45	0.41	45	8.01	19.72	21.28
10	5.54	186.64	0.47	46	5.29	29.01	29.49
11	6.03	245.79	0.48	56	7.56	30.18	31.11
12	6.49	316.77	0.50	75	4.88	41.04	41.33
13	7.01	407.67	0.51	68	6.38	49.29	49.70
14	7.53	516.00	0.52	61	5.93	63.28	63.56
15	8.02	605.60	0.50	71	11.11	59.70	60.72
16	8.51	725.58	0.51	73	7.70	83.83	84.18
17	8.99	831.26	0.49	68	14.16	79.32	80.58
18	9.48	961.48	0.48	67	10.22	100.91	101.42
19	9.98	1,030.57	0.45	72	18.34	55.86	58.79
20	10.48	1,167.87	0.44	60	8.75	115.29	115.62
21	10.98	1,227.96	0.40	63	9.78	53.79	54.67
22	11.54	1,291.73	0.36	51	12.52	54.09	55.52
23	12.02	1,358.14	0.34	57	8.47	66.40	66.94
24	12.47	1,403.64	0.31	59	8.17	52.68	53.31
25	13.01	1,407.81	0.27	39	20.16	14.10	24.60
26	13.51	1,459.32	0.25	55	4.76	57.13	57.32
27	13.96	1,451.06	0.23	36	8.24	17.09	18.97
28	14.51	1,479.57	0.21	32	4.67	33.25	33.58
29	14.95	1,482.17	0.19	34	8.15	14.56	16.68
30	15.42	1,493.91	0.17	21	4.72	20.84	21.36
31	16.02	1,500.60	0.16	22	4.61	15.93	16.59
32	16.44	1,489.06	0.14	12	5.05	22.82	23.37
33	16.99	1,499.79	0.13	15	4.27	19.39	19.86
34	17.50	1,504.21	0.12	12	5.51	15.53	16.48
35	18.07	1,506.73	0.11	18	3.20	14.68	15.02
36	18.55	1,507.27	0.10	15	3.75	14.36	14.84
37	19.00	1,504.36	0.09	17	4.11	15.11	15.66
38	19.54	1,500.59	0.09	14	7.94	15.25	17.19
39	19.90	1,512.63	0.08	7	4.75	30.04	30.41
40	20.48	1,501.23	0.08	9	5.83	21.47	22.25
41	20.98	1,495.36	0.07	3	2.21	17.19	17.33
42	21.55	1,514.39	0.06	3	3.40	31.76	31.94
43	22.02	1,506.40	0.06	7	3.91	20.66	21.03
44	22.50	1,503.50	0.06	2	3.91	20.66	21.03
45	22.95	1,499.10	0.05	4	8.33	16.81	18.76

Table 8. Annual Energy Production (AEP) at Sea-Level Density, 1.225 kg/m^3

Estimated 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	MWh	MWh	%	MWh	
4	1,322	198	15%	1,322	Complete
5	2,491	281	11%	2,491	Complete
6	3,767	336	9%	3,768	Complete
7	4,990	363	7%	4,997	Complete
8	6,056	369	6%	6,096	Complete
9	6,905	362	5%	7,026	Complete
10	7,513	347	5%	7,770	Complete
11	7,886	329	4%	8,321	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 9. Annual Energy Production at Site Average Density, 1.00 kg/m^3

Estimated AEP, Database A (all valid data)					
	Reference air density: 1.00 kg/m^3				
	Cut-out wind speed: 25.0 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	MWh	MWh	%	MWh	
4	1,057	174	16%	1,057	Complete
5	2,085	255	12%	2,085	Complete
6	3,264	318	10%	3,264	Complete
7	4,443	354	8%	4,445	Complete
8	5,521	369	7%	5,536	Complete
9	6,433	369	6%	6,482	Complete
10	7,143	361	5%	7,256	Complete
11	7,640	347	5%	7,843	Complete
AEP measured assumes zero power between highest bin and cut-out. AEP extrapolated assumes power in last bin between last bin and cut-out.					

7.2 Graphical Results Power Performance Test

Figure 5 through Figure 11 show the graphical results of the power performance test. Figure 5 shows a plot of the binned power curve normalized to sea-level air density.

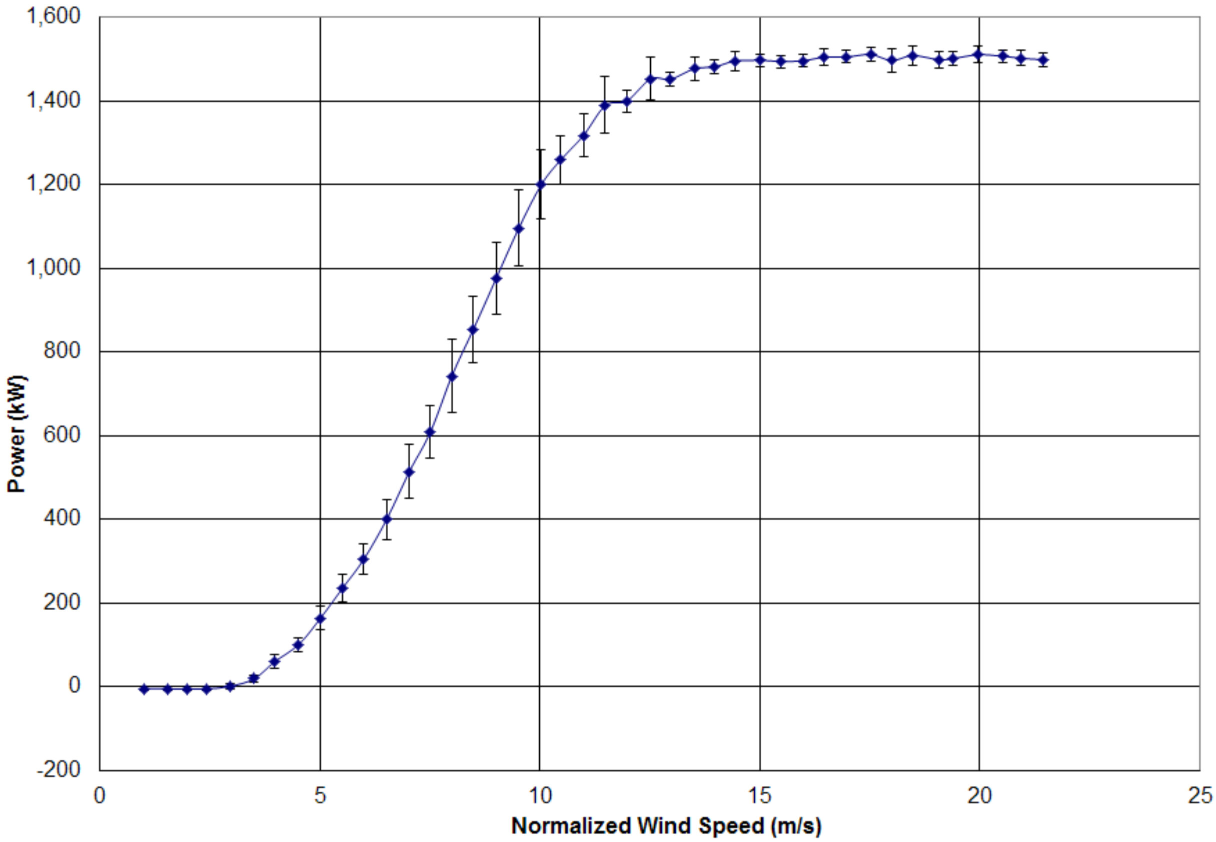


Figure 5. Power curve at sea-level air density, 1.225 kg/m³

Figure 6 shows a plot of the binned power curve at the site average air density during the test period.

