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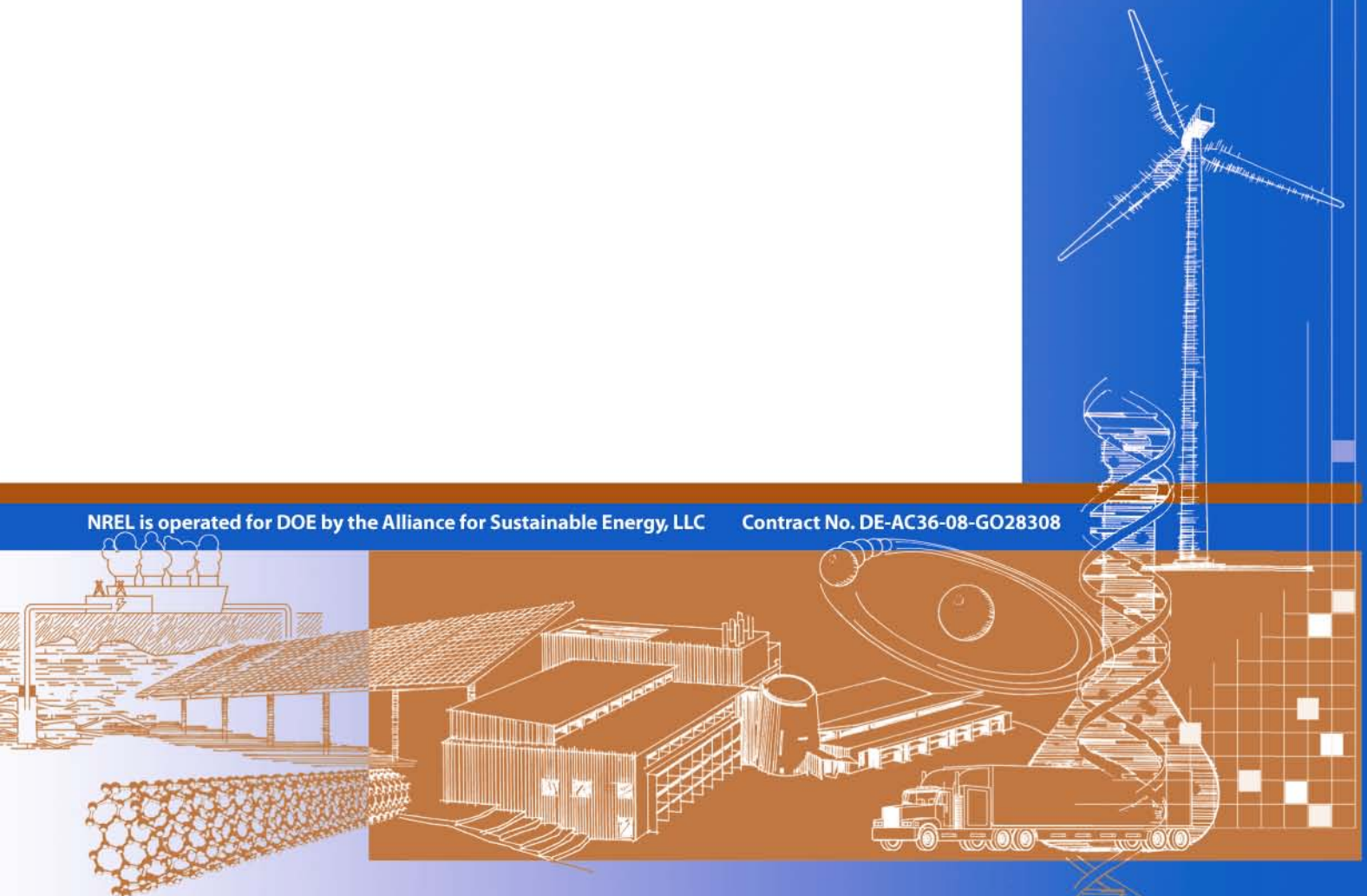
Wind Turbine Generator System Power Performance Test Report for the ARE442 Wind Turbine

Jeroen van Dam and Dave Jager

Technical Report
NREL/TP-500-46191
February 2010



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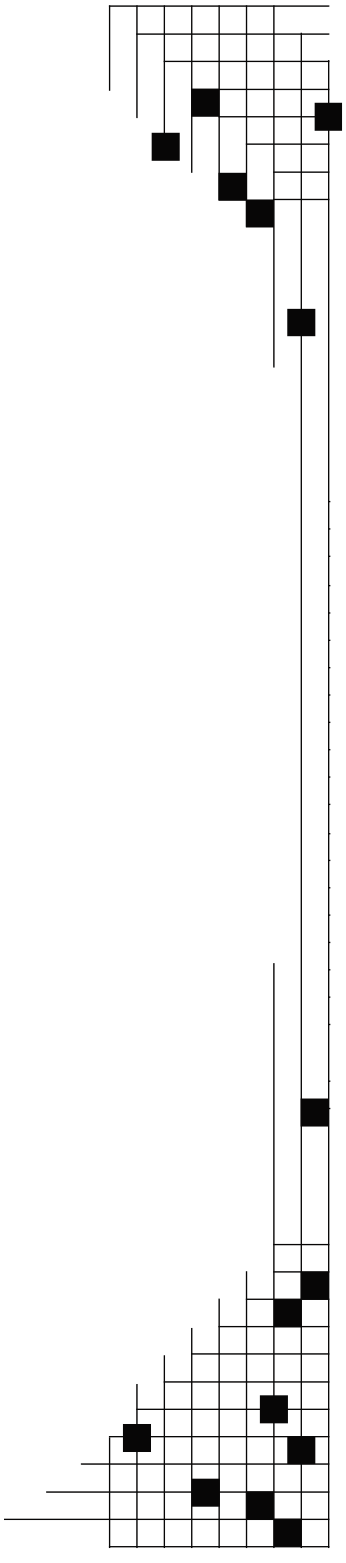

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Approval By: _____

Jeroen van Dam, NREL Test Engineer Date

Review By: _____

Amy Bowen, NREL Test Engineer Date

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1. Background

This test is being conducted as part of the U.S. Department of Energy's (DOE) Independent Testing project. This project was established to help reduce the barriers of wind energy expansion by providing independent testing results for small turbines. In total, four turbines are being tested at the National Wind Technology Center (NWTC) as a part of this project. Power performance testing is one of up to 5 tests that may be performed on the turbines, including duration, safety and function, noise, and power quality tests.

2. Test Summary

Figure 1 is a summary of the results of a power performance test that NREL conducted on the ARE 442 wind turbine. For this test, the ARE 442 turbine was installed at the NWTC, close to Boulder, Colorado. This test was conducted in accordance with the International Electrotechnical Commission's (IEC) standard, *Wind Turbine Generator Systems Part 12: Power Performance Measurements of Electricity Producing Wind Turbines*, IEC 61400-12-1 Ed.1.0, 2005-12. However, because the ARE 442 is a small turbine as defined by IEC, NREL also followed Annex H that applies to small wind turbines. This test report refers to these procedures as the Standard.

In these summary results, wind speed is normalized to sea-level air density. Additional results are given in Section 7**.** This test was begun on December 9, 2008 and was ended on December 28, 2008**.** 303.7 hours of valid data were collected during that time. The highest bin filled was the 18.0 m/s bin. The amount of test data is sufficient to meet the requirements of the Standard, Annex H.

National Renewable Energy Laboratory

Power Performance Test
ARE442

Sea-Level Density Power Curve

Report Created: 31-Dec-08

Turbine Specifications:

Serial number:	Y08-001C	
Rated Power:	10000	W
Cut-in Wind Speed:	2.2	m/s
Cut-out Wind Speed:	-	m/s
Rated Wind Speed:	12	m/s
Rotor Diameter:	7.2	m
Control Type:	Active	
Pitch Setting:	Fixed	

Site Conditions:

Location:	NWTC Boulder, CO
Average Air Density:	1.035 kg/m^3
Measurement Sectors:	214-74 °T

Test Statistics:

Start Date:	9-Dec-2008
End Date:	28-Dec-2008
Amount of Data Collected:	303.70 hours
Highest Bin Filled:	18.0 m/s
Test Completed?	Yes

Bin Wind Speed (m/s)	Bin Power (kW)	Number Data Points	Cp
0.51	-0.03	1,000	-9.00
1.00	-0.04	1,210	-1.61
1.50	-0.04	1,339	-0.53
1.99	-0.05	1,423	-0.27
2.50	-0.05	1,196	-0.13
2.98	-0.01	1,061	-0.02
3.49	0.08	861	0.08
4.00	0.30	713	0.19
4.49	0.59	647	0.26
5.00	0.91	579	0.29
5.51	1.35	604	0.32
6.00	1.86	586	0.35
6.50	2.42	624	0.35
7.00	3.04	647	0.35
7.49	3.70	599	0.35
8.00	4.41	535	0.35
8.49	5.19	544	0.34
9.00	6.02	478	0.33
9.50	6.81	416	0.32
10.00	7.70	404	0.31
10.49	8.47	384	0.29
10.99	9.17	362	0.28
11.50	9.69	340	0.26
12.01	10.10	289	0.23
12.49	10.05	245	0.21
12.97	9.91	243	0.18
13.50	9.42	186	0.15
14.00	9.00	162	0.13
14.48	8.58	138	0.11
15.00	8.28	124	0.10
15.54	7.86	74	0.08
15.99	7.85	78	0.08
16.49	7.59	47	0.07
16.95	7.33	33	0.06
17.51	7.48	27	0.06
18.01	7.57	24	0.05

