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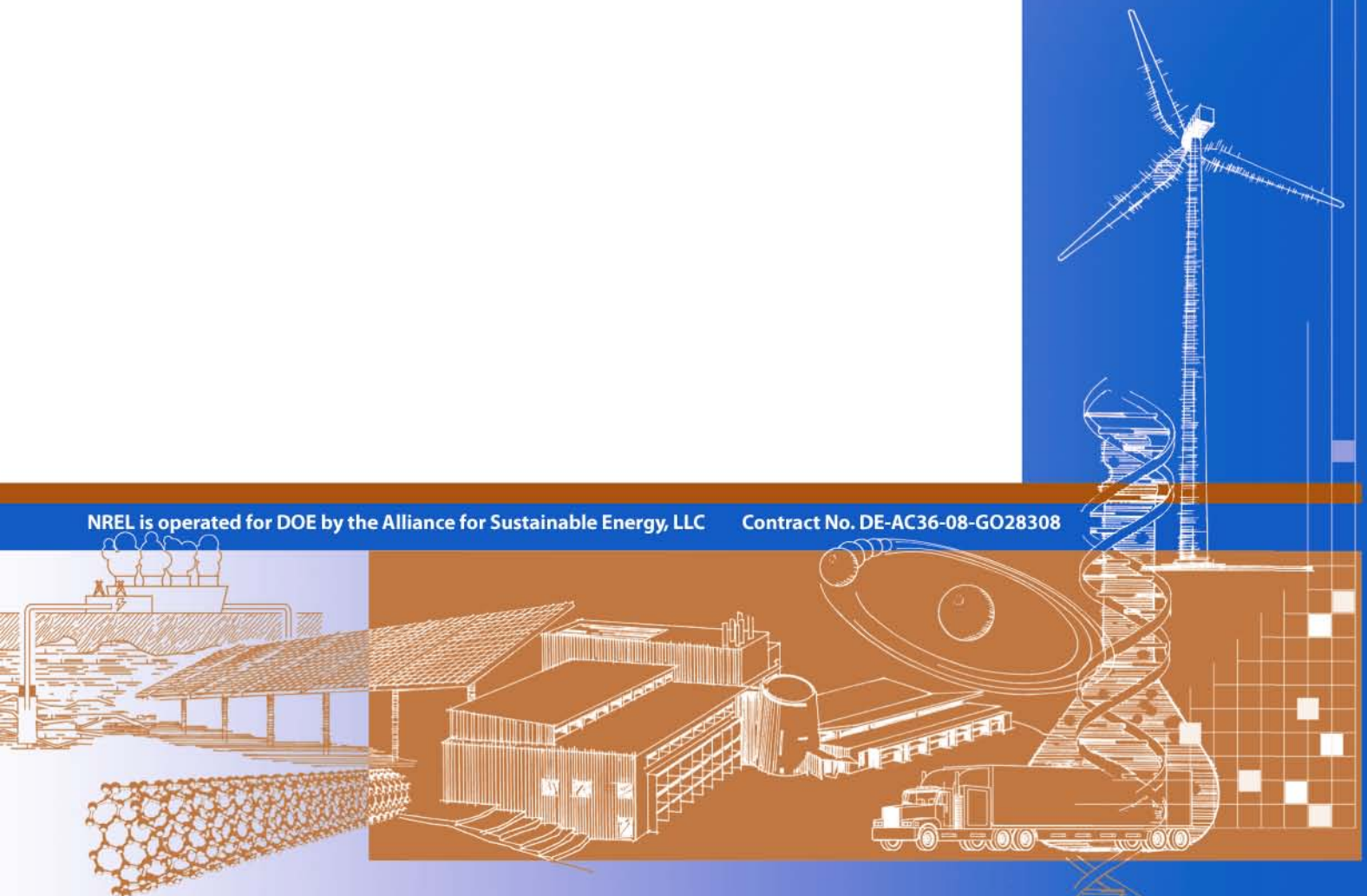
Wind Turbine Generator System Duration Test Report for the ARE 442 Wind Turbine