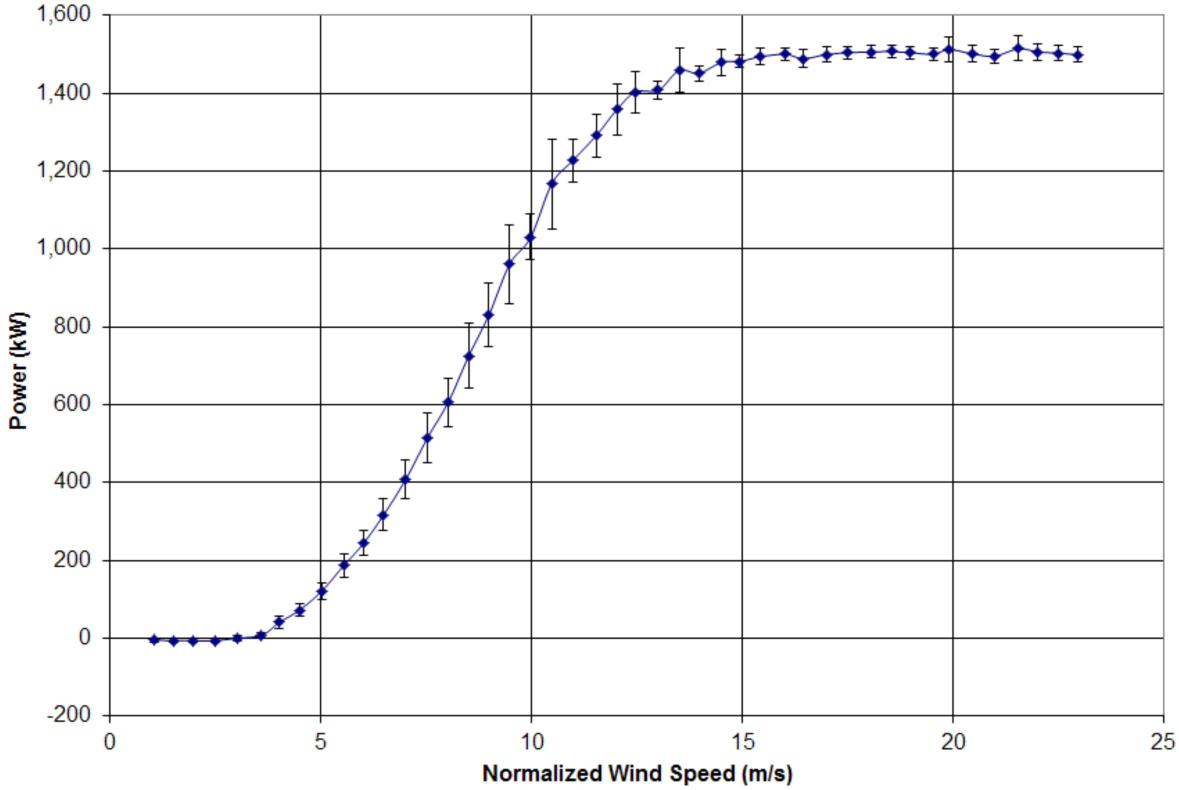


Figure 6. Power curve at site average air density, 1.00 kg/m^3

Figure 7 shows a scatterplot of the turbine power statistics as a function of site average normalized wind speed.

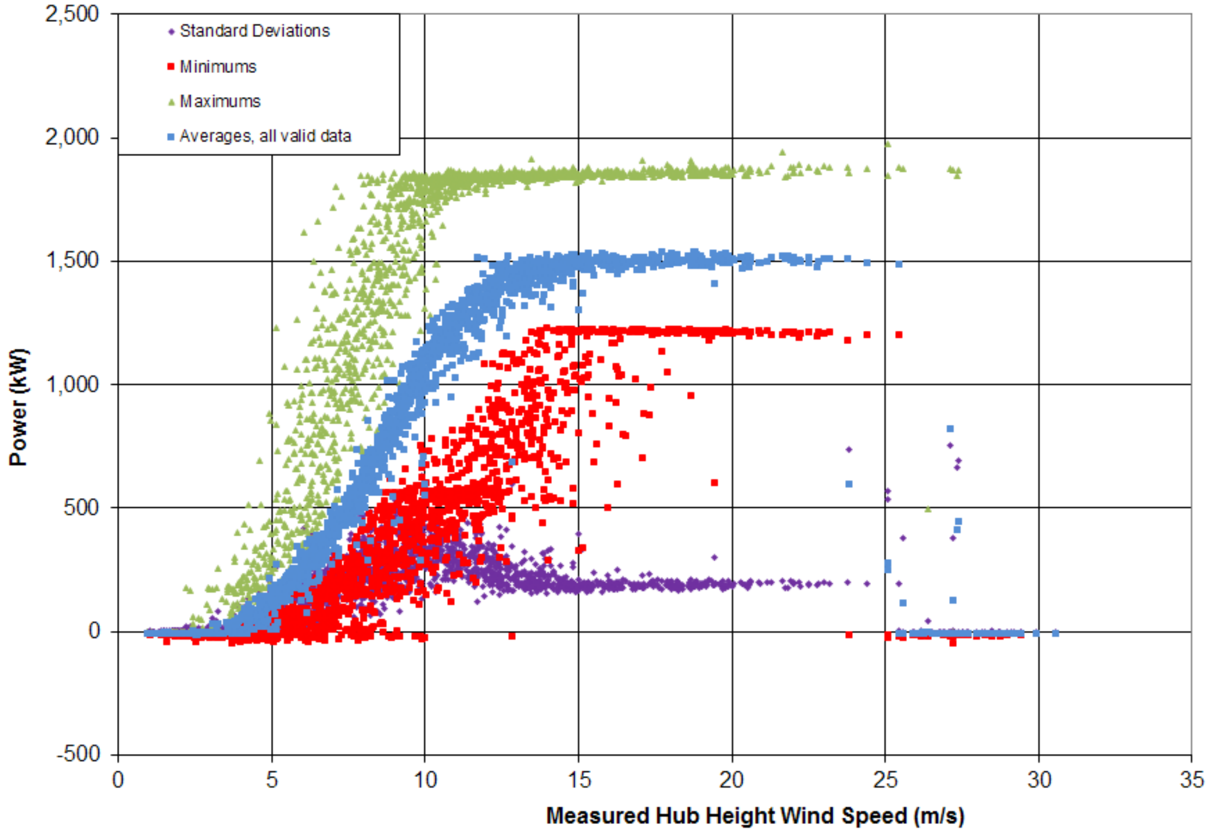


Figure 7. Scatterplot averages, standard deviation, minimum, maximum power as a function of wind speed normalized to site average air density, 1.00 kg/m^3

Figure 8 shows a plot of the binned coefficient of performance as a function of wind speed at sea-level normalized air density.

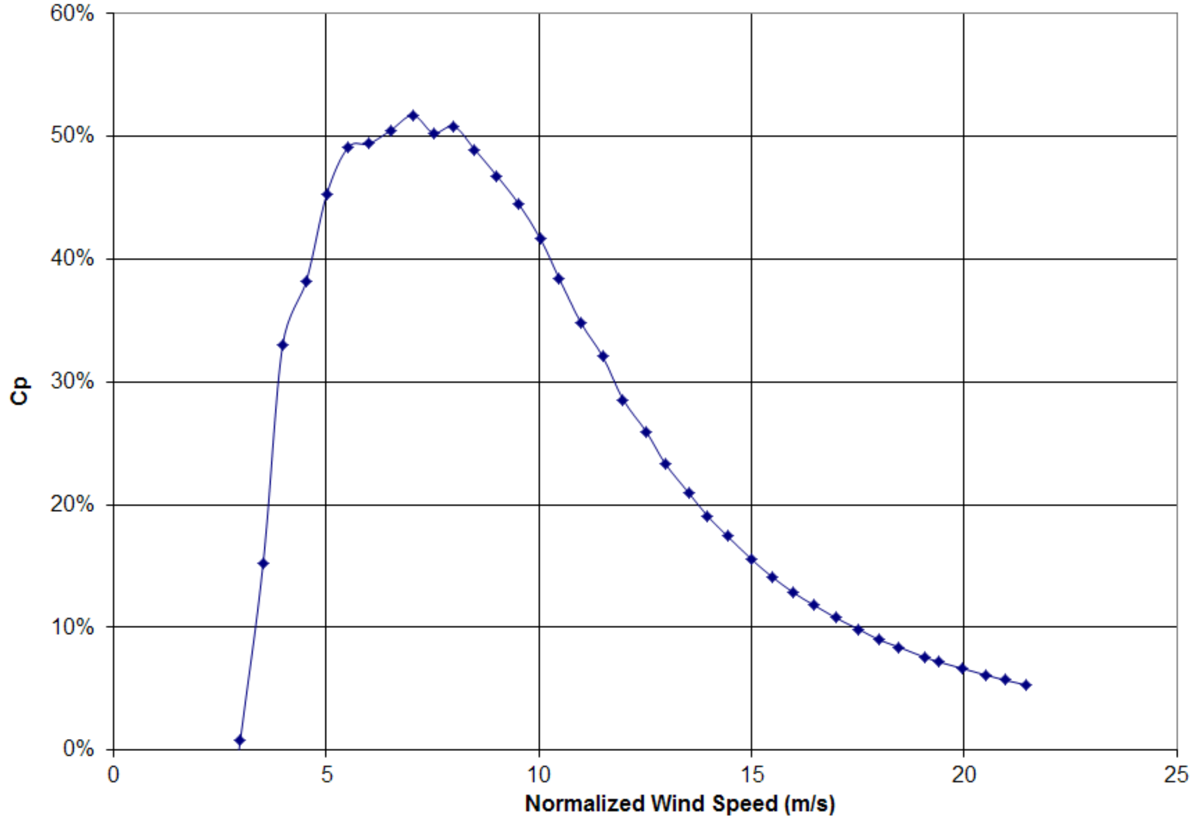


Figure 8. Coefficient of performance at sea-level air density, 1.225 kg/m^3, with turbine rotor swept area = 4,656.63 m^2