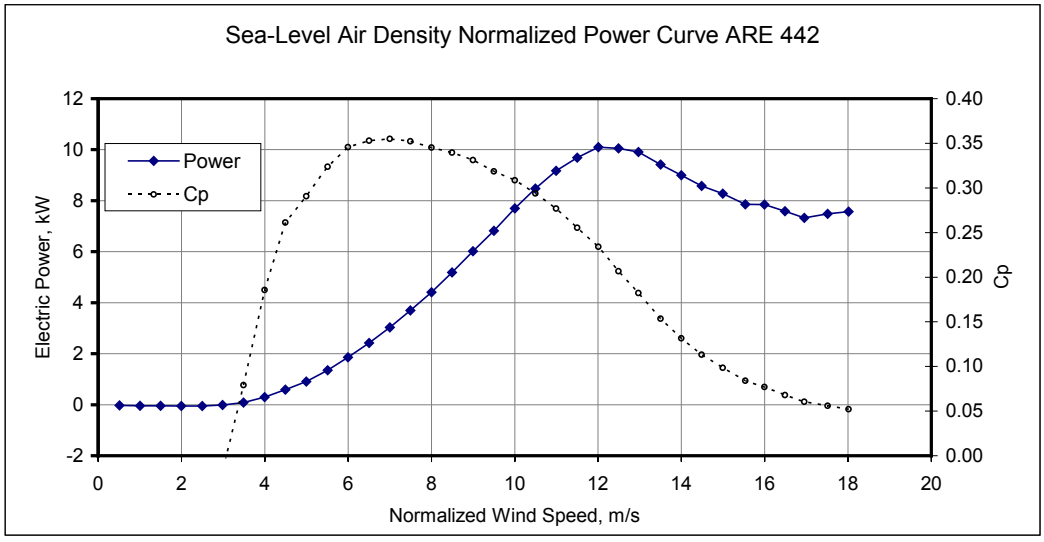

Figure 1. Power curve summary

3. Test Turbine Configuration

Table 1. Test turbine configuration

Turbine make, model, serial number, production year	Abundant Renewable Energy, ARE 442, Y08-001C, 2008
Rotor diameter (m)	7.2
Hub height (m)	30.9
Tower type	Free standing lattice, Valmont U4.5 x 100’
Rated electrical power (kW)	10
Rated wind speed (m/s)	12
Rotor speed range (rpm)	0-140
Fixed or variable pitch	Fixed
Number of blades	3
Blade-tip pitch angle (deg)	0°, blade root flat on alternator
Blade make, type, serial number	Aero Energy 089-028, 089-029, 089-030
Description of control system (device & software version)	Side furling with gravity return; VCL442-HV Voltage Clamp pulse-width modulated resistor-loading; Windy boy 6000US

NREL measured the distance of the blade tip to the center of the rotor as 3.7 m, which would make the diameter 7.4 m. If the turbine has this measured rotor diameter of 7.4m instead of the specified diameter of 7.2m, this would reduce the peak Cp from 0.42 to 0.40.

The power transducer was connected between the NREL grid and the subpanel (Figure 2) to which the voltage clamp and the inverters are connected. It thus captures the combined consumption/production of all three components.

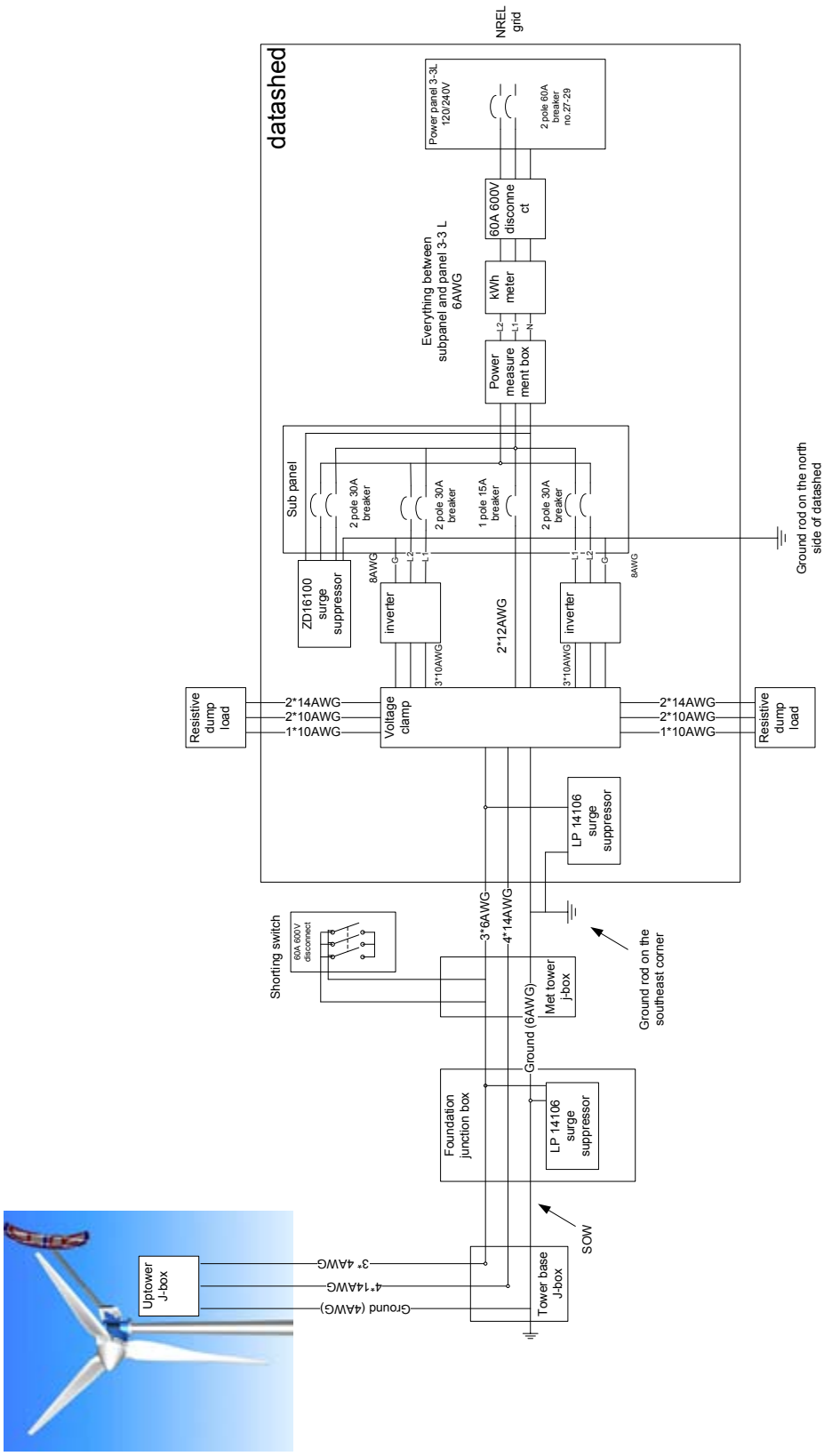

Figure 2. Electrical diagram of the ARE 442 installation

Figure 3. ARE 442 test turbine at the NWTC

4. Test Site Description

The test turbine is located at site 3.3a at the NWTC located 8 miles south of Boulder, Colorado. The terrain primarily consists of mostly flat terrain with short vegetation. The test site has prevailing wind bearing 292° relative to true north. For measurements where it is important to accurately measure wind speed, NREL used data obtained when wind direction is between 214° and 74° true. In this measurement sector, the influence of terrain and obstructions on the anemometer is small. Figure 4 shows the turbine and meteorological tower locations. This figure also shows nearby obstructions and topographical features of the site. A circle indicating 20 rotor diameters is drawn on the map. Sizes and distances of nearby obstructions are provided in Table 2.

