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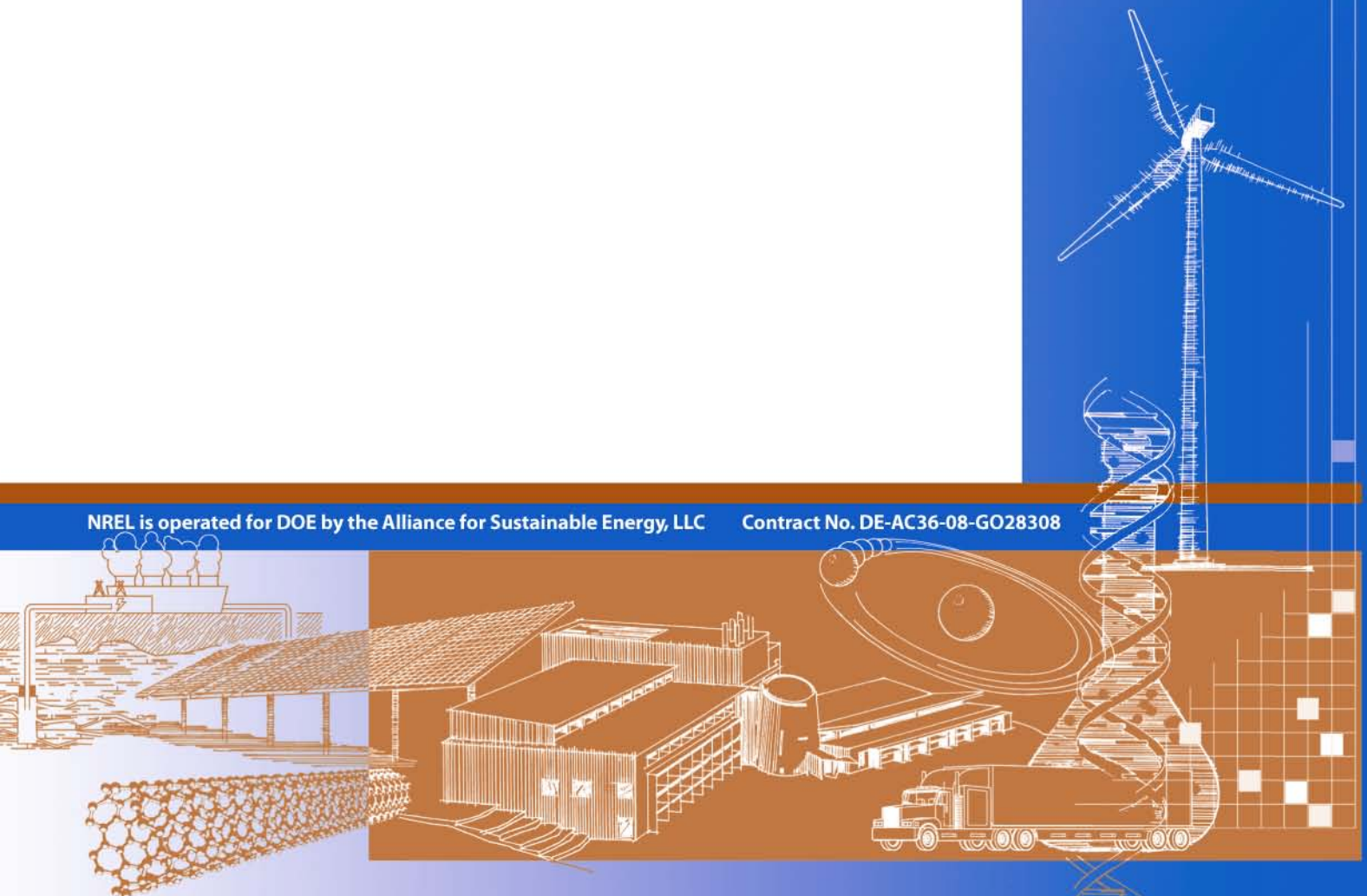
Wind Turbine Generator System Duration Test Report for the Mariah Windspire Wind Turbine

Arlinda Huskey, Amy Bowen, and David Jager

Technical Report
NREL/TP-500-47072
May 2010



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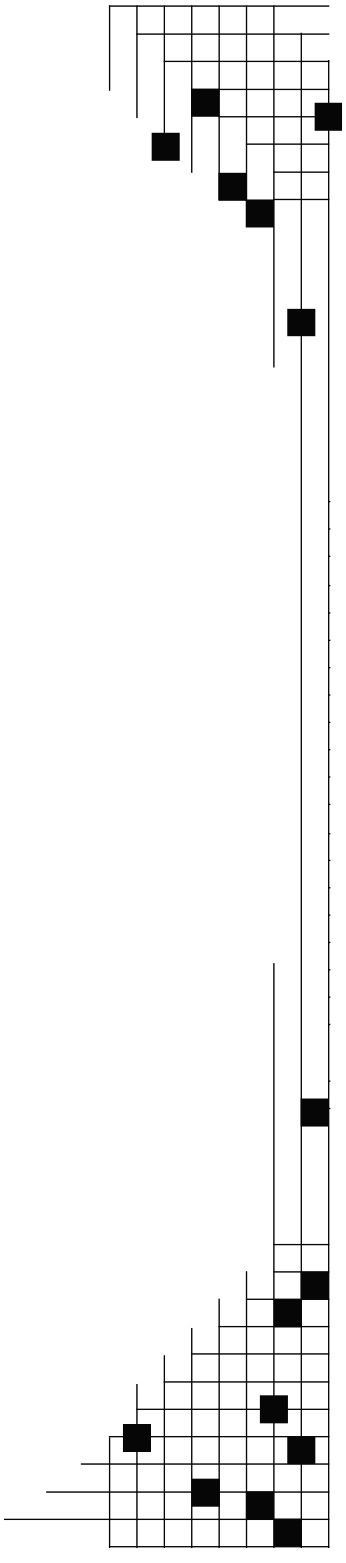
Prepared under Task No. WE10.2211



National Renewable Energy Laboratory
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Contract No. DE-AC36-08-GO28308

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Approval By: _____

Arlinda Huskey, NREL Test Engineer Date

Review 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 Wind Technology Center (NWTC) as a part of the first round of this project. Duration testing is one of up to five tests that may be performed on the turbines. Other tests include power performance, safety and function, noise, and power quality tests. NWTC testing results provide manufacturers with reports that may be used to meet part of small wind turbine certification requirements.

