Wind Turbine Generator System Duration Test Report for the ARE 442 Wind Turbine

Jeroen van Dam, Don Baker, and David Jager
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Table of Contents

Background .................................................................................................................................................. 1
Test Objective and Requirements ............................................................................................................. 1
Description of Test Turbine ..................................................................................................................... 2
  Description of Test Site .......................................................................................................................... 6
Description of Instrumentation ................................................................................................................ 7
Results ...................................................................................................................................................... 8
  Operation Time ....................................................................................................................................... 8
  Months of Operation .............................................................................................................................. 8
  Hours of Power Production .................................................................................................................... 9
  Operational Time Fraction ................................................................................................................ ...... 9
  Failed IGBT’s ........................................................................................................................................ 10
  Over-temperature faults ....................................................................................................................... 10
  Over-voltage faults .............................................................................................................................. 10
  Remaining Ty ....................................................................................................................................... 10
  Environmental Conditions .................................................................................................................... 10
  Power Degradation Checks ................................................................................................................... 10
  Dynamic Behavior ............................................................................................................................... 11
  Tear-Down Inspection .......................................................................................................................... 11
Uncertainty ............................................................................................................................................... 14
  Hours of Power Production ................................................................................................................... 14
  Operational Time Fraction .................................................................................................................... 14
  Highest Instantaneous Wind Speed ....................................................................................................... 14
Deviations and Exceptions ...................................................................................................................... 14
  Deviations from the Standard .............................................................................................................. 14
  Deviations from Quality Assurance ..................................................................................................... 14
Appendix A: Instrument Calibration Certificates .................................................................................. 16
Appendix B: Turbine Commissioning Checklist .................................................................................... 31
Appendix C: Post-Test Teardown Inspection Report ............................................................................. 33
  Nose cone .............................................................................................................................................. 33
  Blades .................................................................................................................................................... 33
  Alternator ............................................................................................................................................. 33
  Yaw head .............................................................................................................................................. 33
  Tail assembly ....................................................................................................................................... 33
  Tower .................................................................................................................................................. 34
  Voltage clamp ..................................................................................................................................... 34
  Diversion loads .................................................................................................................................. 34
  Inverters ............................................................................................................................................... 34
Table of Figures

Figure 1. The ARE 442 wind turbine ............................................................................................................. 4
Figure 2. General electrical arrangement ....................................................................................................... 5
Figure 3. Map of the test site .......................................................................................................................... 6
Figure 4. Location of the data acquisition sensors ........................................................................................ 7
Figure 5. Diversion loads on exterior of data shed ........................................................................................ 12
Figure 6. Operational time fraction for each month ...................................................................................... 12
Figure 7. Scatter plot of power versus wind speed (10-minute averages) .................................................... 13
Figure 8. Power level in several wind speed bins (in m/s) as a function of time ............................................. 13
Figure A.1. Power transducer calibration sheet ............................................................................................ 17
Figure A.2. Primary anemometer calibration sheet I .................................................................................... 18
Figure A.3. Primary anemometer calibration sheet II ................................................................................... 19
Figure A.4. Wind vane calibration report ..................................................................................................... 20
Figure A.5. RTD-Probe calibration sheet I ................................................................................................... 21
Figure A.6. RTD-Probe calibration sheet II .................................................................................................. 22
Figure A.7. Pressure transmitter calibration sheet ........................................................................................ 23
Figure A.8. Pressure transmitter calibration sheet II .................................................................................... 24
Figure A.9. NI 9217 data acquisition module calibration sheet I ................................................................. 25
Figure A.10. NI 9229 data acquisition module calibration sheet I ................................................................. 26
Figure A.11. NI 9205 data acquisition module calibration sheet I ................................................................. 27
Figure A.12. NI 9229 data acquisition module calibration sheet II ............................................................... 28
Figure A.13. NI 9217 data acquisition module calibration sheet II ............................................................... 29
Figure A.14. NI 9205 data acquisition module calibration sheet II ............................................................... 30
Figure C-1. Remnants of trip strip on one of the blade tips .......................................................................... 35
Figure C-2. Crack in trailing edge of one of the blades ................................................................................. 35
Figure C-3. Crack in leading edge near blade root of blade #2. ................................................................. 36
Figure C-4. Crack in leading edge of blade #2 ............................................................................................. 36
Figure C-5. Cracked tail stop bumper ........................................................................................................... 37
Figure C-6. Bent furl stop ............................................................................................................................... 37
Figure C-7. Tail hinge pin ............................................................................................................................. 38
Figure C-8. Bent tower diagonal .................................................................................................................. 38
Figure C-9. Chipped coating on diversion loads .......................................................................................... 39

List of Tables

Table 1. Test turbine configuration and operational data ............................................................................... 3
Table 2. Equipment List for Duration Test ..................................................................................................... 8
Table 3. Monthly and overall results of the ARE 442 duration test ................................................................. 9
Background

This test is being 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, four turbines are being tested at the NWTC as a part of this project. Duration testing is one of up to 5 tests that may be performed on the turbines, including power performance, safety and function, noise, and power quality tests. The results of the testing provide manufacturers with reports that may be used for small wind turbine certification.