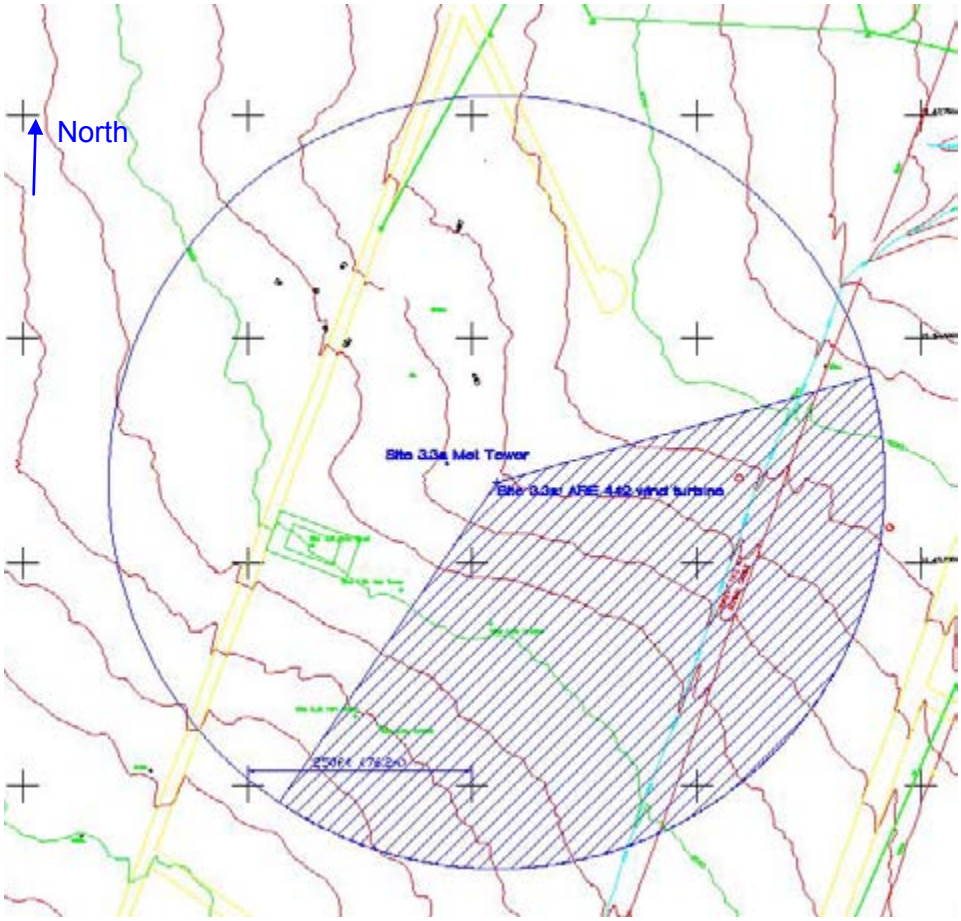

Figure 4. Map of the test site

Table 2. Structures close to test turbine

Obstacle or Turbine	Relative to:	Distance (m)	Bearing (deg T)	Equiv. Dia. (m)	Obstructed Sector Start (deg T)	Obstructed Sector End (deg T)
Met A	Test Turbine	18.3	290	0.8		
Data Shed	Test Turbine	62.8	250.6	4.3	0	0
Gaia	Test Turbine	48.0	182.3	N/A	152	213
Met B	Test Turbine	49.2	221.7	0.8	0	0
Mariah	Test Turbine	92.0	205.6	N/A	0	0
Met C	Test Turbine	93.3	211.2	0.7	0	0
Test Turbine	Met Tower	18.3	110	N/A	73	147
Data Shed	Met Tower	50.0	237	4.3	0	0
Gaia	Met Tower	56.4	164	N/A	136	193
Met B	Met Tower	45.7	200	0.8	0	0
Mariah	Met Tower	92.0	194	N/A	0	0
Met C	Met Tower	91.5	200	0.7	0	0

Based upon this analysis, NREL has established a measurement sector from 214° to 74°. NREL completed a site assessment to determine if the site fails the requirements of Annex A of the Standard and would therefore require a site calibration. Table 3 shows the results from the site assessment. Based on the site assessment results, a site calibration is not required.

Table 3. Criteria for test site without site calibration

Description	Distance	Sector (deg)	Test Site Condition	Pass/Fail
Maximum slope of best fit plane < 3%	<2L	360	2.3%	Pass
Maximum variation from best fit plane < 0.08 D	<2L	360	0.02	Pass
Maximum slope of best fit plane < 5%	2-4L	In	2.7%	Pass
Maximum variation from best fit plane < 0.15 D	2-4L	In	0.02	Pass
Steepest slope maximum < 10%	2-4L	Out	3.1%	Pass
Maximum slope of best fit plane < 10%	4-8L	In	2.7%	Pass
Maximum variation from best fit plane < 0.15 D	4-8L	In	0.02	Pass
No neighboring and operating turbines	$<2D_n$	360	0	Pass
No obstacles	$<2D_e$	360	0	Pass

D = test turbine rotor diameter
L = distance between test turbine and meteorological tower
D_e = equivalent diameter of obstacle
In = inside preliminary measurement sector
Out = outside preliminary measurement sector

The ARE442 was connected to the electrical grid at a nominal voltage of 240 VAC at a frequency of 60 Hz. The grid tolerances are 5% for voltage amplitude and 1% for frequency.

5. Description of Test Equipment

All test equipment was calibrated; calibration sheets are included in Appendix B. Table 4 shows the equipment used and calibration due dates. Figure 5 shows placement of the meteorological instruments on the tower. The anemometer was sent out for recalibration after the test period. The difference between the two calibrations was within the tolerances allowed by the Standard. The data acquisition modules were out of calibration during the test period. They were sent out for post-test calibration and found to be within specification. The post-test calibration sheets are included in Appendix B as well.

Table 4. Equipment used in the power performance test

Instrument	Make, Model	Serial Number	Calibration Due Date
Power transducer	Secondwind Phaser 5FM-4A20	02663	28 Apr 2009
Current transducers	OSI 12974	001235408 001235411	Calibrated with power transducer
Primary anemometer	Thies, First Class	0707886	28 Feb 2009
Reference anemometer	NRG, Max 40	179500049022	In situ
Wind vane	Met One, 020C with aluminum vane	G4706	28 Feb 2009
Pressure sensor	Vaisala, PTB101B	T4730007	26 Aug 2009
Temperature sensor	Met One, T-200	0789020	10 Oct 2009
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	 12EAE14 12A2037 12C73B4 12ECB77	 31 May 2008 3 Aug 2008 9 Oct 2008

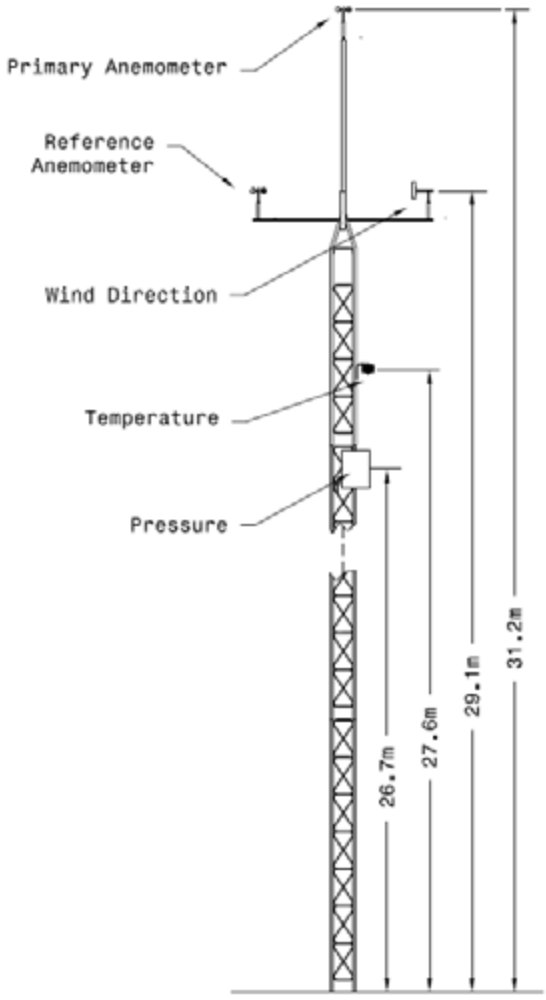

Figure 5. Meteorological tower and instruments

Figure 5 shows placement of the meteorological instruments on the tower. (Note that the Primary Anemometer is within the allowable 2.5% of hub height. To ensure that only data obtained during normal operation of the turbine are used in the analysis, and to ensure data are not corrupted, data sets are excluded from the database under the following circumstances:

- external conditions other than wind speed are out of the normal range for turbine operation,
- turbine cannot operate because of a turbine fault condition, and,
- turbine is manually shut down or in a test or maintenance operating mode.

Two methods were used to track when any of these conditions occur during the test. With the first method, the logbook was checked for such events. For the second, the turbine controller had a status signal which was measured that indicates when the turbine is available or braked. A copy of the logbook is available upon request. No maintenance was performed during the test period.

6. Description of Test Procedure

The test was conducted according to the procedures in the Standard. The sampling rate was 10 kHz, which was then decimated to 1 Hz data. The averaging time was 1 minute for the mean values. Standard deviation, minimum, and maximum values for each averaging period were also collected.

The turbine status signal for the ARE 442 was obtained by checking the release of the up-tower brake relay. The status signal indicated if the turbine was braked or not.

Only database A is reported since the ARE 442 does not have a cut-out wind speed.

Table 5. Uncertainty values used in the analysis

Component	Uncertainty	Source
Power (Inverter)		
voltage transducer	NA	
current sensor/signal	12 W	Specifications (specs)
power transducer *	0.12%	Specs
data acquisition	17 W +0.08%	Specs
resistor	0.01%	Specs
Wind Speed		
calibration	0.02 m/s	Calibration sheet
operational characteristics	0.05 m/s +0.52%	IEC
mounting effects	1.00%	Assumption
terrain effects	2.00%	IEC
data acquisition	< 0.01 m/s	Assumption
Temperature		
temperature sensor	0.15 °C	Specs
radiation shielding	1.15 °C	Assumption
mounting effects	0.11 °C	IEC method
algorithm	0.00 °C	Included in DAS
data acquisition	0.35 °C	Specs
Air Pressure		
pressure sensor	0.20 kPa	Instrument specs.
mounting effects	< 0.01 kPa	IEC method
data acquisition	0.06 kPa	Specs

