April 2003 NREL/EL-500-33452

ACCREDITED
Certificate No. 1239-01

Wind Turbine Generator System

Power Performance Test Report

for the

Bergey Excel-S/60 Wind Turbine

with SH3052 Airfoil Blades

in

Golden, Colorado

by

National Wind Technology Center
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401

Jeroen van Dam,
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February 2003

Approval By: 12 Feb 2003
Jeroen van Dam, NREL Certification Test Engineer Date

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5.0 Test Summary

This report describes the results of a power performance test on a Bergey Excel-S/60 with a Gridtek-10 Inverter and SH 3052 airfoil blades. The test procedures were similar to those described in the test plan in Appendix B, with the exceptions described in Section 7.2

Figure 1 is a summary of the results of the power performance test. These results are normalized to sea level air density using wind speed correction. Further details of these results are given in Section 6.0 Results. Details on the test method, test site, and the turbine under test can be found in the test plan in Appendix B.

The test turbine was located at Site 1.4 of the National Wind Technology Center (NWTC) near Boulder, Colorado. The test started on March 19, 2002 and ended on April 8, 2002. During this time, 241.8 hours of data with the wind out of the acceptable wind directions (153° to 1°) and with the turbine available were collected. According to the standard, the quantity of data collected meets the requirement. The highest bin filled (with wind speed normalized to sea level density) was the 19.5 m/s bin; it meets the standard's requirement.

Power Performance Test
Bergey Excel\ Gridtek-10

Sea-Level Density Power Curve

Report Created:	May 20, 2002

Turbine Specifications:

Rated Power:	10	kW
Cut-in Wind Speed:	3	m/s
Cut-out Wind Speed:	25	m/s
Rated Wind Speed:		m/s
Rotor Diameter:	6.2	m
Control Type:	Variable Speed Furling	
Pitch Setting:	Fixed	

Site Conditions:

Average Air Density:	1.000	kg/m^3
Measurement Sectors:	151-1	°

Test Statistics:

Start Date:	March 19, 2002	
End Date:	April 8, 2002	
Amount of Data Collected:	241.8	hours
Highest Bin Filled:	19.5	m/s
Test Completed?	yes	

Bin Wind Speed (m/s)	Bin Power (kW)	Number Data Points	Cp
2.01	-0.06	129	-0.41
2.50	-0.08	127	-0.28
3.01	-0.08	141	-0.17
3.51	-0.07	145	-0.09
4.01	-0.01	101	-0.01
4.48	0.10	97	0.06
4.97	0.24	84	0.11
5.49	0.45	71	0.15
5.98	0.67	67	0.17
6.47	0.94	68	0.19
7.00	1.21	43	0.19
7.49	1.58	39	0.20
7.98	1.91	37	0.21
8.50	2.33	30	0.21
8.96	2.66	33	0.20
9.49	3.15	26	0.20
9.99	3.66	24	0.20
10.50	4.13	22	0.19
10.99	4.50	21	0.18
11.43	5.00	27	0.18
11.96	5.58	14	0.18
12.54	6.04	21	0.17
12.97	6.69	11	0.17
13.52	7.08	13	0.16
13.98	7.57	7	0.15
14.55	6.53	6	0.12
14.97	7.25	5	0.12
15.48	7.21	7	0.11
16.00	6.12	6	0.08
16.48	5.78	4	0.07
16.94	6.97	3	0.08
17.42	6.92	5	0.07
17.95	5.85	3	0.06
18.54	6.28	7	0.05
19.09	5.01	3	0.04
19.60	6.20	4	0.04

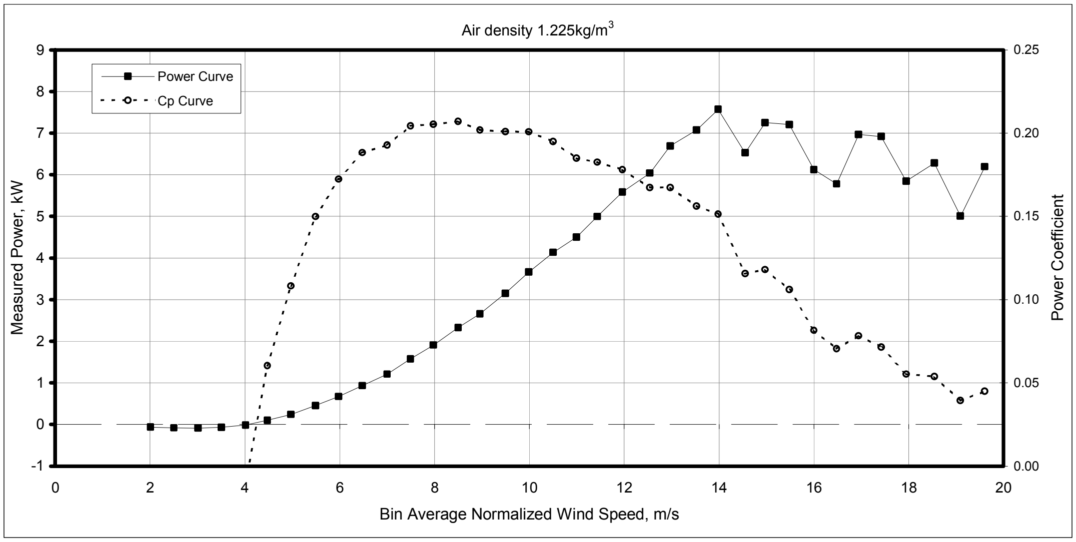


Figure 1. Power curve summary.

6.0 Results

6.1 Site Calibration Test

No site calibration was performed.

6.2 Tabular Results of Power Performance Test

Table 1 and Table 2 show the power performance of the Bergey Excel-S turbine with Gridtek-10 inverter with the wind speed normalized to air densities of sea level and average site conditions during the test. Table 3 and Table 4 indicate annual energy production of the turbine if it were to perform as measured during the test and operate with 100% availability and if the winds were to correspond to the Rayleigh wind speed distribution shown. Table 3 indicates the energy production expected at sea level. Table 4 shows energy production at the test site, assuming the annual average air density is the same as the average air density measured during the test. NREL calculated these production estimates using the method prescribed in the Standard and does not warranty actual performance.

Table 1. Performance at Sea Level Air Density, 1.225 kg/m^3

Bin (m/s)	Normalized Wind Speed (m/s)	Power Output (kW)	Number of 10-Minute Data Sets	Category A Uncertainty (kW)	Category B Uncertainty (kW)	Combined Uncertainty (kW)
0.5	0.6	0.0	25	0.00	0.04	0.04
1	1.0	0.0	73	0.00	0.04	0.04
1.5	1.5	-0.1	105	0.00	0.04	0.04
2	2.0	-0.1	129	0.00	0.04	0.04
2.5	2.5	-0.1	127	0.01	0.04	0.04
3	3.0	-0.1	141	0.01	0.04	0.04
3.5	3.5	-0.1	145	0.00	0.04	0.04
4	4.0	0.0	101	0.01	0.04	0.04
4.5	4.5	0.1	97	0.01	0.05	0.05
5	5.0	0.2	84	0.01	0.06	0.06
5.5	5.5	0.5	71	0.02	0.08	0.08
6	6.0	0.7	67	0.02	0.09	0.09
6.5	6.5	0.9	68	0.02	0.11	0.11
7	7.0	1.2	43	0.03	0.12	0.12
7.5	7.5	1.6	39	0.03	0.17	0.17
8	8.0	1.9	37	0.03	0.17	0.17
8.5	8.5	2.3	30	0.04	0.21	0.21
9	9.0	2.7	33	0.03	0.19	0.20
9.5	9.5	3.1	26	0.05	0.26	0.26
10	10.0	3.7	24	0.04	0.31	0.31
10.5	10.5	4.1	22	0.05	0.29	0.29
11	11.0	4.5	21	0.07	0.24	0.25
11.5	11.4	5.0	27	0.09	0.38	0.39
12	12.0	5.6	14	0.11	0.39	0.40
12.5	12.5	6.0	21	0.13	0.29	0.32
13	13.0	6.7	11	0.15	0.57	0.59
13.5	13.5	7.1	13	0.21	0.28	0.35
14	14.0	7.6	7	0.26	0.45	0.51
14.5	14.6	6.5	6	0.53	0.77	0.93
15	15.0	7.3	5	0.33	0.75	0.82
15.5	15.5	7.2	7	0.32	0.06	0.33
16	16.0	6.1	6	0.45	0.98	1.08
16.5	16.5	5.8	4	0.48	0.35	0.59
17	16.9	7.0	3	1.00	1.26	1.61
17.5	17.4	6.9	5	0.77	0.07	0.77
18	17.9	5.8	3	1.47	1.06	1.81
18.5	18.5	6.3	7	0.61	0.40	0.73
19	19.1	5.0	3	0.53	1.28	1.39
19.5	19.6	6.2	4	0.62	1.32	1.46
> 19.5	insufficient data					

Table 2. Performance at Site Average Density, 1.000 kg/m^3

Bin (m/s)	Normalized Wind Speed (m/s)	Power Output (kW)	Number of 10-Minute Data Sets	Category A Uncertainty (kW)	Category B Uncertainty (kW)	Combined Uncertainty (kW)
0.5	0.6	0.0	19	0.00	0.04	0.04
1	1.0	0.0	60	0.00	0.04	0.04
1.5	1.5	-0.1	99	0.00	0.04	0.04
2	2.0	-0.1	116	0.00	0.04	0.04
2.5	2.5	-0.1	123	0.00	0.04	0.04
3	3.0	-0.1	121	0.01	0.04	0.04
3.5	3.5	-0.1	130	0.00	0.04	0.04
4	4.0	-0.1	117	0.00	0.04	0.04
4.5	4.5	0.0	108	0.01	0.04	0.04
5	5.0	0.2	84	0.01	0.06	0.06
5.5	5.5	0.3	68	0.01	0.06	0.06
6	6.0	0.5	70	0.02	0.08	0.08
6.5	6.5	0.7	63	0.02	0.09	0.09
7	7.0	1.0	55	0.02	0.11	0.12
7.5	7.5	1.2	43	0.03	0.11	0.12
8	8.0	1.6	38	0.03	0.17	0.17
8.5	8.5	1.9	35	0.03	0.17	0.17
9	9.0	2.3	26	0.05	0.21	0.21
9.5	9.5	2.6	33	0.03	0.19	0.19
10	10.0	3.0	25	0.04	0.23	0.23
10.5	10.5	3.5	22	0.04	0.33	0.34
11	11.0	3.9	21	0.05	0.27	0.28
11.5	11.5	4.3	21	0.05	0.28	0.28
12	12.1	4.8	29	0.09	0.30	0.31
12.5	12.5	5.1	14	0.15	0.26	0.30
13	13.0	5.7	13	0.13	0.46	0.47
13.5	13.5	6.2	19	0.12	0.38	0.40
14	13.9	6.7	10	0.17	0.45	0.48
14.5	14.5	7.1	12	0.23	0.27	0.36
15	15.0	7.6	7	0.26	0.48	0.54
15.5	15.5	6.5	5	0.64	0.87	1.08
16	15.9	7.3	5	0.30	1.03	1.07
16.5	16.5	6.9	7	0.26	0.33	0.42
17	17.0	6.3	6	0.58	0.57	0.81
17.5	17.5	6.1	4	0.61	0.18	0.64
18	18.1	6.7	4	0.76	0.52	0.92
18.5	18.5	7.1	3	1.35	0.42	1.41
19	18.9	6.5	3	0.40	1.02	1.10
19.5	19.5	6.5	4	1.25	0.06	1.25
20	19.9	5.8	5	0.67	0.97	1.18
20.5	20.4	5.0	3	0.53	0.94	1.08
21	21.0	6.2	4	0.62	1.32	1.46
21.5	21.6	6.0	3	0.82	0.19	0.84
22.	22.1	6.6	4	0.57	0.67	0.88
> 22	insufficient data					

Table 3. Annual Energy Production at Sea Level Density, 1.225 kg/m^3

Hub Height Annual Avg. Wind Speed (m/s)	AEP-Measured (from measured power curve) (kWh/yr)		Uncertainty of AEP-Measured (kWh/yr)	(%)	AEP-Extrapolated (from extrapolated power curve) (kWh/yr)
4	2,739	Complete	586	21.4%	2,739
5	6,414	Complete	840	13.1%	6,414
6	11,060	Complete	1,152	10.4%	11,073
7	15,991	Complete	1,500	9.4%	16,111
8	20,494	Complete	1,852	9.0%	20,979
9	24,078	Complete	2,165	9.0%	25,310
10	26,559	Incomplete	2,410	9.1%	28,897
11	27,990	Incomplete	2,575	9.2%	31,650

Table 4. Annual Energy Production at Site Average Density, 1.000 kg/m^3

Hub Height Annual Avg. Wind Speed (m/s)	AEP-Measured (from measured power curve) (kWh/yr)		Uncertainty of AEP-Measured (kWh/yr)	(%)	AEP-Extrapolated (from extrapolated power curve) (kWh/yr)
4	1,994	Complete	529	26.5%	1,994
5	5,077	Complete	747	14.7%	5,077
6	9,161	Complete	1,020	11.1%	9,162
7	13,769	Complete	1,329	9.6%	13,791
8	18,339	Complete	1,647	9.0%	18,464
9	22,390	Complete	1,947	8.7%	22,782
10	25,622	Complete	2,201	8.6%	26,481
11	27,929	Incomplete	2,394	8.6%	29,417

6.3 Graphical Results

Figure 2 gives the binned power curve for sea level air density. Figure 3 gives the power coefficient for the same conditions. Figure 4 gives the binned power curve for the site average air density (1.000 kg/m^3). Figure 5 gives the scatter plot of the 10-minute statistics of measured inverter power. Figure 6 and Figure 7 give an indication of the wind conditions during the test period. Figure 8 gives a plot of inverter efficiency. The inverter has an efficiency of about 86% over most of the operating range.