This duration test report focuses on the Mariah Power Windspire wind turbine.

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 Mariah Power Windspire wind turbine:

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

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 $1.2V_{ave}$ (7.2 m/s) and above
- 25 hours of power production in winds of $1.8V_{ave}$ (10.8 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.

Based on the parameters defined in the Standard for small wind turbine classes, Mariah Power identified the Windspire to be a class IV. This corresponds to a V_{ave} of 6 m/s.

In addition, NREL has conducted this test in accordance with our quality system procedures such that this report will meet the full requirements of 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.

The test article includes a Windspire wind turbine mounted on a monopole tower. L&E Machine manufactured the turbine in the United States. The inverter was manufactured separately by Technology Driven Products in the United States. The system was installed by the NWTC site operations group with guidance and assistance from Mariah Power.

3. Description of Test Turbine

The Windspire is a three-bladed vertical axis wind turbine rated at 1 kW output at 11 m/s. The Windspire supplies single-phase, 120 VAC power to the grid through a permanent magnet generator and inverter. The turbine's airfoils are aluminum. Table 1 lists basic turbine configuration and operational data.

Table 1. Test Turbine Configuration and Operational Data

General Configuration:	
Make, Model, Serial Number	Mariah Power, Windspire, 800021
Rotation Axis (H / V)	Vertical
Orientation (upwind / downwind)	n/a
Number of Blades	3
Equivalent Rotor Diameter (m)	3.05
Rotor Center Height (m)	6.10
Small Wind Turbine Class	IV
Performance:	
Rated Electrical Power (kW)	1
Rated Wind Speed (m/s)	11
Cut-in Wind Speed (m/s)	4
Cut-out Wind speed (m/s)	n/a
Rotor:	
Swept Area (m^2)	7.43
Blade Pitch Control	n/a
Direction of Rotation	Counter-clockwise viewed from above
Rotor Speed (rpm)	0 – 500
Power Regulation (active or passive)	Passive
Tower:	
Type	Tubular
Height (m)	3.05
Control / Electrical System:	
Controller: Make, Type	Windspire 1.2G
Electrical Output: Voltage	120 VAC, single-phase
Yaw System:	
Yaw control	n/a

Figure 1. The Mariah Power Windspire wind turbine installed at the NWTC

The test configuration consists of the test turbine, tower, data shed, instrumentation, meteorological tower, associated wiring, data acquisition equipment, and junction boxes. The turbine is installed on a standalone, 3.05-meter tubular tower. The output power from the turbine's inverter, located inside the hub, is 120 VAC, single-phase. The wire run from the base of the turbine to the data shed is approximately 54 meters of #12-2. The wire run then passes through the kilowatt-hour meter, the disconnect switch, and the breaker panel before it connects to the grid. Figure 2 shows the general electrical arrangement.

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

1. The turbine and tower
2. The enclosed inverter and all associated wiring (excluding NREL instrumentation cables)
3. The foundation and the bolt connection to the foundation
4. The power cables from the turbine to the power transducer

The following components were not considered part of the test turbine system:

1. The RPM and turbine status signal cables
2. The power transducer and all wiring and components on the grid side of the power transducer
3. The wireless modem and the associated components that were supplied with the turbine to provide performance data to a computer

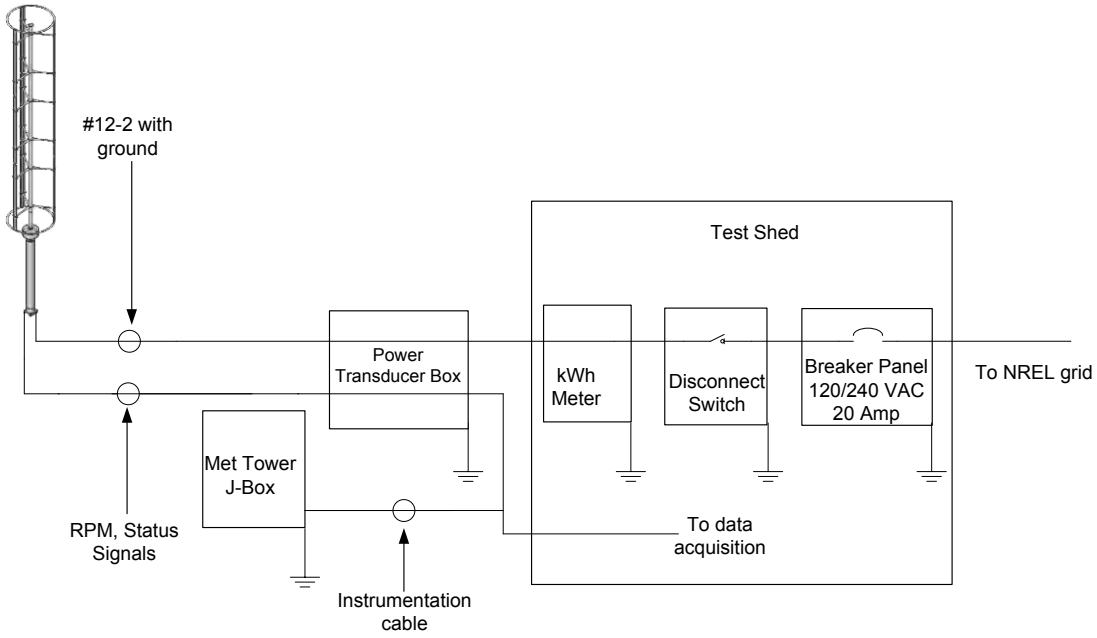

Figure 2. General electrical arrangement

4. Description of Test Site

The Windspire wind turbine under test is located at Test Site 3.3C of the NWTC (hereafter referred to as the test site), approximately 8 miles south of Boulder, Colorado. The site is located on level terrain at an approximate elevation of 1,846 m above sea level. Figure 3 shows a plot of the test site with topography lines listed in feet above sea level.