7. Test Results

7.1. Tabular Results of Power Performance Test

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

Table 6. Performance at sea-level air density; 1.225 kg/m^3

Measured power curve (database A)							
Reference air density: 1.225 kg/m^3					Category A Standard Uncertainty (kW)	Category B Standard Uncertainty (kW)	Combined Standard Uncertainty (kW)
Bin (m/s)	Normalized Wind Speed (m/s)	Power Output (kW)	C_p	Number of 1-Minute Data Sets			
0.5	0.51	-0.03	-9.00	1000	0.00	0.16	0.16
1	1.00	-0.04	-1.61	1210	0.00	0.16	0.16
1.5	1.50	-0.04	-0.53	1339	0.00	0.16	0.16
2.	1.99	-0.05	-0.27	1423	0.00	0.16	0.16
2.5	2.50	-0.05	-0.13	1196	0.00	0.16	0.16
3	2.98	-0.01	-0.02	1061	0.00	0.16	0.16
3.5	3.49	0.08	0.08	861	0.01	0.16	0.16
4	4.00	0.30	0.19	713	0.01	0.17	0.17
4.5	4.49	0.59	0.26	647	0.01	0.18	0.18
5	5.00	0.91	0.29	579	0.02	0.18	0.18
5.5	5.51	1.35	0.32	604	0.02	0.20	0.20
6	6.00	1.86	0.35	586	0.02	0.23	0.23
6.5	6.50	2.42	0.35	624	0.02	0.24	0.24
7	7.00	3.04	0.35	647	0.02	0.27	0.27
7.5	7.49	3.70	0.35	599	0.02	0.29	0.29
8	8.00	4.41	0.35	535	0.02	0.32	0.32
8.5	8.49	5.19	0.34	544	0.02	0.36	0.36
9	9.00	6.02	0.33	478	0.02	0.39	0.39
9.5	9.50	6.81	0.32	416	0.03	0.39	0.39
10	10.00	7.70	0.31	404	0.03	0.45	0.45
10.5	10.49	8.47	0.29	384	0.04	0.42	0.42
11	10.99	9.17	0.28	362	0.04	0.40	0.40
11.5	11.50	9.69	0.26	340	0.05	0.32	0.33
12	12.01	10.10	0.23	289	0.05	0.29	0.29
12.5	12.49	10.05	0.21	245	0.06	0.17	0.19
13	12.97	9.91	0.18	243	0.06	0.20	0.21
13.5	13.50	9.42	0.15	186	0.06	0.33	0.34
14	14.00	9.00	0.13	162	0.05	0.33	0.33
14.5	14.48	8.58	0.11	138	0.04	0.34	0.34
15	15.00	8.28	0.10	124	0.06	0.26	0.27
15.5	15.54	7.86	0.08	74	0.11	0.33	0.35
16	15.99	7.85	0.08	78	0.06	0.17	0.18
16.5	16.49	7.59	0.07	47	0.05	0.26	0.27
17	16.95	7.33	0.06	33	0.14	0.28	0.31
17.5	17.51	7.48	0.06	27	0.14	0.20	0.25
18	18.01	7.57	0.05	24	0.08	0.18	0.20

Table 7. Performance at site average density; 1.05 kg/m^3

Measured power curve (database A)							
Reference air density: 1.05 kg/m^3					Category A Standard Uncertainty (kW)	Category B Standard Uncertainty (kW)	Combined Standard Uncertainty (kW)
Bin (m/s)	Normalized Wind Speed (m/s)	Power Output (kW)	C_p	Number of 1-Minute Data Sets			
0.5	0.52	-0.03	-10.29	928	0.00	0.16	0.16
1	1.00	-0.04	-1.84	1129	0.00	0.16	0.16
1.5	1.50	-0.05	-0.63	1254	0.00	0.16	0.16
2	2.00	-0.05	-0.29	1376	0.00	0.16	0.16
2.5	2.50	-0.05	-0.16	1175	0.00	0.16	0.16
3	2.99	-0.03	-0.05	1079	0.00	0.16	0.16
3.5	3.49	0.04	0.05	862	0.00	0.16	0.16
4	3.99	0.19	0.14	714	0.01	0.17	0.17
4.5	4.50	0.46	0.24	646	0.01	0.17	0.17
5	5.00	0.73	0.27	574	0.01	0.18	0.18
5.5	5.50	1.11	0.31	549	0.02	0.19	0.19
6	6.00	1.53	0.33	585	0.02	0.21	0.21
6.5	6.50	2.04	0.35	546	0.02	0.23	0.23
7	7.00	2.59	0.35	605	0.02	0.25	0.25
7.5	7.49	3.19	0.35	618	0.02	0.27	0.27
8	7.99	3.84	0.35	550	0.02	0.30	0.30
8.5	8.50	4.51	0.34	503	0.02	0.32	0.32
9	8.98	5.25	0.34	514	0.02	0.36	0.37
9.5	9.50	6.06	0.33	459	0.02	0.39	0.39
10	10.00	6.82	0.32	398	0.03	0.39	0.39
10.5	10.51	7.67	0.31	388	0.03	0.45	0.45
11	11.00	8.41	0.30	361	0.04	0.42	0.42
11.5	11.49	9.04	0.28	344	0.04	0.39	0.39
12	12.00	9.62	0.26	327	0.05	0.36	0.37
12.5	12.50	10.02	0.24	283	0.06	0.29	0.30
13	12.98	10.06	0.22	250	0.06	0.17	0.19
13.5	13.49	10.03	0.19	243	0.06	0.17	0.19
14	13.99	9.61	0.16	186	0.06	0.32	0.33
14.5	14.50	9.16	0.14	166	0.05	0.34	0.34
15	14.99	8.83	0.12	143	0.05	0.29	0.29
15.5	15.48	8.44	0.11	126	0.05	0.33	0.33
16	15.98	8.14	0.09	89	0.07	0.28	0.29
16.5	16.52	7.80	0.08	80	0.10	0.30	0.32
17	16.98	7.77	0.07	64	0.07	0.17	0.18
17.5	17.48	7.56	0.07	43	0.05	0.24	0.24
18	17.94	7.24	0.06	27	0.20	0.33	0.39
18.5	18.48	7.60	0.06	26	0.10	0.33	0.34
19	18.98	7.53	0.05	22	0.08	0.18	0.20

Table 8. Annual energy production (AEP) at sea-level density; 1.225 kg/m^3

Estimated annual energy production, 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	7,884	1,717	22%	7,884	Complete
5	15,327	1,948	13%	15,329	Complete
6	23,516	2,144	9%	23,572	Complete
7	30,967	2,271	7%	31,330	Complete
8	36,718	2,325	6%	37,924	Complete
9	40,459	2,314	6%	43,158	Incomplete
10	42,350	2,254	5%	47,049	Incomplete
11	42,770	2,160	5%	49,696	Incomplete
AEP measured assumes zero power between highest bin and cutout AEP extrapolated assumes power in last bin between last bin and cutout					

Table 9. Annual energy production at site average density; 1.05 kg/m^3

Estimated annual energy production, database A (all valid data)					
Reference air density:	1.050	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	kWh	kWh	%	kWh	
4	6,608	1,670	25%	6,608	Complete
5	13,321	1,887	14%	13,322	Complete
6	21,066	2,086	10%	21,091	Complete
7	28,513	2,230	8%	28,714	Complete
8	34,658	2,310	7%	35,419	Complete
9	39,036	2,329	6%	40,886	Complete
10	41,641	2,297	6%	45,046	Incomplete
11	42,734	2,228	5%	47,953	Incomplete
AEP measured assumes zero power between highest bin and cutout AEP extrapolated assumes power in last bin between last bin and cutout					

7.2. Graphical Results

Figure 6 through 9 show the results of the power performance test in graphical format. The 12-kW ceiling of the power maxima in Figure 8 is caused by the maximum output capability of the inverters. Figure 10 through 12 show plots of turbulence intensity and rotor speed.