Figure 9 shows a plot of the binned coefficient of performance as a function of wind speed normalized to site-specific air density.

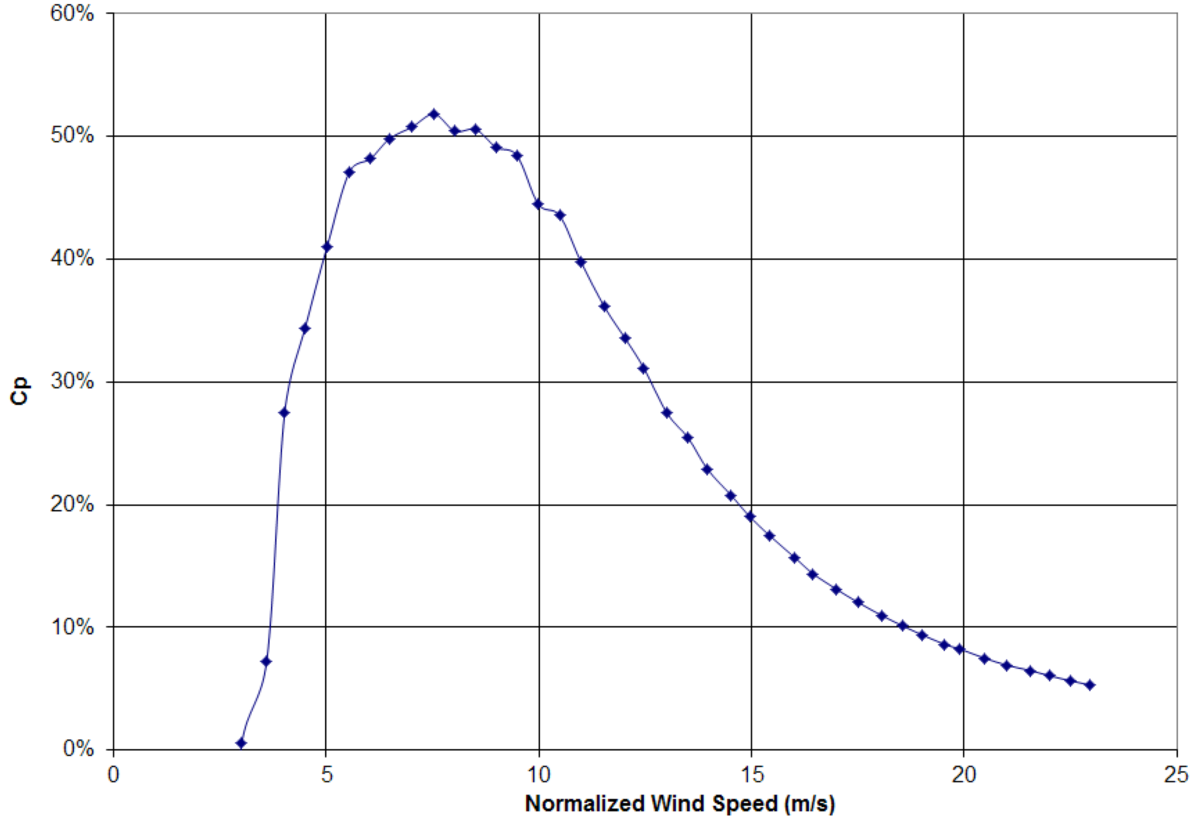


Figure 9. Coefficient of performance at site average air density, 1.00 kg/m^3, with turbine rotor swept area = 4,656.63 m^2

Figure 10 shows a scatterplot of average wind speed and turbulence intensity as a function of wind direction.

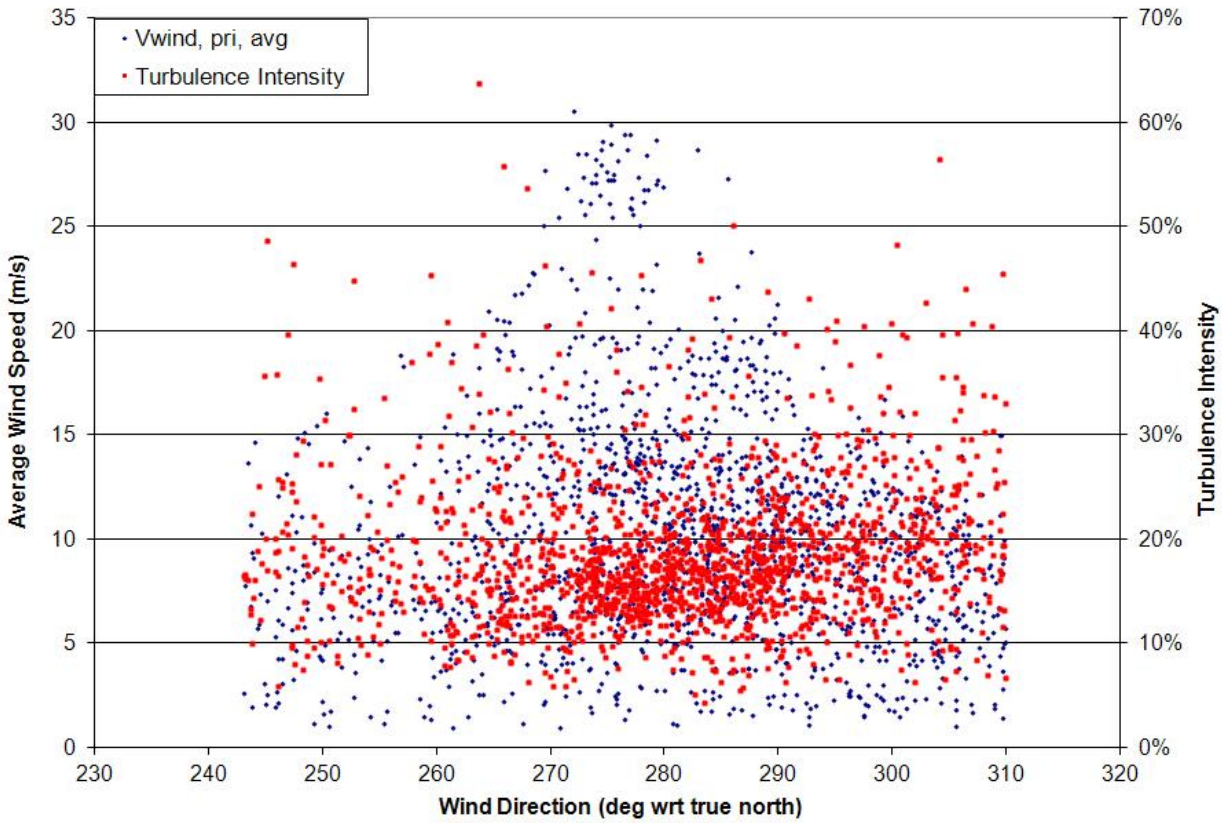


Figure 10. Wind speed and turbulence intensity as a function of wind direction

Figure 11 shows a scatterplot and binned turbulence intensity as a function of wind speed.

