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Arlinda Huskey, Amy Bowen, and Dave Jager

*Technical Report*
NREL/TP-500-47496
July 2010

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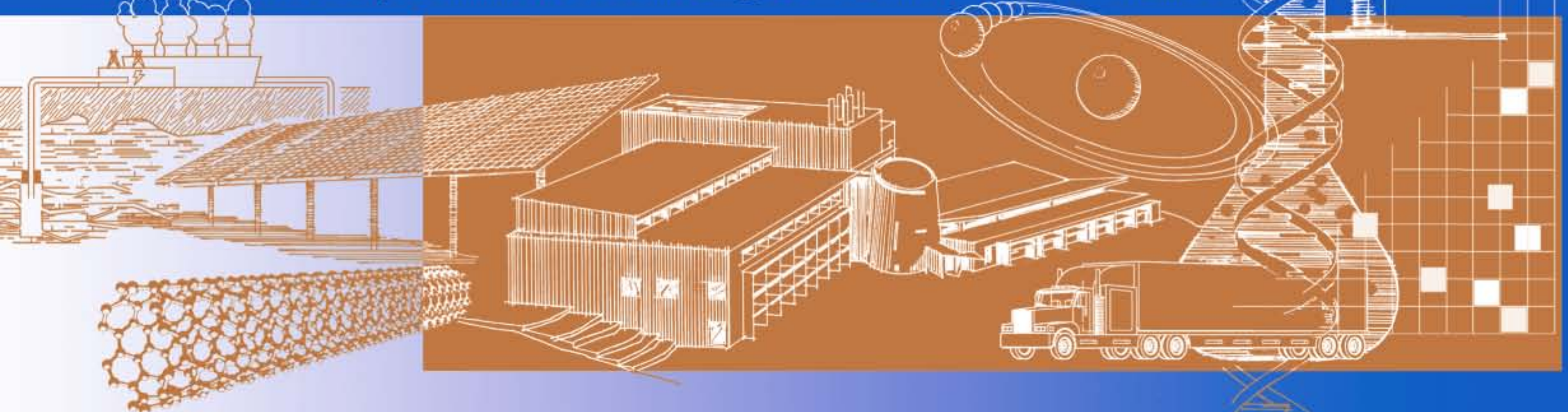

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Arlinda Huskey, Amy Bowen, and Dave Jager

Prepared under Task No. WE10.2211

*Technical Report*
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**July 2010**

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Arlinda Huskey, NREL Test Engineer Date

Approval By:__________________________________________________

Jeroen van Dam, NREL Test Engineer Date

# List of Acronyms

| | |
|---|---|
| AWG | American Wire Gauge |
| DOE | United States Department of Energy |
| NREL | National Renewable Energy Laboratory |
| NWTC | National Wind Technology Center |
| SWT | small wind turbine |

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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 to wind energy expansion by providing independent testing results for small wind turbines (SWT). In total, five turbines were tested at the National Wind Technology Center (NWTC) as a part of this project. Safety and function testing is one of up to five tests performed on the turbines, including power performance, duration, 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.

The test equipment 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.

During this test, two configurations were tested on the same turbine. In the first configuration, the turbine inverter was optimized for power production. In the second configuration, the turbine inverter was set for standard power production. In both configurations, the inverter experienced failures. Tests from both of these configurations are included in the report, though each test was not performed on both configurations of the turbine. Testing on the Windspire was terminated before all of the planned safety and function tests could be completed.

# 2 Test Objective

The objective of this test was to:

- Verify whether the test turbine displays the behavior predicted in the design;
- Determine whether provisions relating to personnel safety are properly implemented; and
- Characterize the dynamic behavior of the wind turbine at rated wind speed and greater speeds.

The National Renewable Energy Laboratory (NREL) does not limit safety and function tests to features described in the wind turbine documentation, and NREL also inspects—possibly tests—and reports on features that are required by IEC 61400-2 and that might not be described in the wind turbine documentation. NREL conducted this test in accordance with Section 9.6 of the IEC standard, "Wind Turbines—Part 2: Design Requirements for Small Wind Turbines," IEC 61400-2, second edition, 2006-03.

# 3 Description of Test Turbine and Setup

The test turbine was a Mariah Power Windspire wind turbine. This turbine is a vertical axis, three-bladed, variable-speed, turbine with a rated power of 1-kW. Figure 1 shows the test turbine installed at the NWTC. Table 1 provides the key descriptive information of the test turbine.

**Table 1. Test Turbine Configuration**

| | |
|---|---|
| Turbine manufacturer name and address | Mariah Power<br>748 S. Meadows Pkwy. A-9, #329<br>Reno, NV 89521 |
| Model name | Windspire |
| Serial number | 800021 |
| Revision number | 1P |
| Production date | 2008 |
| Design nominal voltage at terminals (VAC) | 120 |
| Maximum current at terminals (A) | 20 |
| Design frequency at terminals (Hz) | 60 |
| Small wind turbine (SWT) class | IV |
| Design 50-year extreme wind speed, $V_{e50}$ (m/s) | 42 |
| Equivalent Rotor diameter (m) | 3.08 |
| Hub height (vertical center of rotor) (m) | 6.10 |
| Tower type | Tubular |
| Rated electrical power (kW) | 1 |
| Rated wind speed (m/s) (slowest wind speed at which turbine produces rated power) | 11.0 |
| Rated rotor speed (rpm) (slowest rotor speed at which turbine produces rated power) | 180 |
| Rotor speed range (rpm) | 0 – 500 |
| Fixed or variable pitch | Fixed |
| Number of blades | 3 |
| Blade pitch angle (deg) | 3 |
| Blade make, type, serial number | Mariah Power, Airfoil, NA |
| Description of control system (device & software | Windspire 1.2G |

The Windspire wind turbine was installed at site 3.3C at the NWTC, which is located 8 miles south of Boulder, Colorado. The site's terrain primarily is flat with short vegetation. The test site has prevailing wind bearing 292 degrees relative to true north. For measurements requiring highly accurate wind-speed data, NREL used data obtained when the wind direction was between 132 degrees true to 323 degrees true. In this measurement sector—which was established in accordance with IEC 61400-12-1—the influence of terrain and obstructions on the anemometer and turbine is slight.

