National Renewable Energy Laboratory
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Office of Energy Efficiency & Renewable Energy
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Wind Turbine Generator System Duration Test Report for the Gaia-Wind 11 kW Wind Turbine

Arlinda Huskey, Amy Bowen, and David Jager

Technical Report
NREL/TP-500-49069
August 2010

NREL is operated for DOE by the Alliance for Sustainable Energy, LLC Contract No. DE-AC36-08-GO28308

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Prepared under Task No. WE10.2211

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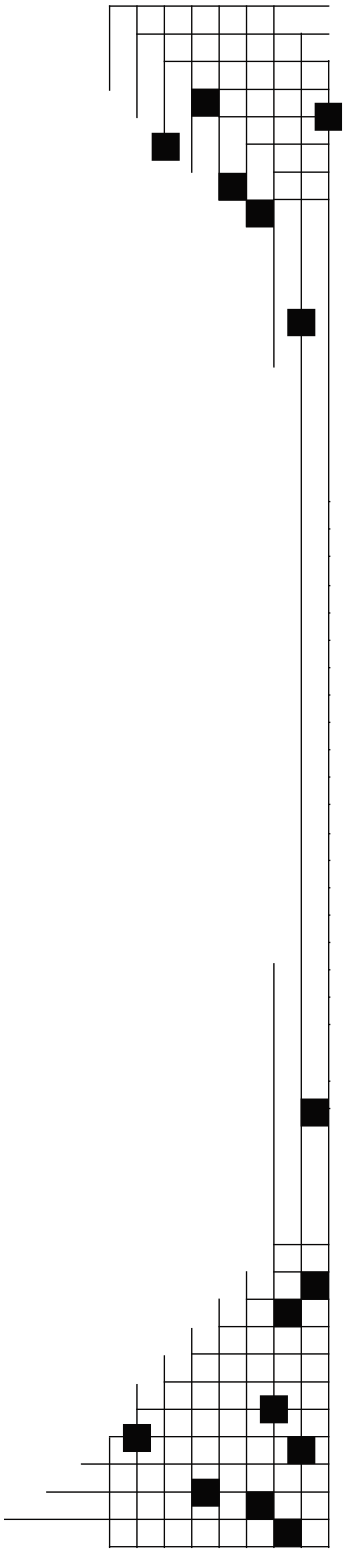

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Approval By: _____

Arlinda Huskey, NREL Test Engineer Date

Approval By: _____

Jeroen van Dam, NREL Test Engineer Date

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1. Background

This test was conducted as part of the U.S. Department of Energy's (DOE) Independent Testing project. This project was established to help reduce the barriers of wind energy expansion by providing independent testing results for small turbines. In total, five turbines are being tested at the National Renewable Energy Laboratory's (NREL's) National Wind Technology Center (NWTC) as a part of this project. Duration testing is one of up to five tests that may be performed on the turbines, including power performance, safety and function, noise, and power quality tests. The results of the testing will provide the manufacturers with reports that may be used for small wind turbine certification.

The test equipment includes a Gaia-Wind 11 kW wind turbine mounted on an 18 m monopole tower. Gaia-Wind Ltd. manufactured the turbine in Denmark, although the company is based in Scotland. The system was installed by the NWTC Site Operations group with guidance and assistance from Gaia-Wind.

2. Test Objective and Requirements

This test was conducted in accordance with Clause 9.4 of the International Electrotechnical Commission's (IEC) standard, *Wind turbines - Part 2: Design requirements for small wind turbines*, IEC 61400-2 Ed. 2.0:2006-03. This test report refers to these procedures as the "Standard." The objective of this test is to assess the following aspects of the Gaia-Wind 11 kW turbine:

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

Based on the parameters defined in the Standard for small wind turbine classes, Gaia-Wind identified the test turbine as a Class III. This corresponds to a V_{ave} of 7.5 m/s.

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

- 6 months of operation
- 2,500 hours of power production in winds of any velocity
- 250 hours of power production in winds of $1.2V_{ave}$ (9.0 m/s) and above
- 25 hours of power production in winds of $1.8V_{ave}$ (13.5 m/s) and above.

Reliable operation means:

- Operational time fraction of at least 90%

- No major failure of the turbine or components in the turbine system
- No significant wear, corrosion, or damage to turbine components
- No significant degradation of produced power at comparable wind speeds.

In addition, NREL has conducted this test in accordance with our quality system procedures such that this report will meet the full requirements of our accreditation by A2LA. Our quality system requires that we meet all applicable requirements specified by A2LA and ISO/IEC 17025 or to note any exceptions in the test report and these are listed in section 8.

3. Description of Test Turbine

The Gaia-Wind 11 kW is a two bladed downwind wind turbine rated at 11 kW output at 9.5 m/s. The Gaia-Wind 11 kW uses an induction generator to produce three-phase, 60 Hz output at 480-volts. The turbine's power output is grid compatible and is supplied directly to the grid. In wind speeds higher than 25 m/s, the turbine uses a mechanical brake to come to a complete stop to protect the turbine from over speeding. The turbine blades are made from fiberglass.

Table 1 lists basic turbine configuration and operational data.

The following components were considered part of the test turbine system:

1. The turbine system includes a tower and foundation that have been designed for installation at the NWTC test site 3.3B.
2. The turbine system is connected to the electrical grid at the test site through a subpanel. All wiring and components on the turbine side of this subpanel are considered part of the turbine system.
3. The turbine system includes all control components including wiring between the up-tower components and the down-tower control panel.

Table 1. Test turbine configuration and operational data

General Configuration:	
Make, Model, Serial Number	Gaia-Wind Ltd., Gaia-Wind 11 kW, 10711114
Rotation Axis (H / V)	Horizontal
Orientation (upwind / downwind)	Downwind
Number of Blades	2
Rotor Hub Type	Teetering
Rotor Diameter (m)	13.0
Small Wind Turbine Class	III
Hub Height (m)	18.2
Performance:	
Rated Electrical Power (kW)	11
Rated Wind Speed (m/s)	9.5
Cut-in Wind Speed (m/s)	3.5
Cut-out Wind speed (m/s)	25
Rotor:	
Swept Area (m^2)	133
Blade Pitch Control	None
Direction of Rotation	Clockwise viewed from upwind
Rotor Speed	0 – 62
Power Regulation (active or passive)	Passive
Tower:	
Type	Tubular
Height (m)	18.0
Control / Electrical System:	
Controller: Make, Type	Gaia-Wind IC-1000
Electrical Output: Voltage	480 VAC, three-phase
Yaw System:	
Yaw control	Passive

Figure 1. The Gaia-Wind 11 kW wind turbine. PIX # 17673

The test configuration consists of the turbine mounted on a tubular tower, the controller, the meteorological tower, associated wiring and junction boxes, and a data shed containing the data acquisition instrumentation. The turbine is installed on a standalone 18 meter, tubular tower. The wire that runs from the base of the tower to the data shed is approximately 64 meters of #6 AWG wire. Inside the data shed there is a disconnect switch and a breaker panel on the turbine side of the transformer. Figure 2 shows the general electrical arrangement.