The test equipment includes a grid connected ARE 442 wind turbine mounted on a 30.5 meter (100 ft) lattice tower manufactured by Abundant Renewable Energy. The system was installed by the NWTC Site Operations group with guidance and assistance from Abundant Renewable Energy.

Test Objective and Requirements

The objective of this test is to assess the following aspects of the ARE 442 wind turbine with Windy Boy US 6000 inverters 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 (throughout the report referred to as the Standard).

- 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 $1.2V_{ave}$ (10.2 m/s) and above
- 25 hours of power production in winds of $1.8V_{ave}$ (15.3 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, Abundant Renewable Energy identified the test turbine to be a class II. This corresponds to a $V_{ave}$ of 8.5 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 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.

**Description of Test Turbine**

The test turbine (Figure 1) is a three bladed, upwind, furling turbine with a rated power of 10kW. Table 1 lists basic turbine configuration and operational data. Figure 2 shows the one-line diagram for the test turbine installation.

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 3.3a.
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>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Make, Model, Serial Number</td>
<td>Abundant Renewable Energy, ARE 442, Y08-001C</td>
</tr>
<tr>
<td>Rotation Axis (H / V)</td>
<td>Horizontal</td>
</tr>
<tr>
<td>Orientation (upwind / downwind)</td>
<td>Upwind</td>
</tr>
<tr>
<td>Number of Blades</td>
<td>3</td>
</tr>
<tr>
<td>Rotor Hub Type</td>
<td>Fixed</td>
</tr>
<tr>
<td>Rotor Diameter (m)</td>
<td>7.2</td>
</tr>
<tr>
<td>Small Wind Turbine Class</td>
<td>II</td>
</tr>
<tr>
<td>Hub Height (m)</td>
<td>30.9</td>
</tr>
<tr>
<td>Performance:</td>
<td></td>
</tr>
<tr>
<td>Rated Electrical Power (kW)</td>
<td>10</td>
</tr>
<tr>
<td>Rated Wind Speed (m/s)</td>
<td>11</td>
</tr>
<tr>
<td>Cut-in Wind Speed (m/s)</td>
<td>2.2</td>
</tr>
<tr>
<td>Cut-out Wind speed (m/s)</td>
<td>N/A</td>
</tr>
<tr>
<td>Rotor:</td>
<td></td>
</tr>
<tr>
<td>Swept Area (m²)</td>
<td>40.7</td>
</tr>
<tr>
<td>Blade Pitch Control</td>
<td>None</td>
</tr>
<tr>
<td>Direction of Rotation</td>
<td>Clockwise viewed from up wind</td>
</tr>
<tr>
<td>Rotor Speed</td>
<td>0 – 200</td>
</tr>
<tr>
<td>Power Regulation (active or passive)</td>
<td>Passive</td>
</tr>
<tr>
<td>Tower:</td>
<td></td>
</tr>
<tr>
<td>Type                                    Freestanding Lattice Valmont U4.5 x 100’</td>
<td></td>
</tr>
<tr>
<td>Height (m)</td>
<td>30.5 (100ft)</td>
</tr>
<tr>
<td>Control / Electrical System:</td>
<td></td>
</tr>
<tr>
<td>Controller: Make, Type</td>
<td>Combination of side furling with gravity return, VCL 442-HV voltage clamp and Windy Boy US6000 inverter software.</td>
</tr>
<tr>
<td>Electrical Output: Voltage</td>
<td>240 VAC, single-phase</td>
</tr>
<tr>
<td>Yaw System:</td>
<td></td>
</tr>
<tr>
<td>Yaw control</td>
<td>Passive</td>
</tr>
</tbody>
</table>
The test configuration consists of the turbine mounted on a lattice 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 freestanding 30.5 meter, lattice tower. The wire run from the base of the tower to the data shed is approximately 98 meters of #6 AWG wire. Inside the data shed there is a voltage clamp, and two inverters. Those are wired to a sub panel which in its turn is hooked up to a disconnect switch. Figure 2 shows the general electrical arrangement.
Figure 2. General electrical arrangement
Description of Test Site

The test turbine is located at site 3.3a at the National Wind Technology Center, located 8 miles south of Boulder, Colorado. The terrain primarily consists of mostly flat terrain with short vegetation. The test site has prevailing wind bearing 292 degrees relative to true north. For measurements where it is important to accurately measure wind speed, NREL use data obtained when wind direction is between 214° and 74° degrees true. 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. Figure 4 shows the turbine and meteorological tower locations. This figure also shows nearby obstructions and topographical features of the site. A circle indicating 20 rotor diameters is drawn in the map.

Figure 3. Map of the test site
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 a signal to monitor the brake resistors in the yaw head as an indication of turbine availability (0V means brake applied; 5V means not applied). 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. The primary anemometer was sent out for recalibration after the test period. The difference between the two calibrations was within the tolerances allowed by IEC 61400-12-1.