Figure 2 shows the general electrical arrangement. The wire run from the base of the tower to the data shed is approximately 54 meters of #12-2 American Wire Gauge (AWG) wire. Inside the data shed, on the turbine side of the transformer, the wire run is connected to a disconnect switch and a dedicated breaker in a breaker panel.

**Figure 1. Windspire wind turbine at the NWTC test site**

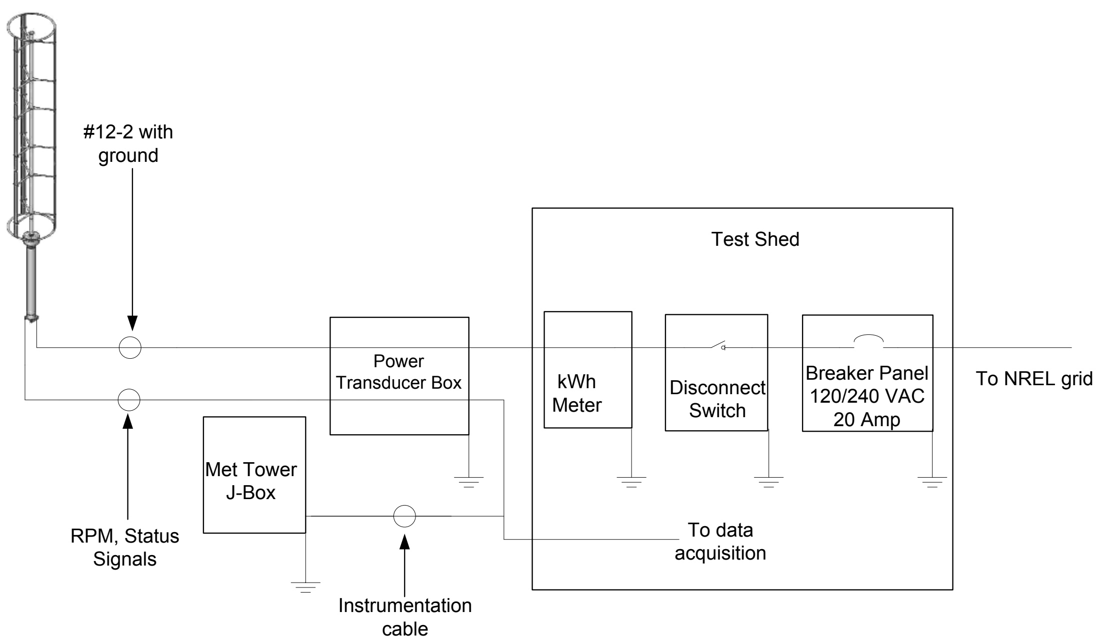


**Figure 2. Electrical drawing**

# 4 Instrumentation

The following parameters were measured in this test: wind speed, electrical power, rotor speed, turbine status, and grid voltage. The rotor speed was calculated by measuring the frequency of an optically isolated signal from the turbine. The turbine does not produce a detectable rotor speed signal at lower rotor speeds. An indication of turbine status was obtained by measuring the voltage of a signal from the turbine that indicated if the turbine's brake was on. The instruments used for these measurements are listed in Table 2. The calibration sheets for the instruments used for this safety and function test are included in Appendix A.

**Table 2. Equipment List for Safety and Function Test**

| Instrument | Make, Model | Serial Number | Calibration Due Date |
|---|---|---|---|
| Power transducer | Second Wind, Phaser 5FM-4A20 | 02061 | February 8, 2009 |
| Voltage transducer | Ohio Semitronics, VT7-010E-11 | 08010700 | Calibrated with power transducer |
| Primary anemometer | Thies, First Class | 0707894 | February 27, 2009 |
| Data acquisition system | Compact DAQ w/LabView<br>cDAQ backplane<br>NI 9229<br>NI 9217<br>NI 9205 | <br>12E4D23<br>12B6DD2<br>12BD192<br>12E9C3E | <br><br>June 28, 2008<br>July 6, 2008<br>October 8, 2008<br>Modules post-test calibrated on May 6, 2009 and found in compliance |

# 5 Procedure

Safety and function testing can involve some risk to personnel and to equipment. By incorporating appropriate controls into testing procedures, NREL endeavors to accomplish its tasks with minimal risk. This test report documents these controls in areas where they might have influenced the results obtained.

## 5.1 Control and Protection System Functions

The first part of the test procedure is assessing the control and protection system functions. The planned control and protection system tests are listed below, though not all were completed before testing was terminated. The turbine's response is observed for each major response category (start-up, normal shutdown, emergency shutdown) in the list below. In circumstances in which faults or other actions cause one of these major responses, NREL staff simulates the appropriate input and verifies that the control and protection system appropriately sensed the condition and provided an indication of the appropriate response. This procedure, for example, enables rotor overspeed functions to be checked without exposing the turbine to multiple potentially damaging stops. In the list below, these items are designated by the term "behavior."

1. Power control
2. Rotor-speed control
3. Start-up
    a. Normal operation—wind speed greater than cut-in
    b. After maintenance or fault clearance at design wind speed or greater
4. Normal shutdown under
    a. Normal operation—wind speed decreasing to less than cut-in
    b. Maintenance or fault conditions at design wind speed or greater
5. Emergency shutdown during operation from any operating condition including:
    a. Emergency stop in wind speeds less than design wind speed;
    b. Emergency stop at design wind speed or greater;
    c. Behavior upon automatic shutdown from overspeed at design wind speed or greater; and
    d. Behavior upon automatic shutdown from other fault at design wind speed or greater.
6. Behavior upon loss of load
    a. Response to grid outage
    b. Response to grid instability

## 5.2 Personnel Safety Provisions

The second part of the test procedure was to evaluate provisions for personnel safety. For the test turbine the following issues were reviewed.