The meteorological tower is a 4.3 meter Rohn, 25 G lattice tower located 9.1 m (about 3 equivalent rotor diameters) from the test turbine at an azimuth of 290° true.

For measurements where it is important to accurately measure wind speed, NREL used data obtained when wind direction is between 132° to 323° with respect to true north. 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 Gaia-Wind 11kW turbine located on an 18 meter tower. It is located approximately 51.5 meters from the test turbine at an azimuth of 47° true on site 3.3B.

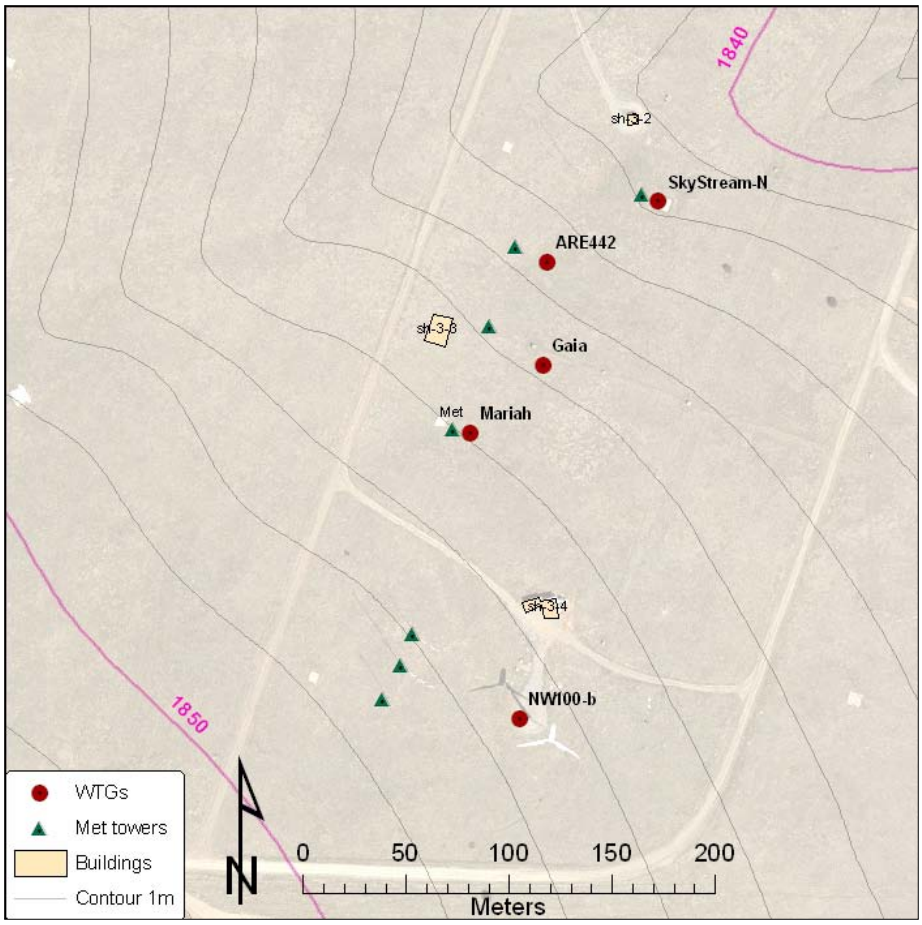

Figure 3. Map of the test site

5. Description of Instrumentation

Equipment used for duration testing differs only slightly from that used for power performance testing. Normal power performance 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 turbine voltage. The brake signal may help identify when the turbine is stopped due to a fault. The turbine voltage signal is used to identify if grid instability or fluctuations in the grid caused the turbine to fault. Figure 4 gives the location of the meteorological tower instruments and Table 2 gives an equipment list that provides the specifications for each of the instruments used. The calibration sheets for the instruments can be found in Appendix A.