Figure 4. Location of the data acquisition sensors
## Table 2. Equipment List for Duration Test

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Make, Model</th>
<th>Serial Number</th>
<th>Calibration Due Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power transducer</td>
<td>Secondwind Phaser 5FM-4A20</td>
<td>02663</td>
<td>28 Apr 2009</td>
</tr>
<tr>
<td>Current transducers</td>
<td>OSI 12974</td>
<td>001235408</td>
<td>Calibrated with power transducer</td>
</tr>
<tr>
<td>Primary anemometer</td>
<td>Thies, First Class</td>
<td>0707886, 0707888</td>
<td>28 Feb 2009, 2 Feb 2010</td>
</tr>
<tr>
<td>Reference anemometer</td>
<td>NRG, Max 40</td>
<td>179500049022</td>
<td>In situ</td>
</tr>
<tr>
<td>Wind vane</td>
<td>Met One, 020C with aluminum vane</td>
<td>G4706</td>
<td>28 Feb 2009</td>
</tr>
<tr>
<td>Temperature sensor</td>
<td>Met One, T-200</td>
<td>0675552, 0789020</td>
<td>29 Oct 2008, 10 Oct 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-based data acquisition cDAQ-9172</td>
<td>12EAE14, 12A2037, 12C73B4, 12ECB77</td>
<td>31 May 2008, 3 Aug 2008, 9 Oct 2008</td>
</tr>
</tbody>
</table>

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 also inserted in Appendix A.

The wind vane calibration also expired during the test. In field calibration checks were performed to verify validity of the calibration.

The power transducer was out of calibration for the last two days of the test. These two days do not significantly affect the test results.

## Results

### Operation Time
The test turbine system was installed on 9 and 10 June 2008. It was ready for testing on 12 June 2008. On 13 June 2008 during a power outage IGBT’s in the voltage clamp failed. These were replaced and the duration test officially started on 7 July 2008. The duration test was completed on 30 April 2009, after enough data was collected to demonstrate sufficient hours of operation as required by the standard. The commissioning checklist from the installation can be found in Appendix B.

### Months of Operation
The duration test was conducted over a period of a little over 9.5 months from July 7th, 2008, to April 30th, 2009 (6 months were required). The turbine has continued to operate since then until it was shut down for removal on 10 December 2009.
**Hours of Power Production**
The hours of power production at any wind speeds: 3,240 hours (2,500 hours required)

The hours of power production above 1.2*V_ave (10.2 m/s): 552 hours (250 hours required)

The hours of power production above 1.8*V_ave (15.3 m/s): 156 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 ARE 442 duration test**

<table>
<thead>
<tr>
<th>Month</th>
<th>Hours of Power Production Above:</th>
<th>Max Gust (m/s)</th>
<th>Tl @ 15 m/s (% Points)</th>
<th>T_r (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>3240.6</td>
<td>552.6</td>
<td>156.7</td>
<td>42.9</td>
<td>18.9</td>
<td>325</td>
<td>99.7</td>
<td>214.8</td>
</tr>
<tr>
<td>Jul 2008</td>
<td>295.8</td>
<td>7.5</td>
<td>0.0</td>
<td>27.8</td>
<td>15.8</td>
<td>3</td>
<td>735</td>
<td>3.1</td>
</tr>
<tr>
<td>Aug 2008</td>
<td>286.8</td>
<td>9.5</td>
<td>0.0</td>
<td>26.5</td>
<td>16.9</td>
<td>1</td>
<td>739</td>
<td>26.0</td>
</tr>
<tr>
<td>Sep 2008</td>
<td>217.5</td>
<td>8.8</td>
<td>0.7</td>
<td>23.2</td>
<td>13.8</td>
<td>8</td>
<td>687</td>
<td>16.6</td>
</tr>
<tr>
<td>Oct 2008</td>
<td>279.7</td>
<td>35.7</td>
<td>6.7</td>
<td>34.0</td>
<td>16.9</td>
<td>13</td>
<td>744</td>
<td>0.9</td>
</tr>
<tr>
<td>Nov 2008</td>
<td>156.0</td>
<td>8.2</td>
<td>0.0</td>
<td>34.3</td>
<td>19.5</td>
<td>44</td>
<td>720</td>
<td>0.0</td>
</tr>
<tr>
<td>Dec 2008</td>
<td>379.2</td>
<td>131.8</td>
<td>41.8</td>
<td>42.9</td>
<td>18.2</td>
<td>72</td>
<td>744</td>
<td>1.0</td>
</tr>
<tr>
<td>Jan 2009</td>
<td>466.5</td>
<td>146.3</td>
<td>44.3</td>
<td>42.9</td>
<td>20.0</td>
<td>93</td>
<td>744</td>
<td>0.7</td>
</tr>
<tr>
<td>Feb 2009</td>
<td>389.3</td>
<td>104.5</td>
<td>46.3</td>
<td>39.5</td>
<td>19.7</td>
<td>33</td>
<td>672</td>
<td>4.0</td>
</tr>
<tr>
<td>Mar 2009</td>
<td>416.8</td>
<td>68.3</td>
<td>13.2</td>
<td>34.9</td>
<td>18.4</td>
<td>44</td>
<td>744</td>
<td>3.9</td>
</tr>
<tr>
<td>Apr 2009</td>
<td>353.0</td>
<td>32.0</td>
<td>3.7</td>
<td>28.4</td>
<td>18.0</td>
<td>14</td>
<td>720</td>
<td>43.5</td>
</tr>
</tbody>
</table>

**Operational Time Fraction**
The operational time fraction is defined as follows:

\[
O = \frac{T_r - T_N - T_U - T_E}{T_r - T_U - T_E} \times 100\%
\]

where:

- \(T_r\) 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 91.2%. Figure 6 and Table 3 show the operational time fraction per month.