1. Safety instructions
    a. Safety instructions must be available for everybody working or operating at the site or in the wind turbine.
    b. Safety instructions must cover installation, operation, and maintenance activities.
2. Climbing facilities must be checked for proper assembly and full function.
    a. Tower climbing cable or equivalent
    b. Tie-off points on outside of nacelle
3. Standing places, platforms, and floors
    a. Trip hazards must be avoided or marked clearly.

   b. Platforms, floors, and walkways must be equipped with nonslip surfaces.
   c. Hatches in the platforms must be lockable.
4. Electrical and grounding system
5. Emergency-stop buttons
6. Lock-out/tag-out provisions
7. Interlock on electrical cabinets
8. Presence and functioning of rotor lock and yaw lock
9. Unauthorized changing of control settings
10. Lightning protection
11. Safety signs

## 5.3 Dynamic Behavior

NREL staff observed the turbine at a range of operating wind speeds to note the dynamic behavior of the turbine, including (but not limited to) vibration, and noise.

# 6 Results

## 6.1 Control and Protection System Functions

NREL limited testing to investigation of single-fault failures and has not investigated failures of "safe life" components.[1] If a second fault occurs during a critical event, unsafe results could occur. Neither NREL nor the IEC turbine-design requirements make judgments on whether such failures are likely or whether additional features in the control and protection system are needed to protect against such consequences.

### *Power Control*

Figure 3 shows the 1-minute mean power data and 1-second maximum power data for the inverter configured for standard power production. For the data collected, both the mean and maximum power values appear to begin leveling off at wind speeds greater than 14 m/s. However, there are not enough data points at these wind speeds to conclude that the turbine exhibits power control.

### *Yaw Control*

This item is not applicable as the test article is a vertical axis turbine.

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[1] The IEC turbine design standard, IEC 61400-1, defines "safe life" as those components for which the designer has "prescribed a service life with a declared probability of failure." These typically are components that transmit wind loads to the ground, such as blades, hubs, low-speed shafts, main bearings, main frames, yaw bearings, towers, and foundations. Failure of any of these components could lead to a catastrophic failure of the turbine; therefore each component should be designed with an appropriate safety factor. NREL has not evaluated these design characteristics and makes no judgment on whether appropriate safety factors have been used.

### Rotor-Speed Control

Rotor-speed measurements over the test period indicate that the turbine system exhibits control over rotor speed in response to winds below about 18 m/s. Figure 4 shows both 1-minute average and 1-second maximum rotor speed for the inverter configured for standard power production. The maxima level off and hold at about 390 rpm. The manufacturer's rated rotor speed is 380 rpm and a rotor overspeed occurs at 430 rpm. The data shows the rotor speed was held at less than 430 rpm.

### Start-Up

Normal Operation—Wind Speed Greater Than Cut-In (4 m/s). This event was captured in June 2008 on the inverter configured for optimized power production. As shown in Figure 5, the wind speeds were slightly greater than the cut-in wind speed when the turbine started. The rotor speed gradually increased as the wind speeds remained constant at approximately 4 m/s. The turbine began producing power at a wind speed of about 4 m/s and a rotor speed of about 180 RPM.

After Maintenance or Fault Clearance at Design Wind Speed (8.4 m/s) or Greater. This event occurred in June 2008 on the inverter configured for optimized power production. The turbine was stopped through the communication software for maintenance. After the turbine was enabled through the communication software, it started in winds between 9 and 13 m/s and began producing power. Figure 6 shows a time series of the events.

### Normal Shutdown

Normal Operation—Wind Speed Decreasing to Less Than Cut-In (4 m/s). This event was recorded in September 2008 on the inverter configured for optimized power production. When the wind speed decreases to less than cut-in the turbine stops producing power and then free wheels. A time series of the event is shown in Figure 7.

Maintenance or Fault Conditions at Design Wind Speed (8.4 m/s) or Greater. This event was recorded in June 2008 on the inverter configured for optimized power production. The turbine was stopped through the communication software for maintenance. The wind speed was between 8.4 m/s and 9.0 m/s at the time the turbine was stopped. The brake was applied and both the detectable rotor speed and power dropped to zero within 2 seconds. Figure 8 shows a time series of the event.

### Emergency Shutdown from Any Operating Condition During Operation

Emergency Stop in Wind Speeds Less Than Design Wind Speed (8.4 m/s). The owner's manual indicates that the owner should disconnect power to the turbine to stop it in high winds. Thus, the emergency shutdown capability was tested by opening the dedicated disconnect switch that NREL installed. This event was recorded in June 2008 on the inverter configured for optimized power production. The wind speeds were between 4 m/s and 6 m/s when the disconnect switch for the turbine was opened. The brake stopped the wind turbine within 2 seconds. Figure 9 shows a time series of the event.

Emergency Stop at Design Wind Speed (8.4 m/s) or Greater. This event was recorded in October 2008 on the inverter configured for standard power production in a data file containing one minute averages. The wind speed was between 10 m/s and 19 m/s during the one minute period when the disconnect switch was opened to shut the turbine down at the request of the manufacturer for high winds. Figure 10 shows the one minute time series of the event.

Behavior Upon Automatic Shutdown from Overspeed at Design Wind Speed or Greater. No data was collected for this category before testing was terminated.

Behavior Upon Automatic Shutdown from other fault at Design Wind Speed (8.4 m/s) or Greater. No data was collected for this category before testing was terminated.