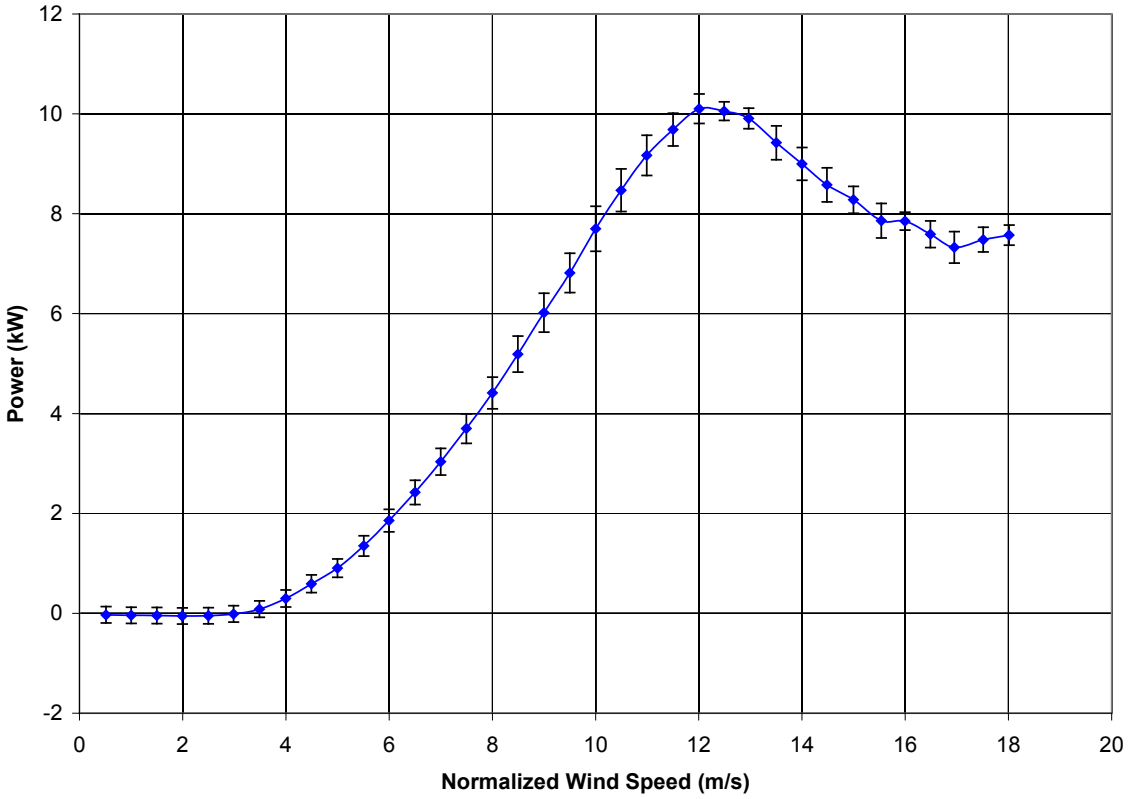

Figure 6. Power curve at sea-level density; 1.225 kg/m^3

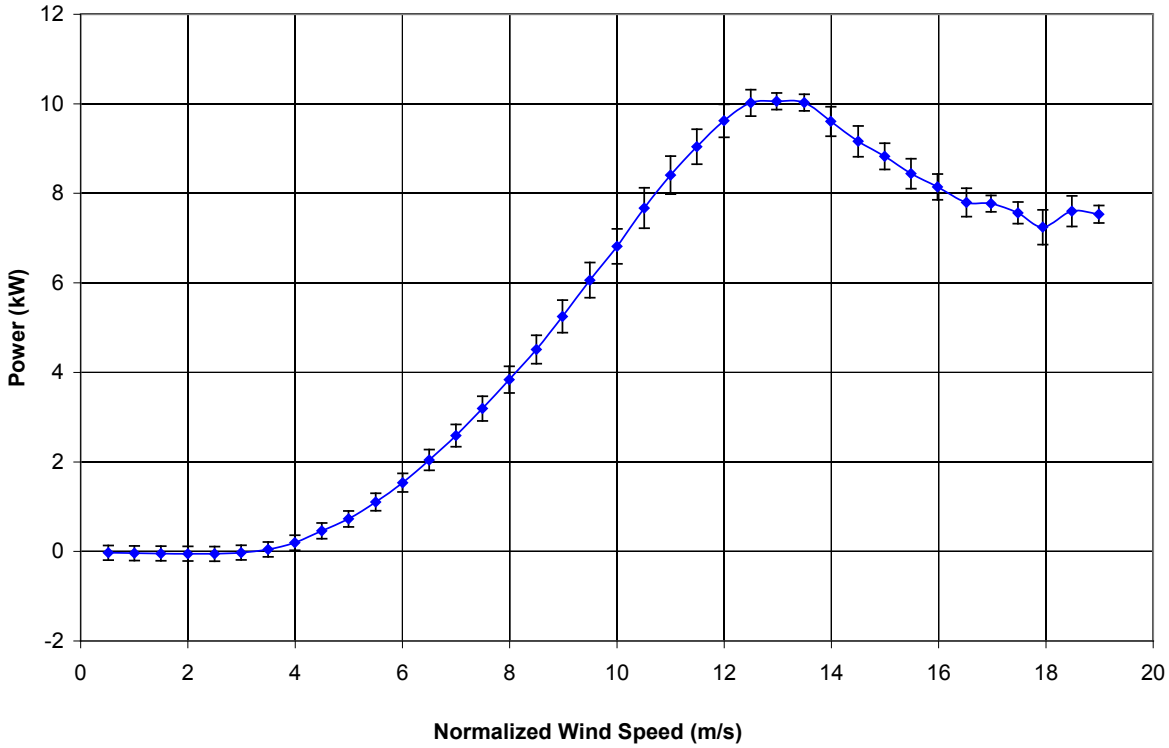

Figure 7. Power curve at site average density; 1.05 kg/m^3

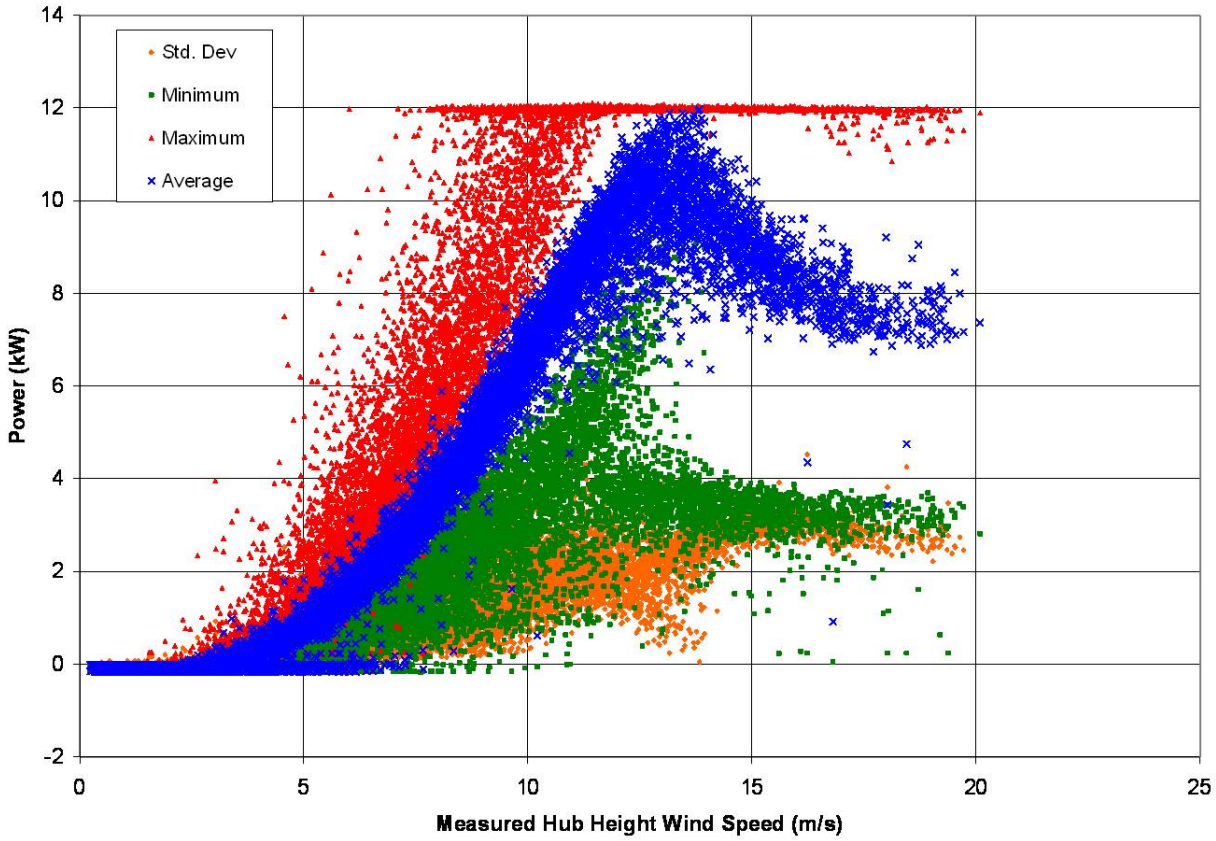

Figure 8. Scatter plot of mean, standard deviation, minimum, and maximum power data. 1 Hz samples with 1 minute averaging.