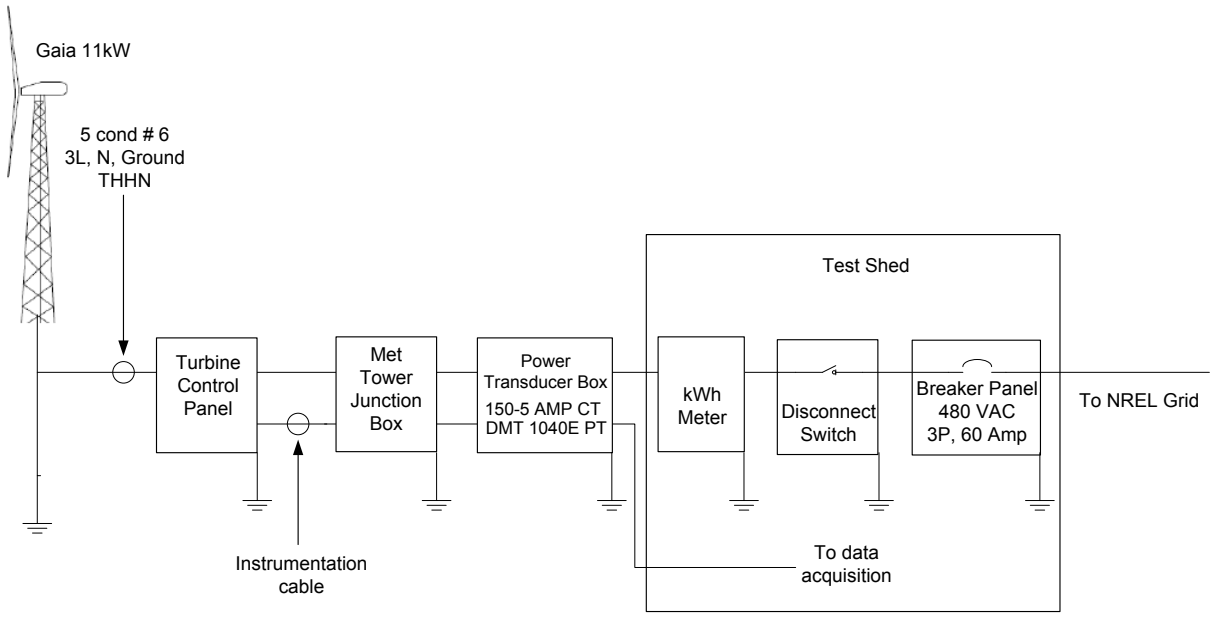

Figure 2. General electrical arrangement

4. Description of Test Site

The Gaia-Wind 11 kW wind turbine was located at Test Site 3.3B at the National Wind Technology Center (hereafter referred to as the test site), approximately 8 km south of Boulder, Colorado. The site is located on level terrain at an approximate elevation of 1845 m above sea level. Figure 3 shows a plot plan of the test site with topography lines listed in meters above sea level.

The meteorological tower is a 16.4 meter Rohn, 25 G lattice tower located 32.8 m (about 2.5 rotor diameters) from the test turbine at an azimuth of 297° true.

For measurements, where it is important to accurately measure wind speed, NREL used data obtained when the wind direction was between 258° to 331° with respect to true north, thus including all westerly winds. In this measurement sector, established in accordance with IEC 61400-12-1, the influence of terrain and obstructions on the anemometer and turbine are small. The closest operating turbine to the test turbine was a 10 kW Abundant Renewable Energy, ARE 442, turbine located on a 30.5 meter tower. It was located approximately 48.0 meters north of the test turbine at site 3.3A.

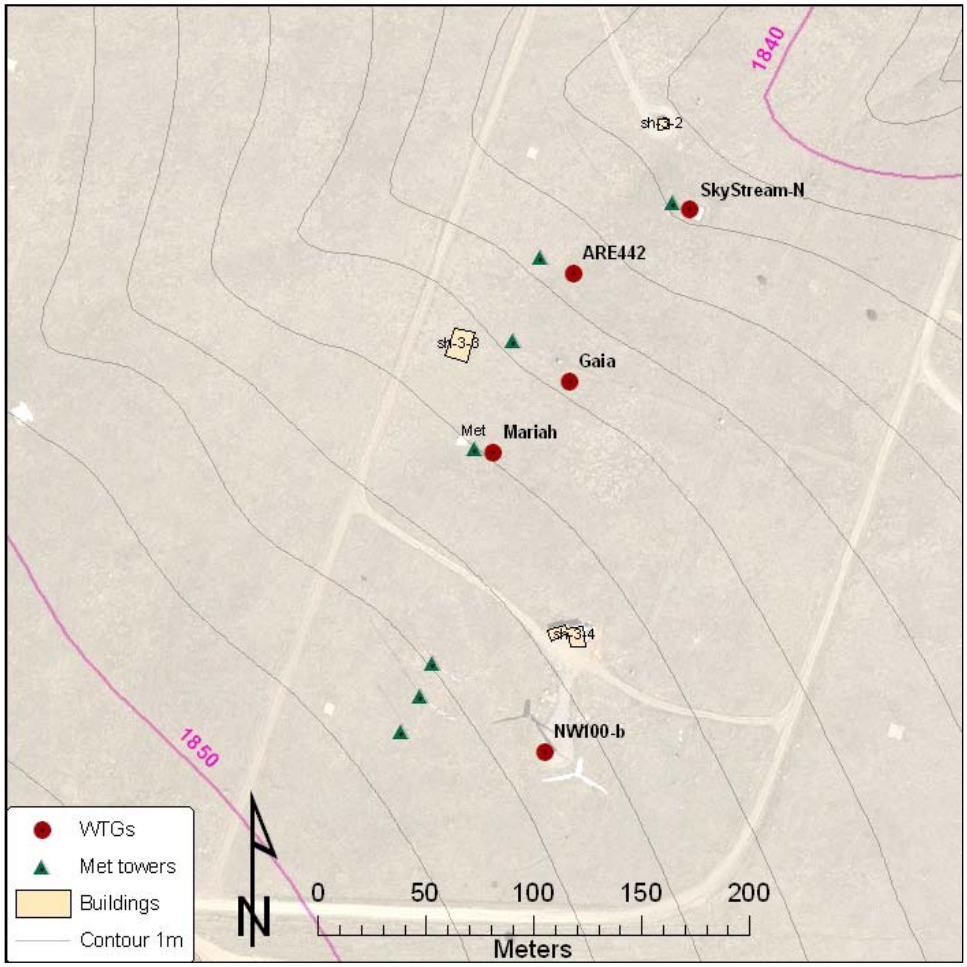

Figure 3. Map of the test site

5. Description of Instrumentation

Equipment used for duration testing differs only slightly from that used for power performance testing. Normal power performance testing requires measurements of wind speed, wind direction, turbine power, air temperature, air pressure, precipitation, and overall turbine system availability. For duration testing, NREL added signals to monitor the turbine brake and the grid voltage.