### *Behavior Upon Loss of Load*

Response to Grid Outage. This event was observed in June 2008 on the inverter configured for optimized power production. The wind speeds were between 4 m/s and 6 m/s when the disconnect switch for the turbine was opened. The brake stopped the wind turbine within 2 seconds. After the switch was opened, the turbine voltage increased to 150 V before dropping to 0 V. Figure 9 shows a time series of the event.

Response to Grid Instability. No data was collected for this category before testing was terminated.

## 6.2 Personnel Safety Provisions

### *Safety Instructions*

The turbine came with an owner's manual detailing the installation, operation, and maintenance procedures. NREL staff checked the manual to determine whether the safety instructions addressed requirements in accordance with the IEC small turbine design standard. NREL staff found the following.

Disengage the load and/or energy sources: The manual indicates that the owner should disconnect power to the turbine if high winds are anticipated, if damage is suspected, or before servicing the turbine. The turbine was not supplied with a means of disconnecting power, though the one line diagram in the manual shows the turbine connected to a disconnect switch. NREL staff installed a dedicated disconnect switch in the data shed as a means to disconnect power to the turbine.

Stop and secure the rotor: The manual states that the rotor should be secured if damage is suspected or if the inverter is disconnected from the generator. The manual does not provide specific instructions on securing the rotor.

Stop and secure the yaw mechanism: This item is not applicable as the test article is a vertical axis turbine.

Climb tower: The turbine is not equipped with a ladder or other means of climbing the tower. The owner's manual indicates that the turbine should be lowered to perform maintenance such as replacing the blades or the bearings.

### *Climbing*

The turbine tower was not intended for climbing. To service or inspect the turbine, NREL staff used a ladder, an aerial lift, or lowered the turbine as suggested in the owner's manual.

### *Standing Places, Platforms, and Floors*

The turbine does not have any standing places, platforms, or floors.

### *Electrical and Grounding System*

The electrical system consists of wiring from the turbine to a disconnect switch and then to a dedicated circuit breaker. The grounding system consists of a pole ground connected to the tower base. The details of the electrical and grounding system are shown in a wiring diagram in the owner's manual.

### *Emergency-Stop Button*

The turbine was not supplied with an emergency-stop button. NREL staff stopped the turbine by opening the disconnect switch. Alternatively the turbine can be stopped through entering a command in the communications software.

### *Lock-Out/Tag-Out Provisions*

NREL provided a lockable switch between the grid and the turbine. The manufacturer shows installation of a disconnect switch in the owner's manual, though they do not specifically require a lockable switch. Limited procedures for de-energizing the turbine system using this disconnect switch are in the owner's manual.

### *Interlock on Electrical Cabinets*

The turbine was not supplied with an electrical cabinet.

### *Safety Signs*

The turbine was not provided with any safety signs, safety notices are not a part of the turbine's bill of materials. NREL personnel labeled the electrical panels, and disconnects, indicating the voltage levels of each.

### *Presence and Functioning of Rotor Lock and Yaw Lock*

The turbine stops the rotor with a redundant electronic brake which can be activated through the communication software, or a disconnect switch. As indicated in the manual, with the electronic brake applied the turbine maintains a low rotor speed in high winds. There are no instructions for locking the rotor to prevent the low rotor speed.  A yaw lock is not applicable for the Windspire as it is a vertical axis turbine.

### *Unauthorized Changing of Control Settings*

The controller functions are performed by the turbine's inverter. The inverter set points can be changed by communicating with the inverter wirelessly through a modem. The access mode in the communication software that NREL was provided with has the ability to be password protected. The control settings may be changed by the turbine owner with the communication software, password, and necessary code provided by Mariah Power.

### *Lighting Protection*

As indicated in the owner's manual, the turbine "has a built-in lightning arrestor in the inverter". During the test period no direct or nearby lightning strikes were observed.

## 6.3 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

This event was observed for the inverter configured for optimized power production. 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 this observation.

October 29, 2008

This event was observed on the inverter configured for standard power production. 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 have shifted. The wind speeds were between 4 and 9 m/s during this observation.