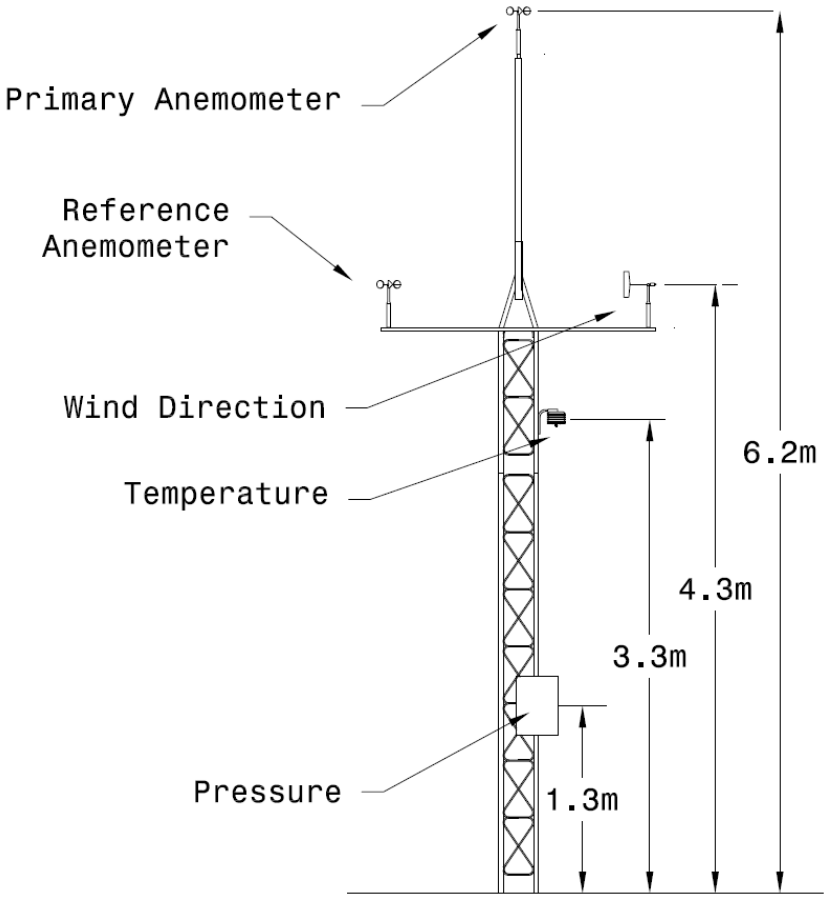

Figure 4. Location of the meteorological sensors

Table 2. Equipment List for Duration Test

Instrument	Make and Model	Serial Number	Calibration Due Date
Power transducer	Second Wind, Phaser 5FM-4A20	02061	Feb. 6, 2009
Voltage transducer	Ohio Semitronics, VT7-010E-11	08010700	Calibrated with power transducer
Primary anemometer	Thies, First Class	0707894	Feb. 27, 2009
Reference anemometer	NRG, Max 40	179500049703	In situ
Wind vane	Met One, 020C with aluminum vane	W5515	Feb. 27, 2009
Data acquisition system	Compact DAQ w/LabVIEW		
	cDAQ backplane	12E4D23	
	NI 9229	12B6DD2	June 28, 2008
	NI 9217	12BD192	July 6, 2008
	NI 9205	12E9C3E	Oct. 8, 2008
			Modules post-test calibrated on May 6, 2009 and found in compliance

6. Results

Operation Time

The mechanical components of the test turbine were installed during the week of March 17, 2008, and the inverter was installed during the week of May 5, 2008. The duration test began on May 7, 2008 following inverter installation and commissioning. The commissioning checklist from the installation can be found in Appendix B. The initial duration test was conducted over a period of approximately four months from May 7, 2008 to September 13, 2008. The test did not meet the requirement in the standard for at least 6 months of operation.

On September 13, 2008, the turbine experienced an inverter failure. This likely occurred because the parameters in the inverter were set to optimize power performance. This may have led to overheating of the electrical components and eventual failure, see Figure 5. The turbine was subsequently inoperable until October 7, 2008 when the inverter was replaced. The parameters in this inverter were set for normal power production. Since an inverter failure is considered a major failure by the Standard, the duration test was restarted on October 7, 2008.

On October 14, 2008, Mariah Power requested that the test team stop and/or lower the turbine in winds above 40 mph (approximately 18 m/s) due to a potential problem with the top shaft. NREL complied with this request, but determined that the turbine would not be able to achieve the 90% required operational time fraction. As a result, the second duration test was terminated on October 14, 2008. Because the turbine operated for only one week between the test restart and termination, those results are not reported here.

Figure 5. Damaged electrical components in the inverter

Hours of Power Production

The hours of power production at any wind speeds: 831 hours(2,500 hours required)

The hours of power production above 1.2*V_{ave} (7.2 m/s): 133 hours(250 hours required)

The hours of power production above 1.8*V_{ave} (10.8 m/s): 12 hours (25 hours required)

The turbine did not meet 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 Windspire duration test

Month	Hours of Power Production Above: 0 m/s	7.2 m/s	10.8 m/s	Max Gust (m/s)	TI @ 15 m/s (%)	T_T (hours)	T_U (hours)	T_E (hours)	T_N (hours)	O (%)
Overall	831.1	132.5	12.3	26.9	18.1	3091	93.7	79.3	198.1	93.2
May 2008	196.2	43.5	3.5	23.5	18.7	589	11.0	44.0	0.0	100.0
June	277.2	56.5	4.8	26.9	17.5	720	29.7	15.3	0.3	100.0
July	175.3	17.3	0.8	23.2		744	19.3	2.2	37.0	94.9
August	124.2	10.2	0.7	21.1		744	0.9	12.3	160.5	78.0
September	58.2	5.0	2.5	21.0		294	32.8	5.5	0.3	99.9

Operational Time Fraction

The operational time fraction, *O*, 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 in the total test period was 93.2%. Therefore, the turbine did meet the requirements for the operational time fraction during the test, though the requirements for hours of power production and at least six months of operation were not met. Figure 6 and Table 3 show the operational time fraction per month. Figure 7 shows a power curve of 10 minute average data points collected during the test.