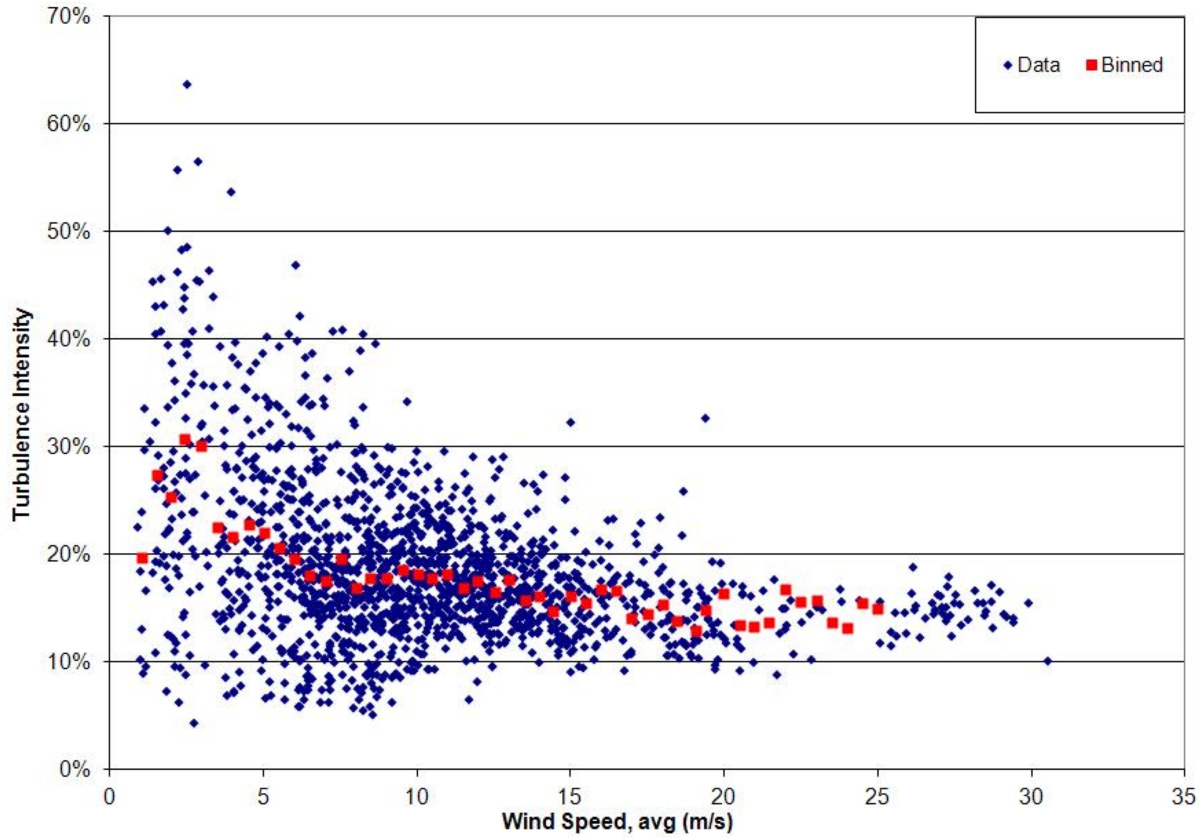


Figure 11. Wind turbulence as a function of wind speed

8 Exceptions

8.1 Exceptions to the Standard

Two exceptions to the Standard were identified:

- The test site did not pass the site assessment as per Annex A of the Standard. The area to the east of the turbine within 5 rotor diameters has a terrain variation greater than the allowed maximum variation from the best fit plane. The Standard requires that a site calibration be performed if the site assessment fails; however, the client and NREL decided not to perform a site calibration. Additional uncertainty has been included in the analysis for flow distortion caused by the terrain.
- Because of the requirement for a 135-m met tower for subsequent activities, the hub height anemometer was not top-mounted but on a side boom at 80 m in a configuration not recommended by the Standard. Additional uncertainty has been included in the analysis for mounting effects on the anemometer.

8.2 Exceptions to the Test Plan

No exceptions were taken to the test plan.

8.2.1 Exceptions to NREL's Quality System

No exceptions were taken to NREL's quality system.

9 References

1. International Electrotechnical Commission (IEC). (2005). "Wind Turbines – Part 12-1: Power Performance Measurements of Electricity Producing Wind Turbines." TS IEC 61400-13. First edition, 2005-12.

Appendix A. Pictures of Test Site

Figure A-1. At the base of the tower facing north. ***Photo by Ismael Mendoza, NREL***

Figure A-2. At the base of the tower facing northeast. ***Photo by Ismael Mendoza, NREL***

Figure A-3. At the base of the tower facing east. ***Photo by Ismael Mendoza, NREL***

Figure A-4. At the base of the tower facing southeast. ***Photo by Ismael Mendoza, NREL***

Figure A-5. At the base of the tower facing south. ***Photo by Ismael Mendoza, NREL***

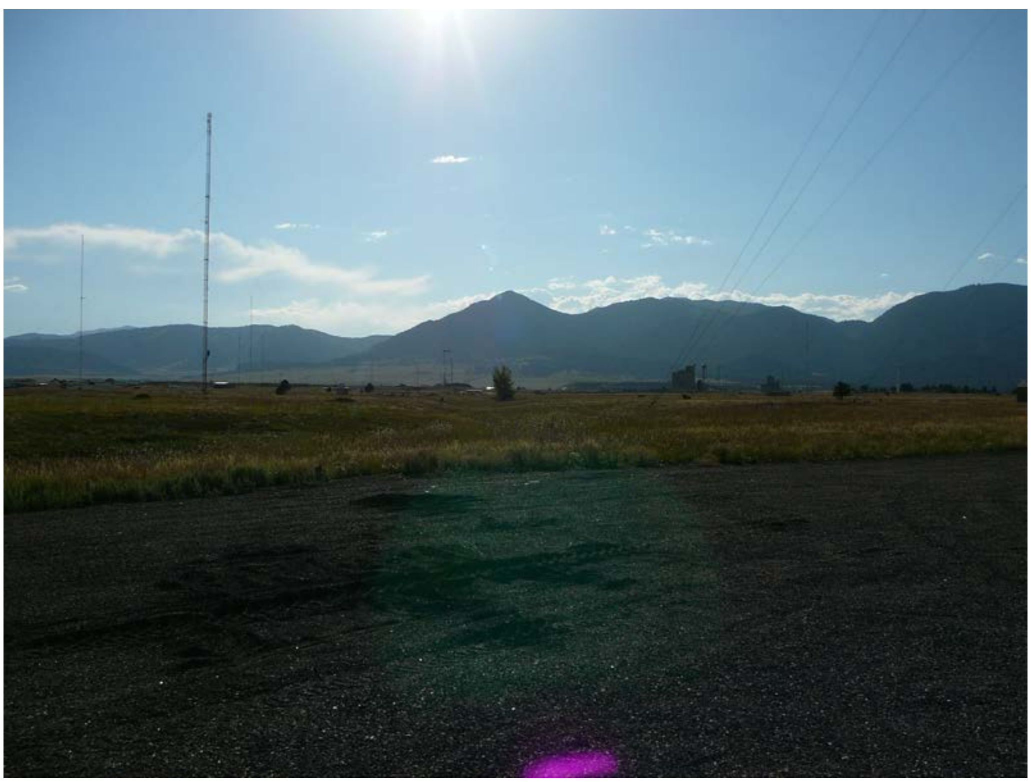


Figure A-6. At the base of the tower facing southwest. ***Photo by Ismael Mendoza, NREL***

Figure A-7. At the base of the tower facing west. ***Photo by Ismael Mendoza, NREL***

Figure A-8. At the base of the tower facing northwest. ***Photo by Ismael Mendoza, NREL***