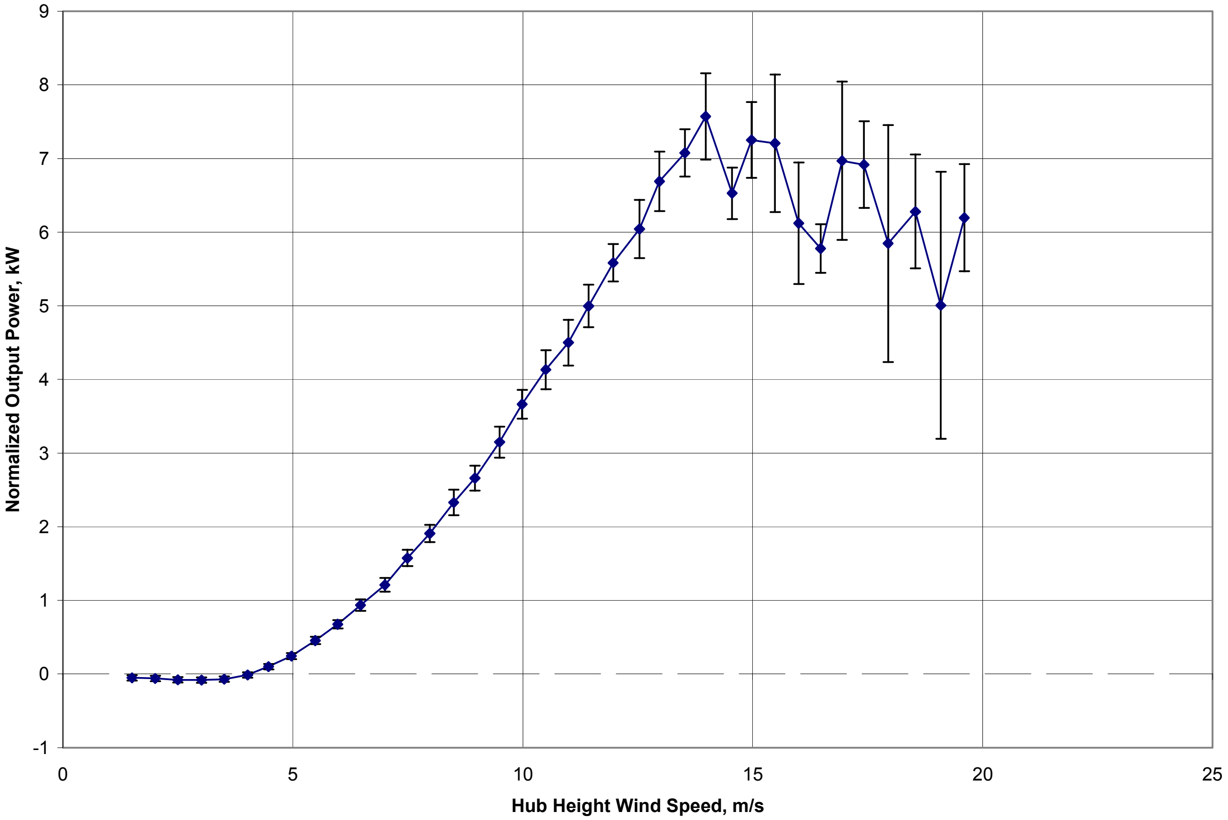


Figure 2. Power curve at sea level density, 1.225 kg/m^3.

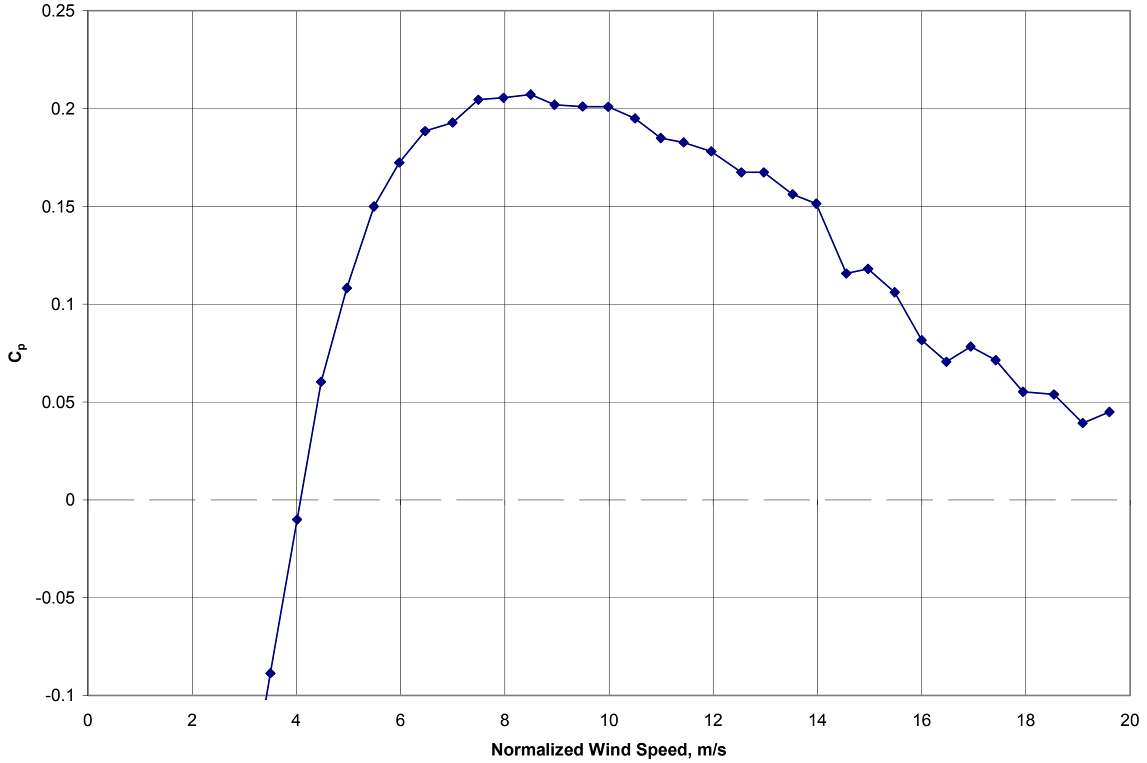


Figure 3. Coefficient of performance at sea level density, 1.225 kg/m^3.

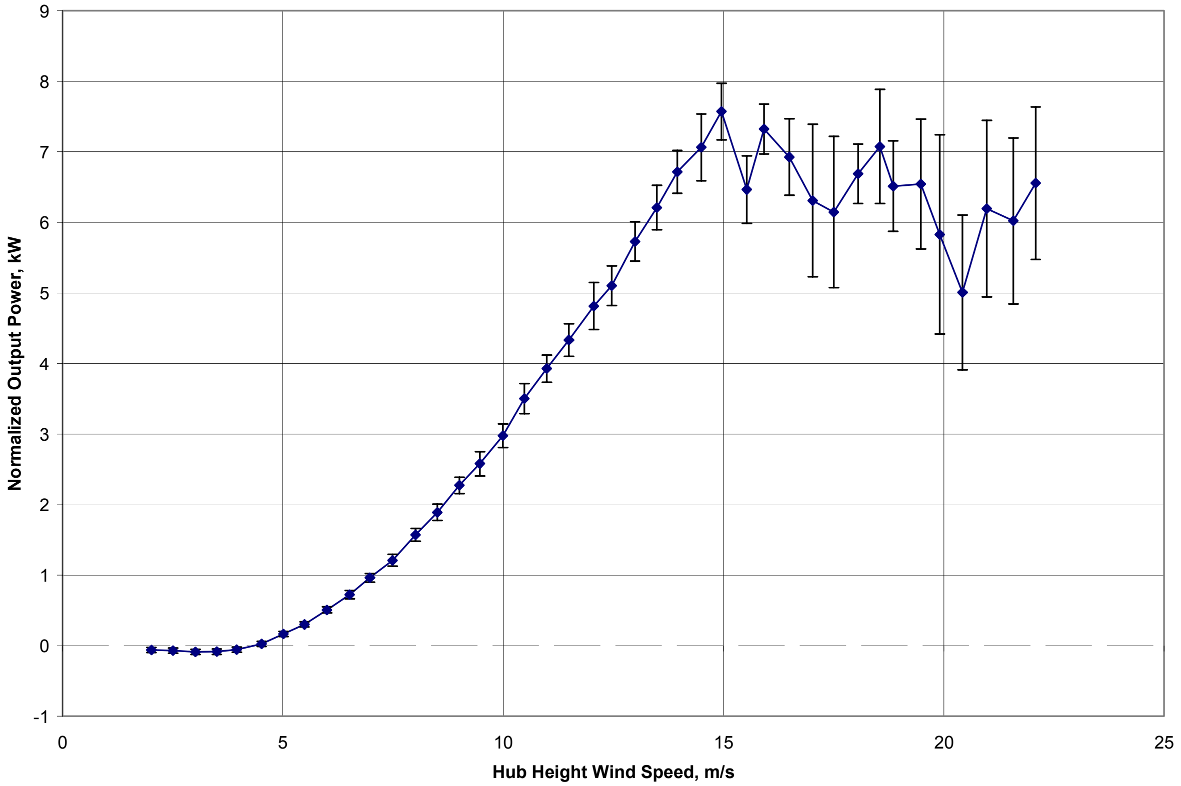


Figure 4. Power curve at site average density, 1.000 kg/m^3.

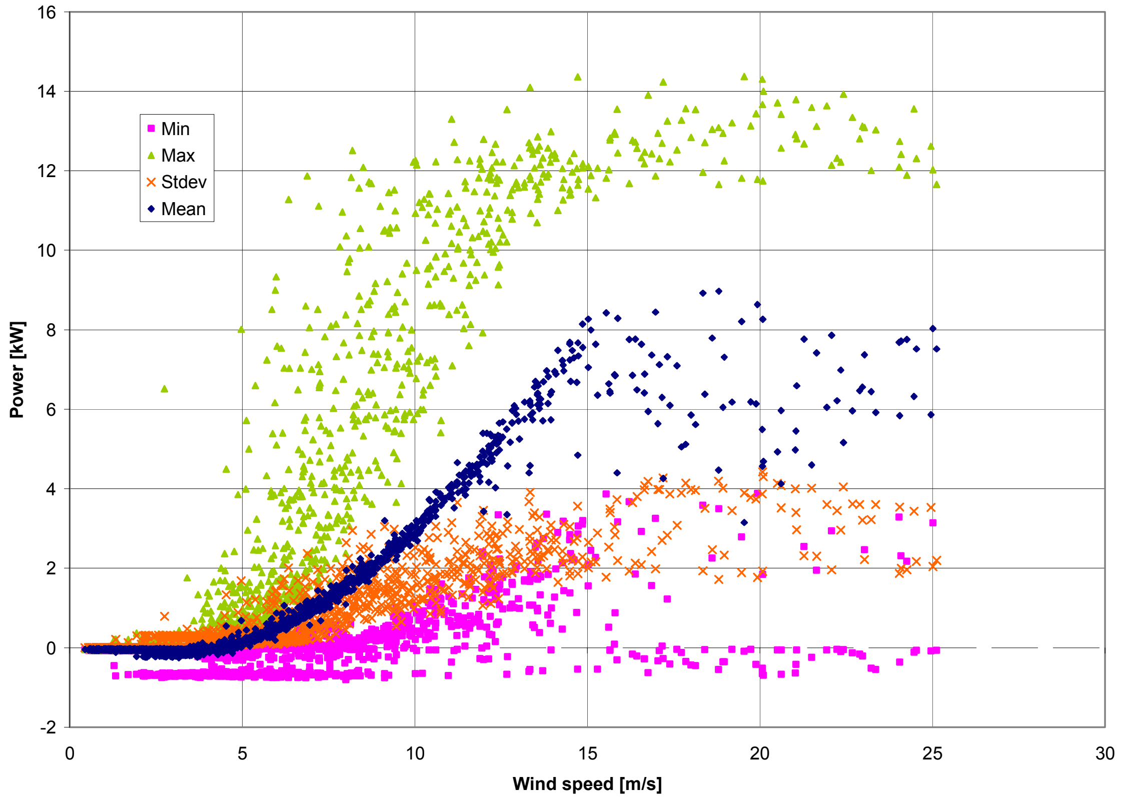


Figure 5. Scatter plot of power data.

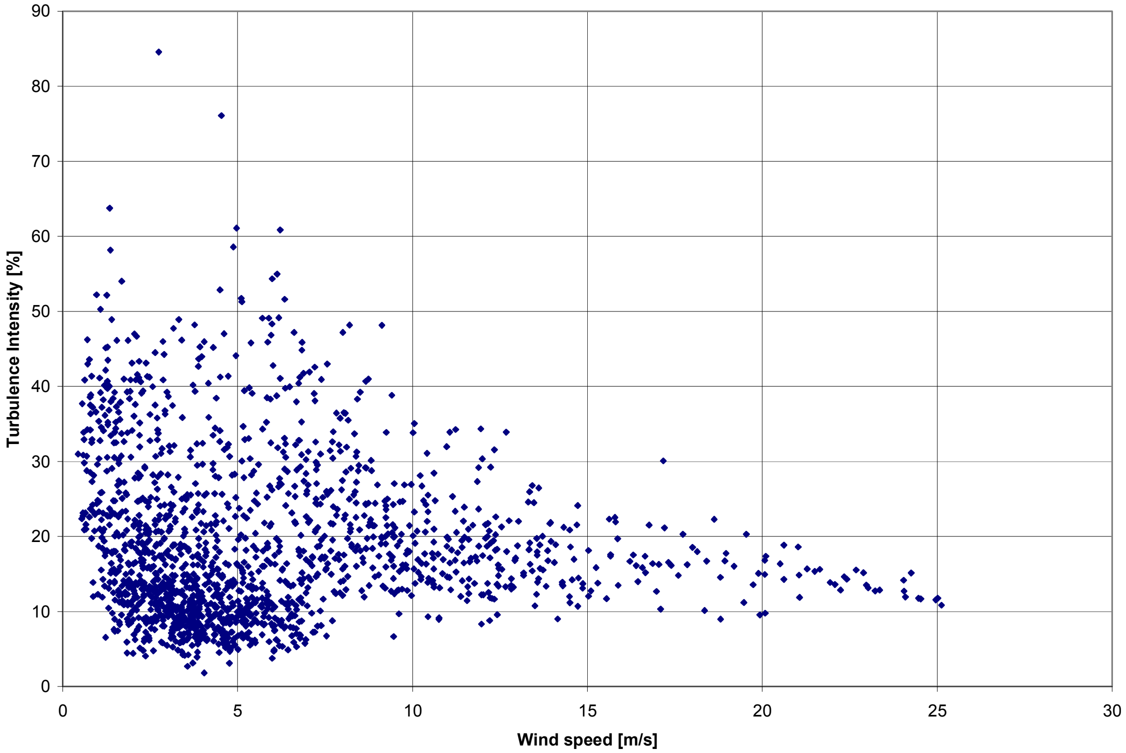


Figure 6. Wind turbulence at the test site as a function of wind speed.