The main reasons for wind turbine system downtime (\(T_N\)) during the test period were failed IGBT’s, over-temperature faults and over-voltage faults. These faults are described in more detail below.
Failed IGBT’s
On November 5, a grid outage was simulated in 6-7 m/s winds by opening the disconnect switch. The turbine shut down but upon reconnection to the grid the turbine would not start up again. It was found that the IGBT’s in the voltage clamp had failed. New chopper boards were received on 19 November 2008. The period from 5 through 19 November 2008 is counted as T_N.

Over-temperature faults
At the start of the test, the diversion loads were installed inside the data shed per the manufacturers installation instructions. The data shed was unable to disperse the heat which caused the turbine to experience over temperature faults in high winds. The ten minute periods in which the turbine was faulted for more than 300 seconds were counted at T_N. On 10 and 11 February 2009, the diversion loads were moved to the exterior of the data shed (Figure 5) to avoid further over temperature faults.

Over-voltage faults
After the diversion loads were moved to the exterior of the building no more over-temperature faults were observed. Instead, in high winds, the turbine would fault to over-voltage faults. The ten minute periods in which the turbine was faulted for more than 300 seconds were counted as T_N.

Remaining T_N
Occasionally the turbine’s controller would get stuck in “Test” mode, even though the winds were above cut-in wind speed. This was resolved by cycling power to the voltage clamp. From the time when the turbine was last running to the time the power was cycled was counted as T_N.

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

- Time during power outages that prevented the turbine from running
- 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.

Environmental Conditions
As an indication of the environmental conditions during the duration test, the standard requires reporting of the highest instantaneous wind speed gust and the average turbulence intensity at 15 m/s. The highest instantaneous wind speed was 42.9 m/s at 16:41 on 7 January 2009. The average turbulence intensity at 15 m/s during the duration test was 18.9%.

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 was plotted as a function of time over the whole test period. This plot is analyzed for any obvious trends in power production.
Figure 8 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.

**Dynamic Behavior**
The turbine has been observed over a wide range of wind speeds. The turbine did not exhibit excessive vibration during any of the recorded observations. The following are paraphrased examples of dynamic behavior observations made in the logbook:

26 August 2008 – Observed turbine in 5-6 m/s. The turbine tracks the wind’s direction but always seems to be 20 degrees off (due to the offset tail). The generator hums audibly, and there was occasional noise of sheet metal vibrations, with the likely cause as the cover of the electrical box. There was no excessive vibration

24 February 2009 – The turbine was observed for 20 minutes in 8-12 m/s. There was no observable excessive vibrations. The turbine tracks wind well.

26 February 2009 - Throughout the day (9:30 to 17:00), the turbine was observed in winds from 25 m/s to 3 m/s. At high winds, the rotor operated at high yaw errors (30-40°) and the furl movements excited the tower lightly. At low wind speeds (<10 m/s), there was hardly any vibration noticeable. At the cut in, metal boxes or sheet metal resonates. Overall, there did not appear to be any excessive vibrations present. Observation times were one hour below 10 m/s, and one hour above 15 m/s

**Tear-Down Inspection**
The tear down inspection was performed on 15 December 2009. The results are documented in Appendix C. The main finding was a leading edge crack in one of the blades.
Figure 5. Diversion loads on exterior of data shed

Figure 6. Operational time fraction for each month
Figure 7. Scatter plot of power versus wind speed (10-minute averages)

Figure 8. Power level in several wind speed bins (in m/s) as a function of time
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 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. 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 continued to run through December 2009. Thus, NREL is confident that it achieved the 2,500 hours required by the standard.

For the hours of power production above 10.2 and 15.3 m/s, the uncertainty in the wind speed was assumed to be the dominant factor. Assuming an uncertainty in wind speed of 0.3 m/s, the hours of power production reduce to 512 (above 10.5 m/s) and 147 (above 15.6 m/s) well exceeded the 250 and 25 hours that the standard requires.

**Operational Time Fraction**

The total test time is 7,249 hours. Even if the classification of $T_N$ was wrong by 5% (which is a conservative assumption), the operational time fraction would be 90.7%.

**Highest Instantaneous Wind Speed**

The uncertainties in the wind speed measurements were 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 42.9 m/s, the uncertainty was 0.99 m/s.

Deviations and Exceptions

**Deviations from the Standard**

None.