Appendix B. Equipment Calibration Sheets

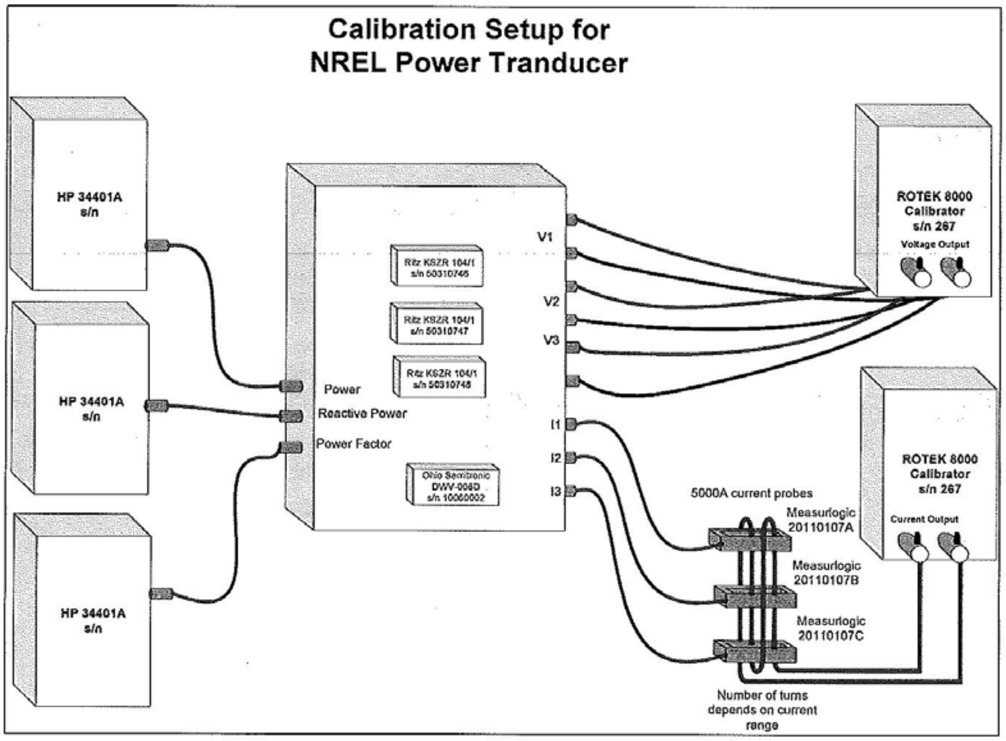
Power

NREL
National Renewable Energy Laboratory

Calibration Report

Report #: NREL Power Performance Sampling System Cal GE/DOE 1.5 (sn PP20110107)

Calibration of: NREL PP Sampling System



Environmental Conditions During Calibration
Temperature: 23C, +/- 1C
Relative humidity: 40%, +/-10%

Calibration Method:	GI28 010717
Calibration Results:	Within tolerance
Device Condition:	good
Date Calibrated:	01/07/11
Calibration Due Date:	01/07/12
Calibrated by:	Morse, Preston/Ismael Mendoza
NREL Metrology Laboratory:	Ibrahim Reda
	Sr. Scientist V
	Date: 1/13/2011

Reda

Page 1 of 4

Figure B-1. Calibration sheet for the power transducer (page 1)

Calibration Standard:

Model:	DOE#	Calibration Due Date:
8000A	126314	7/8/2011
34401A	01886C	1/12/2012
34401A	01888C	3/5/2011
34401A	02301C	3/5/2011

Accuracy

Current (<50A):	0.038	% of setting	+	0.005	% of range
Current (>50A):	0.05	% of reading	+	0.008	% of range
Voltage (Meter)	0.0035	% of reading	+	0.0005	% of range
Voltage(Calibrator): (0.03 + 0.004)		% of reading	+	0.01	V

Full Range

Power Uncertainty, U95 (KW) 0.38

Full Scale Settings

Rotek 8000A Current:	200 A
Rotek 8000A Voltage:	700 V

Unit Under Test (UUT):

Current sensors								
Model:	Measurlogic MLG-TP816			Output:	-5	to	5	V
Accuracy:		0.5 % of F.S.		Nominal Slope:		1000		
Full scale:		-5000	5000 A	Nominal Offset:		0		
Voltage sensors								
Model:	Ritz KSZR 104/1			Output:	-100	to	100	V
Accuracy:		0.5 % of F.S.		Nominal Slope:		10.00		
Full scale:		-1000	1000 V	Nominal Offset:		0		
Power Transducer								
Model:	OSI DWV-008D			Output:	-10	to	10	V
Accuracy:		0.5 % of F.S.		Nominal Slope:		300.00		
		-3000	3000 KW					
Full scale:		-3000	3000 KVAR	Nominal Offset:		0		

Uncertainty of UUT:

Watt Total Uncertainty = 25.98 KW

VAR Total Uncertainty = 25.98 KVAR

TUR 68.4 :1

Note:

1. The Test Uncertainty Ratio (TUR) = The uncertainty of the unit under test (UUT) divided by the uncertainty of the standard.
2. All uncertainties are calculated using the Volt or Amper values, not percentages.
3. The total uncertainty for the UUT is calculated as the RSS of the uncertainties of the current and voltage sensors, and A/D converter

Apparent Power		
Watts(kW)	Voltage Output (V)	Error
2000	6.699	0.25
1400	4.689	0.00
800	2.679	-0.24
200	0.669	-0.49
0	0.000197	-0.21
-200	-0.666	0.84
-800	-2.678	0.00
-1400	-4.689	-0.55
-2000	-6.695	0.40

Rotek 8000 Settings
Voltage: 333.33
Power factor: 1

Slope	298.6295964
Offset	-0.2719852

Page 2 of 4

Figure B-2. Calibration sheet for the power transducer (page 2)

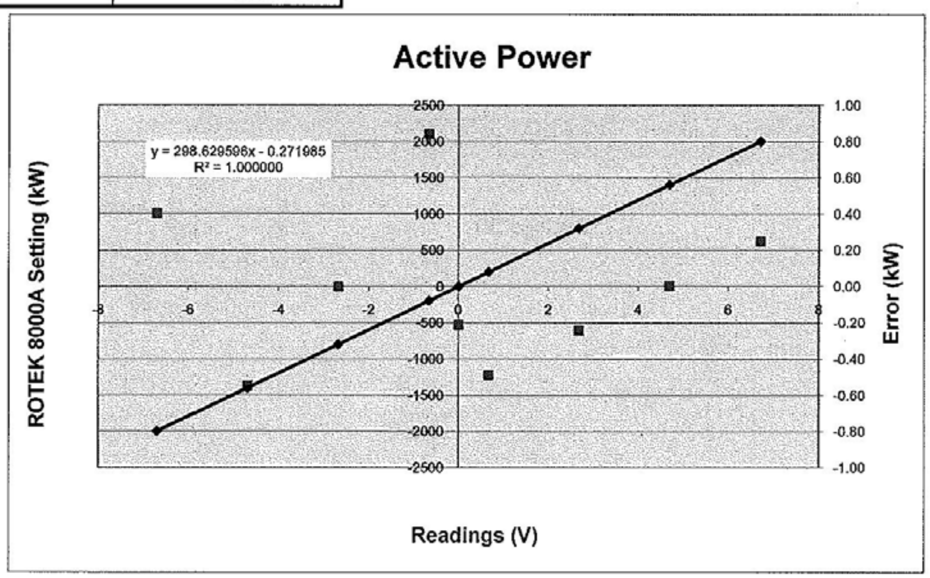
Reactive Power = SQRT[(Apparent Power)^2 - (Apparent Power * PF)^2]

Reactive Power				Rotek 8000 Settings
Power Factor	Reactive power (VAR)	Voltage Output (V)	Error	Voltage: 333.33
1	0.000	0.0154	-0.91	Apparent Power: 2000 kW
0.9	871.780	2.93	-0.59	
0.8	1200.000	4.026	-0.87	
0.7	1428.286	4.812	6.03	
0.6	1600.000	5.37	1.27	
0.5	1732.051	5.802	-1.52	
0.4	1833.030	6.138	-1.96	
0.3	1907.878	6.394	-0.21	
0.2	1959.592	6.572	1.34	
0.1	1989.975	6.665	-1.22	
0	2000.000	6.698	-1.37	