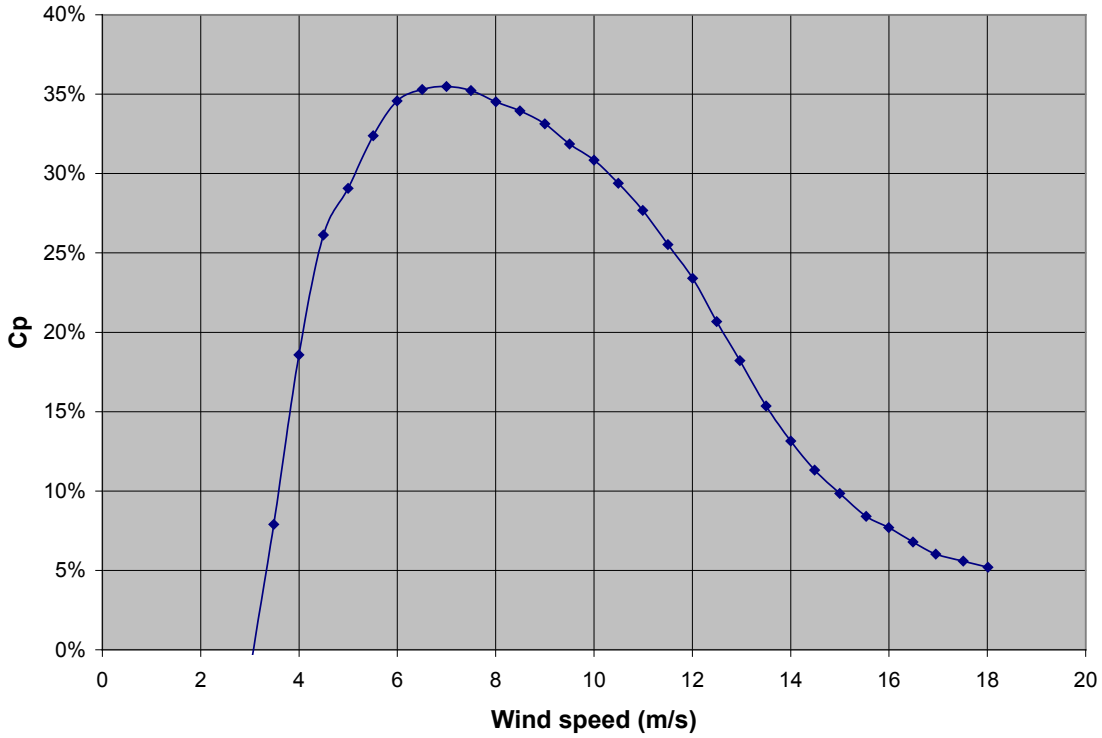

Figure 9. Coefficient of performance at sea level density; 1.225 kg/m^3

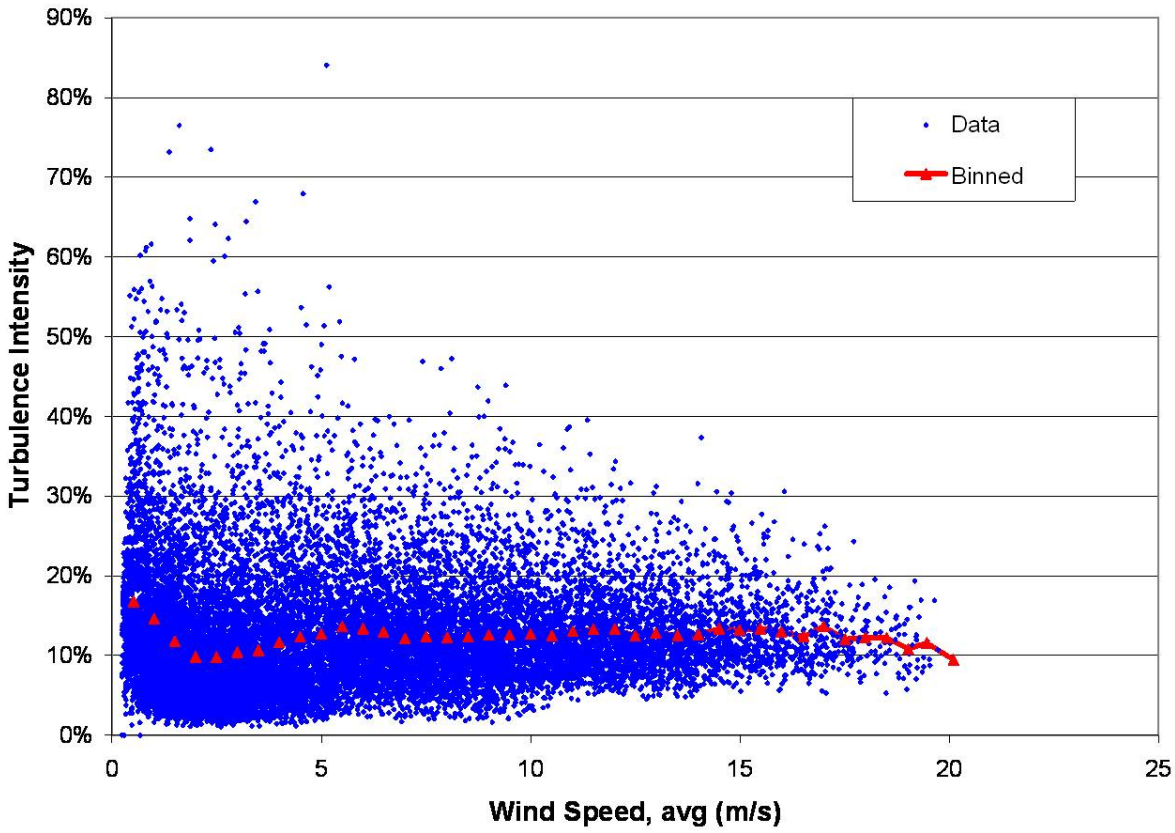

Figure 10. Wind turbulence intensity as a function of wind speed

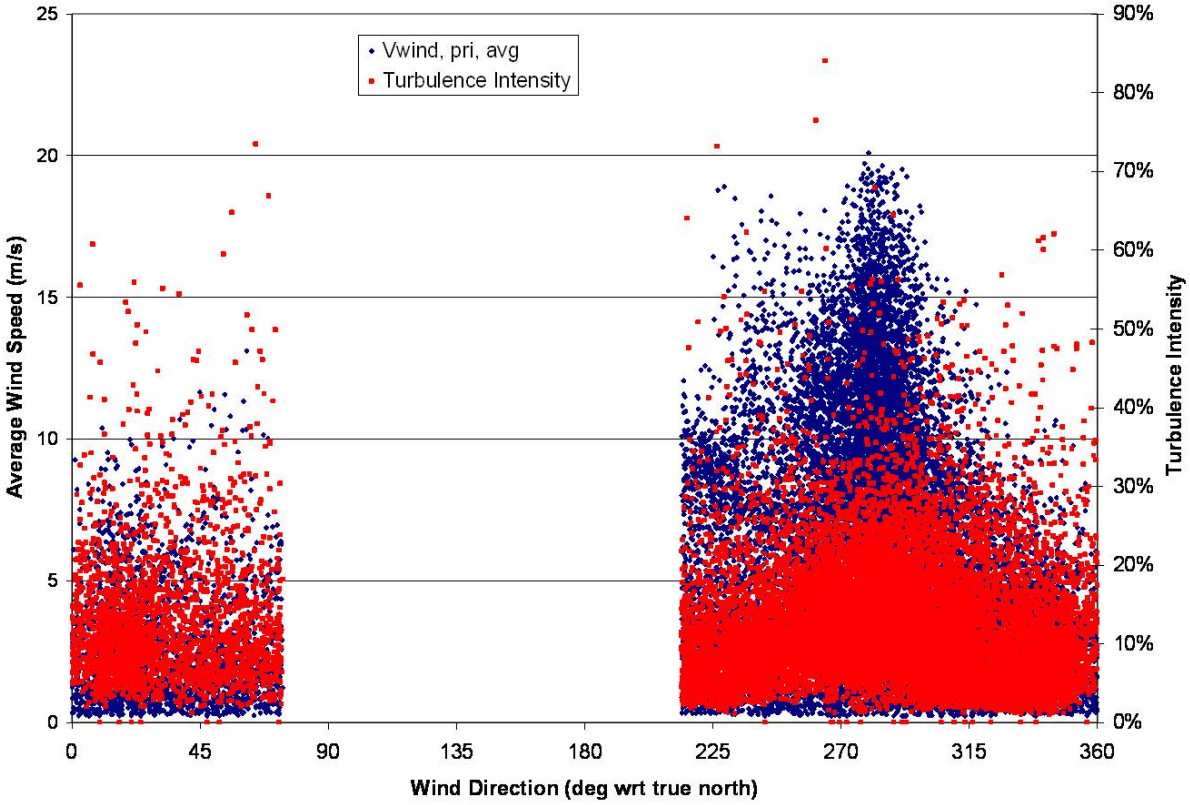

Figure 11. Wind speed and turbulence intensity as a function of wind direction

Wind speed	[m/s]	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
Rotor speed	[rpm]	0	0	1	5	10	17	31	48	71	81	89	97	101	105	108	111	114	117	120	123

Wind speed	[m/s]	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.1
Rotor speed	[rpm]	127	130	134	137	140	142	144	145	145	145	145	146	147	147	148	148	150	154	152	153

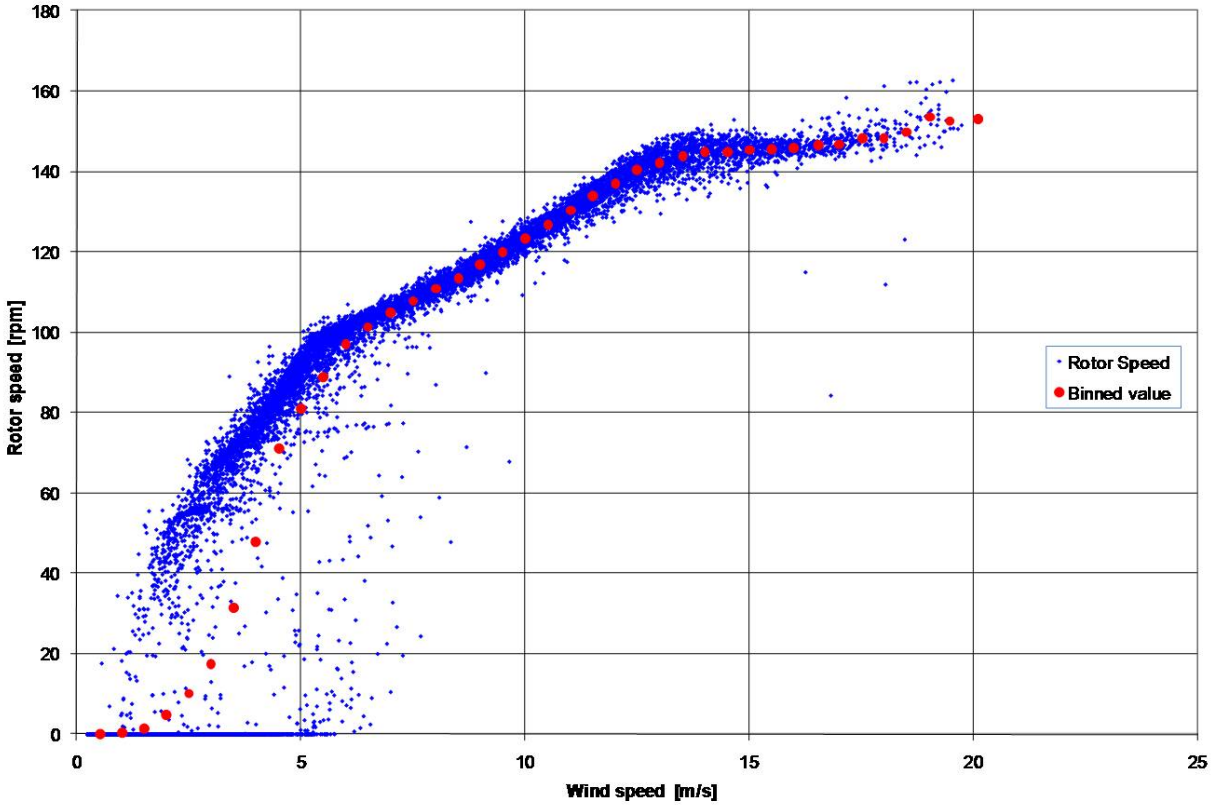

Figure 12. Rotor speed as a function of wind speed (1-minute averages) and binned values

8. Deviations and Exceptions

8.1. Deviations from the Standard

The current transformers are not listed as compliant to IEC 60044-1, but do exceed the minimum accuracy required by the Standard.