**Deviations from Quality Assurance**

The data acquisition modules were used beyond the calibration due date. They were post-test calibrated and found to be in compliance within the specifications. Appendix A includes the post-test calibration sheets.
The wind vane was used beyond its calibration due date. In field calibration verification, checks were performed by pointing the vane at known distant landmarks. It should be noted that the wind vane is not a critical or required instrument for the duration test.

The power transducer was used two days beyond its calibration due date. These two days do not significantly impact test results.
Appendix A: Instrument Calibration Certificates

Figures A.1 through A.14 show the calibration sheets for the instruments used during the duration test.
NREL METROLOGY LABORATORY

Test Report

Test Instrument: Phaser Power Transducer & 2-CTS
Model #: Phaser-5-F-5A
Calibration Date: 01/28/2008

<table>
<thead>
<tr>
<th>Input Current (AAC)</th>
<th>Input Power (KW)</th>
<th>Analog Output-1 (VDC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>6.72</td>
<td>4.790</td>
</tr>
<tr>
<td>21</td>
<td>5.04</td>
<td>4.341</td>
</tr>
<tr>
<td>14</td>
<td>3.36</td>
<td>3.892</td>
</tr>
<tr>
<td>7</td>
<td>1.68</td>
<td>3.444</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>2.995</td>
</tr>
<tr>
<td>-7</td>
<td>-1.68</td>
<td>2.547</td>
</tr>
<tr>
<td>-14</td>
<td>-3.36</td>
<td>2.099</td>
</tr>
<tr>
<td>-21</td>
<td>-5.04</td>
<td>1.651</td>
</tr>
<tr>
<td>-28</td>
<td>-6.72</td>
<td>1.203</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>6.72</td>
<td>1.0</td>
<td>4.989</td>
</tr>
<tr>
<td>&quot;</td>
<td>0.8</td>
<td>4.179</td>
</tr>
<tr>
<td>&quot;</td>
<td>0.6</td>
<td>3.377</td>
</tr>
<tr>
<td>&quot;</td>
<td>0.4</td>
<td>2.577</td>
</tr>
<tr>
<td>&quot;</td>
<td>0.2</td>
<td>1.778</td>
</tr>
</tbody>
</table>

Page 1 of 2

Figure A.1. Power transducer calibration sheet
Kalibrerschein
Calibration Certificate

Gegenstand
Object
Cup Anemometer

Hersteller
Manufacturer
Thies Clima
D-37083 Göttingen

Typ
Type
4.3350.00.000

Fabrikat/Serien-Nr.
Serial number
Body: 0707886
Cup: 0707886

Auftraggeber
Customer
Thies Clima
D-37083 Göttingen

Auftragsnummer
Order No.
VII07255

Anzahl der Seiten des Kalibrierscheines
Number of pages of the certificate
3

Datum der Kalibrierung
Date of calibration
24.07.2007

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

Diese 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
Varel

DKD-K- 36801

07_2417

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)

Deutscher
Kalibrierdienst
DKD

Deutsche WindGuard
Wind Tunnel Services GmbH
Varel

DKD-K- 36801

Figure A.2. Primary anemometer calibration sheet I

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 85
26316 Varel ; Tel. +49 (0)4451 9515 0

18
## Kalibrierschein

### Calibration Certificate

<table>
<thead>
<tr>
<th>Gegenstand</th>
<th>Cup Anemometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hersteller</td>
<td>Thies Clima</td>
</tr>
<tr>
<td>Typ</td>
<td>D-37083 Göttingen</td>
</tr>
<tr>
<td>Typo</td>
<td>4.3350.00.000</td>
</tr>
<tr>
<td>Fabrikat/Serien-Nr.</td>
<td>Body: 0707888 Cup: 0707888</td>
</tr>
<tr>
<td>Auftraggeber</td>
<td>Thies Clima</td>
</tr>
<tr>
<td></td>
<td>D-37083 Göttingen</td>
</tr>
<tr>
<td>Auftragsnummer</td>
<td>VT07255</td>
</tr>
<tr>
<td>Anzahl der Seiten des Kalibrierscheines</td>
<td>3</td>
</tr>
<tr>
<td>Datum der Kalibrierung</td>
<td>24.07.2007</td>
</tr>
</tbody>
</table>

 Dieser Kalibrierschein dokumentiert die Repräsentation auf nationale Normen zur Erstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).

Der DKD ist Zeichner der multi-lateral 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.