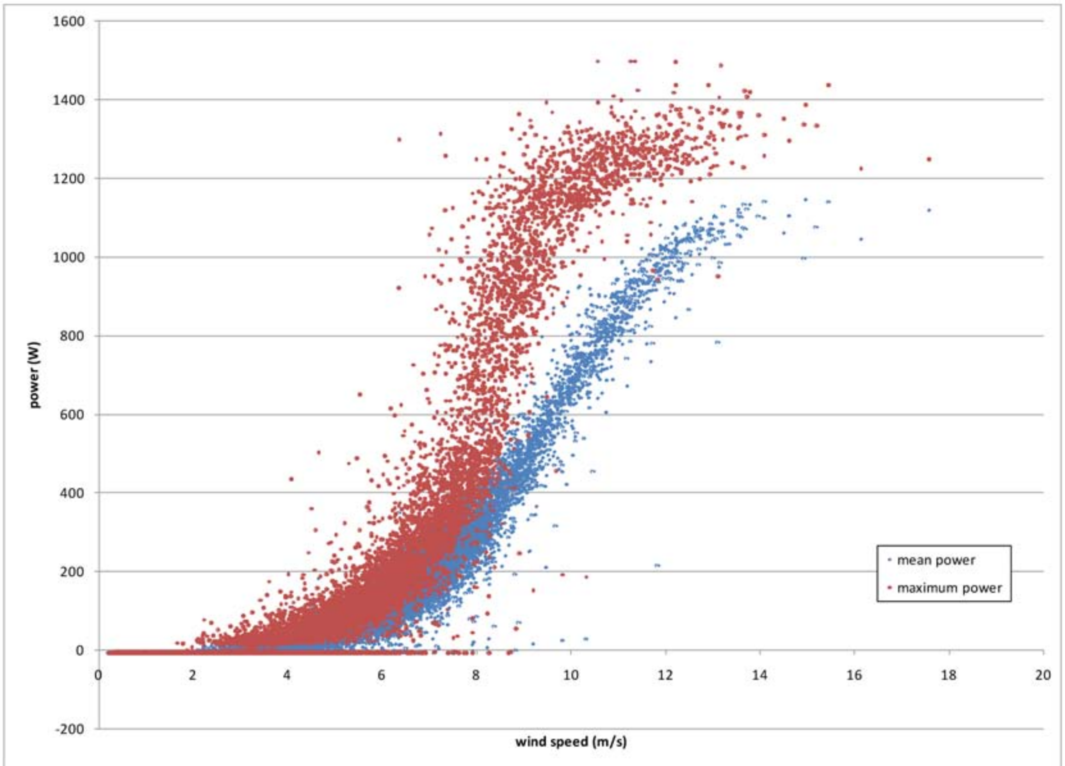


**Figure 3. Power response to wind speed**

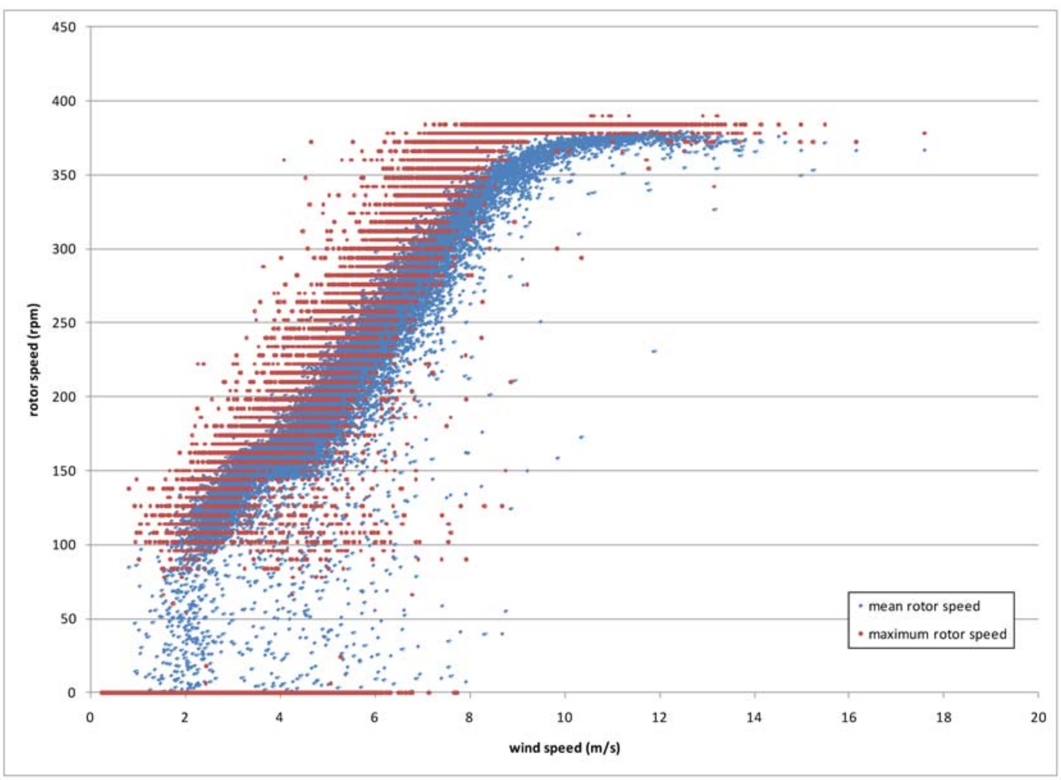


**Figure 4. Rotor-speed response to wind speed**

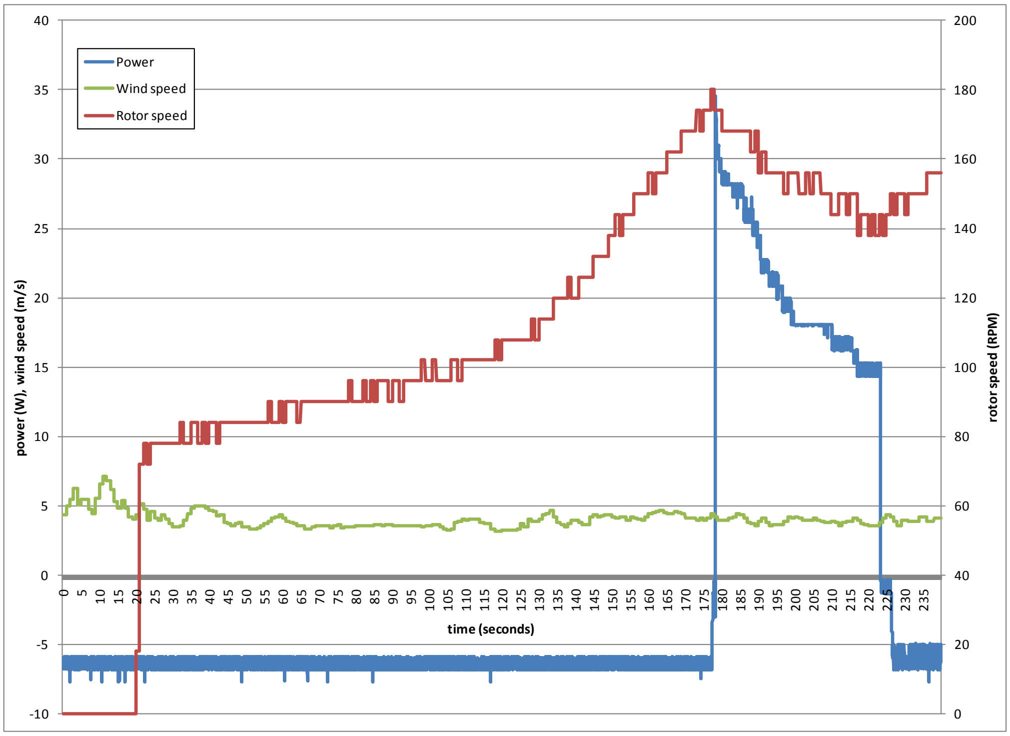


**Figure 5. Normal start-up, wind speeds greater than cut-in**

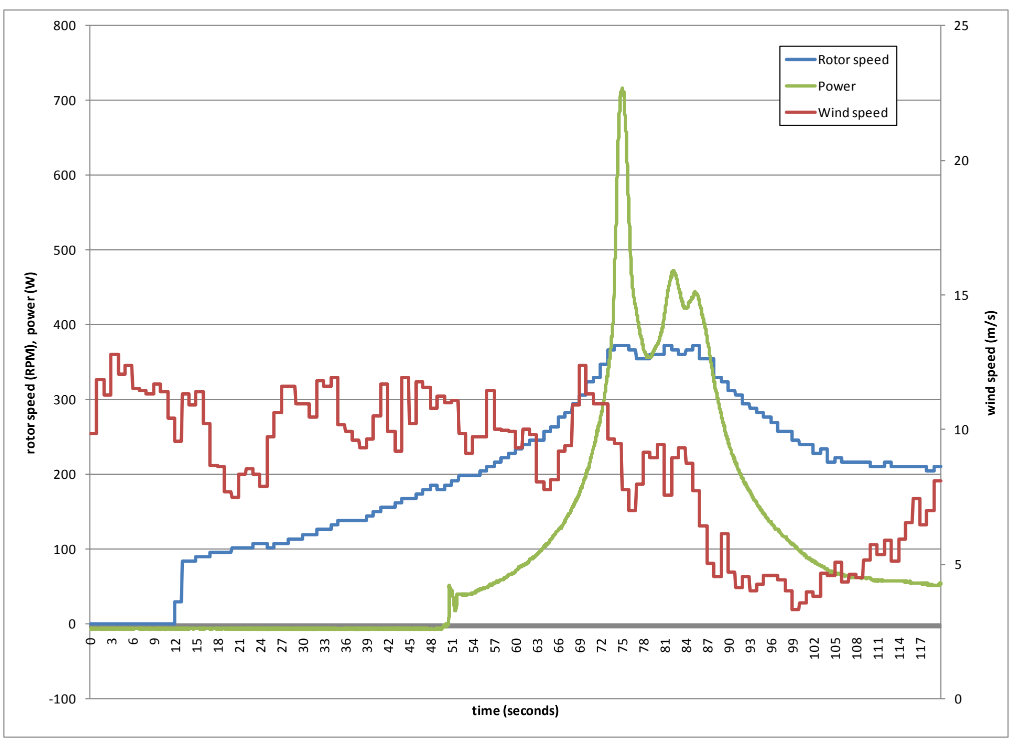


**Figure 6. Normal start-up after maintenance**

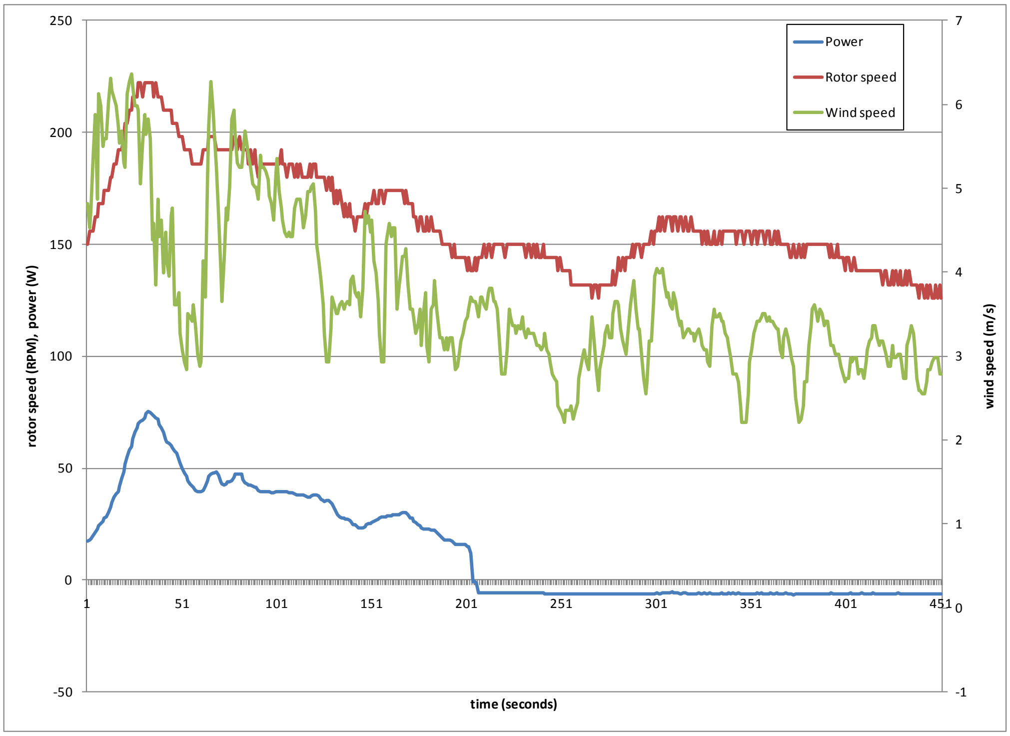


**Figure 7. Normal shut down, winds decreasing below cut in**

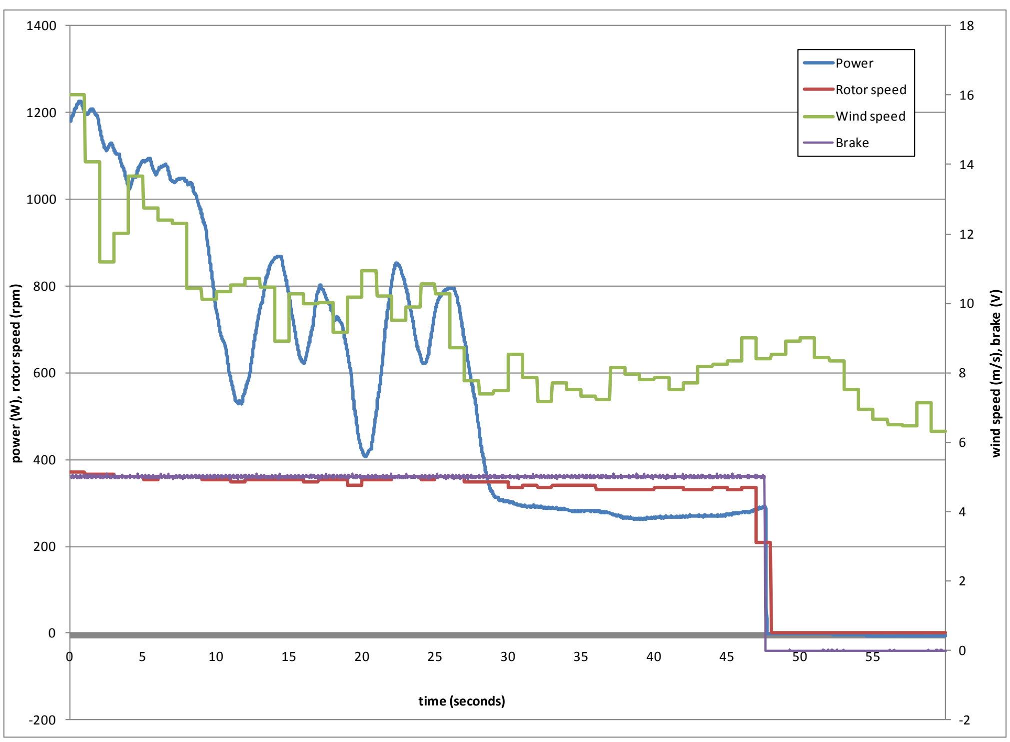


**Figure 8. Normal shut down, maintenance at design wind speed or greater**

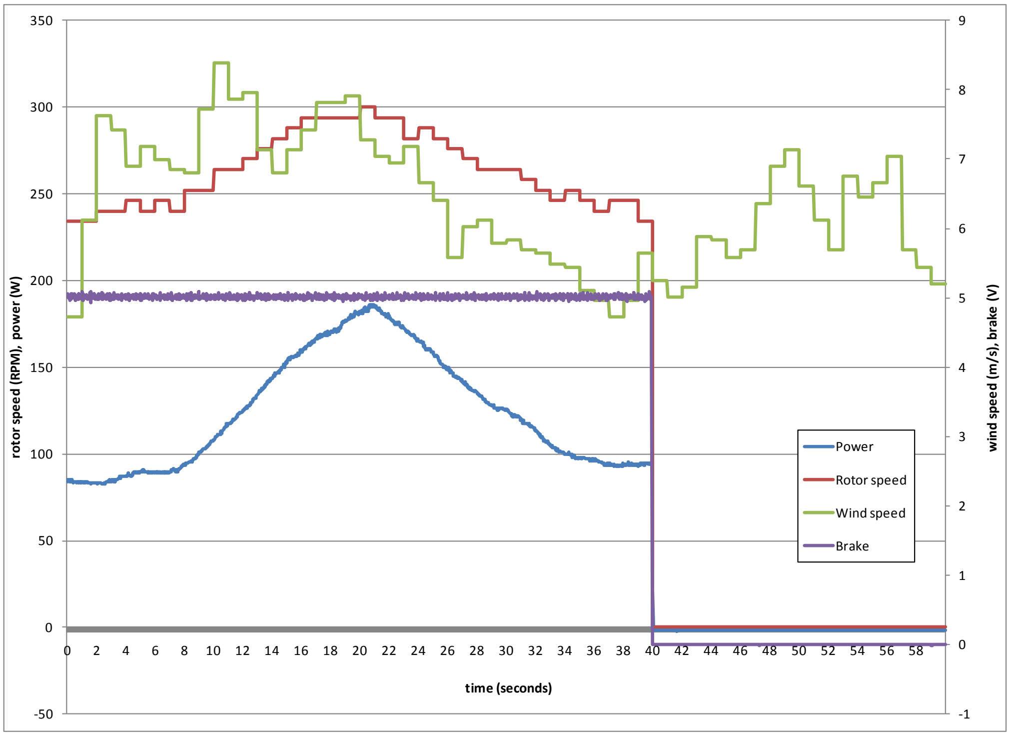


**Figure 9. Emergency stop at wind speeds less than the design wind speed**

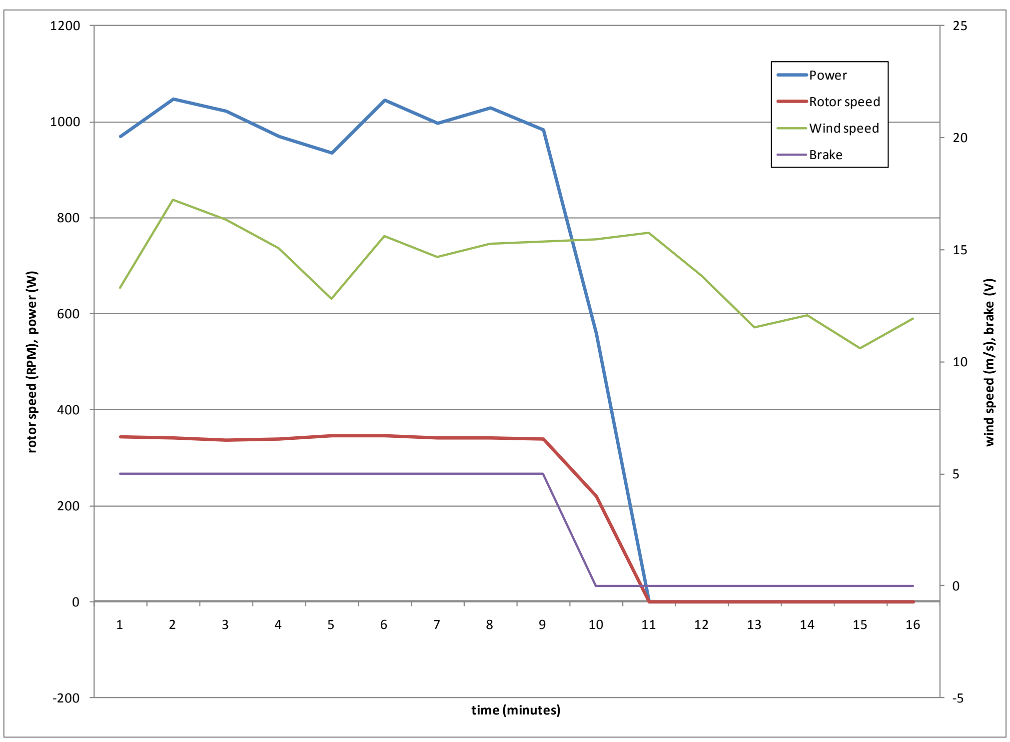


**Figure 10. Emergency stop at design wind speed or greater**

# 7 Deviations and Exceptions

## 7.1 Deviations from the Standard

Testing was terminated on the Windspire before testing of all of the critical functions listed in the IEC standard could be completed. The overspeed protection at design wind speed or above function that is listed in the IEC standard as a critical function was not tested.

## 7.2 Exceptions to the NWTC 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 Sheets

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**

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DAR
DKD-K- 36801

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| | |
|---|---|
| **Kalibrierschein** | Kalibrierzeichen |
