Wind Turbine Generator System Duration Test Report for the Gaia-Wind 11 kW Wind Turbine

Arlinda Huskey, Amy Bowen, and David Jager
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Approval By: ________________________________
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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

<table>
<thead>
<tr>
<th>General Configuration:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make, Model, Serial Number</td>
</tr>
<tr>
<td>Rotation Axis (H / V)</td>
</tr>
<tr>
<td>Orientation (upwind / downwind)</td>
</tr>
<tr>
<td>Number of Blades</td>
</tr>
<tr>
<td>Rotor Hub Type</td>
</tr>
<tr>
<td>Rotor Diameter (m)</td>
</tr>
<tr>
<td>Small Wind Turbine Class</td>
</tr>
<tr>
<td>Hub Height (m)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Performance:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Electrical Power (kW)</td>
</tr>
<tr>
<td>Rated Wind Speed (m/s)</td>
</tr>
<tr>
<td>Cut-in Wind Speed (m/s)</td>
</tr>
<tr>
<td>Cut-out Wind Speed (m/s)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rotor:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swept Area (m²)</td>
</tr>
<tr>
<td>Blade Pitch Control</td>
</tr>
<tr>
<td>Direction of Rotation</td>
</tr>
<tr>
<td>Rotor Speed</td>
</tr>
<tr>
<td>Power Regulation (active or passive)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tower:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
</tr>
<tr>
<td>Height (m)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Control / Electrical System:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controller: Make, Type</td>
</tr>
<tr>
<td>Electrical Output: Voltage</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Yaw System:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yaw control</td>
</tr>
</tbody>
</table>
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

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

### 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 $1.2 \times V_{ave}$ (9 m/s) totaled 711 hours (250 hours required).

The hours of power production above $1.8 \times V_{ave}$ (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

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

### 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 versus 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.
NREL METROLOGY LABORATORY

Test Report

Test Instrument: Multifunction Transducer  
Model #: BMT-1040E  
S/N: 06091906

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 = -15.798K to 15.798K.

<table>
<thead>
<tr>
<th>Input Current (AAC)</th>
<th>Input Power (KW)</th>
<th>Analog Output-1 (VDC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>14.965</td>
<td>4.811</td>
</tr>
<tr>
<td>12</td>
<td>9.977</td>
<td>3.209</td>
</tr>
<tr>
<td>6</td>
<td>4.988</td>
<td>1.604</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0.002</td>
</tr>
<tr>
<td>-6</td>
<td>-4.988</td>
<td>-1.602</td>
</tr>
<tr>
<td>-12</td>
<td>-9.977</td>
<td>-3.206</td>
</tr>
<tr>
<td>-18</td>
<td>-14.965</td>
<td>-4.807</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Power (KW)</th>
<th>Power Factor</th>
<th>Analog Output-2 (VDC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.0</td>
<td>5.001</td>
</tr>
<tr>
<td></td>
<td>0.8</td>
<td>3.995</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
<td>2.993</td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>1.991</td>
</tr>
</tbody>
</table>
**Kalibrierschein**

**Calibration Certificate**

<table>
<thead>
<tr>
<th>Gegenstand Object</th>
<th>Cup Anemometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hersteller Manufacturer</td>
<td>Thies Clima D-37083 Göttingen</td>
</tr>
<tr>
<td>Typ Type</td>
<td>4.3350.00.000</td>
</tr>
<tr>
<td>Fabrikat/Serien-Nr. Serial number</td>
<td>Body: 0707890 Cup: 0707850</td>
</tr>
<tr>
<td>Auftraggeber Customer</td>
<td>Thies Clima D-37083 Göttingen</td>
</tr>
<tr>
<td>Auftragsnummer Order No.</td>
<td>VT07255</td>
</tr>
<tr>
<td>Anzahl der Seiten des Kalibrierscheines Number of pages of the certificate</td>
<td>3</td>
</tr>
<tr>
<td>Datum der Kalibrierung Date of calibration</td>
<td>24.07.2007</td>
</tr>
</tbody>
</table>

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

Der DKD ist Unterzeichner der multi-lateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.

Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

*This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).*

*The DKD is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.*

*The user is obliged to have the object recalibrated at appropriate intervals.*

---

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26318 Varel; Tel. +49 (0)4451 9615 0

**Figure A.2. Primary anemometer calibration sheet**
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

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

Report Number: X4357-070913
Page: 1 of 1

Item Calibrated:
- Manufacturer: Met One Instruments, Inc
- Model: 020C
- Serial Number: X4357
- Vane Material: Aluminium
- Condition: Refurbished

Estimated Uncertainty:
- Inclinometer Uncertainty: 0.10 deg
- Total Uncertainty: 0.35 deg

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

Traceability:
- Inclinometer: Sky-Tronic 31-038-3 26-Mar-07
- Voltmeter: Fluke 74B 695506 13-May-07

Calibration by: Mark Meadows
13-Sep-07

Figure A.4. Wind vane calibration sheet
## NREL METROLOGY LABORATORY

### Test Report

**Test Instrument:** RTD Probe  
**Model #:** 78N01NO0N  
**DOE #:** 02885C  
**S/N #:** 0890084  
**Calibration Date:** 10/29/2007  
**Due Date:** 10/29/2008

<table>
<thead>
<tr>
<th>No</th>
<th>Nominal Values</th>
<th>Measured Values</th>
<th>Temperature Error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nominal resistance</td>
<td>Equivalent Temperature</td>
<td>Measured resistance</td>
</tr>
<tr>
<td>1</td>
<td>96.09 Ω</td>
<td>-10 °C</td>
<td>96.078 Ω</td>
</tr>
<tr>
<td>2</td>
<td>100.00 Ω</td>
<td>0 °C</td>
<td>99.995 Ω</td>
</tr>
<tr>
<td>3</td>
<td>103.90 Ω</td>
<td>10 °C</td>
<td>103.903 Ω</td>
</tr>
<tr>
<td>4</td>
<td>107.79 Ω</td>
<td>20 °C</td>
<td>107.796 Ω</td>
</tr>
<tr>
<td>5</td>
<td>111.67 Ω</td>
<td>30 °C</td>
<td>111.677 Ω</td>
</tr>
<tr>
<td>6</td>
<td>115.54 Ω</td>
<td>40 °C</td>
<td>115.546 Ω</td>
</tr>
</tbody>
</table>

**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:** Reds  
**QA by:** Bev

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

---

Figure A.5. RTD probe calibration sheet I
**Test Report**

**Test Instrument:** RTD-Probe  
**Model #:** 78N01N00N  
**S/N:** 0789021  
**Calibration Date:** 10/10/2008  
**Due Date:** 10/10/2009

<table>
<thead>
<tr>
<th>No</th>
<th>Function Tested</th>
<th>Nominal Value (°C)</th>
<th>Measured Values (°C)</th>
<th>( ) Mfr. Specs. OR (X) Data only</th>
</tr>
</thead>
<tbody>
<tr>
<td>*</td>
<td>Temperature:</td>
<td>0</td>
<td>99.96</td>
<td>Same</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25</td>
<td>109.41</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50</td>
<td>118.95</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

**Notes:**
- Calibration was performed using instruments that are traceable to NIST. DOM #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
# NREL METROLOGY LABORATORY

## Test Report

**Test Instrument:** Pressure Transmitter  
**Model #:** PTB101B  
**S/N:** C1040014

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

<table>
<thead>
<tr>
<th>No</th>
<th>Function Tested</th>
<th>Nominal Value (kPa)</th>
<th>Measured Output Voltage (VDC)</th>
<th>( )Mfr. Specs. OR (X)Data only (mb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Absolute Pressure</td>
<td></td>
<td>As Found</td>
<td>As Left</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>0.275</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>0.548</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>0.822</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>1.092</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>85</td>
<td>1.364</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>1.635</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>95</td>
<td>1.907</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>2.178</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>105</td>
<td>2.451</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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 02361C.

Calibrated By: Reds  
**Date:** 10/29/2007  
QA By: Bev  
**Date:** 10/29/2007

Figure A.7. Pressure transmitter calibration sheet
<table>
<thead>
<tr>
<th>Board Information:</th>
<th>Certificate Information:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serial Number: 12CBD7A</td>
<td>Certificate Number: 793243</td>
</tr>
<tr>
<td>NI Part Number: 192580D-02</td>
<td>Date Printed: 20-NOV-08</td>
</tr>
<tr>
<td>Description: NI 9229</td>
<td></td>
</tr>
</tbody>
</table>

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

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 Euronet 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.
Certificate of Calibration

Board Information:
Serial Number: 1219C99
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.