Figure 4 gives the location of the met tower instruments and Table 2 gives an equipment list that provides the specifications for each of the instruments used. Per the power performance standard IEC 61400-12-1, the primary anemometer was sent out for recalibration after the test period. The difference between the two calibrations was within the tolerances allowed by the power performance standard.

The data acquisition system ran out of calibration during the test. It was sent out for post test calibration and found within specification. The calibration sheet of the post test calibrations are in Appendix A.

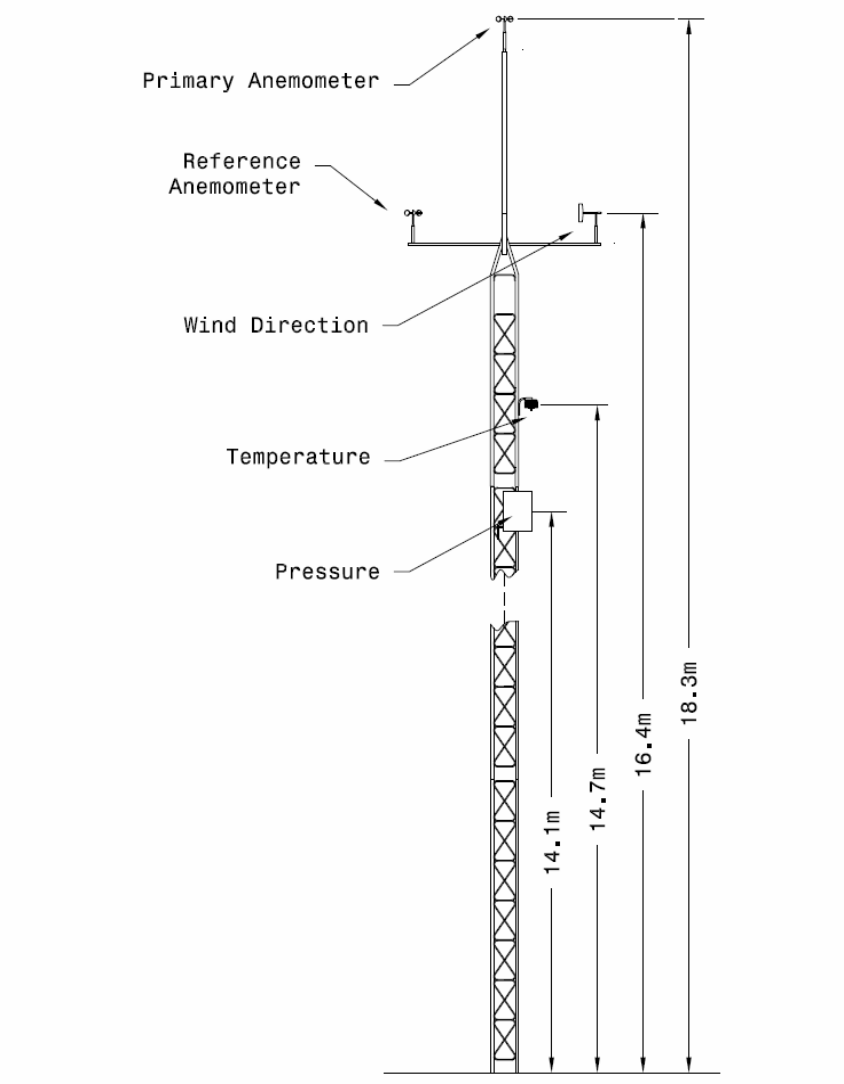

Figure 4. Location of the data acquisition sensors

Table 2. Equipment List for Duration Test

Instrument	Make and Model	Serial Number	Calibration Due Date
Power transducer	Ohio Semitronics, DMT 1040E	06091046	February 15, 2010
Current transformers	Ohio Semitronics, 12974	001293045 001235428 001293049	February 15, 2010
Primary anemometer	Thies, First Class	0707890	April 7, 2009
Reference anemometer	NRG, Max 40	179500049023	In situ
Wind vane	Met One, 020C with Aluminum Vane	X4357	April 7, 2009
Pressure sensor (replaced during test)	Vaisala, PTB101B	C1040014 T5030003	October 29, 2008 August, 26 2009
Temperature sensor (replaced during test)	Met One, T200	0890084 0789021	October 29, 2008 October 10, 2009
Precipitation sensor	Campbell Scientific, 237	None	In situ
Data acquisition system	Compact DAQ w/LabView cDAQ backplane NI 9229 NI 9217 NI 9205 NI 9229 NI 9217 NI 9205	 12E4DA3 12CBC7A 12BFEE2 12E9C99 140A596 140DCB9 140E2BD	 August 14, 2008 July 20, 2008 October 8, 2008 Modules post-test calibrated on May 5, 2009, was in compliance February 10, 2010 February 12, 2010 February 10, 2010

6. Results

6.1 Operation Time

The test turbine system was installed during the week of May 12, 2008, and operated continuously until May 6, 2010 when it was shut down for removal. The commissioning checklist from the installation is in Appendix B. After installation, the turbine experienced a ”break-in” period of approximately one month. During this period, several bolts from the hub were found on the ground at the base of the turbine. It was assumed the bolts were from the hub fork since there were bolts missed from that area. It was determined that the originally installed bolts were not long enough to fully engage the nuts and longer bolts were installed. In early June 2008, a “brake pads worn” warning appeared on the controller screen. It was determined that the mechanical brake needed to be re-calibrated. After the break in period, the duration test was officially started on June 9,

2008. The duration test was completed on March 31, 2009, after enough data was collected to demonstrate sufficient hours of operation, as required by the standard.

6.2 Months of Operation

The duration test was conducted over a period of approximately 9.5 months from June 9, 2008, to March 31, 2009, (6 months were required). The turbine continued to operate until May 6, 2010 when it was shut down for removal.

6.3 Hours of Power Production

The hours of power production at any wind speed totaled 2,705 hours (2,500 hours required).

The hours of power production above 1.2*V_{ave} (9 m/s) totaled 711 hours (250 hours required).

The hours of power production above 1.8*V_{ave} (13.5 m/s) totaled 215 hours (25 hours required).

Thus the turbine met the requirements for hours of power production during the test. Table 3 shows the overall and month-by-month results of the duration test.