8.2. Exceptions to NWTC-CT Quality Assurance System

During the test period, the data acquisition system was out of calibration. A post test calibration has been performed which showed that the system was within specification without adjustment. Thus, it can be assumed the system was within specification during the test period and no additional uncertainty needs to be applied.

Appendix A. Pictures of the Test Site

Figure A.1. West

Figure A.2. Southwest

Figure A.3. South-south-west

Figure A.4. South southeast

Figure A.5. East

Figure A.6. Northeast

Figure A.7. North northeast

Figure A.8. North

Figure A.9. Northwest

Appendix B. Equipment Calibration Sheets

Branch #: 5000

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Phaser Power Transducer & 2-CTs DOE #: 02824C

Model # : Phaser-5-F-5A S/N : 02663

Calibration Date: 01/28/2008 Due Date: 01/28/2010

A. Set-Up for Total Real Power Calibration:
A.1. Voltage is applied to phases A&B = 120 V @ 60 Hz.
A.2. Current is applied to n = 5-TURNS through two current transformers that are connected to phases A&B.
A.3. Analog Output-1 is measured across precision resistor = 250 Ω.
A.4. Phaser Full Scale setting = -7.2KW to 7.2KW.

Input Current (AAC)	Input Power (KW)	Analog Output-1 (VDC)
28	6.72	4.790
21	5.04	4.341
14	3.36	3.892
7	1.68	3.444
0	0	2.995
-7	-1.68	2.547
-14	-3.36	2.099
-21	-5.04	1.651
-28	-6.72	1.203

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)
6.72	1.0	4.989
"	0.8	4.179
"	0.6	3.377
"	0.4	2.577
"	0.2	1.778

Page 1 of 2

Figure B.1. Power transducer calibration sheet

DEUTSCHER KALIBRIERDIENST DKD

Kalibrierlaboratorium für Strömungsgeschwindigkeit von Luft
Calibration laboratory for velocity of air flow
Akkreditiert durch die / *accredited by the*
Akkreditierungsstelle des DKD bei der
PHYSIKALISCH-TECHNISCHEN BUNDESANSTALT (PTB)

Deutsche WindGuard
Wind Tunnel Services GmbH
Varel

DKD-K- 36801

Kalibrierschein
Calibration Certificate

Kalibrierzeichen / *Calibration label*: DKD-K- 36801 / 07_2417

Gegenstand *Object*	Cup Anemometer
Hersteller *Manufacturer*	Thies Clima D-37083 Göttingen
Typ *Type*	4.3350.00.000
Fabrikat/Serien-Nr. *Serial number*	Body: 0707886 Cup: 0707886
Auftraggeber *Customer*	Thies Clima D-37083 Göttingen
Auftragsnummer *Order No.*	VT07255
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	3
Datum der Kalibrierung *Date of calibration*	24.07.2007

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 DKD-K- 36801 Kalibrierdienst	24.07.2007	Dipl. Phys. D. Westermann	Tech. Ass. Inf. H. Westermann

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

Figure B.2. Primary anemometer calibration sheet I

DEUTSCHER KALIBRIERDIENST DKD

Kalibrierlaboratorium für Strömungsgeschwindigkeit von Luft
Calibration laboratory for velocity of air flow
Akkreditiert durch die / *accredited by the*
Akkreditierungsstelle des Deutschen Kalibrierdienstes

DEWI GmbH
Deutsches Windenergie-Institut

DKD-K-28901

Kalibrierschein
Calibration certificate

Kalibrierzeichen
Calibration label

1295_09
DKD-K-28901
16.06.09

Gegenstand *Object*	Cup Anemometer
Hersteller *Manufacturer*	Thies Clima D-37083 Göttingen
Typ *Type*	4.3350.00.000
Fabrikat/Serien-Nr. *Serial number*	body: 0707886 cup: -
Auftraggeber *Customer*	Thies Clima D-37083 Goettingen,
Auftragsnummer *Order No.*	AB0901617
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	3+3
Datum der Kalibrierung *Date of calibration*	16.06.09

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Der DKD ist Unterzeichner der multilateralen 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.

Stempel *Seal*	Datum *Date*	Stellv. Leiter des Kalibrierlaboratoriums *Deputy head of the calibration laboratory*	Bearbeiter *Person in charge*
Deutscher DKD-K-28901 Kalibrierdienst	16.06.09	Dipl.-Ing. (FH) P. Busche	R.Kluin

DEWI GmbH DEUTSCHES WINDENERGIE - INSTITUT
Ebertstr. 96, D-26382 Wilhelmshaven
Tel. +49 (0)4421 4808-0, Fax. +49 (0)4421 4808-43

Figure B.3. Primary anemometer calibration sheet II

Wind Vane Calibration Report

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

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

Calibration Location:
National Wind Technology Center
Room 101, Building 256

Calibration Date: **13-Sep-07**

Report Number: G4706-070913

Page: 1 of 1

Procedure:
NWTC-CT: GI24-000613, Wind Vane Calibration

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

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	020C
Serial Number	**G4706**
Vane Material	Aluminum
Condition	Refurbished

Results:

Slope:	**72.17**	**deg/V**
Offset to boom:	**94.81**	**deg**
Max error:	0.99	deg

Estimated Uncertainty:

Inclinometer Uncertainty (deg)	Total Uncertainty (deg)
0.10	0.57

Traceability:

	Mfg & Model	Serial Number	Cal Date
Inclinometer:	Spi-Tronic	31-038-3	22-Mar-07
Voltmeter:	Fluke743B	6965608	10-May-07

Calibration by: Mark Meadors — 13-Sep-07 Date

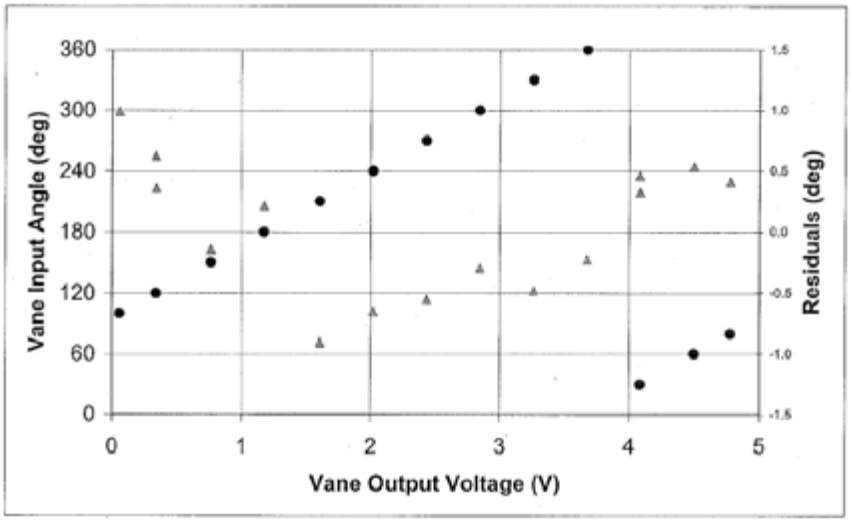

Figure B.4. Wind vane calibration report

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: RTD-Probe DOE #: 03722C

Model # : 78N01N00N S/N : 0789020

Calibration Date: 10/10/2008 Due Date: 10/10/2009

No	Function Tested	Nominal Value (°C)	Measured Values (Ω)		( )Mfr. Specs. OR (X)Data only
			AS Found	AS Left	
*	Temperature:	0	99.96	Same	
		25	109.68	"	
		50	119.32	"	
	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 = 38. - Uncertainty of Nominal Values = ± 0.03 °C, k = 2.				

Tested By: Reda

Date : 10/10/2008

Figure B.5. RTD-Probe calibration sheet

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Pressure Transmitter DOE #: 02795C

Model # : PTB101B S/N : T4730007

Calibration Date: 08/26/2008 Due Date: 08/26/2009

No	Function Tested	Nominal Value (kPa)	Measured Output Voltage (VDC)		( )Mfr. Specs. OR (X)Data only (mb)
			As Found	As Left	
*	Absolute Pressure				
		65	0.287	Same	
		70	0.560	"	
		75	0.832	"	
		80	1.105	"	
		85	1.377	"	
		90	1.648	"	
		95	1.921	"	
		100	2.194	"	
		105	2.467	"	
	Notes: 1. Uncertainty of the nominal value is ± 0.2 kPa, k = 2. 2. Calibration was performed at 23°C and 37% RH. 3. Calibration was performed using standards that are traceable to NIST. DOE numbers: 02625C, 02727C, and 02301C.				