Jeroen van Dam, Don Baker, and David Jager

Technical Report
NREL/TP-500-47203
May 2010



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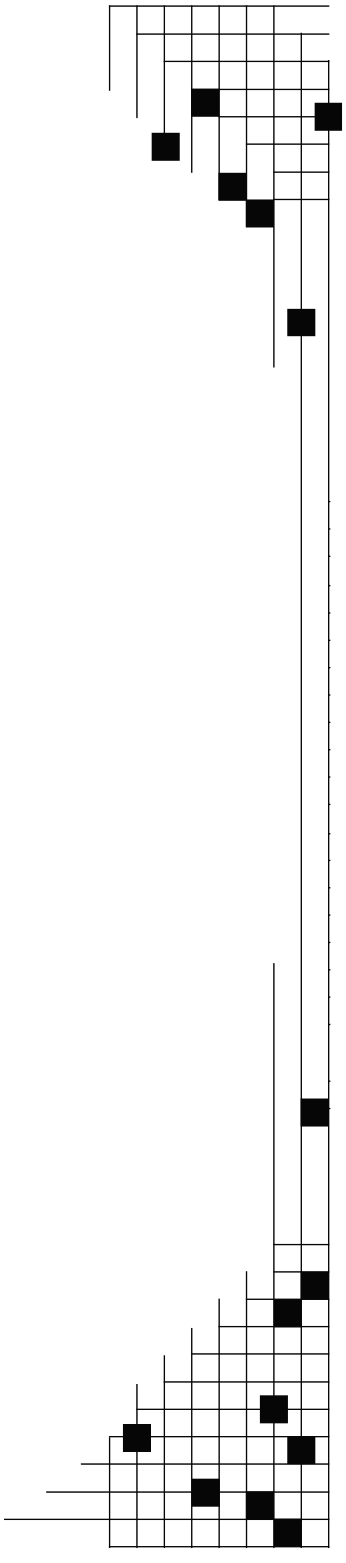

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Contract No. DE-AC36-08-GO28308

Notice

This report was prepared by the National Renewable Energy Laboratory (NREL), operated for the United States Department of Energy (DOE) by the Alliance for Sustainable Energy, LLC (Alliance), as an account of work sponsored by the United States government. The test results documented in this report define the characteristics of the test article as configured and under the conditions tested.

Approval By: _____

Jeroen van Dam, NREL Test Engineer Date

Review By: _____

Arlinda Huskey, NREL Test Engineer Date

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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

General Configuration:	
Make, Model, Serial Number	Abundant Renewable Energy , ARE 442, Y08-001C
Rotation Axis (H / V)	Horizontal
Orientation (upwind / downwind)	Upwind
Number of Blades	3
Rotor Hub Type	Fixed
Rotor Diameter (m)	7.2
Small Wind Turbine Class	II
Hub Height (m)	30.9
Performance:	
Rated Electrical Power (kW)	10
Rated Wind Speed (m/s)	11
Cut-in Wind Speed (m/s)	2.2
Cut-out Wind speed (m/s)	N/A
Rotor:	
Swept Area (m^2)	40.7
Blade Pitch Control	None
Direction of Rotation	Clockwise viewed from up wind
Rotor Speed	0 – 200
Power Regulation (active or passive)	Passive
Tower:	
Type	Freestanding Lattice Valmont U4.5 x 100’
Height (m)	30.5 (100ft)
Control / Electrical System:	
Controller: Make, Type	Combination of side furling with gravity return, VCL 442-HV voltage clamp and Windy Boy US6000 inverter software.
Electrical Output: Voltage	240 VAC, single-phase
Yaw System:	
Yaw control	Passive

Figure 1. The ARE 442 wind turbine

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.