Table 3. Monthly and overall results of the Gaia-Wind 11 kW duration test

	Hours of power production above:			*max gust*	*TI @ 15*	*# Data*	T_T	T_U	T_E	T_N	*O*
Month	*0 m/s*	*9 m/s*	*13.5 m/s*	*(m/s)*	*m/s (%)*	*points*	*(hours)*	*(hours)*	*(hours)*	*(hours)*	*(%)*
Overall	2704.9	710.6	215.0	41.9	19.0	255	7094	172.5	152.0	624.6	90.8
Jun 2008	238.2	36.2	3.8	28.6	18.5	5	518	11.3	7.8	3.3	99.3
Jul	256.0	8.5	0.3	23.9	-	0	744	78.2	2.2	38.8	94.1
Aug	115.8	4.5	0.0	19.2	-	0	744	6.3	20.0	323.0	55.0
Sep	120.5	11.7	1.8	22.4	-	0	720	36.2	30.3	174.7	73.3
Oct	236.0	45.0	12.2	32.8	17.3	10	744	0.7	1.3	0.0	100.0
Nov	348.0	98.7	22.5	37.0	20.9	40	720	22.1	0.0	0.0	100.0
Dec	339.7	160.5	54.8	41.4	17.4	68	744	7.9	27.2	32.8	95.4
Jan 2009	385.0	155.5	56.0	38.8	19.9	76	744	4.9	32.0	36.5	94.8
Feb	333.2	107.3	36.8	41.9	20.0	23	672	3.2	27.0	0.0	100.0
Mar	332.5	82.7	26.8	36.7	18.0	33	744	1.7	4.2	15.5	97.9

6.4 Operational Time Fraction

The operational time fraction is defined as follows:

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

where:

T_T is the total time period under consideration,

T_N is the time during which the turbine is known to be non-operational,

T_U is the time during which the turbine status is unknown,

T_E is the time which is excluded in the analysis.

The overall operational time fraction of the combined wind turbine system (wind turbine, tower, and controller) in the total test period was 90.8%. Figure 5 and Table 3 show the operational time fraction per month. Figure 6 shows a scatter plot of power verses wind speed during the test.

The main reasons for the wind turbine system's downtime (T_N) during the test period were electric contactor failures, brake-time errors, and vibration errors. These faults are described in more detail below.

Electric Contactor Failure

The low operational time fraction for August and September of 2008 was caused by the failure of two contactors in the controller. Investigations suggest that the 2-pin flat connectors used to wire the contactors were poorly connected when installed at Gaia-Wind's electrical supplier. Additionally, the Gaia-Wind 11 kW turbine controller was originally designed for a 50-Hz grid, and it is possible that the contactors that originally were installed in the controller were underrated for the 60-Hz grid at the NWTC. Approximately 78% of the total time classified as T_N during the test can be attributed to the contactor failures. Since September 10, 2008 when both contactors were replaced with higher rated models and the pin connectors were replaced, there have been no further contactor failures.

Brake-time Errors

The brake-time errors occurred when the turbine took longer to brake than designed; this usually occurred during high winds. Although this error occurred, the turbine successfully braked each time. The brake-time error requires permission from Gaia-Wind to manually reset the turbine.

Vibration Errors

Based on evidence found in the nacelle, the vibration errors are believed to have occurred from birds entering the nacelle and physically brushing against the vibration sensor. This activated the vibration error. With permission from Gaia-Wind, NREL installed a screen over the opening in the nacelle to prevent birds from entering the nacelle. After the installation of the screen on September 19, 2008, the turbine ran without any further vibration errors.

Remaining T_N

The remaining time classified as T_N was due to manufacturer mandated maintenance, auto motor start errors, generator over speed errors, and a tachometer defect error.

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

- On site activities that either prevented NREL from performing needed maintenance on the turbine or caused an error

- The time difference between the NWTC and Gaia-Wind in the United Kingdom occasionally prevented Gaia-Wind from responding to error reset requests promptly
- Noise or safety and function testing that required the turbine to be shut down.

If no reliable measurements were available, the time was classified as T_U since the turbine's status was unknown.

6.5 Environmental Conditions

As an indication of the environmental conditions during the duration test, the standard requests reporting of the maximum wind speed gust and the average turbulence intensity at 15 m/s. The maximum recorded gust was 41.9 m/s at 12:51 PM on February 17, 2009. The average turbulence intensity at 15 m/s during the duration test was 19.0%.

6.6 Power Degradation Checks

A factor of reliable operation is that the turbine should experience no significant power degradation. During the power degradation analysis, the average power level for each wind speed bin is plotted as a function of time over the whole test period. This plot is analyzed for any obvious trends in power production.

Figure 7 shows the power degradation plot, which gives the power level in individual wind speed bins for each month. Variations in the power levels from season to season are caused by air density variations. The apparent degradation in power for winds above 13 m/s in December 2008 through March 2009 was caused by the turbine reaching high wind cut-out. This resulted in a lower average power at higher wind speeds, but is not considered power degradation.

6.7 Dynamic Behavior

The turbine was observed over a wide range of wind speeds. The turbine did not exhibit excessive vibration during any of the recorded observations. The following are specific examples of dynamic behavior observations made in the logbook:

23 February 2009 – "Observed the turbine start up from low winds and run in 8 m/s winds. Some slight tower vibration and rattling during motor start pulses. Observed a very slight thumping noise as blades passed behind tower. When standing next to the tower, some per revolution noise can be heard resonating down the tower, though it is very minimal. Blade noise is audible, more so as winds slow. The turbine yaws slightly in higher winds (greater than 8 m/s). No excessive tower vibration was noticed. Overall observation time 15 minutes in winds from approximately 1 m/s up to 9 m/s."

24 February 2009 – "Observed the turbine in 8 – 15 m/s. A slight whooshing noise is coming from the blades. The turbine tracks the wind well and yaws back and forth slightly in gusty winds. Some slight tower movements. The turbine was producing 12 – 14 kW instantaneously during the observation. The overall observation time was 10 minutes."

24 February 2009 – “Observed turbine operating in winds between 7 – 13 m/s. The turbine tracks wind direction well. No big vibrations, slight thumping heard. The overall observation time was approximately 2.5 hours.”

6.8 Tear-Down Inspection

The tear down inspection was performed on May 10, 2010. The results are documented in Appendix C. The main finding was a crack along the seam between the two halves of both blades, see Figure C.1.