<table>
<thead>
<tr>
<th>Stempel</th>
<th>Datum</th>
<th>Leiter des Kalibrierlaboratoriums</th>
<th>Beauftragter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24.07.2007</td>
<td>Head of the calibration laboratory</td>
<td></td>
</tr>
</tbody>
</table>

Deutscher WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 55
29318 Varel; Tel. ++49 (0)451 8915 0

**Figure A.3. Primary anemometer calibration sheet II**
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: G4705-070913

Page: 1 of 1

Item Calibrated:
- Manufacturer: Met One Instruments, Inc
- Model: 020C
- Serial Number: G4708
- Vane Material: Aluminum
- Condition: Refurbished

Estimated Uncertainty:
- Inclinometer Uncertainty (deg): 0.10
- Total Uncertainty (deg): 0.57

Calibration by: Mark Meadors

Customer: National Wind Technology Center - Certification Team National Renewable Energy Laboratory 1617 Cole Boulevard Golden, Colorado 80401

Calibration Date: 13-Sep-07

Procedure:
NWTC-CT: G244-000813, Wind Vane Calibration

Deviations from procedure:
- Calibrated on 5V range
- Calibrated in Volts (not mV)

Results:
- Offset to beam: 94.81 deg
- Max error: 0.99 deg

Traceability:
- Inclinometer: Spi-Tronic 31-033-3 22-Mar-07
- Voltmeter: Fluke 7438 695608 10-May-07

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

## Test Report

**Test Instrument:** RTD Probe  
**Model #:** 78NO01NO0004  
**Calibration Date:** 10/29/2007  
**Due Date:** 10/29/2008

<table>
<thead>
<tr>
<th>No</th>
<th>Nominal Resistance / Equivalent Temperature</th>
<th>Measured Resistance / Equivalent Temperature</th>
<th>Temperature Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>96.09 Ω / -10 °C</td>
<td>96.082 Ω / -10.02 °C</td>
<td>0.02 °C</td>
</tr>
<tr>
<td>2</td>
<td>100.00 Ω / 0 °C</td>
<td>100.002 Ω / 0.01 °C</td>
<td>-0.01 °C</td>
</tr>
<tr>
<td>3</td>
<td>103.90 Ω / 10 °C</td>
<td>103.906 Ω / 10.02 °C</td>
<td>-0.02 °C</td>
</tr>
<tr>
<td>4</td>
<td>107.79 Ω / 20 °C</td>
<td>107.780 Ω / 19.97 °C</td>
<td>-0.03 °C</td>
</tr>
<tr>
<td>5</td>
<td>111.67 Ω / 30 °C</td>
<td>111.678 Ω / 30.02 °C</td>
<td>-0.02 °C</td>
</tr>
<tr>
<td>6</td>
<td>115.54 Ω / 40 °C</td>
<td>115.548 Ω / 40.02 °C</td>
<td>-0.02 °C</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: Reda  
Date: 10/29/2007  
QA by: Bev  
Date: 10/29/2007

---

Figure A.5. RTD-Probe calibration sheet I
<table>
<thead>
<tr>
<th>No</th>
<th>Function Tested</th>
<th>Nominal Value (°C)</th>
<th>Measured Value (°C)</th>
<th>(X) Mfr. Specs. OR (X) Data only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temperature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>99.95</td>
<td>Same</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>109.68</td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>119.32</td>
<td>&quot;</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- Calibration was performed using instruments that are traceable to NIST. DOEs 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
## Test Report

**Test Instrument:** Pressure Transmitter  
**Model #:** PTB101B  
**S/N:** C1020015  
**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. Spec. OR (X)Data only (mb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>*</td>
<td>Absolute Pressure</td>
<td>65</td>
<td>0.274</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>70</td>
<td>0.547</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>75</td>
<td>0.818</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>80</td>
<td>1.081</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>85</td>
<td>1.362</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>90</td>
<td>1.634</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>95</td>
<td>1.905</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>100</td>
<td>2.177</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>105</td>
<td>2.450</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 02301C.

**Calibrated By:** Reda  
**Date:** 10/29/2007  
**QA By:** Rev  
**Date:** 10/29/2007

---

**Figure A.7.** Pressure transmitter calibration sheet
## Test Report

**Test Instrument:** Pressure Transmitter  
**Model #:** PTBI01B  
**Calibration Date:** 08/26/2008  
**Due Date:** 08/26/2009

<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 (nb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>As Found</td>
<td>As Left</td>
</tr>
<tr>
<td>*</td>
<td>Absolute Pressure</td>
<td>65</td>
<td>0.287</td>
<td>Same</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70</td>
<td>0.569</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75</td>
<td>0.832</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80</td>
<td>1.105</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>85</td>
<td>1.377</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90</td>
<td>1.648</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>95</td>
<td>1.921</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100</td>
<td>2.194</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>105</td>
<td>2.467</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

**Notes:**  
1. Uncertainty of the nominal value is ± 0.2 kPa, k = 2.  
2. Calibration was performed at 23°C and 37% RH.  
3. Calibration was performed using standards that are traceable to NIST. DOE numbers: 02625C, 02727C, and 02301C.

Calibrated By: Rada  
Date: 08/26/2008  
QA By: Bev  
Date: 08/26/2008

---

**Figure A.8. Pressure transmitter calibration sheet II**
<table>
<thead>
<tr>
<th>Board Information:</th>
<th>Certificate Information:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serial Number: 12C73B4</td>
<td>Certificate Number: 786529</td>
</tr>
<tr>
<td>NI Part Number: 192547D-01</td>
<td>Date Printed: 05-JAN-09</td>
</tr>
<tr>
<td>Description: NI 9217</td>
<td></td>
</tr>
</tbody>
</table>

Calibration Date: 03-AUG-07  
Recommended Calibration Due Date: 03-AUG-08*

Ambient Temperature: 23 °C  
Relative Humidity: 46 %

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,  

[Signature]

Andrew Krupp  
Quality Director

* Recommended calibration due date is based on a combination of calibration interval and, when applicable, calibration shelf life. This date may vary depending on your application requirements.