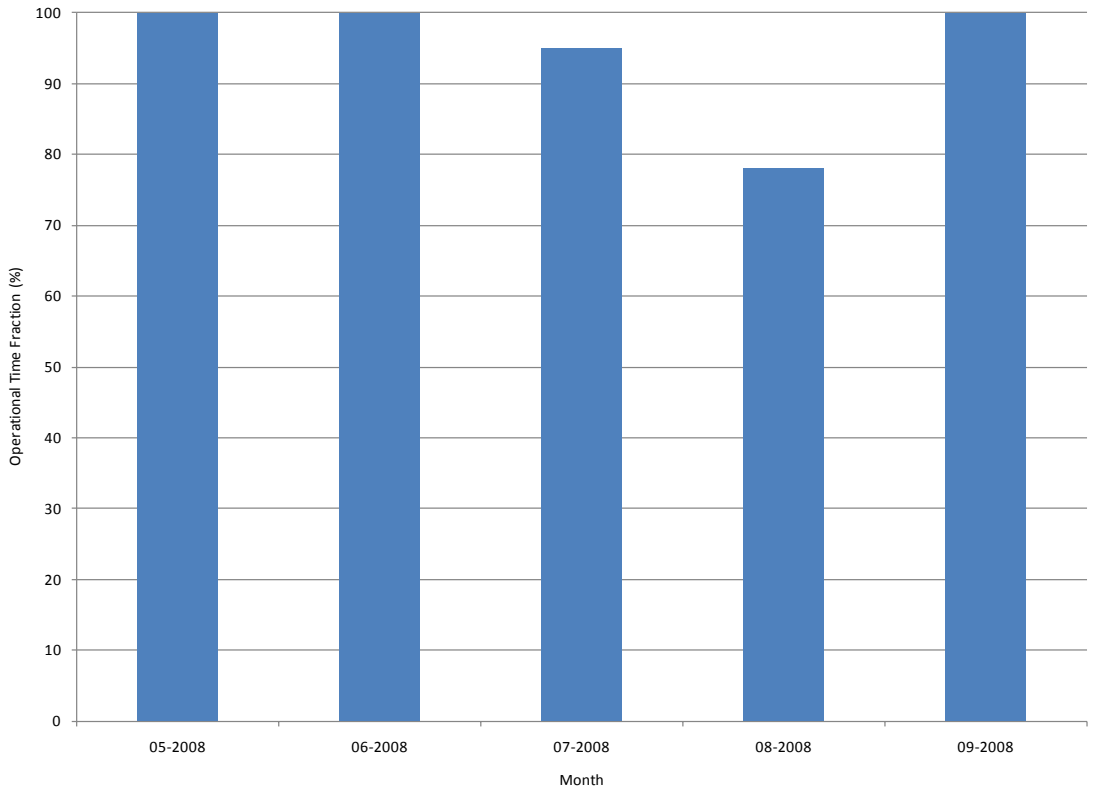

Figure 6. Operational time fraction for each month

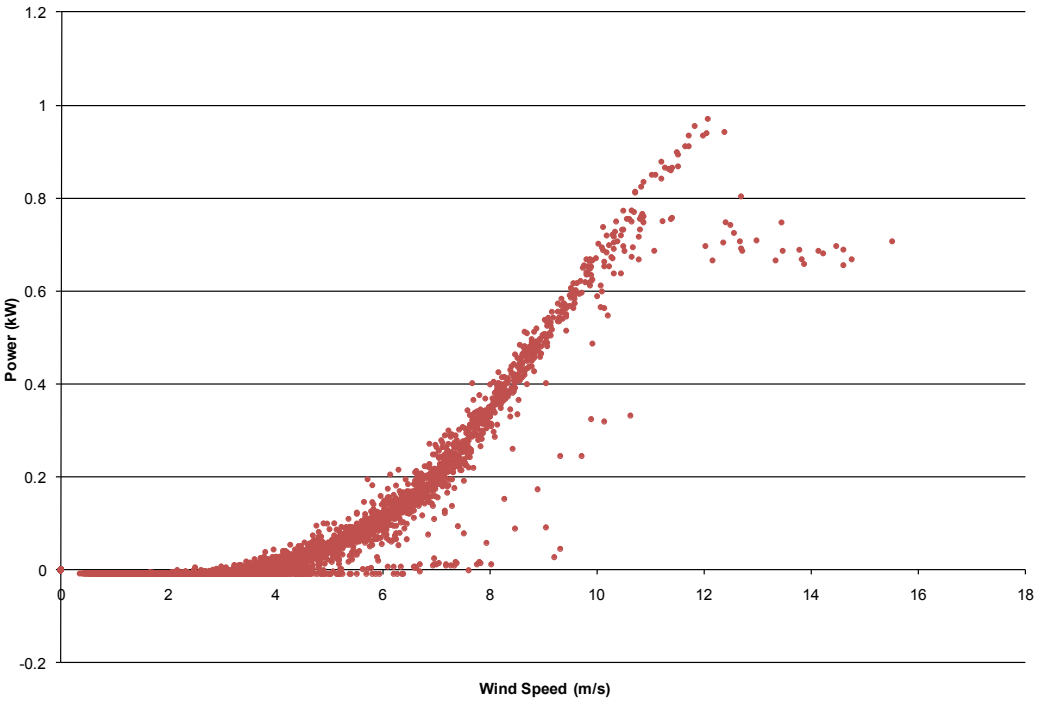

Figure 7. Scatter plot of power versus wind speed (10-minute averages)

The main causes for wind turbine system downtime (T_N) during the test period were a broken washer and weld failures. This downtime is described in more detail below. A timeline of the failures that occurred during testing can be found in Appendix C.

Broken Washer and Loose Nuts

On July 21, 2008, a routine inspection found a broken washer, loose nuts, and movement in the base tower plate. The washer was replaced and the loose nuts were tightened.

Broken Welds

On July 20, 2008, NREL discovered cracks in some of the spot welds that held the airfoils to their end caps. On one airfoil, the cracks had completely separated the airfoil from the end cap, see Figure 8. On a different airfoil, there were cracks observed in the welding but separation had not taken place. It was also noted that the airfoils had moved in the struts that are meant to hold them in place. This is a possible cause for the broken welds, see Figure 9. Mariah Power replaced the airfoils and struts on August 7, 2008. The new airfoils were welded to the end caps with a continuous weld instead of spot welds. Additionally, the struts were redesigned to prevent slipping.

Figure 8. Separated weld between airfoil and cap

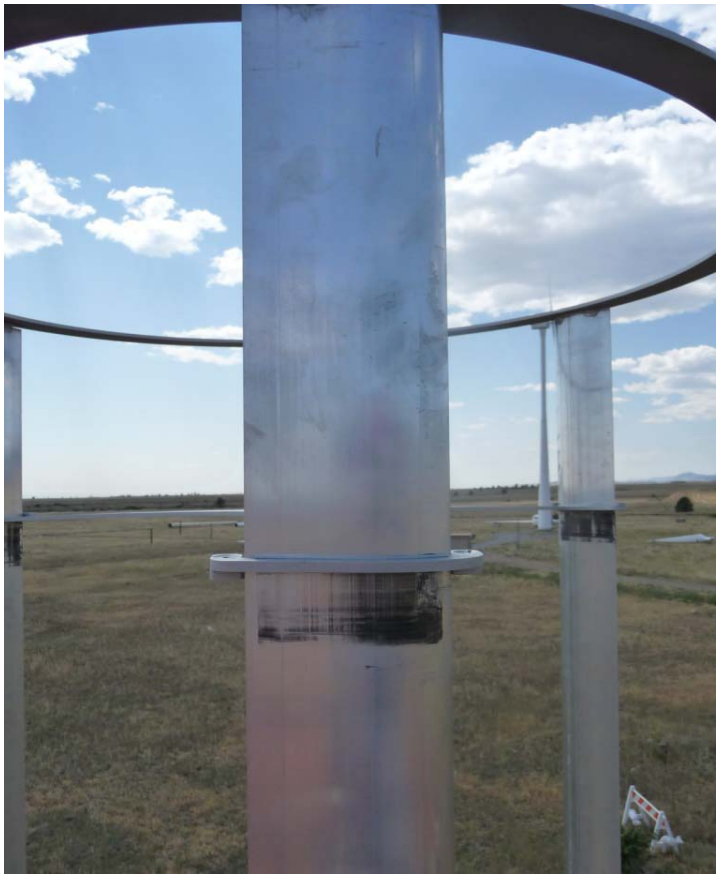

Figure 9. Evidence of airfoil movement in struts

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

- On site activities that required the turbine to be shut down
- NREL mandated inspections that required the turbine to be shut down
- The original ground fault circuit interrupter that was installed in the power transducer box faulted frequently. It was replaced and the faults ceased
- Grid faults.