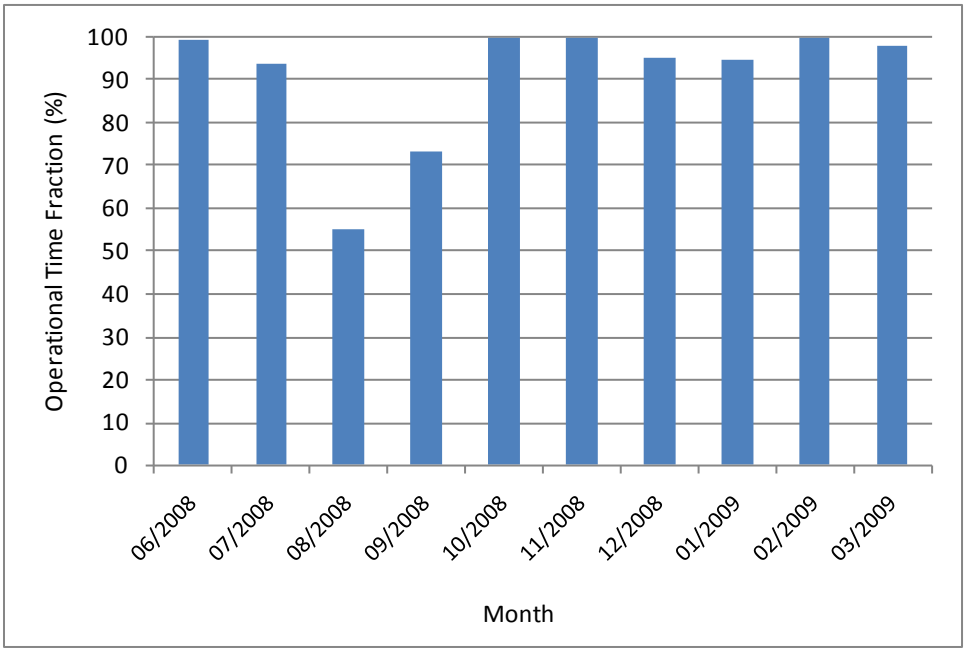

Figure 5. Operational time fraction for each month

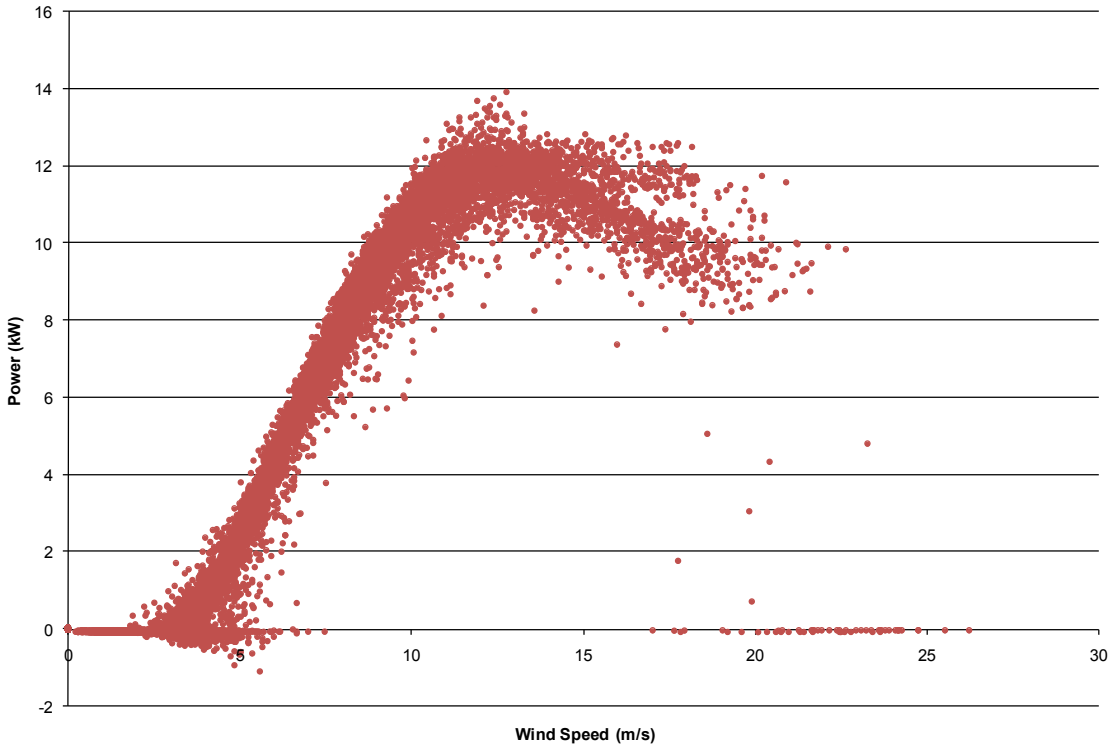

Figure 6. Scatter plot of power versus wind speed (10-minute averages)

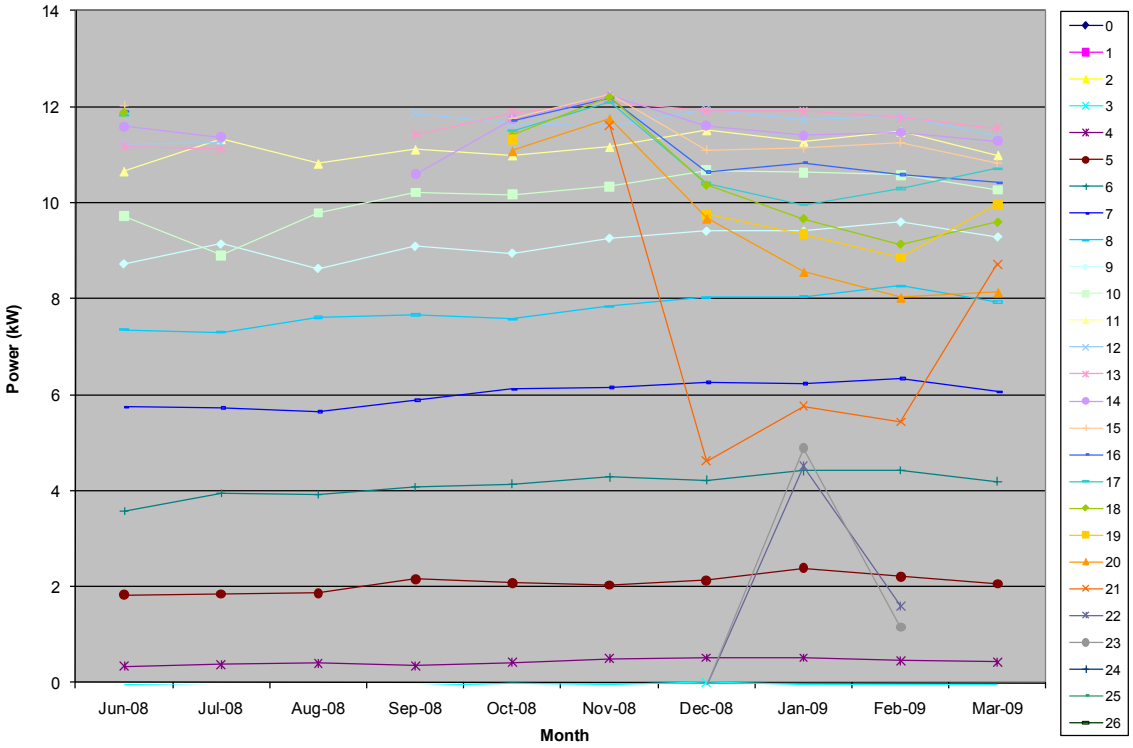

Figure 7. Power level in several wind speed bins (in m/s) as a function of time

7. Uncertainty

The uncertainty is estimated for the following parameters:

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

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

Hours of Power Production

NREL assumes that the turbine is producing power for the entire 10-minute period whenever the average power for that period is positive. This method overestimates time for power production in wind speeds between 4 and 6 m/s. At these wind speeds, the turbine may have been producing power for about half of the time recorded by NREL. At higher wind speeds, this method would produce less of an overestimate. NREL estimates that the reported time of power production in wind speeds greater than 0 m/s may be 20% less than calculated. However, the turbine operated for over a month before the duration test was started in June 2008 and it continued to run after the duration test was complete until May 6, 2010. Thus, NREL is confident that it has achieved the 2,500 hours required by the standard.