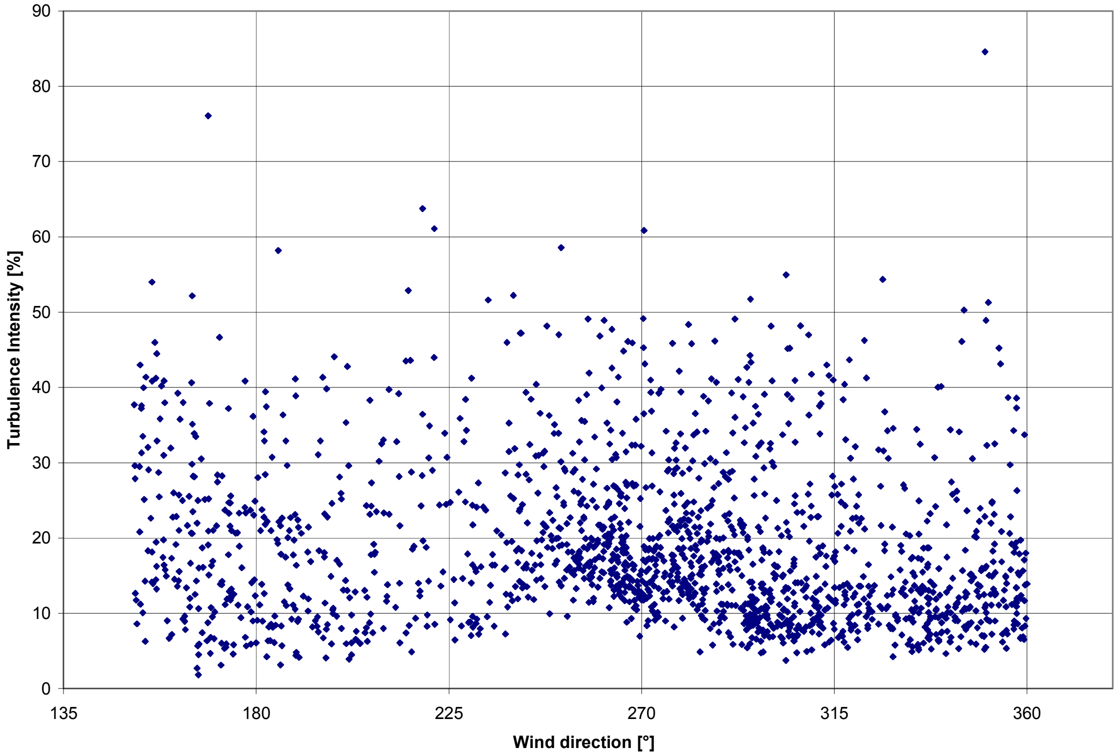


Figure 7. Wind turbulence at the test site as a function of wind direction.

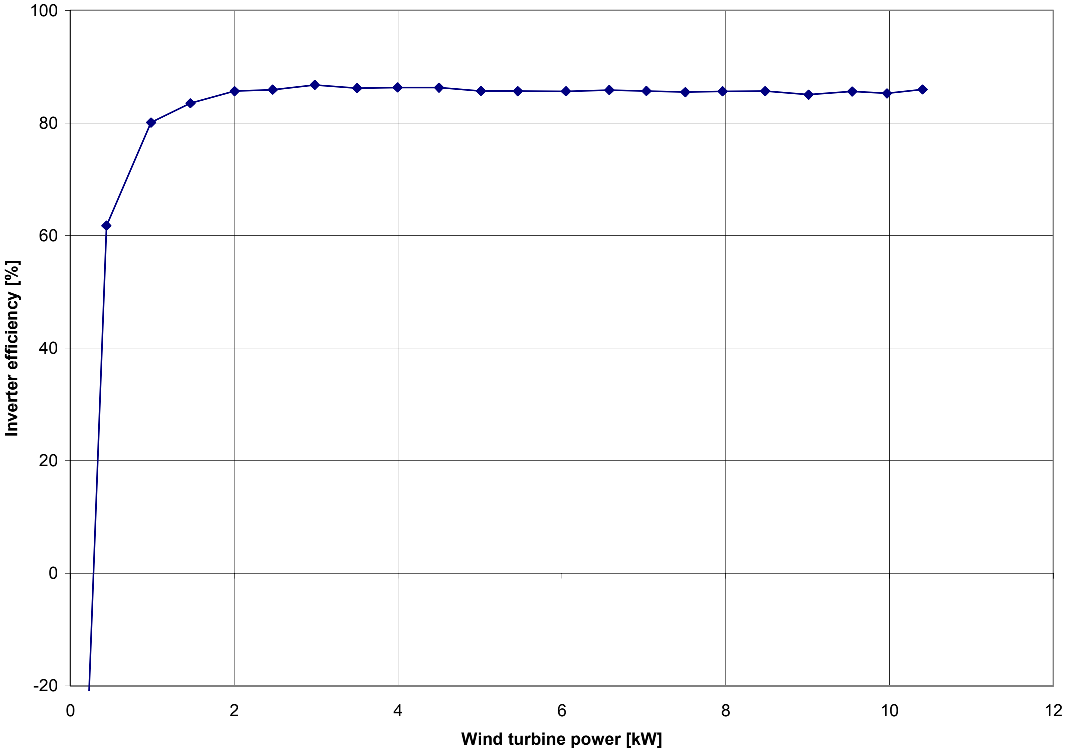


Figure 8. Binned inverter efficiency as a function of the power produced by the wind turbine.

7.0 Exceptions

7.1 Exceptions to Standard

1. The power transducer was not tested for compliance with IEC 60688.

2. The current transformers were not tested for compliance with IEC 60044.

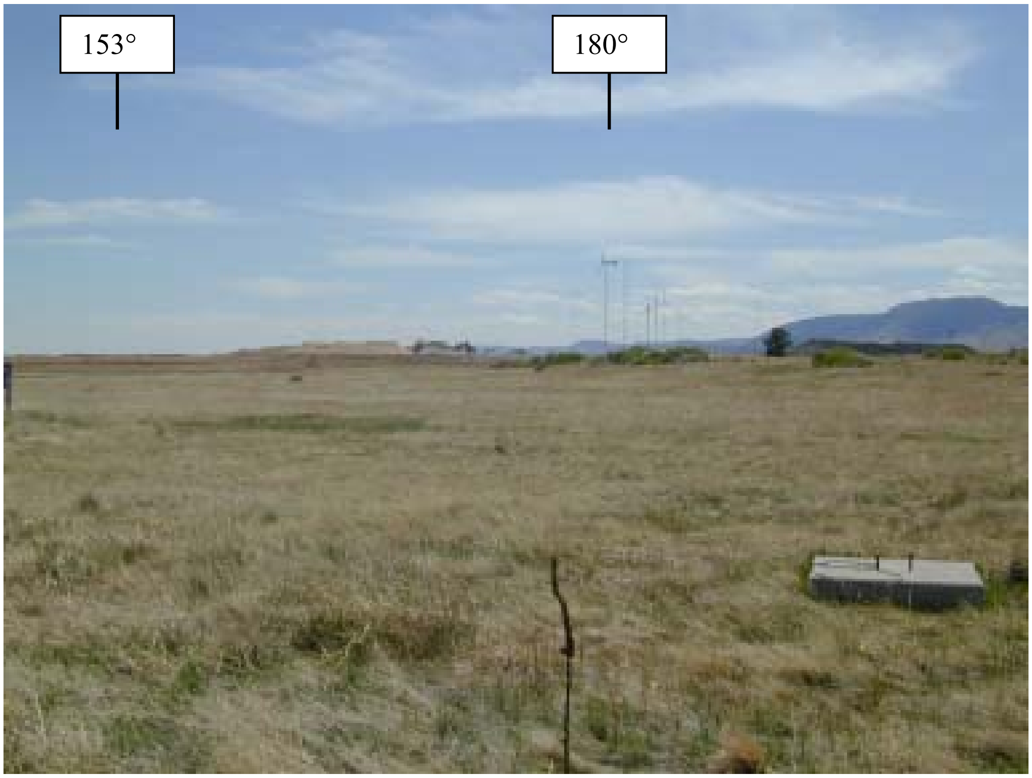
3. The terrain does not meet the requirements of the IEC standard for variations within a distance of 4-8L from the test turbine.

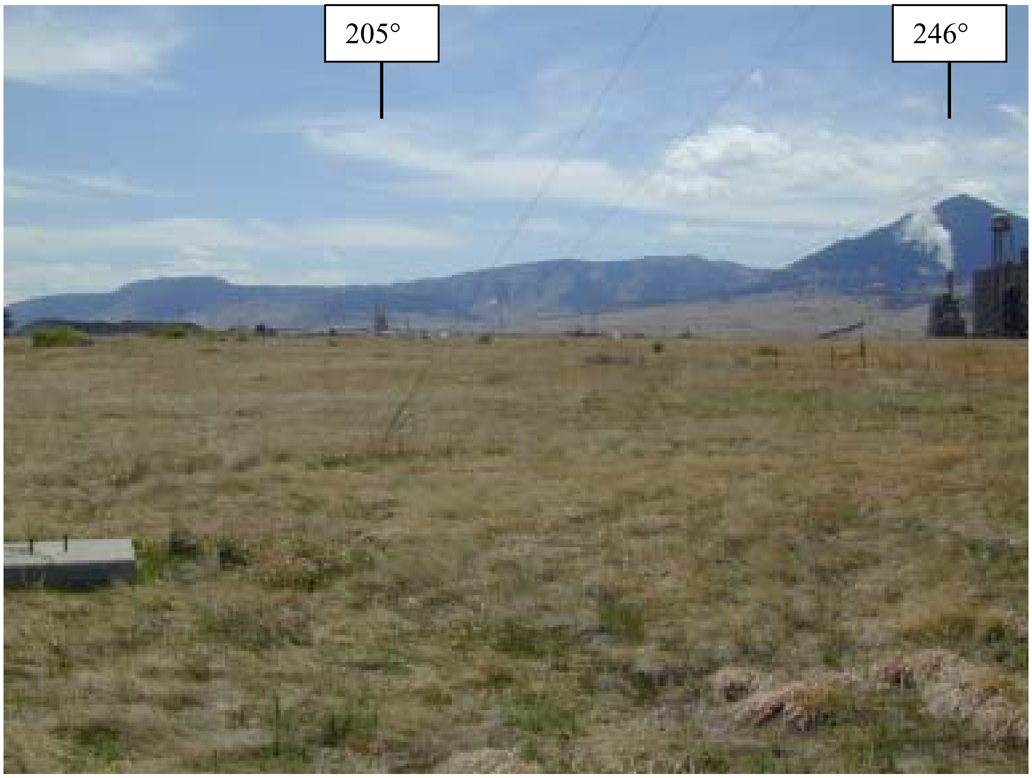
7.2 Exceptions to the Test Plan

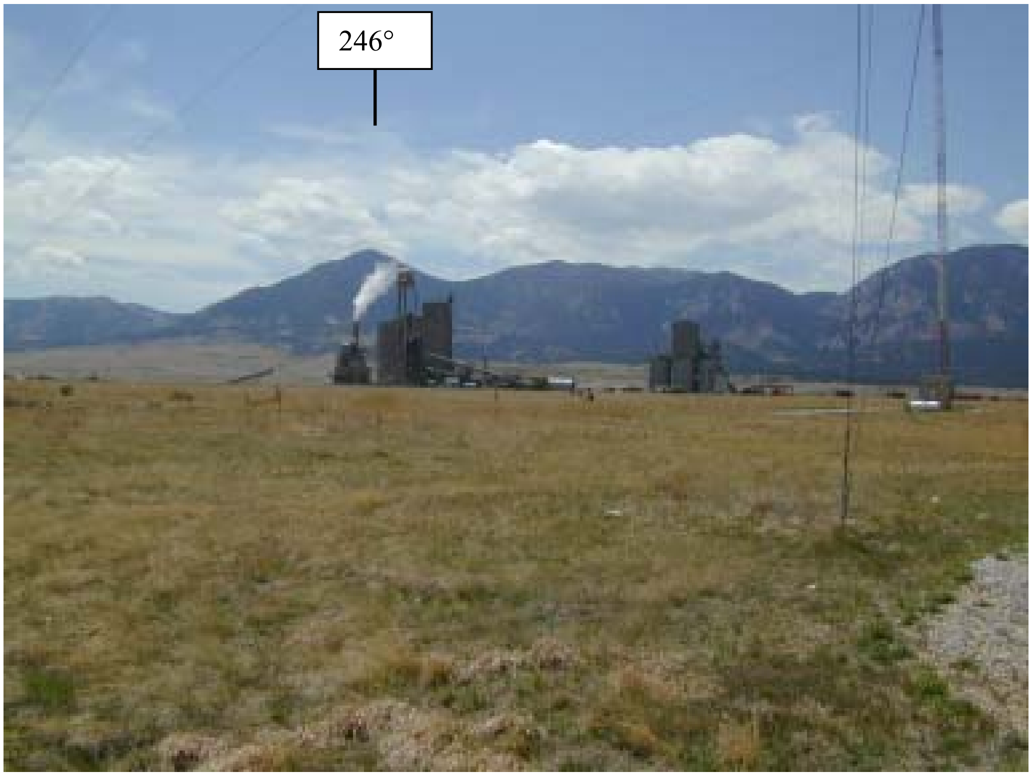
No exceptions were made to the test plan.