If no reliable measurements were available, the time was classified as T_U since the turbine's status was unknown. The main reasons for attributing time to T_U in the duration test were:

- Irresolvable events
- Data acquisition system or computer updates.

Environmental Conditions

As an indication of the environmental conditions during the duration test, the standard requires reporting of the maximum wind speed gust and the average turbulence intensity at 15 m/s. The maximum recorded gust was 26.9 m/s at 11:24 a.m. on June 12, 2008. The average turbulence intensity at 15 m/s during the duration test was 18.1%.

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 10 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 may be caused by air density variations. The apparent degradation in power in July 2008 may have been caused by the broken welds or the shifting airfoils.

Dynamic Behavior

Turbine operation was observed by NREL personnel for at least 5 minutes at wind speeds of approximately 5 m/s, 10 m/s, 15 m/s, and 20 m/s for a total observation period of at least 1 hour. The following are a few dynamic behavior observations that were made during the test period:

July 21, 2008: The leading edge tape on the turbine is beginning to separate from the blade. There is an unknown vibration and noise that seems to be coming from the foundation. The wind speeds were between 4 and 7 m/s during the observation.

October 29, 2008: The turbine was exhibiting unsteady behavior periodically. There was a noise that seemed to come from the tower approximately three times per revolution. The washers at the foundation base were loose and the bolts and nuts on the foundation had shifted. The wind speeds were between 4 and 9 m/s during the observation.

Tear-Down Inspection

An official tear-down inspection was not performed on the turbine due to early termination of testing. However, when the turbine was uninstalled in January 2009 a couple of observations were made. It was noted that two of the top air foil welds were beginning to break and the struts that held the airfoils in place were beginning to shift again. Additionally, insulation was separating from cables that were attached to the generator, exposing bare wire.

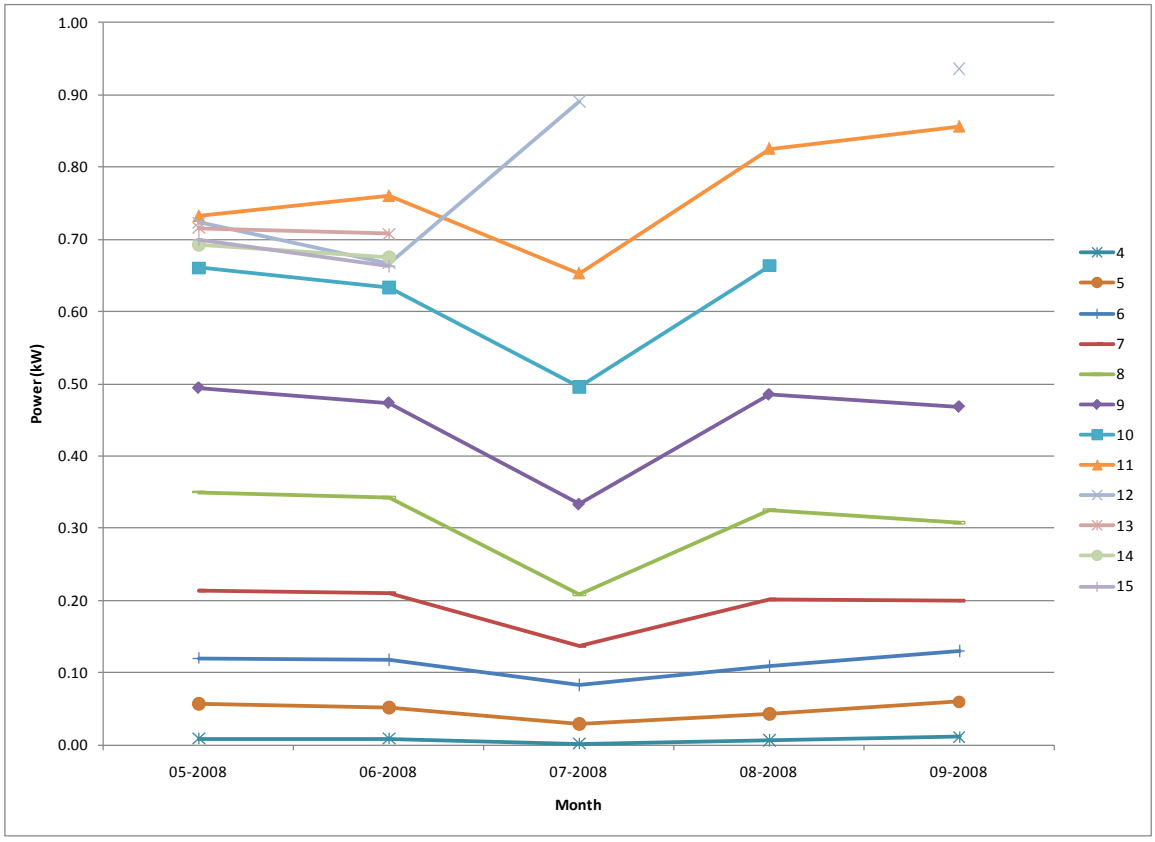

Figure 10. Power level in several wind speed bins (in m/s) as a function of time

7. Uncertainty

Uncertainty is estimated for the following parameters:

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

No uncertainty analyses were done within the power degradation results. These results are used only to find relative trends which 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. NREL estimates that the reported time of power production in any wind speed may be 20% less than calculated.

For the hours of power production above 7.2 and 10.8 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

A conservative estimate that the classification of T_E and T_N are 5% off from the true value would result in an operational time fraction of 92.9% or 93.6%.

Highest Instantaneous Wind Speed

The uncertainties in the wind speed measurements are 0.017 m/s calibration uncertainty, 0.052 m/s + 0.52% operational characteristics, 1% mounting effects, and 2% terrain effects. For the peak recorded, instantaneous gust of 26.9 m/s, the uncertainty is 0.62 m/s.

8. Deviations and Exceptions

8.1. Deviations from the Standard

The current transformers are not compliant with IEC 60044-1 but do exceed the minimum accuracy required by the standard.