For the hours of power production above 9 and 13.5 m/s, the uncertainty in the wind speed is assumed to be the dominant factor. Assuming an uncertainty in wind speed of 0.3 m/s, there is an approximate variation of 8% in the hours of power production at these wind speeds.

Operational Time Fraction

The total test time is 7,094 hours. Even if the classification of T_E and T_N was wrong by 5% (which is a very conservative assumption), the operational time fraction would still be above 90% at 90.3%.

Highest Instantaneous Wind Speed

The uncertainties in the wind speed measurements are 0.009 m/s calibration uncertainty, 0.052 m/s + 0.52% operational characteristics, 1% mounting effects, and 2% terrain effects. For the maximum instantaneous gust of 41.9 m/s, the uncertainty is 0.96 m/s.

8. Deviations and Exceptions

8.1. Deviations from the Standard

There were no deviations from the standard.

8.2. Deviations from Quality Assurance

The data acquisition modules were used beyond the calibration due date. The modules were post-test calibrated and found to be in compliance within the specifications. Appendix B includes the post-test calibration sheets.

Appendix A: Instrument Calibration Certificates

Figures A.1 through A.13 show the calibration sheets for the instruments used during the duration test.

Branch #: 5000

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Multifunction Transducer — DOE #: 03575C

Model # : DMT-1040E — S/N : 06091046

Calibration Date: 02/15/2008 — Due Date: 02/15/2010

A. Set-Up for Total Power Calibration:
A.1. Voltage is applied to Lines 1, 2, & 3 = 277.128 V @ 60 Hz.
A.2. Current is applied to n = 8-TURNS through three current transformers that are connected to Lines 1, 2, & 3 .
A.3. Analog Output-1 is measured across precision resistor = 250 Ω.
A.4. Full Scale setting = -15.796KW to 15.796KW.

Input Current (AAC)	Input Power (KW)	Analog Output-1 (VDC)
18	14.965	4.811
12	9.977	3.209
6	4.988	1.604
0	0	0.002
-6	-4.988	-1.602
-12	-9.977	-3.206
-18	-14.965	-4.807

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)
10	1.0	5.001
"	0.8	3.995
"	0.6	2.993
"	0.4	1.991

Figure A.1. Power transducer calibration sheet

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Varel

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DAR
DKD-K- 36801

Kalibrierschein
Calibration Certificate

Kalibrierzeichen
Calibration label

DKD-K-
36801
07_2415

Gegenstand *Object*	Cup Anemometer
Hersteller *Manufacturer*	Thies Clima D-37083 Göttingen
Typ *Type*	4.3350.00.000
Fabrikat/Serien-Nr. *Serial number*	Body: 0707890 Cup: 0707890
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

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26316 Varel ; Tel. ++49 (0)4451 9515 0

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Figure A.2. Primary anemometer calibration sheet

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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

1499_09
DKD-K-28901
15.07.09

Gegenstand *Object*	Cup Anemometer
Hersteller *Manufacturer*	Thies Clima D-37083 Göttingen
Typ *Type*	4.3350.00.000
Fabrikat/Serien-Nr. *Serial number*	body: 0707890 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*	15.07.09

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.

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Stempel *Seal*	Datum *Date*	Stellv. Leiter des Kalibrierlaboratoriums *Deputy head of the calibration laboratory*	Bearbeiter *Person in charge*
Deutscher DKD-K-28901 Kalibrierdienst	15.07.09	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 A.3. Primary anemometer post-test calibration sheet

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: X4357-070913

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	**X4357**
Vane Material	Aluminum
Condition	Refurbished

Results:

Slope:	**71.12**	**deg/V**
Offset to boom:	**91.02**	**deg**
Max error:	0.78	deg

Estimated Uncertainty:

Inclinometer Uncertainty (deg)	Total Uncertainty (deg)
0.10	0.33

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

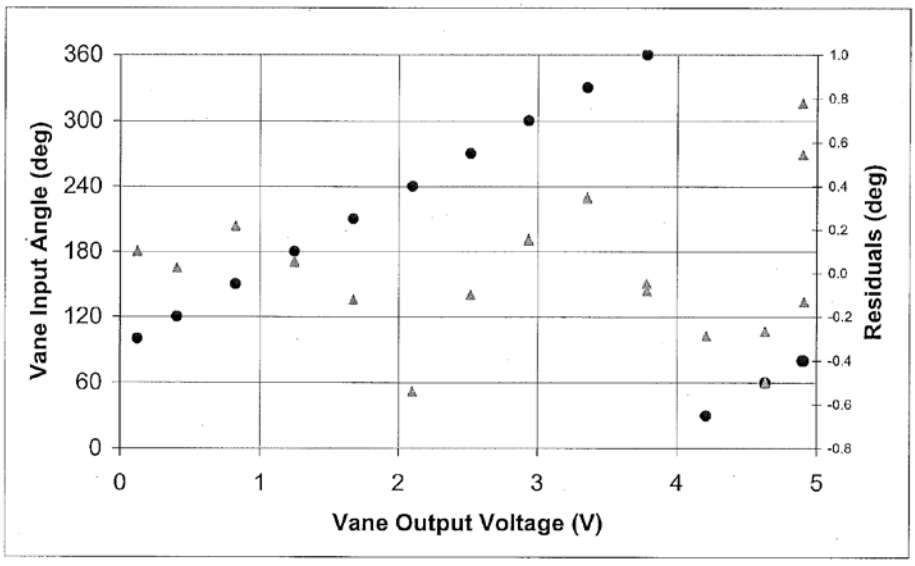

Figure A.4. Wind vane calibration sheet

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: RTD Probe DOE #: 02885C

Model # : 78N01N00N S/N : 0890084

Calibration Date: 10/29/2007 Due Date: 10/29/2008

No	Nominal Values		Measured Values		
	Nominal Resistance /	Equivalent Temperature /	Measured Resistance /	Equivalent Temperature /	Temperature Error /
1	96.09 Ω	-10 °C	96.078 Ω	-10.03 °C	0.03 °C
2	100.00 Ω	0 °C	99.996 Ω	-0.01 °C	0.01 °C
3	103.90 Ω	10 °C	103.903 Ω	10.01 °C	-0.01 °C
4	107.79 Ω	20 °C	107.796 Ω	20.02 °C	-0.02 °C
5	111.67 Ω	30 °C	111.677 Ω	30.02 °C	-0.02 °C
6	115.54 Ω	40 °C	115.546 Ω	40.02 °C	-0.02 °C

Notes:

1. Total Uncertainty of Nominal Values = ±0.02 °C
2. Calibration was performed at 23 °C and 37% RH
3. Resistance is measured using 4-wire technique