Appendix A: Pictures of Test Site

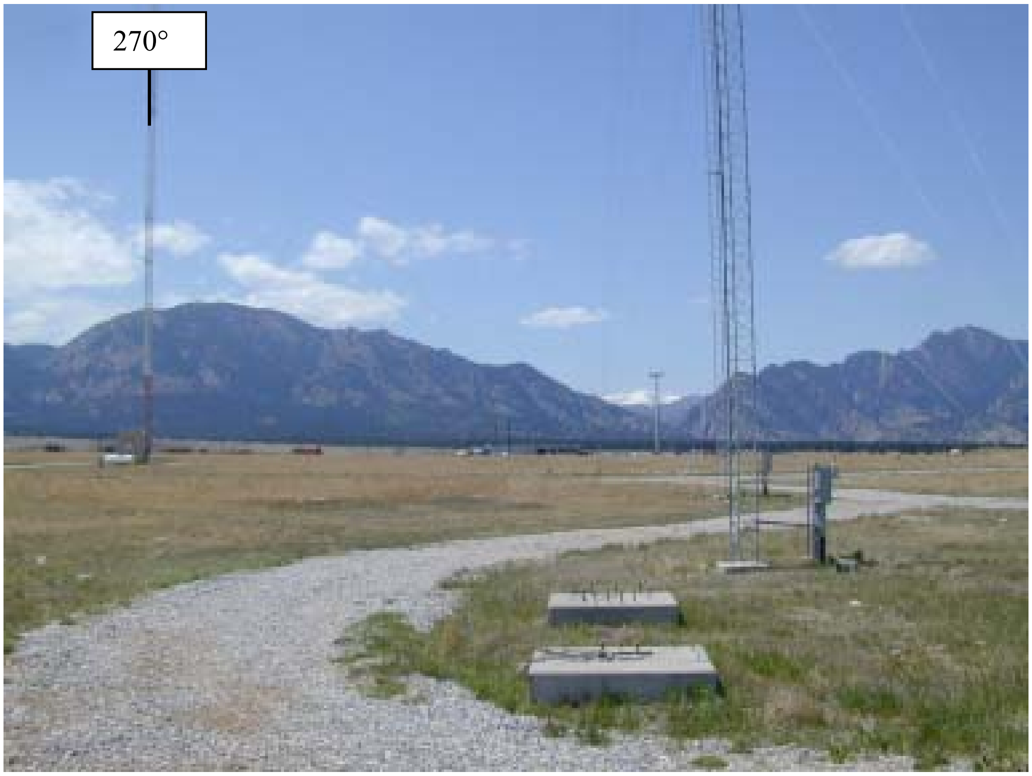
Bearings are magnetic, which are 11° lower than bearings relative to true north.



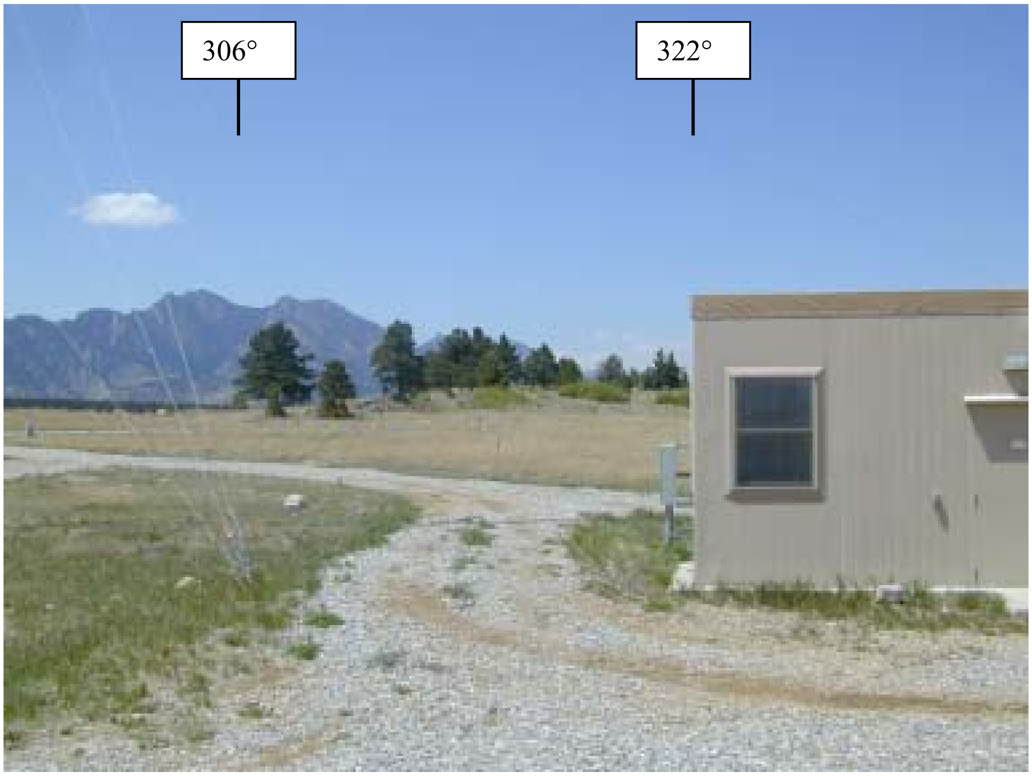


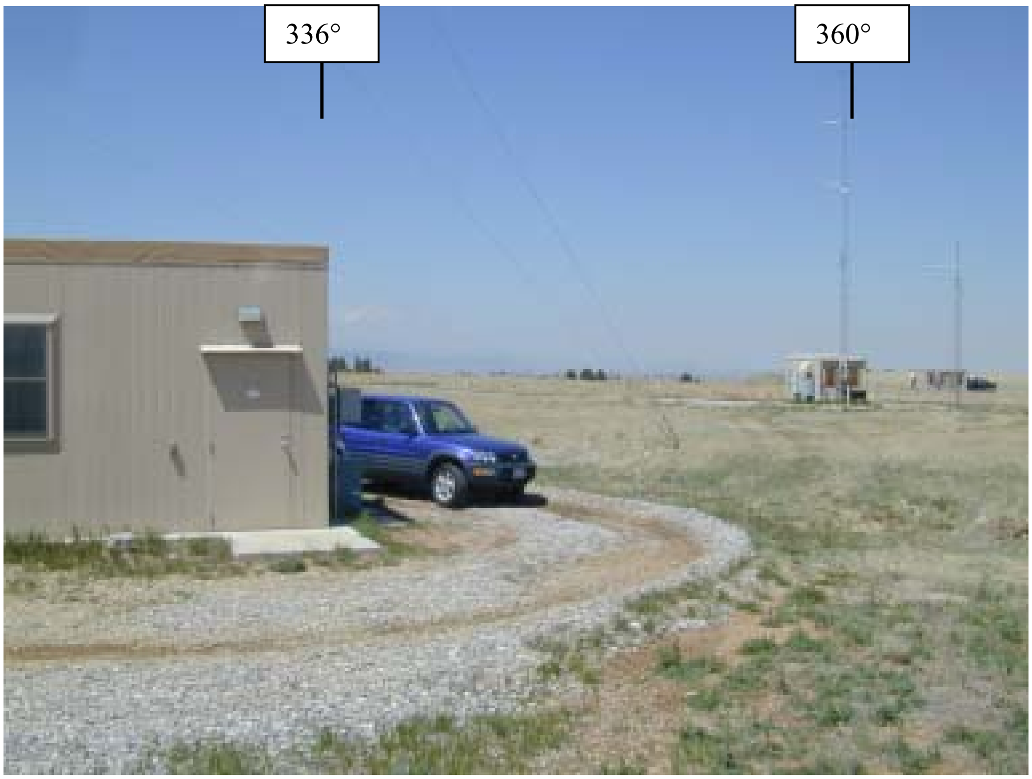


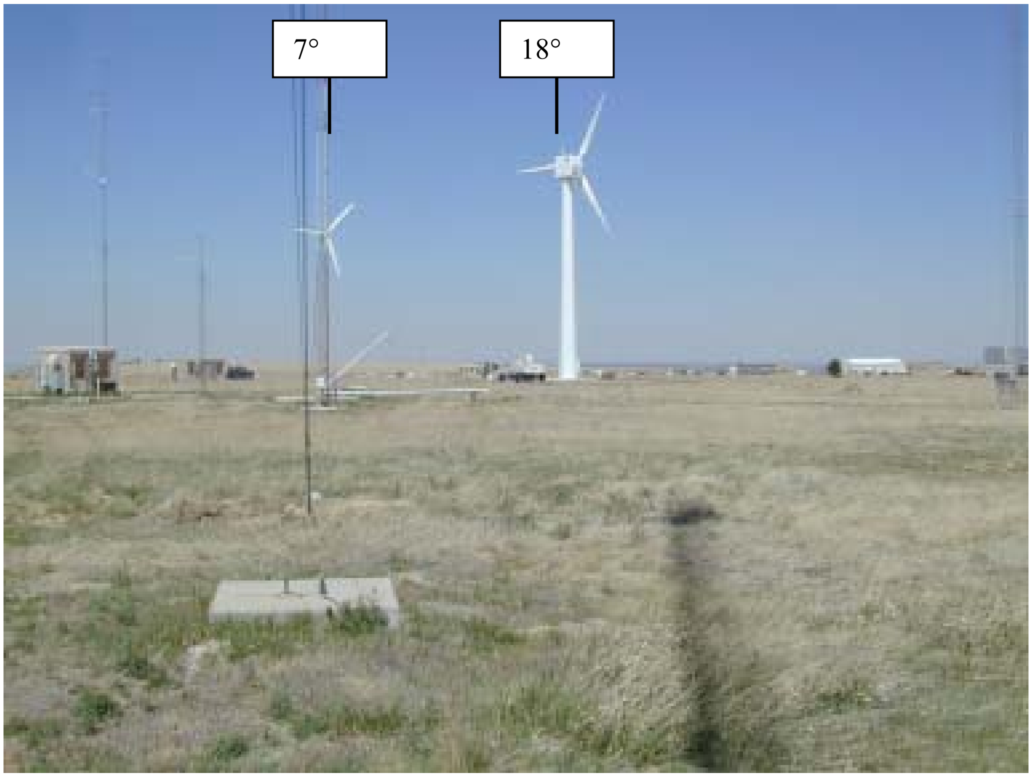
246°



270°


306°
322°


336°
360°



7°
18°

Appendix B: Test Plan

ACCREDITED
Certificate Number 1239-01

Wind Turbine Generator System

Power Performance Test Plan

for the

Bergey Excel-S/60 Wind Turbine

with SH3052 Airfoil Blades

in

Golden, Colorado

Conducted by

National Wind Technology Center
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401

for

Bergey Windpower Company, Inc.
2001 Priestley Avenue
Norman, Oklahoma 73069

Mark Meadors, Jeroen van Dam

December 2002

Approval By: 12 Feb 2003
Jeroen van Dam, NREL Certification Test Engineer Date

Approval By: Harold F. Link 12 Feb 2003
Harold F. Link, NREL Certification Test Manager Date

Approval By: Trudy Forsyth 2/12/03
Trudy Forsyth, NREL Project Engineer Date

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4 Test Objective

The objective of this test is to obtain the power performance characteristics of the Bergey Excel-S wind turbine for participation in the U.S. Department of Energy/Golden Field Office (DOE/GO) Field Verification Program. The power performance characteristics will be measured in accordance with the International Electrotechnical Commission's (IEC's) standard, *Wind Turbine Generator Systems Part 12: Power Performance Measurement Techniques*, IEC 61400-12 Ed.1.0, 1998. Hereafter this document is referred to as the Standard or the IEC standard.

5 Background

This test is being conducted as part of the DOE's Small Wind Turbine Field Verification Program. The primary purpose of this program is to provide consumers, manufacturers, and host site organizations with an independent assessment of the performance and reliability of small wind turbines manufactured in the United States. As part of the DOE/GO Field Verification Program, each turbine must pass a suite of IEC tests, including duration, system safety and function, power performance, and noise tests.

The Bergey Excel test turbine, located at the National Wind Technology Center (NWTC), is owned by AWS Scientific, Inc. This turbine was erected at the NWTC in October 1999 and tested to determine power performance characteristics. In March 2002, the original blades were replaced with a new set of blades, and this second test was conducted.

6 Test Turbine

The Bergey Excel is a three-bladed upwind wind turbine rated at a 10-kW output at 13.0 m/s. It is connected to a Bergey Gridtek-10 inverter, which provides power to the NWTC public service electrical grid.

The Excel uses a permanent magnet alternator to produce three-phase variable frequency output at a nominal 240 volts. The three-phase output is then rectified to DC power and converted to single-phase, 240-volt, 60-Hz AC power in the Gridtek inverter.

As with the original set, the modified turbine blades are made from pultruded fiberglass. The configuration of the blades was changed, however. They are 41.5 cm shorter and use the SH3052 airfoil—changes that were intended to improve performance and decrease noise. In high wind speeds (greater than about 15.6 m/s), the turbine will turn out of the wind (known as furling) to protect the turbine from over-speeding. Table 1 lists basic turbine configuration and operational data.

Figure 1. The Bergey Excel wind turbine.