Slope	299.2167532
Offset	-5.519904617

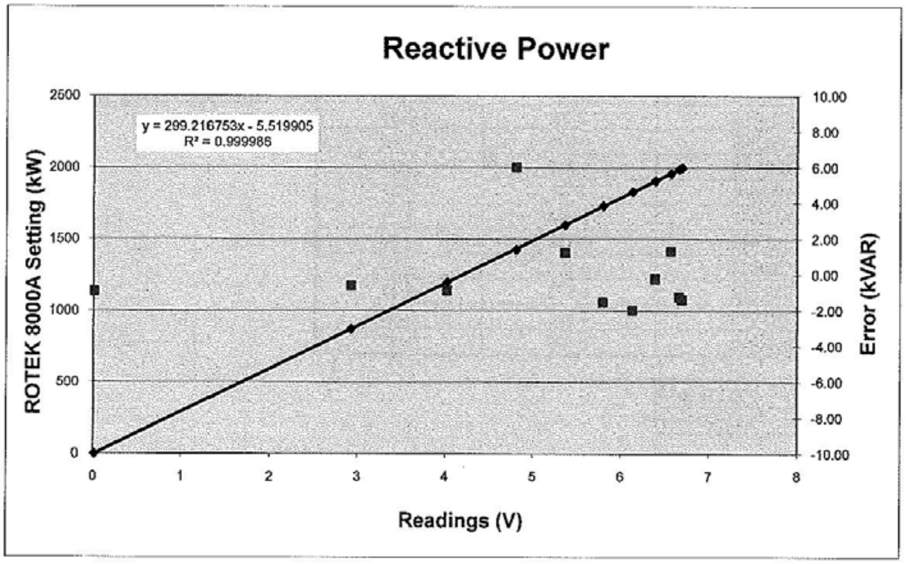
Power Factor (PF)			Rotek 8000 Settings
Power Factor	Voltage Output (V)	Error	Voltage: 333.33
1	10.007	0.00	Apparent Power: 2000 kW
0.9	8.987	0.00	
0.8	8.004	0.00	
0.7	6.993	0.00	
0.6	5.999	0.00	
0.5	4.99	0.00	
0.4	3.985	0.00	
0.3	2.982	0.00	
0.2	1.993	0.00	
0.1	0.983	0.00	
0	0.02333	0.00	

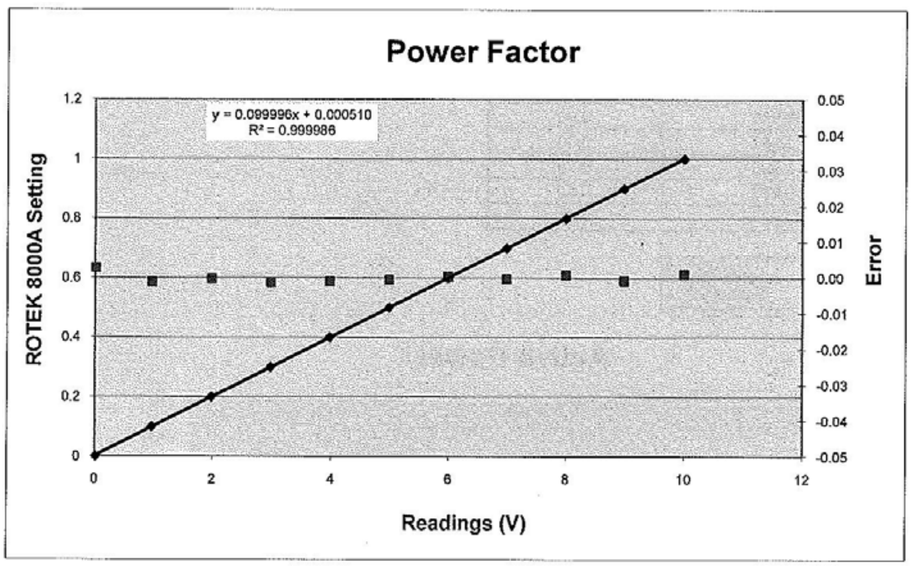
Slope	0.099995543
Offset	0.000510174



Page 3 of 4

Figure B-3. Calibration sheet for the power transducer (page 3)





Page 4 of 4

Figure B-4. Calibration sheet for the power transducer (page 4)

Wind Speed

DEUTSCHER KALIBRIERDIENST DKD

Kalibrierlaboratorium / Calibration laboratory
Akkreditiert durch die / *accredited by the*
Akkreditierungsstelle des Deutschen Kalibrierdienstes

Deutsche WindGuard
Wind Tunnel Services GmbH
Varel

Deutscher Akkreditierungs Rat
DAR
DKD-K- 36801

Kalibrierschein
Calibration Certificate

Kalibrierzeichen *Calibration label*	
	09/5843
	DKD-K-36801
	09/2009

Gegenstand *Object*	Cup Anemometer
Hersteller *Manufacturer*	Thies Clima D-37083 Göttingen
Typ *Type*	4.3351.10.000
Fabrikat/Serien-Nr. *Serial number*	Body: 0909219 Cup: 0909219
Auftraggeber *Customer*	Sky Power International LLC USA - Liberty, SC 29657
Auftragsnummer *Order No.*	VT09556
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	3
Datum der Kalibrierung *Date of calibration*	26.09.2009

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Der DKD ist Unterzeichner der multi- lateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.
This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DKD is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Dieser Kalibrierschein darf nur vollständig und unverändert weiterverbreitet werden. Auszüge oder Änderungen bedürfen der Genehmigung sowohl der Akkreditierungsstelle des DKD als auch des ausstellenden Kalibrierlaboratoriums. Kalibrierscheine ohne Unterschrift und Stempel haben keine Gültigkeit.
This calibration certificate may not be reproduced other than in full except with the permission of both the Accreditation Body of the DKD and the issuing laboratory. Calibration certificates without signature and seal are not valid.

Stempel *Seal*	Datum *Date*	Leiter des Kalibrierlaboratoriums *Head of the calibration laboratory*	Bearbeiter *Person in charge*
Deutscher Kalibrierdienst DKD-K-36801	26.09.2009	Dipl. Phys. D. Westermann	M. Meyer zu Himmern Dipl.-Ing. (FH) M. Meyer zu Himmern

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0)4451 9515 0

Deutsche WindGuard Wind Tunnel Services GmbH

Figure B-5. Calibration sheet for the primary anemometer (page 1)

Seite 2
Page

09/5843
DKD-K-36801
09/2009

Kalibriergegenstand *Object*	Anemometer		
Kalibrierverfahren *Calibration procedure*	IEC 61400 12 1 - Wind Turbine Power Performance Testing 12 2005 MEASNET - Cup Anemometer Calibration Procedure – 09 1997 ISO 3966 – Measurement of fluid in closed conduits - 1977		
Ort der Kalibrierung *Place of calibration*	Windtunnel of Deutsche WindGuard, Varel		
Messbedingungen *Test Conditions*	wind tunnel area [1]	10000 cm²	
	anemometer frontal area [2]	230 cm²	
	diameter of mounting pipe [3]	34 mm	
	blockage ratio [4]	0.023 [-]	
	blockage correction [5]	1.000 [-]	
	average WindGuard reference [6]	203.8 1/s (Thies First Class)	
	present WindGuard reference [7]	203.7 1/s	
Umgebungsbedingungen *Test conditions*	air temperature	23.3 °C	± 1.0 K
	air pressure	1027.0 hPa	± 1.0 hPa
	relative air humidity	47.6 %	± 2.5 %
Dateiinformation *File info*			
Anmerkungen *Remarks*		-	
Auswertesoftware *Software version*		4.0	

[1] Querschnittsfläche der Auslassdüse des Windkanals
[2] Vereinfachte Querschnittsfläche (Schattenwurf) des Prüflings inkl. Montagerohr
[3] Durchmesser des Montagerohrs
[4] Verhältnis von 2) zu 1)
[5] Korrekturfaktor durch die Verdrängung der Strömung durch den Prüfling
[6] Referenzwert des Referenzanemometers bei 10 m/s (Mittelwert)
[7] Aktueller Wert des Referenzanemometers

Dieser Kalibrierschein wurde elektronisch erzeugt
This calibration certificate has been generated electronically

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Deutsche WindGuard Wind Tunnel Services GmbH

Figure B-6. Calibration sheet for the primary anemometer (page 2)

09/5843
DKD-K-36801
09/2009

Kalibrierergebnis:
Result:

Test Item (1/s)	Tunnel Speed (m/s)	Uncertainty (k=2) (m/s)
86.363	4.193	0.10
129.019	6.143	0.10
170.212	8.052	0.10
210.679	9.898	0.10
253.862	11.878	0.10
297.703	13.858	0.10
339.982	15.828	0.11
317.337	14.775	0.10
276.809	12.867	0.10
232.163	10.870	0.10
190.126	8.932	0.10
148.153	7.021	0.10
108.825	5.222	0.10

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor k=2 ergibt. Sie wurde gemäß DKD-3 ermittelt. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von 95 % im zugeordneten Wertintervall.