Calibrated by: Reda QA by: Bev

Date : 10/29/2007 Date : 10/29/2007

Figure A.5. RTD probe calibration sheet I

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: RTD-Probe DOE #: 02883C

Model # : 78N01N00N S/N : 0789021

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	109.41	"	
		50	118.95	"	
	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 A.6. RTD probe calibration sheet II

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Pressure Transmitter DOE #: 03510C

Model # : PTB101B S/N : C1040014

Calibration Date: 10/29/2007 Due Date: 10/29/2008

No	Function Tested	Nominal Value (kPa)	Measured Output Voltage (VDC)		( )Mfr. Specs. OR (X)Data only (mb)
			As Found	As Left	
*	Absolute Pressure				
		65	0.275		
		70	0.548		
		75	0.820		
		80	1.092		
		85	1.364		
		90	1.635		
		95	1.907		
		100	2.178		
		105	2.451		
	Notes: 1. Expanded Uncertainty of the nominal value is ± 0.2 kPa, with k = 2. 2. Calibration was performed at 23°C and 37% RH. 3. Calibration was performed using standards that are traceable to NIST. DOE numbers: 02625C, 02727C, and 02301C.				

Calibrated By: Reda
Date: 10/29/2007

QA By: Bev
Date: 10/29/2007

Figure A.7. Pressure transmitter calibration sheet

NATIONAL INSTRUMENTS

Certificate of Calibration

Board Information:
Serial Number: 12CBC7A
NI Part Number: 192580D-02
Description: NI 9229

Certificate Information:
Certificate Number: 793243
Date Printed: 20-NOV-08

Calibration Date: 14-AUG-07
Recommended Calibration Due Date: 14-AUG-08*

Ambient Temperature: 23 °C
Relative Humidity: 60 %

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 A.8. NI 9229 data acquisition module calibration sheet

NATIONAL INSTRUMENTS

Certificate of Calibration

Board Information:
Serial Number: 12BFEE2
NI Part Number: 192547D-01
Description: NI 9217

Certificate Information:
Certificate Number: 775348
Date Printed: 20-NOV-08

Calibration Date: 20-JUL-07
Recommended Calibration Due Date: 20-JUL-08*

Ambient Temperature: 26 °C
Relative Humidity: 45 %

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 A.9. NI 9217 data acquisition module calibration sheet

NATIONAL INSTRUMENTS

Certificate of Calibration

Board Information:
Serial Number: 12E9C99
NI Part Number: 193299F-01
Description: NI-9205

Certificate Information:
Certificate Number: 835019
Date Printed: 20-NOV-08

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

Ambient Temperature: 23 °C
Relative Humidity: 38 %

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 A.10. NI 9205 data acquisition module calibration sheet

Davis Calibration

ACCREDITED CALIBRATION

Certificate of Calibration

3214337

Instrument Identification

Company ID: 229037
NATIONAL INSTRUMENTS

PO Number: 337683

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

Instrument ID: **12CBC7A**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CHANNEL, ±60 V, 24-BIT SIMULTANEOUS ANALOG INPUT

Model Number: NI 9229
Serial Number: 12CBC7A

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 AppB, 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

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

Figure A.11. NI 9229 data acquisition module post-test calibration sheet

Davis Calibration

ACCREDITED CALIBRATION

Certificate of Calibration

3214181

Instrument Identification

Company ID: 229037
NATIONAL INSTRUMENTS

PO Number: 337683

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

Instrument ID: **12BFEE2**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CH 100 OHM 24-BIT RTD ANALOG INPUT

Model Number: NI 9217
Serial Number: 12BFEE2

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 AppB, 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

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Figure A.12. NI 9217 data acquisition module post-test calibration sheet

Davis Calibration

ACCREDITED CALIBRATION

Certificate of Calibration

3214135

Instrument Identification

Company ID: 229037
NATIONAL INSTRUMENTS

PO Number: 337683

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

Instrument ID: **12E9C99**
Manufacturer: NATIONAL INSTRUMENTS
Description: 32-CH ±200 MV TO ±10 V, 16-BIT, 250 KS/S ANALOG INPUT MODULE

Model Number: NI 9205
Serial Number: 12E9C99

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

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

Figure A.13. NI 9205 data acquisition module post-test calibration sheet

Appendix B: Turbine Commissioning Checklist

Commissioning Procedure for Gaia-Wind 11kW Grid-Connected Wind Turbine Generator at Site 3.3B
5/15/08

1.0 Introduction

NREL will perform an acceptance test for the Gaia-Wind 11kW to ensure proper installation and operation of the system prior to certification testing. This test will include, but not be limited to, an inspection of the wind generator installation, the tower, all electrical connections and fusing, the inverter for the system, the electrical connections throughout the system, and a safety inspection of the system. NREL staff will not do anything that will alter the long-term reliability or performance of the system during the acceptance test. NREL staff will not change any system set points without direct involvement of the vendor.

2.0 Documentation Review

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

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

3.0 Visual Inspection

The system will be visually inspected for safety and compliance with accepted installation practices. Any deviation from the as-built will be noted. All fuses, circuit breakers, disconnect switches and wires will be inspected and their current ratings and type will be verified and compared to the 1-line electrical diagram. The grounding system will be inspected. The turbine mounting and all turbine fasteners will be inspected.

Commissioning Checklist

Date: Conducted by:

Task		Recorded Observation
Wind Turbine Generator:		
Electrical Inspection Completed	AB	
Gaia-Wind commissioning check list completed	AB	
Visually inspect blades for any cracks or deviations from normal	AB	
Inspect tower grounding	AB	
Verify freedom from excessive vibration	AB	
Verify that turbine blades spin freely at 8 m/s or above	AB	
Verify absence of excessive noise from generator	AB	
Verify power production to manufacturer's power curve at 8 m/s or above	AB	
Verify tower alignment	AB	
Verify all wire sized per manufacturer drawing	AB	
Verify conductor sizing (tower - #6 or better)	AB	
Verify RPM signal from controller	AB	
Verify "turbine status" signal from controller	AB	
Measure the frequency under load	AB	
Measure the current under load	AB	
Measure the voltage under load	AB	
Verify manual shutdown from turbine specific disconnect	AB	
Verify 60 amp breaker size in power panel 3.3	AB	

Verify manual shutdown from 60 amp breaker function in power panel 3.3	AB	
Verify turbine re-connects after 3.3 breaker is tripped	AB	
At least one NREL employee trained	AB	
Review final as-built drawings for system installation and verify that drawings and installation are in agreement	AB	

4.0 Acceptance of Commissioning Procedures

The installation of the Gaia-Wind 11kW Wind Turbine Generator at Site 3.3B has been reviewed and is in conformance with the commissioning procedures above. As a result, we hereby agree that this installation has been completed satisfactorily and approve that the turbine system is ready for field verification testing.