Table 1. Test Turbine Configuration and Operational Data

General Configuration:	
Make, Model, Serial Number	Bergey WindPower, Excel, #9900550
Rotation Axis (H/V)	Horizontal
Orientation (upwind/downwind)	Upwind
Number of Blades	3
Rotor Hub Type	Rigid
Rotor Diameter (m)	6.17
Hub Height (m)	37
Performance:	
Rated Electrical Power (kW)	10
Rated Wind Speed (m/s)	13.0
Cut-In Wind Speed (m/s)	3.1
Cut-Out Wind Speed (m/s)	none
Rotor:	
Swept Area (m^2)	29.9
Direction of Rotation	Counterclockwise
Rotor Speed (rpm)	0-400
Power Regulation (active or passive)	Passive
Tower:	
Type	Bergey Guyed Lattice
Height (m)	36.6
Control/Electrical System:	
Controller: Make, Type	Bergey Gridtek Inverter
Electrical Output Voltage	Nominal 240-Volt Single Phase
Yaw System:	
Wind Direction Sensor	Tail Vane

7 Test Site

7.1 *General Description*

The Bergey Excel wind turbine under test is located at Test Site 1.4 of the NWTC (hereafter referred to as the test site), approximately 8 km south of Boulder, Colorado. The site is located in somewhat complex terrain at an approximate elevation of 1850 m above sea level. Figure 2 shows a picture of the turbine toward the prevailing wind direction 292°. Figure 3 shows a plot plan of the test site with topography lines listed in feet above sea level.

The meteorological tower is located 22.7 m from the test turbine at an azimuth of 292 degrees true. The distance is about three rotor diameters from the turbine.

Figure 2. View of test turbine toward the prevailing wind direction (292°).

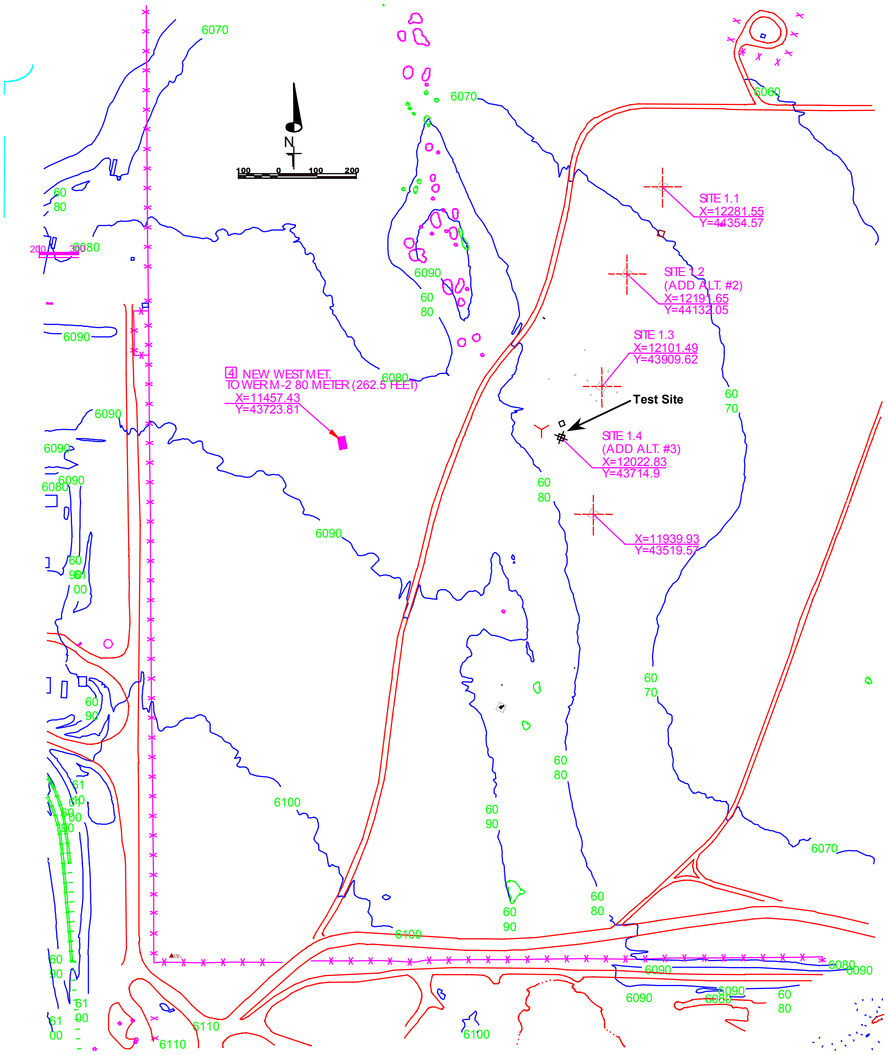


Figure 3. Plot plan of the test site.

7.2 *Evaluation of Obstructions*

The IEC standard uses the expression "measurement sector" to define wind directions that can be used for power performance measurements. The National Renewable Energy Laboratory (NREL) defines a "preliminary measurement sector" as part of the site assessment procedure. Using data obtained during site calibration or the power performance test, NREL may change the measurement sector to avoid wind directions in which terrain or obstacles affect the wind.

The first step in defining the measurement sector is to consider historic wind data, if available. Experience at the NWTC has shown that the prevailing wind direction is 292° for winds above 4 m/s. These winds usually come during the "wind season," which normally lasts from November to April.

Next we analyze the site to estimate the wakes from obstructions. The preliminary measurement sector should avoid wake effects on the turbine and the meteorological tower. This includes the potential for the turbine wake to affect the anemometers on the meteorological tower. Table 2 lists the positions and characteristics of structures close to the Bergey Excel. This table does not include the data shed because the IEC standard permits small data acquisition sheds within the measurement sector. NREL will evaluate the effect of this shed using the power performance data. If we find that the shed has a significant effect, the measurement sector will be adjusted accordingly. Based on the effects of the obstructions listed in Table 2, the preliminary measurement sector is 151° to 1° true.

Table 2. Obstructions Close to the Bergey Excel Test Turbine

Obstruction	Tower Height	Diameter (rotor or equiv.)	Distance	Bearing	Relative to:	Excluded sector [°]	
	[m]	[m]	[m]	[°]		Start	End
AOC 15/50 (site 1.1)	25.0	15.0	210	22.0	Test Turbine	1	43
NPS NW100 (site 1.2)	23.5	16.6	140	32.6	Test Turbine	7	59
AOC 15/50 (site 1.1)	25.0	15.0	211.6	28.2	Anno	7	50
NPS NW100 (site 1.2)	23.5	16.6	145.4	41.5	Anno	16	67
Bergey XL10 (site 1.4)	36.6	6.2	22.7	112.1	Anno	74	151

7.3 *Evaluation of Terrain*

To conduct a power performance test without a site calibration, the terrain surrounding the test turbine must meet all the criteria listed in Section A.1 of the IEC standard. Table 3 lists these criteria and the results of the NWTC-CT's assessment. The site failed criterion #7; however, because the turbine is placed on a relatively high tower, the expectation is that the influence on the power performance is negligible. In this case, NREL chose to forgo the site calibration. We will evaluate the power performance data to determine whether small obstructions have any influence on the power curve measurements.

Table 3. Criteria for Acceptance of Test Site without Site Calibration Testing

Criterion	Description	Distance[1)]	Sector (deg)	Test Site Condition	Pass/Fail
1	Maximum slope of best fit plane < 3%	<2L	360	1.9%	Pass
2	Maximum variation from best fit plane < 0.08 D	<2L	360	0.04	Pass
3	Maximum slope of best fit plane < 5%	2-4L	Inside prel. meas. sector	2%	Pass
4	Maximum variation from best fit plane < 0.15 D	2-4L	Inside prel. meas. sector	0.06	Pass
5	Steepest slope maximum < 10%	2-4L	Outside prel. meas. sector	2.1%	Pass
6	Maximum slope of best fit plane < 10%	4-8L	Inside prel. meas. sector	2.5%	Pass
7	Maximum variation from best fit plane < 0.15 D	4-8L	Inside prel. meas. sector	0.48	Fail
8	No neighboring and operating turbines	<2D_n	360	8.4	Pass
9	No obstacles	<2D_e	360	43.1	Pass
10	Preliminary measurement sector within available measurement sector	n/a	n/a	Yes	Pass

1) L is the distance between the turbine and the meteorological tower,
D_n is the rotor diameter of a neighboring turbine, and
D_e is the equivalent rotor diameter of obstacles.

8 Power Performance Test

8.1 *Description of Test Equipment*

Table 4 is an equipment list that provides the requirements and specifications for each of the instruments used for performance testing. Figure 4 shows the overall locations of the instrumentation. Figure 5 shows the location of instruments at the top of the meteorological tower.

Table 4. Equipment List for Power Performance Tests

Power Transducer and CTs (Inverter Power)	
Make/Model:	OSI, GWV5-001EY24 CT pn 12975
Serial Number (Transducer & CTs):	9101376
Range with CTs:	-13.33 to 13.33 kW/kVar
Calibration Due Date:	15 November 2002
Power Transducer and CTs (WT Watts)	
Make/Model:	OSI, P-143E
Serial Number (Transducer & CTs):	9100896
Range with CTs:	0 to 40 kW
Calibration Due Date:	15 November 2002
Primary Anemometer	
Make/Model:	Met One, 010C with Aluminum Cups
Serial Number:	T2345
Calibration Due Date:	21 February 2003
Secondary Anemometer	
Make/Model:	Met One, 010C with Aluminum Cups
Serial Number:	U2645
Calibration Due Date:	21 February 2003
Wind Direction Sensor	
Make/Model:	Met One, 020C with Aluminum Vane
Serial Number:	T1010
Calibration Due Date:	21 February 2003
Barometric Pressure Sensor	
Make/Model:	Vaisala, PTB101B
Serial Number:	S2830007
Calibration Due Date:	16 November 2002

Atmospheric Temperature Sensor	
Make/Model:	Met One, T-200 RTD
Serial Number:	0464507
Calibration Due Date:	19 November 2002
Datalogger	
Make/Model:	Campbell Scientific CR23X
Serial Number:	3101
Calibration Due Date:	30 October 2002

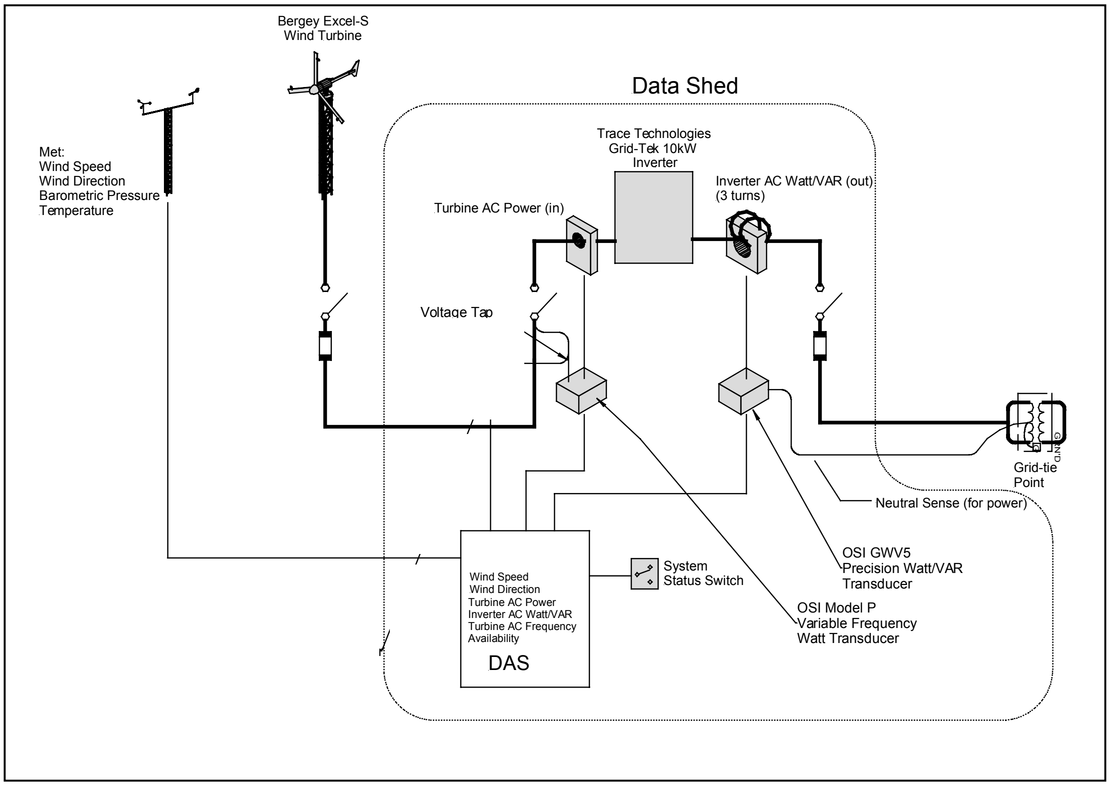


Figure 4. Layout of instrumentation for power performance tests.