| *Calibration Certificate* | *Calibration label* |

DKD-K-
36801
**07_2407**

| | |
|---|---|
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| Hersteller<br>*Manufacturer* | Thies Clima<br>D-37083 Göttingen |
| Typ<br>*Type* | 4.3350.00.000 |
| Fabrikat/Serien-Nr.<br>*Serial number* | Body: 0707894<br>Cup: 0707894 |
| Auftraggeber<br>*Customer* | Thies Clima<br>D-37083 Göttingen |
| Auftragsnummer<br>*Order No.* | VT07255 |
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*The DKD is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.*
*The user is obliged to have the object recalibrated at appropriate intervals.*

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

| Stempel<br>*Seal* | Datum<br>*Date* | Leiter des Kalibrierlaboratoriums<br>*Head of the calibration laboratory* | Bearbeiter<br>*Person in charge* |
|---|---|---|---|
| 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**

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.3. National Instruments 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.*

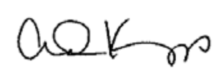
*The environment in which this product was calibrated is maintained within the operating specifications of the instrument and the standards.*

*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 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. National Instruments 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.5. National Instruments 9205 data-acquisition module calibration sheet I**

Davis Calibration

ACLASS ACCREDITED CALIBRATION

# Certificate of Calibration

3214335

Certificate Page 1 of 1

## 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 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.*

*This certificate shall not be reproduced except in full, without written consent of Davis Calibration Laboratory.*

Approved By: VICTOR PENA
Service Representative

## Calibration Standards

| NIST Traceable# | Inst. ID# | Description | Model | Cal Date | Date Due |
|---|---|---|---|---|---|
| 3143036 | 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.6. National Instruments 9229 data-acquisition module calibration sheet II**

Davis 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 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.*

*This certificate shall not be reproduced except in full, without written consent of Davis Calibration Laboratory.*

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.7. National Instruments 9217 data-acquisition module calibration sheet II**

Davis Calibration

ACLASS ACCREDITED CALIBRATION

# Certificate of Calibration

3214141

Certificate Page 1 of 1

## 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 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 |

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**Figure A.8. National Instruments 9205 data-acquisition module calibration sheet II**

| REPORT DOCUMENTATION PAGE | | *Form Approved* *OMB No. 0704-0188* |