Scott Love, Gaia-Wind — 15/05/08 · Date

Amy Bowen, NREL — 15 May 08 Date

Appendix C: Post-Test Inspection

The Gaia Wind 11-kW wind turbine was removed from Site 3.3B on May 6, 2010, after NREL completed all testing activities in the Independent Testing project. At the end of the duration test, a post test inspection is performed on the turbine. This report describes the tear down inspection.

C.1 Blades

Both blades had cracks along the seam between the two halves near the hub, see Figure C.1. The putty at the blade ends, where the tip brakes are located, had deteriorated slightly, see Figure C.2. One of the blades was chipped, see Figure C.3.

C.2 Hub

The nacelle cover was in good condition. Some grease was observed around the rotor shaft, see Figure C.4. Some slight rust on the rotor plate and rotor assembly was discovered, see Figure C.5.

C.3 Brakes

Part of the brake actuator system was damaged during uninstall. The brake pad assembly was removed and the brake pads were measured. The brake pad on the rotor side measured 0.72 inches. The brake pad on the generator side measured 0.78 inches. The original brake pad measured 0.805 inches. The pins on the brake caliper were inspected; no wear was observed. The brake caliper arms appeared free of rust and binding.

C.4 Vibration Sensor

The rubber seal on the vibration sensor was degraded and partially ripped, see Figure C.7. It was noted that during uninstall, the vibration sensor was damaged and was no longer in a vertical position. However, the degradation of the rubber seal does not seem to have been caused by this.

C.5 Electrical

All wiring in the hub and the control cabinet was inspected. No degradation or evidence of overheating was observed.

C.6 Yaw system

The yaw bearing moves smoothly. Some grease was observed around the yaw bearing.

C.7 Tower

The welds, bolts, and ladder were inspected on the tower. No abnormalities or cracks were observed.

C.8 Gearbox

The gearbox was drained and inspected using a borescope. Some small scratches and abrasions were found on the gear teeth. No clunking or noise was heard when rotating the shaft. The inspection window on the side of the gearbox still showed an adequate amount of oil, even after a complete drain. The oil appeared to be in good shape; no particles were found.

Figure C.1 Crack in blade along seam. PIX # 17672.

Figure C.2 Deteriorating putty on tip brake. PIX #17676.

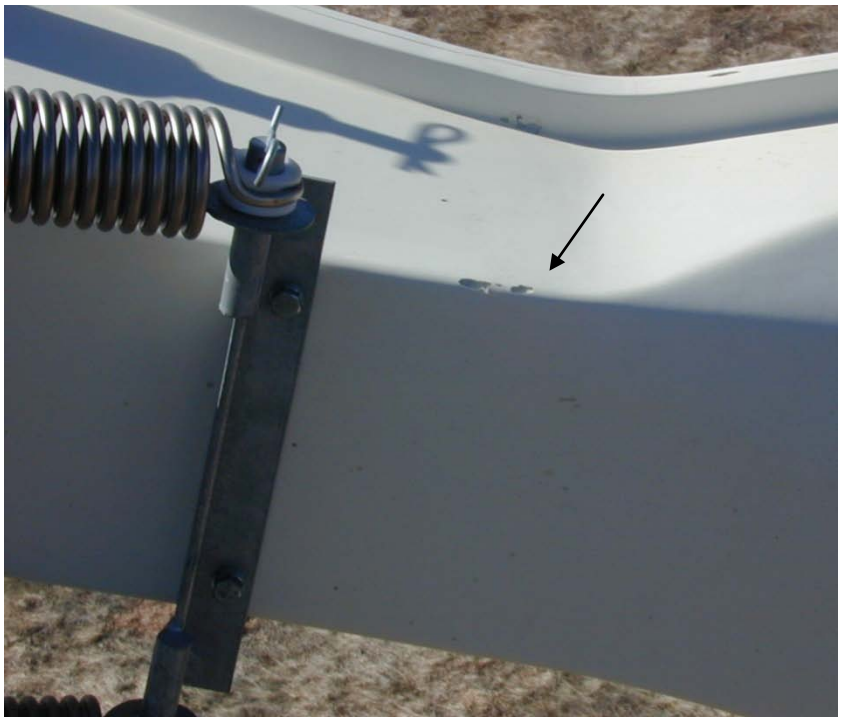

Figure C.3 Chip in blade. PIX #17669.

Figure C.4 Grease on shaft. PIX #17670.

Figure C.5 Rust on rotor assembly. PIX #17671.

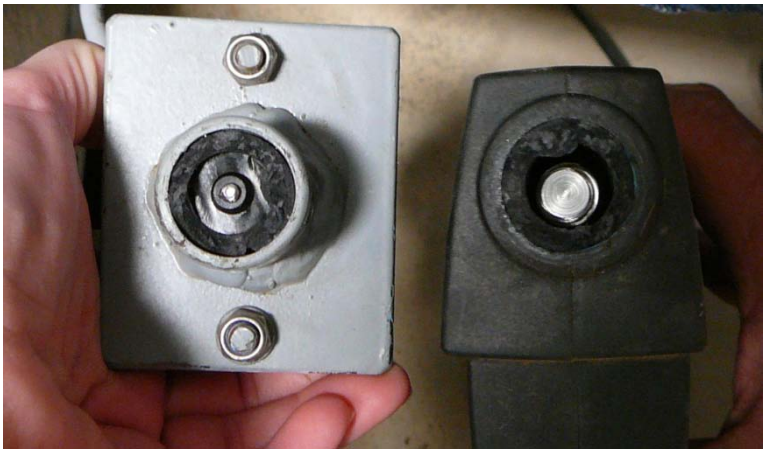

Figure C.6 Broken brake actuator. PIX #17675.

Figure C.7 Broken vibration sensor and deteriorating rubber seal. PIX #17674.

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)*
September 2010	Technical Report	

4. TITLE AND SUBTITLE
Wind Turbine Generator System Duration Test Report for the Gaia-Wind 11 kW Wind Turbine

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

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
A. Huskey, A. Bowen, and D. Jager

5d. PROJECT NUMBER
NREL/TP-500-49069

5e. TASK NUMBER
WE102211

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/TP-500-49069

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*

This test was conducted as part of the U.S. Department of Energy's (DOE) Independent Testing project. This project was established to help reduce the barriers of wind energy expansion by providing independent testing results for small turbines. In total, five turbines are being tested at the National Renewable Energy Laboratory's (NRELs) National Wind Technology Center (NWTC) as a part of this project. Duration testing is one of up to five tests that may be performed on the turbines, including power performance, safety and function, noise, and power quality tests. The results of the testing will provide the manufacturers with reports that may be used for small wind turbine certification. The test equipment includes a Gaia-Wind 11 kW wind turbine mounted on an 18 m monopole tower. Gaia-Wind Ltd. manufactured the turbine in Denmark, although the company is based in Scotland. The system was installed by the NWTC Site Operations group with guidance and assistance from Gaia-Wind.

15. SUBJECT TERMS
small wind turbine; wind turbine; independent testing; Gaia; duration test

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (*Include area code*)
Unclassified	Unclassified	Unclassified	UL		