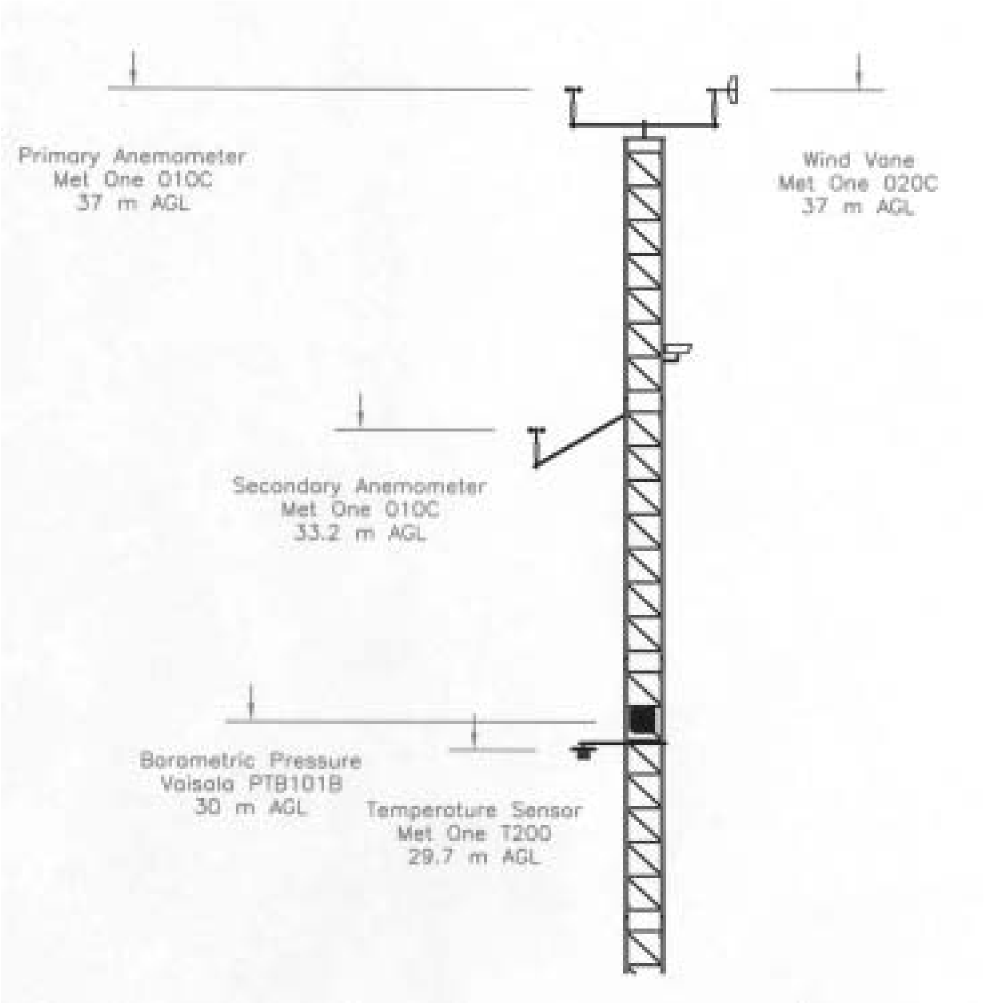


Figure 5. Detail of instrument locations and mounting booms on the meteo tower.

In addition to the instruments listed in Table 4, the performance test requires a signal to determine turbine operational status.

For the Bergey Excel with Gridtek inverter, the logbook will be checked on manual resets of inverter faults. The logbook will also be checked for further information on turbine availability (DAS or turbine maintenance). If the grid goes down, power to the power transducer is lost and the power signal is invalid; in this way, those data points will be sorted out automatically.

8.2 *Test Preparations*

In preparation for the test, the test technician will:

- install and check all instrumentation for the power performance test using procedures defined in this section of the test plan
- perform a series of "in-field" checks on each of the instruments
- leave the datalogger in "logging" mode to collect a short, 6-12 hour, data set. This data set will be checked to identify any problems that might not be apparent in the in-field checks.

- perform a third check if a data acquisition system is available that can provide comparable signals to those monitored by the NREL system. In this check, data sets are compared to identify any unexplainable differences in any of the comparable signals.

In parallel with instrumentation checkouts, the turbine owner will:

- complete final modifications to the test turbine and test site, if any
- notify NREL in writing that the turbine and test site configurations are fixed
- provide NREL with updated information on the final test configuration of the turbine and the test site.

After all instrumentation checks are complete, and upon receipt of verification that the turbine and test site configurations are fixed, NREL will change the site identification code on the datalogger to signify the beginning of testing. NREL will also inform the NWTC management that the test has begun.

8.3 *Measurement Procedures*

Measurements during the power performance test will be obtained automatically by the Campbell datalogger at a sample rate of 1 Hz. At the end of each 10-minute period, as indicated on the datalogger's clock, it records the averages of these data with their standard deviations and minimum and maximum values for the ten minutes. It also records the percentage of time that the turbine or system is not available. Finally, the logger records the number of samples in each record. If the datalogger is interrupted by a program change, its first or last record will contain less than 10 minutes. The IEC standard does not allow use of such records.

On a weekly basis, NREL will transfer data from the datalogger to computers at NREL offices. Also on a weekly basis, NREL personnel will check instruments located on the meteorological tower from ground level. They will note whether there are any obvious failures such as broken or missing cups from the anemometers; bent, broken, or missing wind vane; or misalignment of any sensors. They will also note whether 120 VAC power is being provided to the datalogger. NREL personnel will also record any unusual occurrences with the turbine or instrumentation in the appropriate logbook inside the turbine control shed.

NREL will analyze the data sets once per week. Using the procedures described in the next section, the test engineer will note whether any problems have arisen. The test will be considered as suspended pending resolution of the problem. The test engineer will determine whether data obtained during the period when the problem was active can be used in the determination of power performance and note whether data are used in the test report.

If the test site or turbine changes during the test, the test engineer will determine whether it is appropriate to continue the test, restart the test, or cancel the test. All actions will be documented in the test report. NREL will monitor the quantity of data obtained during testing and will report on test progress to NREL management on a weekly basis.

The power curve must be well defined over a range of wind speeds specified by the IEC standard. In this test, the low end of the range is 2.1 m/s, which is 1 m/s below the Bergey Excel's cut-in wind speed. The high end of the range is 20 m/s, which is 1.5 times the wind speed at which the turbine produces 85% of its rated power. The test will continue until 180 hours of usable data have been obtained in the specified wind speed range and when each 0.5 m/s wind bin in this range contains at least 30 minutes of data. Once sufficient data are obtained to fulfill these requirements, the NREL test engineer will inform NREL management that the test is complete.

9 Analysis Methods

NREL analyzes power performance data in two steps. First we determine which of the data are usable. Then we process the usable data to obtain power curves and to estimate annual energy production and uncertainty.

In the first step, the analyst enters the data into a spreadsheet in which time series plots are used to review the various instrument readings. The data acquisition system has failed if:
1) voltage of the datalogger's power supply is below 11 volts DC
2) temperature at the datalogger is less than -40°C or greater than 80°C
3) the record contains less than 600 samples
4) any channel is over range as indicated by a record of –99999.

Other checks are made to ensure to the greatest extent practical that all signals are valid. Also, the analyst tags as unusable any data obtained when the logbook indicates that the turbine or external conditions prevented normal operation. Occasionally such periods are noted in the logbook but not recorded by the datalogger. Any data that are found to be unusable are filtered from the data set.

The usable data are then entered into a second spreadsheet with custom macros for processing. These macros apply additional filters in accordance with the IEC standard. The IEC standard requires that all data be used unless the following conditions are present:

- The wind turbine is unavailable
- The test equipment fails
- The wind direction is outside of the valid measurement sector.

NREL defines unavailable as:

- The turbine is faulted (the inverter is waiting for a manual reset)
- The turbine is not in automatic run mode (i.e. the turbine has manually been furled)
- The utility grid is not available (utility power is not within specifications).

Once the above criteria have been applied, the remaining data from the primary test data set and the resulting power performance from this set are analyzed and reported. The macros perform the following calculations on that data set:

1. When site calibration data are available, Equation 1 is used to adjust the average wind speeds measured on the meteorological tower (MET) to calculate turbine wind speeds according to the site calibration results. If no site calibration test was performed, then the Γ_{Site} = 1.0.

$$V_{Turb} = \Gamma_{Site} \cdot V_{MET}$$

Equation 1

where: V_{Turb} = wind speed at turbine (m/s)
Γ_{Site} = site calibration factor
V_{MET} = wind speed at MET (m/s)

2. If the pressure sensor is more then 10 meters below hub height, then for each data point the measured pressure is corrected to hub height by Equation 2 (from ISO 2533).

$$p = p_b \cdot \left[1 + \frac{\beta}{T_b} \cdot (H - H_b) \right]^{-\frac{g_n}{\beta \cdot R}}$$ **Equation 2**

where: p = pressure at hub height (Pa)
p_b = measured pressure (Pa)
β = temperature gradient (-6.5 K/m)
T_b = measured temperature (K)
H = hub height above ground (m)
H_b = pressure transducer height above ground (m)
g_n = acceleration of gravity (9.807 m/s^2)
R = specific gas constant (287.053 m/Ks^2)

3. For each data point, the average air density is calculated by the Ideal Gas Law (Equation 3):

$$\rho_{10\,\min} = \frac{B_{10\,\min}}{R * T_{10\,\min}}$$ **Equation 3**

where: ρ_{10min} = derived air density averaged over 10 minutes (kg/m^3)
T_{10min} = measured absolute air temperature averaged over 10 minutes (K)
B_{10min} = measured air pressure averaged over 10 minutes (Pa)
R = gas constant for air (287.05 J/kgK)

4. For each data point, the derived site air density is used to calculate the average site air density for the test period, rounded to the nearest 0.05 kg/m^3.

5. For small turbines that use furling, NREL has determined that the most appropriate method to use for normalize the power curve is to adjust wind speed in accordance with Equation 4. In this test, normalization will be performed using monthly averages instead of 10-minute averages of air density:

$$V_n = V_{10\,\min} \cdot \left(\frac{\rho_{10\,\min}}{\rho_0} \right)^{1/3}$$ **Equation 4**

where: V_n = normalized wind speed (m/s)
V_{10min} = measured wind speed averaged over 10 minutes (m/s)
ρ_0 = site average air density (kg/m^3)
ρ_{10min} = measured air density averaged over 10 minutes (kg/m^3)

6. Equation 4 is applied a second time with ρ_o replaced with the standard sea-level air density (1.225 kg/m^3), creating a standard normalized wind speed (V_{ns})

7. All data are sorted according to normalized wind speeds into bins which are 0.5 m/s wide, with bin centers at integer multiples of 0.5 m/s. Each power, DC and AC, is averaged for each bin. As a result, two power curves and AEPs are calculated.

8. For each data bin, the following parameters are calculated:

   - bin average air temperature (K)

- bin average corrected air pressure (Pa)
- bin average measured wind speed (m/s)
- bin average standard deviation of wind speed (m/s)
- bin average measured power (W)
- bin average standard deviation of measured power (W)
- bin average site average density normalized power (W)
- bin average site average density standard deviation normalized power (W)
- bin average sea level density normalized power (W)
- bin average sea level density standard deviation normalized power (W)
- site average density (kg/m^3)
- amount of 10-minute data points in bin
- bin average uncorrected air pressure (Pa)
- bin power coefficient

9. The test power curve is then formed by the resulting average normalized wind speed and average power (average for site average density, standard for sea-level density) at each bin. For each bin the generator power coefficient is calculated by Equation 5:

$$C_{P,i} = \frac{P_i}{0.5 * \rho_0 A V_i^3} \qquad \textbf{Equation 5}$$

where:
$C_{P,i}$ = generator power coefficient in bin i (non-dimensional)
V_i = normalized wind speed in bin i (m/s)
P_i = average power in bin i (W)
A = swept area of the turbine rotor
ρ_0 = reference air density (same as used to normalize V_i)

10. The measured power curve is then used to estimate annual energy production (AEP) for a variety of Rayleigh wind speed distributions, where for each case the distributions are specified at turbine hub height and assumed to be constant over the swept area of the rotor. The AEP estimations are made according to Equations 6 and 7:

$$AEP = N_h \sum_i^N \left[F(V_i) - F(V_{i-1})\right]\left(\frac{P_{i-1} + P_i}{2}\right) \qquad \textbf{Equation 6}$$

where:
AEP = annual energy production (kWh)
N_h = number of hours in one year ≈ 8760 hr
N = number of bins
V_i = normalized and averaged wind speed in bin i
V_{i-1} = normalized and averaged wind speed in bin i-1
P_i = averaged measured power in bin i
P_{i-1} = averaged measured power in bin i-1
F(V) = the accumulated Rayleigh distribution, given by:

$$F(V) = 1 - \exp\left(-\frac{\pi}{4}\left(\frac{V}{V_{ave}}\right)^2\right) \qquad \textbf{Equation 7}$$

where:
V_{ave} = annual average wind speed at hub height
V = wind speed

11. The summation of Equation 6 is initiated by setting V_{i-1} equal to V_i-0.5 m/s, and P_{i-1} equal to 0 kW. The AEP calculations are made for integer values of annual average wind speeds ranging between 4 and 11 m/s.

12. An uncertainty analysis is performed per Annex C of the IEC standard for both the measured power curve and estimated AEP.

AEP is calculated in two ways, one designated AEP-measured and the other AEP-extrapolated. AEP-measured is calculated assuming that power in winds above the highest bin in the power curve is zero. AEP-extrapolated is calculated assuming that power in winds above the highest bin in the power curve is equal to the power in the highest wind bin. If AEP-measured is less than 95% of AEP-calculated, then the table reporting AEP-measured values must indicate "Incomplete."

10 Uncertainty

NREL considers two types of uncertainty in the calculation of overall measurement uncertainty of the power curve. Type A is calculated from the scatter of test data. Type B accounts for uncertainty in calibration, installation, and for instrument accuracy.

Table 5 indicates values for known and estimated uncertainty levels for this test.
Once the test data are obtained, NREL calculates the Type A uncertainties based on data scatter and combines these with the Type B uncertainties listed to obtain an overall uncertainty.

Table 5. Uncertainty in Power Performance Measurements

Component	*Uncertainty*		*Source*
Power (Inverter)			
Power Transducer	6W or 0.12%		Specs
Data Acquisition	36	W	Specs
Resistor	0.006	%	Specs
Wind Speed			
Anemometer	0.06 m/s		Calibration
Operational Characteristics	1.73%		Assumption
Mounting Effects	1.15%		Assumption
Terrain Effects	2.00%		IEC Recommendation
Data Acquisition	0.00		Estimate
Temperature			
Temperature Sensor	0.15	K	Instrument Specs
Radiation Shielding	1.15	K	Shield Specs
Mounting Effects	0.24	K	IEC Method
Linearization	0.12	K	Estimate

Data Acquisition	0.03	K	Datalogger Specs/ Resistor Specs
Air Pressure			
Pressure Sensor	2.0	hPa	Specs
Mounting Effects	0.07	hPa	IEC Method
Data Acquisition	0.8	hPa	Datalogger Specs

11 Reporting

When the data collection and analysis are completed, NREL will generate a test report. This report will include the power curves and AEP for the Bergey Excel, as well as detailed explanations of any deviations from this test plan. The report will also examine the uncertainty of the measurements and whether the test passes the minimum requirements of the Standard.