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
Figure A.11. NI 9229 data acquisition module post-test calibration sheet
Figure A.12. NI 9217 data acquisition module post-test calibration sheet
Certificate of Calibration

3214135
Certificate Page 1 of 1

Instrument Identification

Company ID: 250037
NATIONAL INSTRUMENTS
11500 N. MOPAC EXPWY
ATTN: EMA DEPT.
AUSTIN, TX 78759

Instrument ID: 1E05C99
Manufacturer: NATIONAL INSTRUMENTS
Model Number: NI 9205
Serial Number: 1E05C99
Description: 32-CH ±200 MV TO ±10 V, 16-BIT, 250 KSAM ANALOG INPUT MODULE

Accuracy: Mfr Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025

As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND

Procedure: NATIONAL INSTRUMENTS CAL EXECUTIVE REV 3.3.1

Remarks: Reference attached Data

Technician: WAYNE GETCHEL
Cal Date: 03May2009
Cal Due Date: 03May2010
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 47.0 %

The equipment on this certificate 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 common standards.

A test uncertainty ratio (T.U.R.) of ±1 % (95% Confidence Limit) was maintained unless otherwise stated.

Davis Calibration Laboratory is certified to ISO 17025:2005 by Eagle Registrations (证书 # 6496). Lab Operations meet the requirements of


All results contained within this certificate 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

<table>
<thead>
<tr>
<th>NIST Traceable#</th>
<th>Inst. ID#</th>
<th>Description</th>
<th>Model</th>
<th>Cal Date</th>
<th>Due Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>314838</td>
<td>15-0271</td>
<td>MULTIFUNCTION CALIBRATOR</td>
<td>5700A</td>
<td>15Apr2009</td>
<td>14Jul2009</td>
</tr>
</tbody>
</table>

Davis Calibration • 2324 Ridgeway Drive, Suite D • Austin, TX 78754 • Phone: 800-365-0147 • Fax: 512-926-8460

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.

<table>
<thead>
<tr>
<th>Task</th>
<th>Recorded Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Turbine Generator:</td>
<td></td>
</tr>
<tr>
<td>Electrical Inspection Completed</td>
<td></td>
</tr>
<tr>
<td>Gaia-Wind commissioning check list completed</td>
<td></td>
</tr>
<tr>
<td>Visually inspect blades for any cracks or deviations from normal</td>
<td></td>
</tr>
<tr>
<td>Inspect tower grounding</td>
<td></td>
</tr>
<tr>
<td>Verify freedom from excessive vibration</td>
<td></td>
</tr>
<tr>
<td>Verify that turbine blades spin freely at 8 m/s or above</td>
<td></td>
</tr>
<tr>
<td>Verify absence of excessive noise from generator</td>
<td></td>
</tr>
<tr>
<td>Verify power production to manufacturer's power curve at 8 m/s or above</td>
<td></td>
</tr>
<tr>
<td>Verify tower alignment</td>
<td></td>
</tr>
<tr>
<td>Verify all wire sized per manufacturer's drawing</td>
<td></td>
</tr>
<tr>
<td>Verify conductor sizing (tower - #6 or better)</td>
<td></td>
</tr>
<tr>
<td>Verify RPM signal from controller</td>
<td></td>
</tr>
<tr>
<td>Verify &quot;turbine status&quot; signal from controller</td>
<td></td>
</tr>
<tr>
<td>Measure the frequency under load</td>
<td></td>
</tr>
<tr>
<td>Measure the current under load</td>
<td></td>
</tr>
<tr>
<td>Measure the voltage under load</td>
<td></td>
</tr>
<tr>
<td>Verify manual shutdown from turbine specific disconnect</td>
<td></td>
</tr>
<tr>
<td>Verify 60 amp breaker size in power panel 3.3</td>
<td></td>
</tr>
<tr>
<td>Task</td>
<td>Status</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>Verify manual shutdown from 60 amp breaker function in power panel 3.3</td>
<td>45</td>
</tr>
<tr>
<td>Verify turbine re-connection after 3.3 breaker is tripped</td>
<td>45</td>
</tr>
<tr>
<td>At least one NREL employee trained</td>
<td>45</td>
</tr>
<tr>
<td>Review final as-built drawings for system installation and verify that drawings and installation are in agreement</td>
<td>45</td>
</tr>
</tbody>
</table>

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

Amy Bowen, NREL

15/05/08

15 May 08
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.
Wind Turbine Generator System Duration Test Report for the Gaia-Wind 11 kW Wind Turbine

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.