8.2. Deviations from Quality Assurance System

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 A includes the post-test calibration sheets.

Appendix A: Instrument Calibration Certificates

Figures A.1 through A.9 show the calibration sheets for the instruments used during the duration test.

Branch #: 5000

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Phaser Power Transducer & 1-CT DOE #: 02825C

Model # : Phaser-5-4A 20 S/N : 02061

Calibration Date: 02/08/2008 Due Date: 02/08/2010

A. Set-Up for Total Real Power Calibration:
A.1. Voltage is applied to phases A&N = 100 V @ 60 Hz.
A.2. Current is applied to n = 10-TURNS through the current transformer that is connected to phases A.
A.3. Analog Output-1 is measured across precision resistor = 250 Ω.
A.4. Phaser Full Scale setting = -1.5KW to 1.5KW.

Input Current (AAC)	Input Power (KW)	Analog Output-1 (VDC)
15	1.5	4.991
10	1.0	4.328
5	0.5	3.662
0	0	2.995
-5	-0.5	2.329
-10	-1.0	1.663
-15	-1.5	0.999

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)
1.5	1.0	4.988
"	0.8	4.182
"	0.6	3.382
"	0.4	2.582

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Figure A.1. Power transducer calibration sheet

DEUTSCHER KALIBRIERDIENST DKD

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

Deutsche WindGuard
Wind Tunnel Services GmbH
Varel

Deutscher Akkreditierungs Rat
DAR
DKD-K- 36801

Kalibrierschein
Calibration Certificate

Kalibrierzeichen / *Calibration label*: DKD-K- 36801 / 07_2407

Gegenstand *Object*	Cup Anemometer
Hersteller *Manufacturer*	Thies Clima D-37083 Göttingen
Typ *Type*	4.3350.00.000
Fabrikat/Serien-Nr. *Serial number*	Body: 0707894 Cup: 0707894
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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Deutscher Kalibrierdienst DKD-K- 36801	24.07.2007	Dipl. Phys. D. Westermann	Tech. Ass. Inf. H. Westermann

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

Deutsche WindGuard
Wind Tunnel Services GmbH

Figure A.2. Primary anemometer 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: **28-Sep-06**

Report Number: W5515-060928

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	**W5515**
Vane Material	Aluminum
Condition	Refurbished

Results:

Slope:	**0.14242**	**deg/mv**
Offset to boom:	**89.563**	**deg**
Max error:	0.77	deg

Estimated Uncertainty:

Inclinometer Uncertainty (deg)	Total Uncertainty (deg)
0.10	0.44

Traceability:

	Mfg & Model	Serial Number	Cal Date
Inclinometer:	Spi-Tronic	31-038-3	9-Nov-05
Voltmeter:	Fluke743B	6965608	5-May-06

Calibration by: Mark Meadors for

28-Sep-06
Date

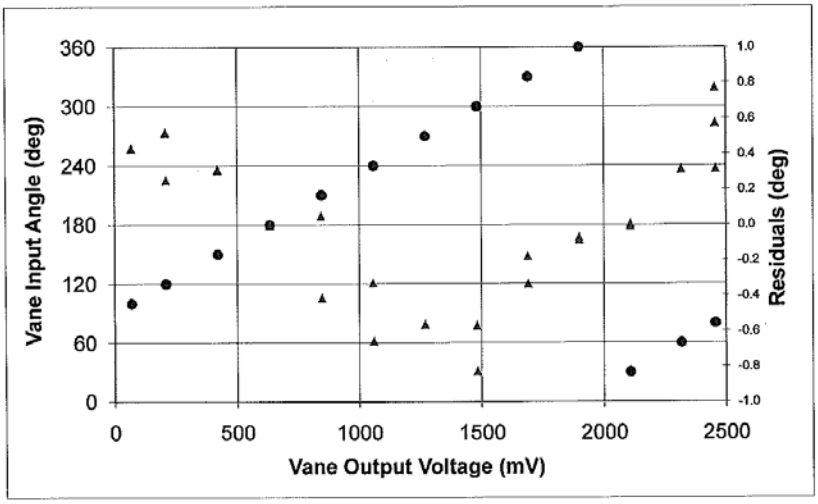

Figure A.3. Wind vane calibration sheet

NATIONAL INSTRUMENTS

Certificate of Calibration

Board Information:
Serial Number: 12B6DD2
NI Part Number: 192580D-02
Description: NI 9229

Certificate Information:
Certificate Number: 756395
Date Printed: 02-JUN-09

Calibration Date: 28-JUN-07
Recommended Calibration Due Date: 28-JUN-08*

Ambient Temperature: 24 °C
Relative Humidity: 39 %

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
Vice President, Quality and
Continuous Improvement

* 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.4. NI 9229 data acquisition module calibration sheet I

NATIONAL INSTRUMENTS

Certificate of Calibration

Board Information:
Serial Number: 12BD192
NI Part Number: 192547D-01
Description: NI 9217

Certificate Information:
Certificate Number: 762337
Date Printed: 02-JUN-09

Calibration Date: 06-JUL-07
Recommended Calibration Due Date: 06-JUL-08*

Ambient Temperature: 23 °C
Relative Humidity: 43 %

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
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4031 Debrecen, Határ út
1/A.
HUNGARY

Signed,

Andrew Krupp
Vice President, Quality and
Continuous Improvement

* 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.5. NI 9217 data acquisition module calibration sheet I

NATIONAL INSTRUMENTS

Certificate of Calibration

Board Information:
Serial Number: 12E9C3E
NI Part Number: 193299F-01
Description: NI-9205

Certificate Information:
Certificate Number: 834976
Date Printed: 02-JUN-09

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

Ambient Temperature: 22 °C
Relative Humidity: 39 %

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
Vice President, Quality and
Continuous Improvement

* 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.6. NI 9205 data acquisition module calibration sheet I

Davis Calibration

ACCREDITED CALIBRATION

Certificate of Calibration

3214335

Instrument Identification

Company ID: 229037
NATIONAL INSTRUMENTS

PO Number: 337683

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

Instrument ID: **12B6DD2**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CHANNEL, ±60 V, 24-BIT SIMULTANEOUS ANALOG INPUT