12 Exceptions to Standard Practice

Power performance instrumentation deviates from the IEC standard as follows:

1. The power transducer was not tested for compliance with IEC 60688.
2. The current transformers were not tested for compliance with IEC 60044.
3. The terrain does not meet the requirements of the IEC standard for variations within a distance of 4-8L from the test turbine.

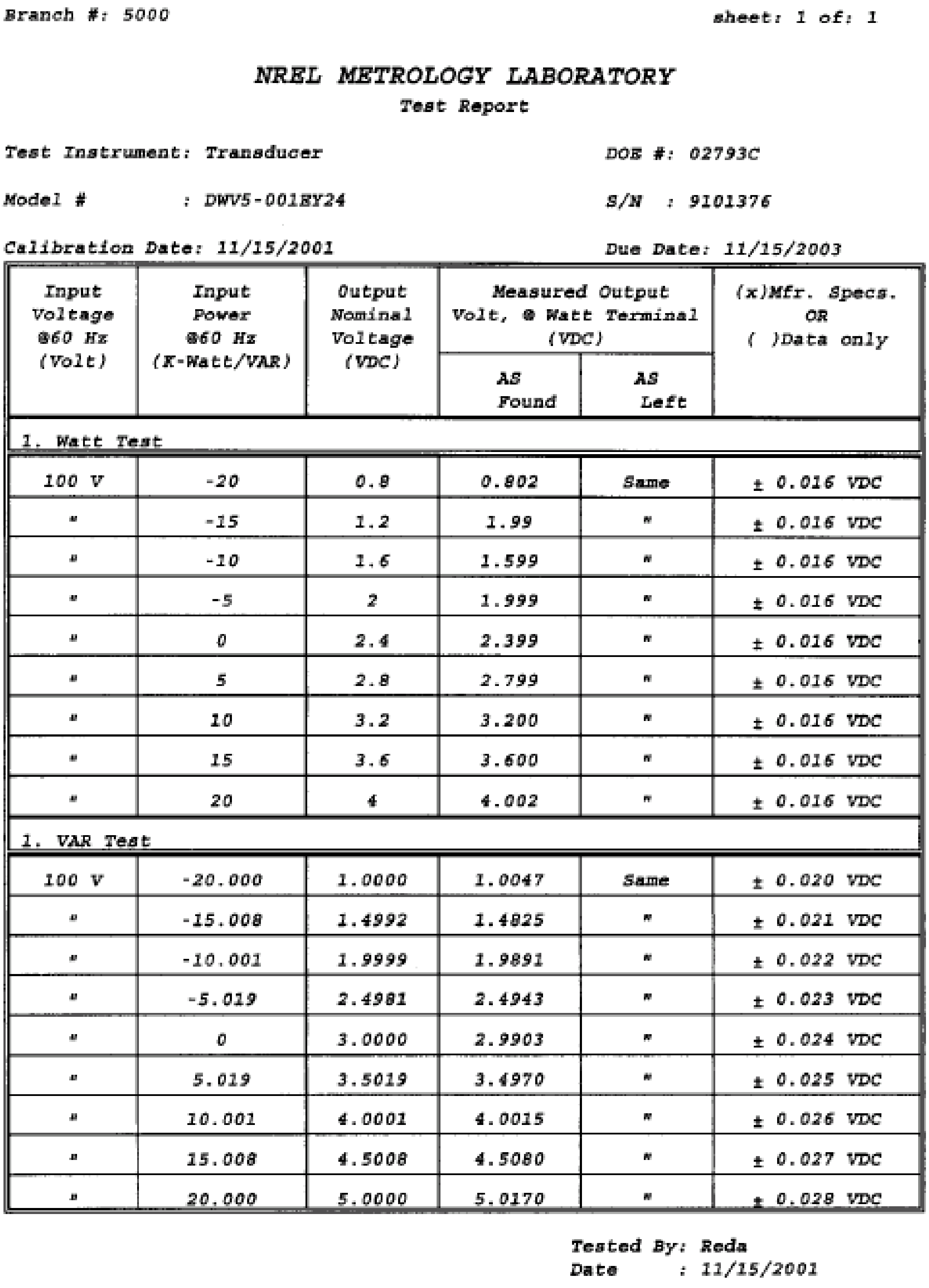
13 Roles and Responsibilities

Table 6 lists the planned test team and identifies roles and responsibilities for each team member.

Table 6. Roles of Test Participants

Test Team Title	Name	Employer	Role(s)
Certification Test Manager	Hal Link	NREL	Approves NREL test plan
Test Engineer	Jeroen van Dam	NREL	Manages and is responsible for test Serves as customer contact person Authorizes any deviations from planned test procedures Supervises performance test set-up, checkout, and conduct Periodically reviews test data Identifies problems based on data analysis results Analyzes test data Reports test results Serves as the primary point of contact between NWTC-CT and the test site manager
Test Technician	Mark Meadors	NREL	Selects instruments Installs and checks out test equipment Implements corrective actions for problems Downloads and stores test data
Turbine Maintenance Technician	Scott Wilde	NREL	Maintains test turbine in accordance with manufacturer's recommendations Records all maintenance activities or observations in test log

Appendix A: Instrument Calibration Sheets



Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Transducer DOE #: 02793C

Model # : DWV5-001EY24 S/N : 9101376

Calibration Date: 11/15/2001 Due Date: 11/15/2003

Input Voltage @60 Hz (Volt)	Input Power @60 Hz (K-Watt/VAR)	Output Nominal Voltage (VDC)	Measured Output Volt, @ Watt Terminal (VDC)		(x)Mfr. Specs. OR ( )Data only
			AS Found	AS Left	
1. Watt Test					
100 V	-20	0.8	0.802	Same	± 0.016 VDC
"	-15	1.2	1.99	"	± 0.016 VDC
"	-10	1.6	1.599	"	± 0.016 VDC
"	-5	2	1.999	"	± 0.016 VDC
"	0	2.4	2.399	"	± 0.016 VDC
"	5	2.8	2.799	"	± 0.016 VDC
"	10	3.2	3.200	"	± 0.016 VDC
"	15	3.6	3.600	"	± 0.016 VDC
"	20	4	4.002	"	± 0.016 VDC
1. VAR Test					
100 V	-20.000	1.0000	1.0047	Same	± 0.020 VDC
"	-15.008	1.4992	1.4825	"	± 0.021 VDC
"	-10.001	1.9999	1.9891	"	± 0.022 VDC
"	-5.019	2.4981	2.4943	"	± 0.023 VDC
"	0	3.0000	2.9903	"	± 0.024 VDC
"	5.019	3.5019	3.4970	"	± 0.025 VDC
"	10.001	4.0001	4.0015	"	± 0.026 VDC
"	15.008	4.5008	4.5080	"	± 0.027 VDC
"	20.000	5.0000	5.0170	"	± 0.028 VDC

Tested By: Reda
Date : 11/15/2001

Center #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Transducer DOE #: 02792C

Model # : P-143E S/N : 9100896

Calibration Date: 11/15/2001 Due Date: 11/15/2003

Input Voltage @60 Hz (Volt)	Input Power @60 Hz (KWatt)	Output Nominal Voltage (VDC)	Measured Output Volt, @ Watt Terminal (VDC)		(x)Mfr. Specs. OR ( )Data only
			AS Found	AS Left	
200	0	1.0	1.000	Same	± 0.05 VDC
"	4	1.4	1.396	"	"
"	8	1.8	1.796	"	"
"	12	2.2	2.196	"	"
"	16	2.6	2.597	"	"
"	20	3.0	2.999	"	"
"	24	3.4	3.400	"	"
"	28	3.8	3.804	"	"
"	32	4.2	4.205	"	"
"	36	4.6	4.609	"	"
"	40	5	5.012	"	"

Tested By: Reda
Date : 11/15/2001

Met One
Instruments

1600 Washington Blvd.
Grants Pass, Oregon 97526
Telephone 541-471-7111
Facsimile 541-471-7116

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

Test Certification

Model W/S SENSOR 010 Serial No. U2645

Job Number 15168 Customer NREL

Test Date 1-2-2002 **Next Calibration Due** 1-2-2003 Tested By

Room Temperature 23.7°C Room Relative Humidity 40.8%

Test Standards:

Standards	Model	SN	Cal Date
DMM	HP3468B	2231A01057	4/19/2001
TEMPERATURE	FISHER T-200	746835	7/19/2001
RELATIVE HUMIDITY	VAISALA HMP-35	10025	4/14/2001
BAROMETRIC PRESSURE	M.O.I. 090B-STD	H6507	2/28/2001
FREQUENCY	PROTEK B-2000A	U20003371	3/6/2001

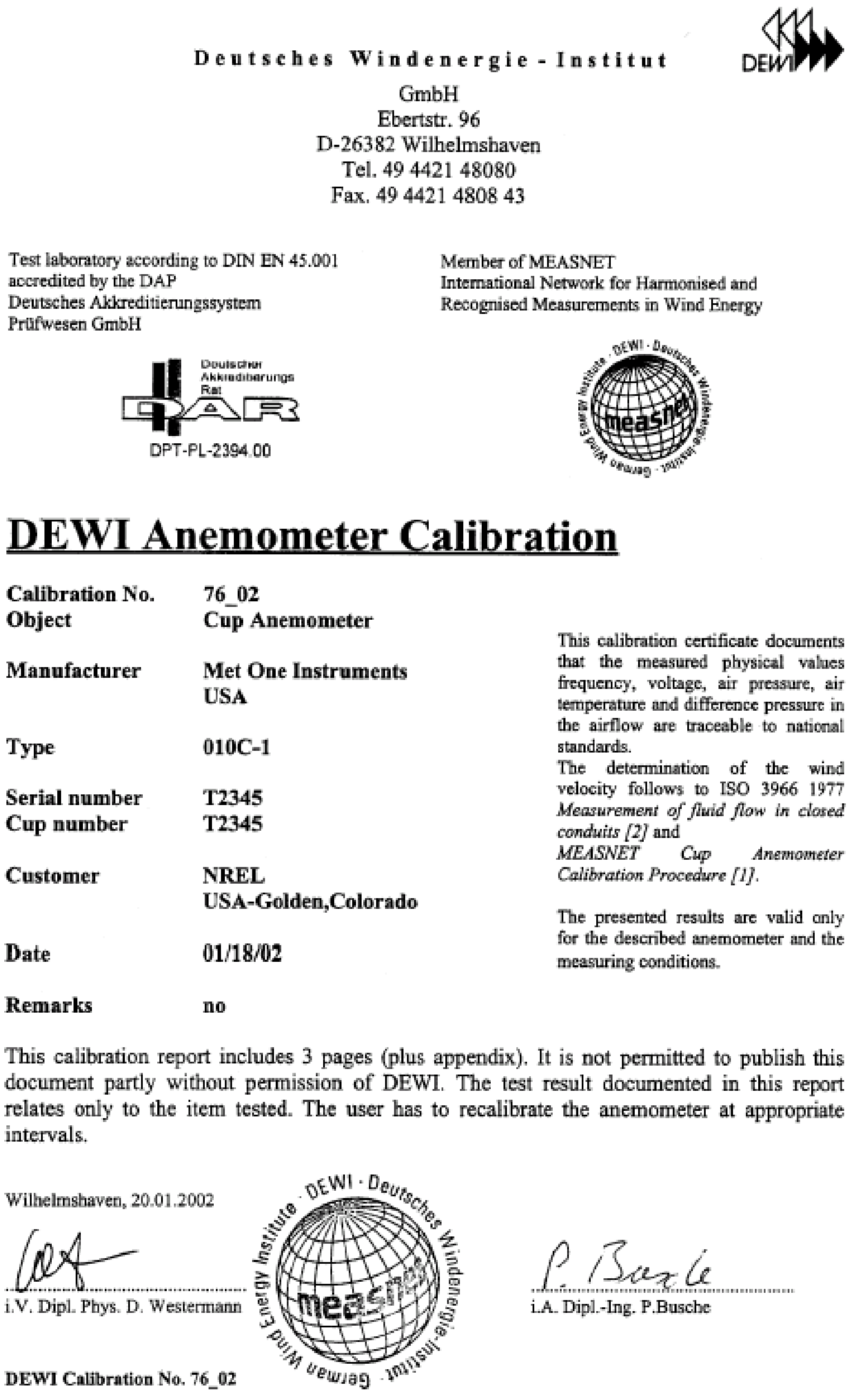
TEST	EXPECTED	ACTUAL	ERROR	SPEC	NOTES
Torque	<0.003in oz	<.003 in oz	[✓ Pass]/Fail	<0.003in oz	
Output Freq	200.0 Hz	200.00	0.0	±1.7 Hz	300RPM

END PLAY	Ok
HARDWARE TORQUE	Ok
CUPS/ARMS	—

CONNECTOR	OK
LABELS	OK
FINISH	—

Test Procedure # 010C-61

The Standards used for 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 institutes calibration facility. Unless other wise stated heron, all instruments are calibrated to meet manufacture's published specifications. The calibration system complies with MIL-STD-45662A.



Deutsches Windenergie - Institut
GmbH
Ebertstr. 96
D-26382 Wilhelmshaven
Tel. 49 4421 48080
Fax. 49 4421 4808 43

Test laboratory according to DIN EN 45.001
accredited by the DAP
Deutsches Akkreditierungssystem
Prüfwesen GmbH

Deutscher Akkreditierungs Rat
DPT-PL-2394.00

Member of MEASNET
International Network for Harmonised and
Recognised Measurements in Wind Energy

DEWI Anemometer Calibration

Calibration No.	**76_02**
Object	**Cup Anemometer**
Manufacturer	**Met One Instruments** **USA**
Type	**010C-1**
Serial number	**T2345**
Cup number	**T2345**
Customer	**NREL** **USA-Golden,Colorado**
Date	**01/18/02**
Remarks	**no**

This calibration certificate documents that the measured physical values frequency, voltage, air pressure, air temperature and difference pressure in the airflow are traceable to national standards.
The determination of the wind velocity follows to ISO 3966 1977 *Measurement of fluid flow in closed conduits [2]* and *MEASNET Cup Anemometer Calibration Procedure [1].*

The presented results are valid only for the described anemometer and the measuring conditions.