Figure A.9. NI 9217 data acquisition module calibration sheet I
### Board Information:
- **Serial Number:** 12A2037
- **NI Part Number:** 192580D-02
- **Description:** NI 9229

- **Calibration Date:** 31-MAY-07
- **Recommended Calibration Due Date:** 31-MAY-08*

- **Ambient Temperature:** 22 °C
- **Relative Humidity:** 50 %

---

### Certificate Information:
- **Certificate Number:** 733748
- **Date Printed:** 05-JAN-09

---

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.

---

*Signed,*

Andrew Krupp
Quality Director

* Recommended calibration due date is based on a combination of calibration interval and, when applicable, calibration shelf life. This date may vary depending on your application requirements.

---

**Figure A.10. NI 9229 data acquisition module calibration sheet I**
Board Information:
Serial Number: 12ECCB77
NI Part Number: 193299F-01
Description: NI-9205

Certificate Information:
Certificate Number: 837236
Date Printed: 05-JAN-09

Calibration Date: 09-OCT-07
Recommended Calibration Due Date: 09-OCT-08*

Ambient Temperature: 23 °C
Relative Humidity: 37 %

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 I/A.
HUNGARY

Signed,

[Signature]

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.11. NI 9205 data acquisition module calibration sheet I
Certificate of Calibration

Company ID: 229037
NATIONAL INSTRUMENTS
11500 N. MOPAC EXPWY
ATTN: RMA DEPT.
AUSTIN, TX 78759

Instrument ID: 12A2037
Manufacturer: NATIONAL INSTRUMENTS
Model Number: NI 9229
Serial Number: 12A2037
Description: 4-CHANNEL, ±60 V, 24-BIT SIMULTANEOUS ANALOG INPUT
Accuracy: Mfr Specifications

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

Technician: WAYNE GETCHELL
Cal Date: 06May2009
Cal Due Date: 06May2010
Interval: 12 MONTHS
Temperature: 23.0 °C
Humidity: 44.0%

The instrument 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 consensus standards.

A test uncertainty ratio (T.U.R.) of 6:1 (K=2, approx. 95% Confidence Level) was maintained unless otherwise stated.


ISO/IEC 17025-2005 accredited calibrations are per ACLASS certificate # 56-1187 within the scope for which the lab is accredited.

All results contained within this certificate relate only to items calibrated. Any number of factors may cause the calibration note 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>Date Due</th>
</tr>
</thead>
<tbody>
<tr>
<td>3143038</td>
<td>15-9271</td>
<td>MULTIFUNCTION CALIBRATOR</td>
<td>5703A</td>
<td>15Apr2009</td>
<td>14Jul2009</td>
</tr>
</tbody>
</table>

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

Figure A.12. NI 9229 data acquisition module calibration sheet II
Figure A.13. NI 9217 data acquisition module calibration sheet II
Certificate of Calibration

Company ID: 229037
NATIONAL INSTRUMENTS
11500 N. MOPAC EXPWY
ATTN: RMA DEPT.
AUSTIN, TX 78759

Instrument ID: 12ECB77
Manufacturer: NATIONAL INSTRUMENTS
Model Number: NI 9205
Serial Number: 12ECB77

Description: 32-CH ±200 MV TO ±10 V, 16-BIT, 250 KS/S 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 GETCHELL
Cal Date: 06May2008
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 national type measurements, or compared to nationally or internationally recognized consensus standards.

A test uncertainty ratio (T.U.R.) of 4:1 [R=4], approx. 95% Confidence Level, was maintained unless otherwise stated.


ISO/IEC 17025-2005 accredited calibrations are per ACLASS certificate #AC-11W1 within the scope for which the lab is accredited.

All results contained within this certification relate only to items(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>Date Due</th>
</tr>
</thead>
<tbody>
<tr>
<td>3143038</td>
<td>15-0271</td>
<td>MULTIFUNCTION CALIBRATOR</td>
<td>5700A</td>
<td>15Apr2009</td>
<td>14Jul2009</td>
</tr>
</tbody>
</table>

Figure A.14. NI 9205 data acquisition module calibration sheet II
Appendix B: Turbine Commissioning Checklist

Commissioning Procedure for ARE 442 Wind Turbine Generator at Site 3.3A
6/6/08

1.0 Introduction

NREL will perform an acceptance test for the ARE 442 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 inverters 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