Der Deutsche Kalibrierdienst ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die weiteren Unterzeichner innerhalb und außerhalb Europas sind den Internetseiten von EA (www.european-accreditation.org) und ILAC (www.ilac.org) zu entnehmen.

The expanded uncertainty assigned to the mea-surement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.

The DKD is signatory to the multilateral agree-ments of the European co-operation for Accredita-tion (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.

Figure B-7. Calibration sheet for the primary anemometer (page 3)

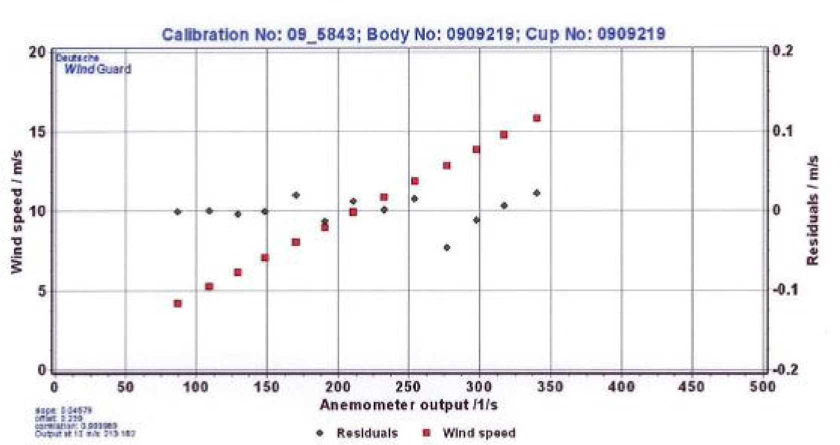
1 Detailed MEASNET[1] Calibration Results

DKD calibration no.	09/5843
Body no.	0909219
Cup no.	0909219
Date	26.09.2009
Air temperature	23.3 °C
Air pressure	1027.0 hPa
Humidity	47.6 %

Linear regression analysis

Slope	0.04579 (m/s)/(1/s) ±0.00006 (m/s)/(1/s)
Offset	0.239 m/s ±0.015 m/s
St.err(Y)	0.017 m/s
Correlation coefficient	0.999989

Remarks	no



[1]) According to MEASNET Cup Anemometer Calibration Procedure 09/1997.
Deutsche WindGuard Wind Tunnel Services is accredited by MEASNET and by the Deutscher Kalibrierdienst – DKD (German Calibration Service). Registration: DKD – K – 36801

Figure B-8. Calibration sheet for the primary anemometer (page 4)

2 Instrumentation

Pos.	Sensor	Manufa.	Identification	Year	Calibration
1	Pitot static tube	Airflow	483/8 Nr. 000142	02	06/02
2	Pitot static tube	Airflow	483/8 Nr. 000143	02	06/02
3	Pitot static tube	Airflow	483/8 Nr. 000144	02	06/02
4	Pitot static tube	Airflow	483/8 Nr. 000145	02	06/02
5	Pressure transducer	Setra	C 239 Nr. 1688081	02	DWG12/07
6	Pressure transducer	Setra	C 239 Nr. 1688082	02	DWG12/07
7	Pressure transducer	Setra	C 239 Nr. 1688083	02	03/07
8	Pressure transducer	Setra	C 239 Nr. 1688084	02	03/05
9	El. Barometer	Vaisala	100 A Nr. X2010004	02	DWG12/07
10	El. Thermometer	Galltec	KPK 1/6-ME	02	DWG12/07
11	El. Humidity sensor	Galltec	KPK 1/6-ME	02	DWG12/07
12	Wind tunnel control	-	-	-	-
13	CAN-BUS / PC	esd	-	04	05/04
14	Anemometer		-		
15	Universal Isolator	Knick	P2700 - 58285/8198430	05	01/06

Table 1 Description of the data acquisition system

3 Photo of the calibration set-up

Calibration set-up of the anemometer calibration in the wind tunnel of Deutsche WindGuard, Varel.
The anemometer shown is of the same type as the calibrated one.
Remark: The proportion of the set-up are not true to scale due to imaging geometry.

4 Deviation to MEASNET procedure

The calibration procedure is in all aspects in accordance with the IEC 61400-12-1 Procedure

5 References

[1] J. Mander, D. Westermann, 12/2007 - Verfahrensanweisung DKD-Kalibrierung von Windgeschwindigkeitssensoren
[2] IEC 61400-12-1 12/2005 - Wind Turbine Power Performance Testing
[3] ISO 3966 1977 - Measurement of fluid flow in closed conduits
[4] MEASNET 09 1997 - Cup Anemometer Calibration Procedure

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Figure B-9. Calibration sheet for the primary anemometer (page 5)

Met One Instruments, Inc.
1600 NW Washington Blvd.
Grants Pass, Oregon 97526
Telephone 541-471-7111
Facsimile 541-541-7116

Regional Service
3206 Main St. Suite 106
Rowlett, Texas 75088
Telephone 972-412-4715
Facsimile 972-412-4716

Test Certificate

Model: SS201 **Sensor Serial No:** K16684

Job Number: **Customer:**

Test Date: 12/10/2010 **Tested by:** D. Hoagland

Room Temperature: 24.6 °C **Room Relative Humidity:** 42.9 %

Recommended calibration interval is 12 months from the first day of use.

Calibration Standards

Standards	Manufacturer	Model	SN	Cal Due
DMM	HEWLETT PACKARD	3468B	2231A01057	April 7, 2011
TEMPERATURE	ROSEMONT	T-200	1171688	January 12, 2011
RH Sensor	Met One Instruments	083D-1-35	W3673	June 26, 2011
BAROMETRIC PRESSURE	MET ONE INSTRUMENTS	090B	H6507	July 2, 2011

Test Data

TEST	UUT	SPEC	NOTES
OUTPUT Vpp	10.6 Vpp	8.0 Vpp Min	
SYMMETRY %Duty	55.90%	50 ±10%	
CURRENT DRAIN	3.5 mA	5.0 mA TYP.	
STARTING TORQUE	0.324 GM-CM	1.0 GM-CM MAX	
SHAFT END PLAY	0.0145 in	0.006 to 0.020 in	
SHAFT & HUB RUNOUT	0.0005 in	0.000 to 0.005 in	

Test Procedure # 42061-6101, 53645-6101

The standards used for this calibration have accuracies equal to or greater than the instruments tested. These standards are on record and traceable to NIST to the extent allowed by the institute's calibration facility. Unless otherwise stated hereon, all instruments are calibrated to meet the manufacturer's published specifications. The Calibration system complies with MIL-STD-45662A.

SS201-9600 Rev B

Figure B-10. Calibration sheet for the reference anemometer (page 1)

Wind Direction

Met One Instruments, Inc.
1600 NW Washington Blvd.
Grants Pass, Oregon 97526
Telephone 541-471-7111
Facsimile 541-541-7116

Regional Service
3206 Main St. Suite 106
Rowlett, Texas 75088
Telephone 972-412-4715
Facsimile 972-412-4716

Test Certificate

Model: SD201 **Sensor Serial No:** K16689

Job Number: **Customer:**

Test Date: 12/10/2010 **Tested by:** D. Hoagland

Room Temperature: 24.6 °C **Room Relative Humidity:** 42.9 %

Recommended calibration interval is 12 months from the first day of use.

Calibration Standards

Standards	Manufacturer	Model	SN	Cal Due
DMM	HEWLETT PACKARD	3468B	2231A01057	April 7, 2011
TEMPERATURE	ROSEMONT	T-200	1171688	January 12, 2011
RH Sensor	Met One Instruments	083D-1-35	W3673	June 26, 2011
BAROMETRIC PRESSURE	MET ONE INSTRUMENTS	090B	H6507	July 2, 2011

Test Data

TEST	OUTPUT VOLTS	INDICATED °	ERROR °	SPEC	NOTES
0°	0.001	0.1	0.1	±5°	
30°	0.299	29.9	-0.1	±5°	
60°	0.601	60.1	0.1	±5°	
90°	0.905	90.5	0.5	±5°	
120°	1.204	120.4	0.4	±5°	
150°	1.503	150.3	0.3	±5°	
180°	1.804	180.4	0.4	±5°	
210°	2.109	210.9	0.9	±5°	
240°	2.416	241.6	1.6	±5°	
270°	2.723	272.3	2.3	±5°	
300°	3.030	303.0	3.0	±5°	
330°	3.337	333.7	3.7	±5°	

END PLAY	0.005
TORQUE	0.040

NOISE CW	N/A
NOISE CCW	N/A

Test Procedure #42062-6200

The standards used for this calibration have accuracies equal to or greater than the instruments tested. These standards are on record and traceable to NIST to the extent allowed by the institute's calibration facility. Unless otherwise stated hereon, all instruments are calibrated to meet the manufacturer's published specifications. The Calibration system complies with MIL-STD-45662A.