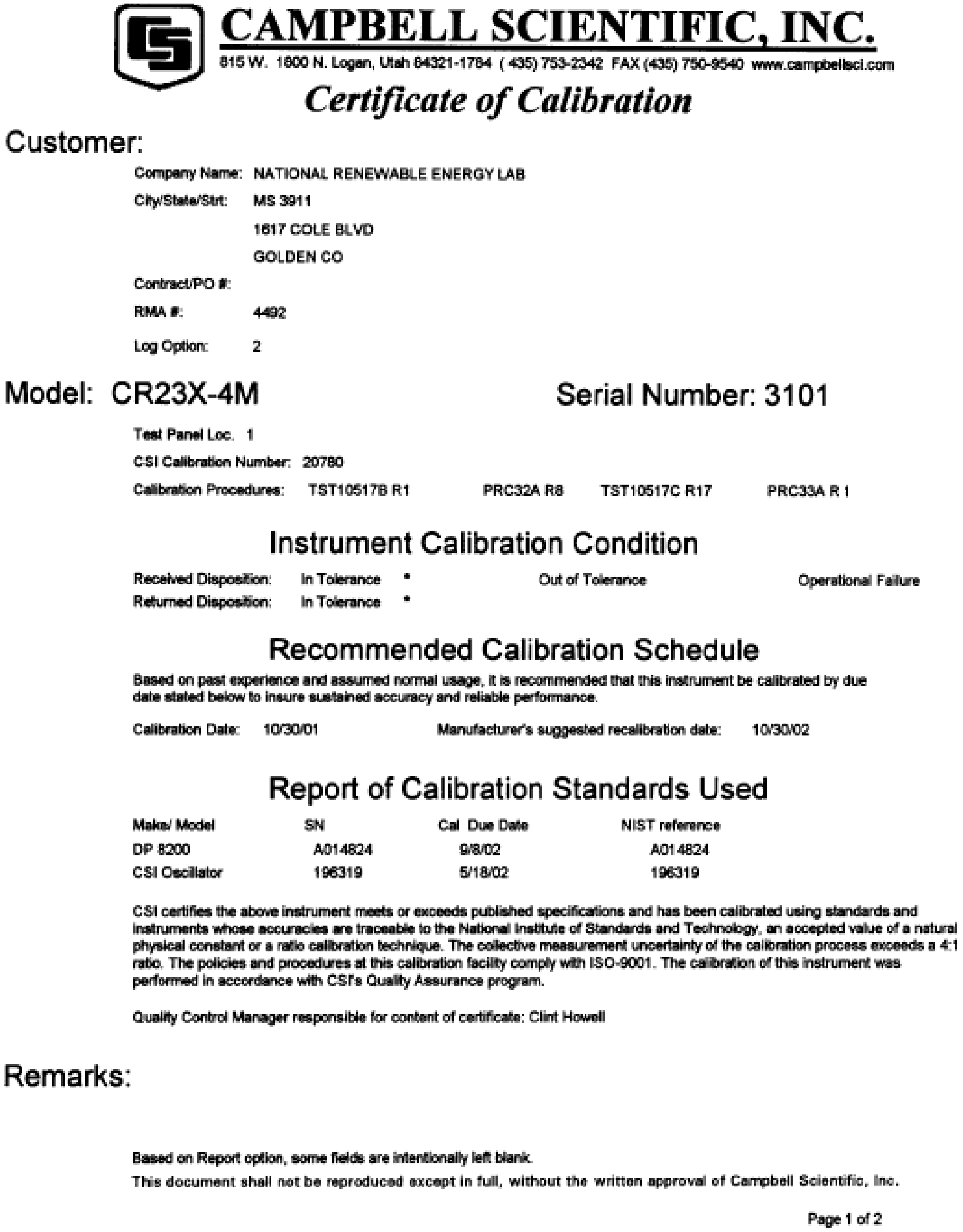
This calibration report includes 3 pages (plus appendix). It is not permitted to publish this document partly without permission of DEWI. The test result documented in this report relates only to the item tested. The user has to recalibrate the anemometer at appropriate intervals.

Wilhelmshaven, 20.01.2002

i.V. Dipl. Phys. D. Westermann

i.A. Dipl.-Ing. P.Busche

DEWI Calibration No. 76_02



CAMPBELL SCIENTIFIC, INC.

815 W. 1800 N. Logan, Utah 84321-1784 (435) 753-2342 FAX (435) 750-9540 www.campbellsci.com

Certificate of Calibration

Customer:

Company Name: NATIONAL RENEWABLE ENERGY LAB
City/State/Strt: MS 3911
1617 COLE BLVD
GOLDEN CO
Contract/PO #:
RMA #: 4492
Log Option: 2

Model: CR23X-4M Serial Number: 3101

Test Panel Loc. 1
CSI Calibration Number: 20780
Calibration Procedures: TST10517B R1 PRC32A R8 TST10517C R17 PRC33A R 1

Instrument Calibration Condition

Received Disposition: In Tolerance * Out of Tolerance Operational Failure
Returned Disposition: In Tolerance *

Recommended Calibration Schedule

Based on past experience and assumed normal usage, it is recommended that this instrument be calibrated by due date stated below to insure sustained accuracy and reliable performance.

Calibration Date: 10/30/01 **Manufacturer's suggested recalibration date:** 10/30/02

Report of Calibration Standards Used

Make/ Model	SN	Cal Due Date	NIST reference
DP 8200	A014824	9/8/02	A014824
CSI Oscillator	196319	5/18/02	196319

CSI certifies the above instrument meets or exceeds published specifications and has been calibrated using standards and instruments whose accuracies are traceable to the National Institute of Standards and Technology, an accepted value of a natural physical constant or a ratio calibration technique. The collective measurement uncertainty of the calibration process exceeds a 4:1 ratio. The policies and procedures at this calibration facility comply with ISO-9001. The calibration of this instrument was performed in accordance with CSI's Quality Assurance program.

Quality Control Manager responsible for content of certificate: Clint Howell

Remarks:

Based on Report option, some fields are intentionally left blank.

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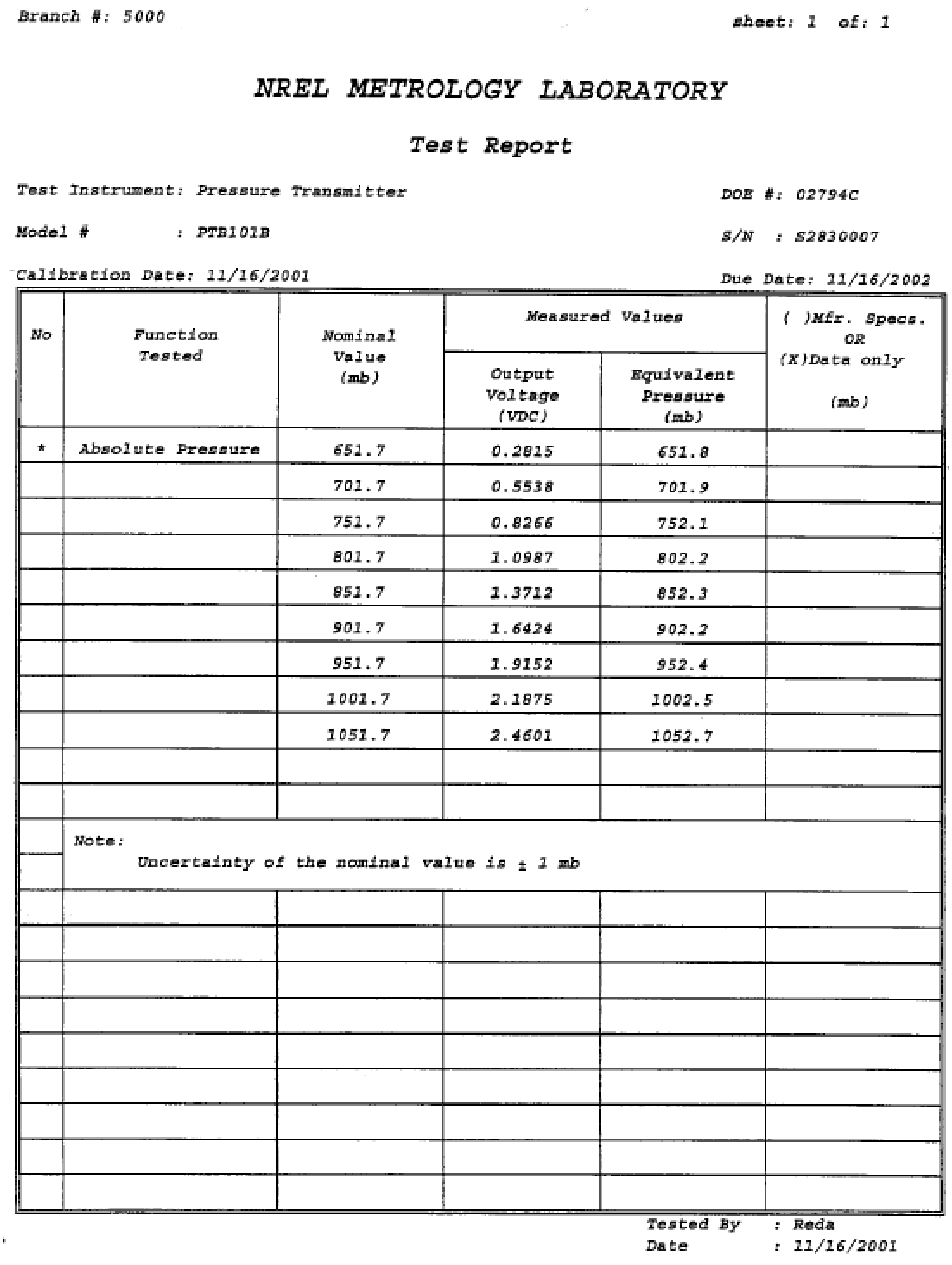


Branch #: 5000

sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Pressure Transmitter

DOE #: 02794C

Model # : PTB101B

S/N : S2830007

Calibration Date: 11/16/2001

Due Date: 11/16/2002

No	Function Tested	Nominal Value (mb)	Measured Values		( )Mfr. Specs. OR (X)Data only (mb)
			Output Voltage (VDC)	Equivalent Pressure (mb)	
*	Absolute Pressure	651.7	0.2815	651.8	
		701.7	0.5538	701.9	
		751.7	0.8266	752.1	
		801.7	1.0987	802.2	
		851.7	1.3712	852.3	
		901.7	1.6424	902.2	
		951.7	1.9152	952.4	
		1001.7	2.1875	1002.5	
		1051.7	2.4601	1052.7	

Note:
Uncertainty of the nominal value is ± 1 mb

Tested By : Reda
Date : 11/16/2001

RTD Calibration Certificate

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

Calibration Location:
National Wind Technology Center
Building 257 room 101-04

Calibrated for:
NWTC - Certification Team

Procedure:
CI02 Calibrate RTD 011128
Deviations: NONE

Reference Standard:
Hart Scientific, Model 9102 HDRC Dry-Well Calibrator
Last Calibration: Hart Scientific, 8/28/2001, A182823

Item Calibrated:
Mfgr: Met One Instruments, Inc
Model: T200
Serial No: **0464507**
Condition: good

Cal Date: November 19, 2001

Results:
Slope: **2.6034** C/ohm
Offset: **-260.20** C
Max Uncert*: 0.65 C
*over temperature range of -20 to +45 C

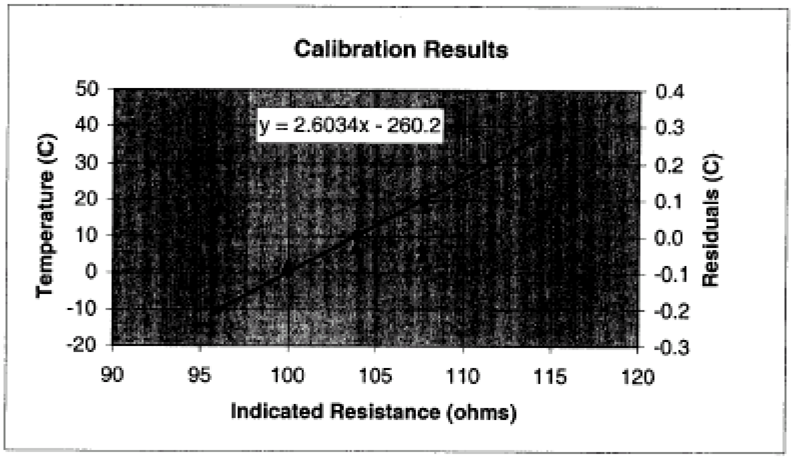
Certificate Number / File Name:
RTD Cal 0464507, 011119.xls

Associated Equipment
Campbell Scientific, CR23X, Datalogger, s/n 3099
Vishay, S102C, 10 kohm Precision Resistor

The standard used in this calibration is traceable to the National Institute of Standards and Technology (NIST). Measurement uncertainty for this calibration was determined in accordance with the ISO "Guide to the Expression of Uncertainty in Measurement." It is based upon a 95% confidence level (coverage factor = 2).

Mark Meadors
Mark Meadors

11/29/01
Date



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 129, Industrial Users Facility

Calibration Date: **28 Jan, 2002**

Report Number: T1010-28 Jan, 2002

Page: 1 of 1

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

Deviations from procedure: None

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	020C
Serial Number	**T1010**
Vane Material	Aluminum
Condition	Refurbished

Results:

Slope:	**0.1428**	**deg/mv**
Offset to boom:	**91.9**	**deg**
Max error:	0.5	deg

Estimated Uncertainty:

Inclinometer Uncertainty (deg)	Total Uncertainty (deg)
0.10	0.24

Traceability:

	Mfg & Model	Serial Number	Cal Date
Inclinometer:	Lucas DP45	82860032	12/13/02
Voltmeter:	Fluke 743B	6965608	1/2/03

Calibration by: Mark Meadors
Mark Meadors

28-Jan-02
Date