Calibrated By: Reda
Date: 08/26/2008

QA By: Bev
Date: 08/26/2008

Figure B.6. Pressure transmitter calibration sheet

NATIONAL INSTRUMENTS

Certificate of Calibration

Board Information:
Serial Number: 12C73B4
NI Part Number: 192547D-01
Description: NI 9217

Certificate Information:
Certificate Number: 786529
Date Printed: 05-JAN-09

Calibration Date: 03-AUG-07
Recommended Calibration Due Date: 03-AUG-08*

Ambient Temperature: 23 °C
Relative Humidity: 46 %

National Instruments certifies that at the time of manufacture, the above product was calibrated in accordance with applicable National Instruments procedures. These procedures are in compliance with relevant clauses of ISO 9001 and are designed to assure that the product listed above meets or exceeds National Instruments specifications.

National Instruments further certifies that the measurements standards and instruments used during the calibration of this product are traceable to National and/or International Standards administered by NIST or Euromet members or are derived from accepted values of natural physical constants.

The environment in which this product was calibrated is maintained within the operating specifications of the instrument and the standards.

The information shown on this certificate applies only to the instrument identified above and the certificate may not be reproduced, except in full, without prior written consent by National Instruments.

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

NI Hungary Software és
Hardware Gyártó Kft.
4031 Debrecen, Határ út
1/A.
HUNGARY

Signed,

Andrew Krupp
Quality Director

* Recommended calibration due date is based on a combination of calibration interval and, when applicable, calibration shelf life. This date may vary depending on your application requirements.

Figure B.7. NI 9217 data acquisition module calibration sheet I

NATIONAL INSTRUMENTS

Certificate of Calibration

Board Information:
Serial Number: 12A2037
NI Part Number: 192580D-02
Description: NI 9229

Certificate Information:
Certificate Number: 733748
Date Printed: 05-JAN-09

Calibration Date: 31-MAY-07
Recommended Calibration Due Date: 31-MAY-08*

Ambient Temperature: 22 °C
Relative Humidity: 50 %

National Instruments certifies that at the time of manufacture, the above product was calibrated in accordance with applicable National Instruments procedures. These procedures are in compliance with relevant clauses of ISO 9001 and are designed to assure that the product listed above meets or exceeds National Instruments specifications.

National Instruments further certifies that the measurements standards and instruments used during the calibration of this product are traceable to National and/or International Standards administered by NIST or Euromet members or are derived from accepted values of natural physical constants.

The environment in which this product was calibrated is maintained within the operating specifications of the instrument and the standards.

The information shown on this certificate applies only to the instrument identified above and the certificate may not be reproduced, except in full, without prior written consent by National Instruments.

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

NI Hungary Software és
Hardware Gyártó Kft.
4031 Debrecen, Határ út
1/A.
HUNGARY

Signed,

Andrew Krupp
Quality Director

* Recommended calibration due date is based on a combination of calibration interval and, when applicable, calibration shelf life. This date may vary depending on your application requirements.

Figure B.8. NI 9229 data acquisition module calibration sheet I

NATIONAL INSTRUMENTS

Certificate of Calibration

Board Information:
Serial Number: 12ECB77
NI Part Number: 193299F-01
Description: NI-9205

Certificate Information:
Certificate Number: 837236
Date Printed: 05-JAN-09

Calibration Date: 09-OCT-07
Recommended Calibration Due Date: 09-OCT-08*

Ambient Temperature: 23 °C
Relative Humidity: 37 %

National Instruments certifies that at the time of manufacture, the above product was calibrated in accordance with applicable National Instruments procedures. These procedures are in compliance with relevant clauses of ISO 9001 and are designed to assure that the product listed above meets or exceeds National Instruments specifications.

National Instruments further certifies that the measurements standards and instruments used during the calibration of this product are traceable to National and/or International Standards administered by NIST or Euromet members or are derived from accepted values of natural physical constants.

The environment in which this product was calibrated is maintained within the operating specifications of the instrument and the standards.

The information shown on this certificate applies only to the instrument identified above and the certificate may not be reproduced, except in full, without prior written consent by National Instruments.

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

NI Hungary Software és
Hardware Gyártó Kft.
4031 Debrecen, Határ út
1/A.
HUNGARY

Signed,

Andrew Krupp
Quality Director

* Recommended calibration due date is based on a combination of calibration interval and, when applicable, calibration shelf life. This date may vary depending on your application requirements.

Figure B.9. NI 9205 data acquisition module calibration sheet I

Davis Calibration

ACCREDITED CALIBRATION

Certificate of Calibration

3214191

Instrument Identification

Company ID: 229037
NATIONAL INSTRUMENTS

PO Number: 337683

11500 N. MOPAC EXPWY
ATTN. RMA DEPT.
AUSTIN, TX 78759

Instrument ID: **12A2037**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CHANNEL, ±60 V, 24-BIT SIMULTANEOUS ANALOG INPUT

Model Number: NI 9229
Serial Number: 12A2037

Accuracy: Mfr Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: NATIONAL INSTRUMENTS CAL EXECUTIVE REV 3.3.1
Remarks: *Reference attached Data.*

Technician: WAYNE GETCHELL
Cal Date 06May2009
Cal Due Date: 06May2010
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 44.0 %

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

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

Davis Calibration Laboratory is certified to ISO 9001:2000 by Eagle Registrations (certificate # 3046). Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994, ISO 10012:2003, 10CFR50 AppxB, and 10CFR21.

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

Approved By: VICTOR PENA
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
3143038	15-0271	MULTIFUNCTION CALIBRATOR	5700A	15Apr2009	14Jul2009

Figure B.10. NI 9229 data acquisition module calibration sheet II

Davis Calibration

ACCREDITED CALIBRATION

Certificate of Calibration

3214178

Instrument Identification

Company ID: 229037
NATIONAL INSTRUMENTS

11500 N. MOPAC EXPWY
ATTN. RMA DEPT.
AUSTIN, TX 78759

PO Number: 337683

Instrument ID: **12C73B4**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CH 100 OHM 24-BIT RTD ANALOG INPUT

Model Number: NI 9217
Serial Number: 12C73B4

Accuracy: Mfr. Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: CAL EXEC 3.3.1 CAL EXEC 3.3.1

Remarks: *Reference attached data.*

Technician: WAYNE GETCHELL
Cal Date 06May2009
Cal Due Date: 06May2010
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 46.0 %

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

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

Davis Calibration Laboratory is certified to ISO 9001:2000 by Eagle Registrations (certificate # 3046). Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994, ISO 10012:2003, 10CFR50 AppxB, and 10CFR21.

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

Approved By: VICTOR PENA
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
3078982	15-0011	DECADE RESISTOR	DB52	24Mar2009	24Mar2010
3004176	15-0060	DIGITAL MULTIMETER (GOLDEN CAL)	3458A OPT 002	17Feb2009	17May2009

Figure B.11. NI 9217 data acquisition module calibration sheet II

Davis Calibration

ACCLASS ACCREDITED CALIBRATION

Certificate of Calibration

3214150

Instrument Identification

Company ID: 229037
NATIONAL INSTRUMENTS

PO Number: 337683

11500 N. MOPAC EXPWY
ATTN. RMA DEPT.
AUSTIN, TX 78759

Instrument ID: **12ECB77**
Model Number: NI 9205
Manufacturer: NATIONAL INSTRUMENTS
Serial Number: 12ECB77
Description: 32-CH ±200 MV TO ±10 V, 16-BIT, 250 KS/S ANALOG INPUT MODULE

Accuracy: Mfr Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: NATIONAL INSTRUMENTS CAL EXECUTIVE REV 3.3.1

Remarks: *Reference attached Data.*

Technician: WAYNE GETCHELL
Cal Date 06May2009
Cal Due Date: 06May2010
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 47.0 %

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

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

Davis Calibration Laboratory is certified to ISO 9001:2000 by Eagle Registrations (certificate # 3046). Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994, ISO 10012:2003, 10CFR50 AppxB, and 10CFR21.

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

Approved By: VICTOR PENA
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
3143038	15-0271	MULTIFUNCTION CALIBRATOR	5700A	15Apr2009	14Jul2009

Figure B.12. NI 9205 data acquisition module calibration sheet II

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
February 2010	Technical report	

4. TITLE AND SUBTITLE
Wind Turbine Generator System - Power Performance Test Report: ARE442 Wind Turbine

5a. CONTRACT NUMBER
DE-AC36-08-GO28308

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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14. ABSTRACT *(Maximum 200 Words)*

This report summarizes the results of a power performance test that NREL conducted on the ARE 442 wind turbine. This test was conducted in accordance with the International Electrotechnical Commission's (IEC) standard, Wind Turbine Generator Systems Part 12: Power Performance Measurements of Electricity Producing Wind Turbines, IEC 61400-12-1 Ed.1.0, 2005-12. However, because the ARE 442 is a small turbine as defined by IEC, NREL also followed Annex H that applies to small wind turbines. In these summary results, wind speed is normalized to sea-level air density.

15. SUBJECT TERMS
ARE442 wind turbine; power performance; small wind turbine

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