<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>Verify all wire sized per manufacturer drawing and one liner</td>
<td></td>
</tr>
<tr>
<td>Verify 60 amp breaker size in power panel 3.3L</td>
<td></td>
</tr>
<tr>
<td>Visually inspect turbine components for any damage or deviations from normal</td>
<td></td>
</tr>
<tr>
<td>Inspect tower grounding</td>
<td></td>
</tr>
<tr>
<td>Verify tower alignment</td>
<td></td>
</tr>
<tr>
<td>ARE 442 commissioning procedure (chapter 11 in manual) followed for first start up</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</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 conductor sizing (tower - #6 or better)</td>
<td></td>
</tr>
<tr>
<td>Verify RPM signal from controller</td>
<td></td>
</tr>
<tr>
<td>Verify “turbine status” 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 manual shutdown from 60 amp breaker function in power panel 3.3</td>
<td></td>
</tr>
</tbody>
</table>

Date: Conducted by:
4.0 Acceptance of Commissioning Procedures
The installation of the ARE 442 Wind Turbine Generator at Site 3.3A 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.

Robert Preus, Abundant Renewable Energy  6/13/08

Jeroen van Dam, NREL  6/13/08
Appendix C: Post-Test Teardown Inspection Report

The ARE 442 turbine was taken down from site 3.3a on December 15 after NREL completed all testing activities as part of the Independent Testing project. A tear down inspection is performed as a part of the duration test. This report describes that teardown inspection.

Nose cone
The nose cone did not show any signs of wear. No cracks were found near any of the bolt holes.

Blades
All the blades had the trip strip missing on the high pressure side (Figure C-9). All three blades also had some cracking in the trailing edge bond line in the root area (Figure C-10). Blade 2 also had some more severe cracking in the leading edge near the root (Figure C-11 and Figure C-12). All blade roots showed signs of light rubbing on the clamping plates and alternator.

Alternator
The coils of the alternator were visually inspected. No signs of overheating were found. Also no traces of rubbing between the stator and rotor were found. The alternator spins smoothly and no damage to the main bearing was evident.

Yaw head
All welds on the yaw head were visually inspected. No cracks were found.

Tail assembly
The tail vane was inspected visually, no cracks were found. The tail boom did not have any cracks or signs of wear. The tail stop bumper was found to be cracked (Figure C-13). This bumper gets hit by the tail when the turbine comes out of furl. This may have been caused by over-torquing of the mounting bolts by ARE during the turbine production. The plate that contacts the tail stop bumper when the turbine comes out of furl was found to be bent (Figure C-14).

The tail hinge pin and bronze sleeve bearings showed very little wear. Most wear was likely caused by the disassembly process. See Figure C-15.

Yaw system
The turbine is free yaw; the turbine was manually yawed. The turbine yaws smoothly. No play in the bearing was observed.
Up-tower Electrical components

The electrical components up-tower consist of:

1. Brake resistors. The brake resistors were visually inspected. They did not show any signs of overheating or any other wear
2. Contactor operating the brake resistors. The contactor box was opened and one of the contactors was disassembled. No damage or wear was observed.
3. Slipring assembly. The slipring assembly did not show any unexpected wear.
4. Terminal block. The terminal block was intact. However one of the wires was not tight. NREL has found it very hard to tighten any wires in the terminal block in the yaw head. According to ARE this issue has been addressed in a design change.

Tower

The tower was visually inspected. No cracked welds were found. All fasteners were present. A couple of diagonal supports were found to be bent (Figure C-16). Although no clear evidence is present, this was most likely caused by shipping and did not occur during the test.

Voltage clamp

The voltage clamp was opened and inspected for any discoloration, loose wires, etc. Nothing was noted that looked unexpected.

Diversion loads

The enclosure was taken apart and inspected for cracks or deformation, neither were found.

The diversion loads were opened and the resistors and wires were inspected. No cracks or discoloration was found. Some of the coating was chipping off the resistors, where drips had formed from dipping the resistors in the coating during manufacturing (Figure C-17).

Inverters

The inverters were opened and visually inspected. No sign of wear, overheating or damage was found.
Figure C-9. Remnants of trip strip on one of the blade tips

Figure C-10. Crack in trailing edge of one of the blades
Figure C-11. Crack in leading edge near blade root of blade #2.

Figure C-12. Crack in leading edge of blade #2
Figure C-13. Cracked tail stop bumper

Figure C-14. Bent furl stop
Figure C-15. Tail hinge pin

Figure C-16. Bent tower diagonal
Figure C-17. Chipped coating on diversion loads
**Wind Turbine Generator System Duration Test Report for the ARE 442 Wind Turbine**

The test is being 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, four turbines are being tested at the NWTC as a part of this project. Duration testing is one of up to 5 tests that may be performed on the turbines, including power performance, safety and function, noise, and power quality tests. The results of the testing provide manufacturers with reports that may be used for small wind turbine certification. The test equipment includes a grid connected ARE 442 wind turbine mounted on a 30.5 meter (100 ft) lattice tower manufactured by Abundant Renewable Energy. The system was installed by the NWTC Site Operations group with guidance and assistance from Abundant Renewable Energy.

### Subject Terms
- wind turbines; independent testing; duration testing; ARE 442; Abundant Renewable Energy wind turbine