Model Number: NI 9229
Serial Number: 12B6DD2

Accuracy: Mfr Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025
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

Figure A.7. NI 9229 data acquisition module calibration sheet II

Davis Calibration

ACCREDITED CALIBRATION

Certificate of Calibration

3214168

Instrument Identification

Company ID: 229037
NATIONAL INSTRUMENTS

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

PO Number: 337683

Instrument ID: 12BD192
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CH 100 OHM 24-BIT RTD ANALOG INPUT

Model Number: NI 9217
Serial Number: 12BD192

Accuracy: Mfr. Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025
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

Figure A.8. NI 9217 data acquisition module calibration sheet II

Davis Calibration

ACCREDITED CALIBRATION

Certificate of Calibration

3214141

Instrument Identification

Company ID: 229037
NATIONAL INSTRUMENTS

PO Number: 337683

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

Instrument ID: 12E9C3E
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: 12E9C3E

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 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

Figure A.9. NI 9205 data acquisition module calibration sheet II

Appendix B: Turbine Commissioning Checklist

Commissioning Procedure for Mariah Power Windspire Grid-Connected Wind Turbine Generator at Site 3.3

1.0 Introduction

NREL will perform an acceptance test for the Windspire 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: 2 May 2008 Conducted by: Amy Bowen, Mark Meadors

Task	Initial	Recorded Observation
Electrical Inspection Completed	AMC	
Verify generator gap	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 - #10 or better)	MM	10 AWG
Verify inverter re-connects after 3.3 breaker is tripped	AB	
Verify RPM signal from inverter	AB	
Verify "turbine status" signal from inverter	AB	
Measure the inverter frequency under load	AB	60.02 Hz
Measure the inverter current under load	AB	1.0 A
Measure the inverter voltage under load	AB	122.9 V

Verify manual shutdown from turbine disconnect	AB	
Verify 20 amp breaker size in power panel 3.3	MM	BKR # 30
Verify manual shutdown from 20 amp breaker function in power panel 3.3	MM/AB	BKR # 30
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 Mariah Power Windspire Wind Turbine Generator at Site 3.3 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.

Chris Gabrys
Project Leader
Mariah Power — 5/7/08 Date

Amy Bowen
Test Engineer
NREL, NWTC — 15May08 Date

Mark Meadors
Master Research Technician
NREL, NWTC — 5/14/08 Date

Hal Link
Certification Project Manager
NREL, NWTC — 13 May 2008 Date

Appendix C: Windspire Test Chronology

5/5/08	The turbine was fully installed and operational. The turbine was installed without the inverter on March 17, 2008. The inverter was not installed until May 5, 2008.
5/9/08	Two screws were found missing at the top of the turbine where the ring attaches to the airfoil. The tower base bolts/nuts were retightened/loosened and marked to show alignment.
6/12/08	The inverter parameters were changed to increase output at rated levels from 1,000 watts to 1,100 watts.
6/23/08	The testing team found two loose bolts at the tower base. The nuts were retightened and re-marked, and a small adjustment was made to vertical.
7/21/08	Routine inspection found a noise emanating from the turbine, a broken washer, loose nuts, and movement in the base tower plate.
7/30/08	While the leading edge tape was being replaced (due to detachment), a broken weld was found at the top of the turbine and another crack was observed on a different weld. Initially, the welding was done in two spots per airfoil side. The airfoils also slid out of the struts that are supposed to clamp them. This may have caused the broken weld. The turbine was visibly wobbling and was tilted down.
8/7/08	The manufacturer was on-site to replace the airfoils and struts. This is a change that will be required for all production machines. The tower base bolts were replaced with bolts with set screws to keep bolts from loosening. The weld was improved to a continuous weld.
8/18/08	The magnetic bearing was replaced. The initial magnetic bearing did not have a dust cover and was susceptible to iron dust getting into the magnetic air gap, which can stop operation of the turbine.
9/13/08	The inverter failure occurred because the set points of the inverter were set to optimize power performance. The increased performance caused the temperature to rise, and over time, caused the inverter to fail.
10/7/08	The inverter was replaced. The set points were set for normal production. The power performance test was stopped because the inverter failed. The test was not completed because the wind speed range requirement was not fulfilled/met. A new power performance test was started after the inverter was replaced.
10/14/08	Mariah Power informed NREL that: "the welding of the top shaft has not been stress relieved properly and has a heat affected zone that has reduced strength and fatigue life below the design." Based on the findings from an accelerated life test conducted at the Mariah Power facility, they requested that the testing team stop and/or lower the turbine in winds above 40 mph until a fix could be implemented. The fix was not expected until January 2009. The testing team complied with Mariah's request. However, they decided to terminate duration testing because the turbine did not meet the operation requirements. The testing team decided to continue power performance and noise testing.
10/21/08	The testing team confirmed that the turbine does not shut down in high winds.
10/30/08	The testing team found three loose nuts at the base of the tower. The nuts were tightened per Mariah Power's direction.
11/19/08	Two of the airfoils slid down through the struts.

12/16/08	During the noise testing, a clanging sound emanated from the turbine. The testing team found two broken welds at the top of the turbine. The turbine was shut down until further notice. The airfoil did not completely separate as it did in the previous occurrence.
1/14/09	The testing team checked the turbine after it observed possible higher rotational speeds while the turbine was shut off. Measurements that were taken to check for generator continuity were varied when they should have been less than 5 ohms. The team found that two of the three wires from the generator were missing insulation and bare wire was exposed. There was no noticeable difference in resistance when force was applied, whether the generator was connected or not. The turbine was lowered.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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

4. TITLE AND SUBTITLE
Wind Turbine Generator System Duration Test Report for the Mariah Power Windspire 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-500-47072

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-500-47072

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 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 Wind Technology Center (NWTC) as a part of the first round of this project. Duration testing is one of up to five tests that may be performed on the turbines. Other tests include power performance, safety and function, noise, and power quality tests. NWTC testing results provide manufacturers with reports that may be used to meet part of small wind turbine certification requirements. This duration test report focuses on the Mariah Power Windspire wind turbine.

15. SUBJECT TERMS
wind turbine testing; duration test; Mariah Windspire Wind Turbine

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

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18