SD210-9600 Rev B

Figure B-11. Calibration sheet for the wind vane

Temperature

Branch #: 5000

sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: RTD

DOE #: 03507C

Model # : 78N01N00N04

S/N : 0673552

Calibration Date: 09/23/2010

Due Date: 09/23/2011

No	Function Tested	Nominal Value (°C)	Measured Values (Ω) AS Found	Measured Values (Ω) AS Left	( )Mfr. Specs. OR (X)Data only
*	Temperature:	-15	94.118	Same	
		0	100.005	"	
		15	105.854	"	
		30	111.680	"	
		45	117.481	"	

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 = ± 0.02 °C, k = 2.

Calibrated By: P. Morse
Date: 9/23/2010

Approved By: D. Myers
Date: 9/23/2010

Figure B-12. Calibration sheet for the temperature sensor

Pressure

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Pressure Transmitter DOE #: 03466C

Model # : PTB101B S/N : B2130018

Calibration Date: 09/22/2010 Due Date: 09/22/2011

No	Function Tested	Nominal Value (kPa)	Measured Output Voltage (VDC)		( )Mfr. Specs. OR (X)Data only (mb)
			As Found	As Left	
*	Absolute Pressure				
		65	0.265		
		70	0.538		
		75	0.809		
		80	1.081		
		85	1.352		
		90	1.624		
		95	1.895		
		100	2.167		
		103	2.330		

Notes:
1. Expanded Uncertainty of the nominal value is ± 0.2 kPa, with k = 2.
2. Calibration was performed at 24°C and 39% RH.
3. Calibration was performed using standards that are traceable to NIST. DOE numbers: 128120, and 02301C.

Calibrated By: P. Morse
Date: 09/22/2010

Approved By: D. Myers
Date: 09/22/2010

Figure B-13. Calibration sheet for the pressure sensor

Data Acquisition

Certificate of Conformance

		Date:	22-FEB-2012
Serial Number:	12B6DD2	**Part Number:**	192580D-02
Description:	CCA,NI 9229,PRECISION +/- 60V ISOLATION AMPLIFIER WITH ANTI-ALIAS FILTER		
Manufacture Date:			

National Instruments (NI) hereby certifies that the NI part numbers and quantity of this shipment are in accord with the Customer's Purchase Order. NI further certifies that the product(s) is/are new material; that the product(s) has/have been inspected and tested and conform(s) to quality and performance standards as documented in the National Instruments Quality Management System (QMS), in conformance with the ISO 9001:2000 standard.

National Instruments further certifies that the environment in which the products were tested is maintained within the operating specifications of the instrument and the standards. If any product requires calibration, the instruments used to perform the calibration are traceable to the National Institute of Standards and Technology (NIST) and/or other National Measurements Institutes (NMI's) that are signatories of the International Committee of Weights and Measures (CIPM) Mutual Recognition Arrangement (MRA).

For questions or comments, please contact National Instruments Technical Support.

Andrew Krupp
Vice President, Quality and Continuous Improvement

National Instruments Corporation
11500 N. Mopac Expressway
Austin, TX 78759-3504
USA
Tel: 512-683-0100

NATIONAL INSTRUMENTS

Figure B-14. Certificate of conformance sheet for NI 9229 signal module

Davis Calibration

ACLASS ACCREDITED CALIBRATION

Certificate of Calibration

4415557

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: **03893C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CHANNEL, ±60 V, 24-BIT SIMULTANEOUS ANALOG INPUT

Model Number: NI 9229
Serial Number: 12B6DD2

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

Technician: COREY CLAXTON
Cal Date 21Aug2010
Cal Due Date: 21Aug2011
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 55.0 %

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.

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

Approved By: COREY CLAXTON
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
4291519	15-0271	MULTIFUNCTION CALIBRATOR	5700A	07Jul2010	05Oct2010

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Figure B-15. Calibration sheet for NI 9229 signal module 12B6DD2

Certificate of Conformance

		Date:	22-FEB-2012
Serial Number:	12BD192	**Part Number:**	192547D-01
Description:	CCA,NI 9217,4-CHANNEL CRIO MODULE FOR RTD INPUTS		
Manufacture Date:			

National Instruments (NI) hereby certifies that the NI part numbers and quantity of this shipment are in accord with the Customer's Purchase Order. NI further certifies that the product(s) is/are new material; that the product(s) has/have been inspected and tested and conform(s) to quality and performance standards as documented in the National Instruments Quality Management System (QMS), in conformance with the ISO 9001:2000 standard.

National Instruments further certifies that the environment in which the products were tested is maintained within the operating specifications of the instrument and the standards. If any product requires calibration, the instruments used to perform the calibration are traceable to the National Institute of Standards and Technology (NIST) and/or other National Measurements Institutes (NMI's) that are signatories of the International Committee of Weights and Measures (CIPM) Mutual Recognition Arrangement (MRA).

For questions or comments, please contact National Instruments Technical Support.

Andrew Krupp
Vice President, Quality and Continuous Improvement

National Instruments Corporation
11500 N. Mopac Expressway
Austin, TX 78759-3504
USA
Tel: 512-683-0100

NATIONAL INSTRUMENTS

Figure B-16. Certificate of conformance sheet for NI 9217 signal module 12BD192

Davis Calibration

ACLASS ACCREDITED CALIBRATION

Certificate of Calibration

4415599

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: **03889C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CH 100 OHM 24-BIT RTD ANALOG INPUT

Model Number: NI 9217
Serial Number: 12BD192

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

Technician: COREY CLAXTON
Cal Date: 21Aug2010
Cal Due Date: 21Aug2011
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 55.0 %

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.

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

Approved By: COREY CLAXTON
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
3730238	15-0247	REFERENCE MULTIMETER	8508A	02Dec2009	02Dec2010

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Figure B-17. Calibration sheet for NI 9217 signal module 12BD192

Certificate of Conformance

		Date:	22-FEB-2012
Serial Number:	12E9CD3	**Part Number:**	193299F-01
Description:	CCA,9205,16 BIT 32 CH VOLTAGE ANALOG INPUT MODULE (MIO CLASS)		
Manufacture Date:			

National Instruments (NI) hereby certifies that the NI part numbers and quantity of this shipment are in accord with the Customer's Purchase Order. NI further certifies that the product(s) is/are new material; that the product(s) has/have been inspected and tested and conform(s) to quality and performance standards as documented in the National Instruments Quality Management System (QMS), in conformance with the ISO 9001:2000 standard.

National Instruments further certifies that the environment in which the products were tested is maintained within the operating specifications of the instrument and the standards. If any product requires calibration, the instruments used to perform the calibration are traceable to the National Institute of Standards and Technology (NIST) and/or other National Measurements Institutes (NMI's) that are signatories of the International Committee of Weights and Measures (CIPM) Mutual Recognition Arrangement (MRA).

For questions or comments, please contact National Instruments Technical Support.

Andrew Krupp
Vice President, Quality and Continuous Improvement

National Instruments Corporation
11500 N. Mopac Expressway
Austin, TX 78759-3504
USA
Tel: 512-683-0100

Figure B-18. Certificate of conformance sheet for NI 9205 signal module 12E9CD3

Davis Calibration

ACLASS ACCREDITED CALIBRATION

Certificate of Calibration

4415656

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: **03886C**
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: 12E9CD3

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

Technician: COREY CLAXTON
Cal Date: 21Aug2010
Cal Due Date: 21Aug2011
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 55.0 %

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.

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

Approved By: COREY CLAXTON
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
4291519	15-0271	MULTIFUNCTION CALIBRATOR	5700A	07Jul2010	05Oct2010

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Figure B-19. Calibration sheet for NI 9205 signal module 12E9CD3