|---|---|---|



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

| **4. TITLE AND SUBTITLE** | **5a. CONTRACT NUMBER** |
|---|---|
| Wind Turbine Safety and Function Test Report for the Mariah Windspire Wind Turbine | DE-AC36-08-GO28308 |
| | **5b. GRANT NUMBER** |
| | **5c. PROGRAM ELEMENT NUMBER** |
| **6. AUTHOR(S)** | **5d. PROJECT NUMBER** |
| A. Huskey, A. Bowen, and D. Jager | NREL/TP-500-47496 |
| | **5e. TASK NUMBER** |
| | WE10.2211 |
| | **5f. WORK UNIT NUMBER** |

| **7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)** | **8. PERFORMING ORGANIZATION REPORT NUMBER** |
|---|---|
| National Renewable Energy Laboratory<br>1617 Cole Blvd.<br>Golden, CO 80401-3393 | NREL/TP-500-47496 |
| **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 to wind energy expansion by providing independent testing results for small wind turbines (SWT). In total, five turbines were tested at the National Wind Technology Center (NWTC) as a part of this project. Safety and function testing is one of up to five tests performed on the turbines, including power performance, duration, 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. The test equipment includes a Mariah 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.

**15. SUBJECT TERMS**

wind turbine; Windspire; Independent testing; safety and function test; DOE; small wind turbine certification

| **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*) |

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