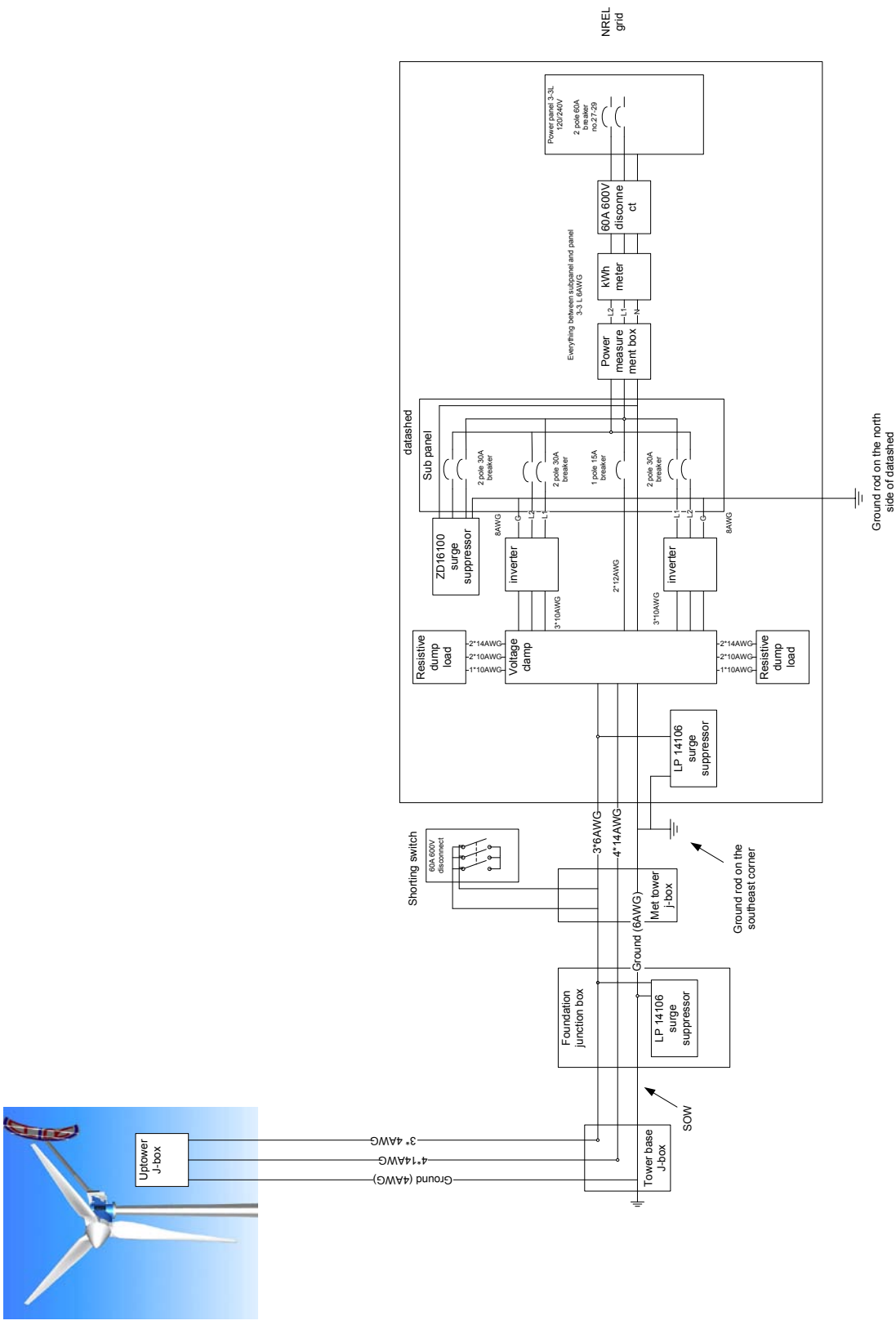

Figure 2. General electrical arrangement

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.

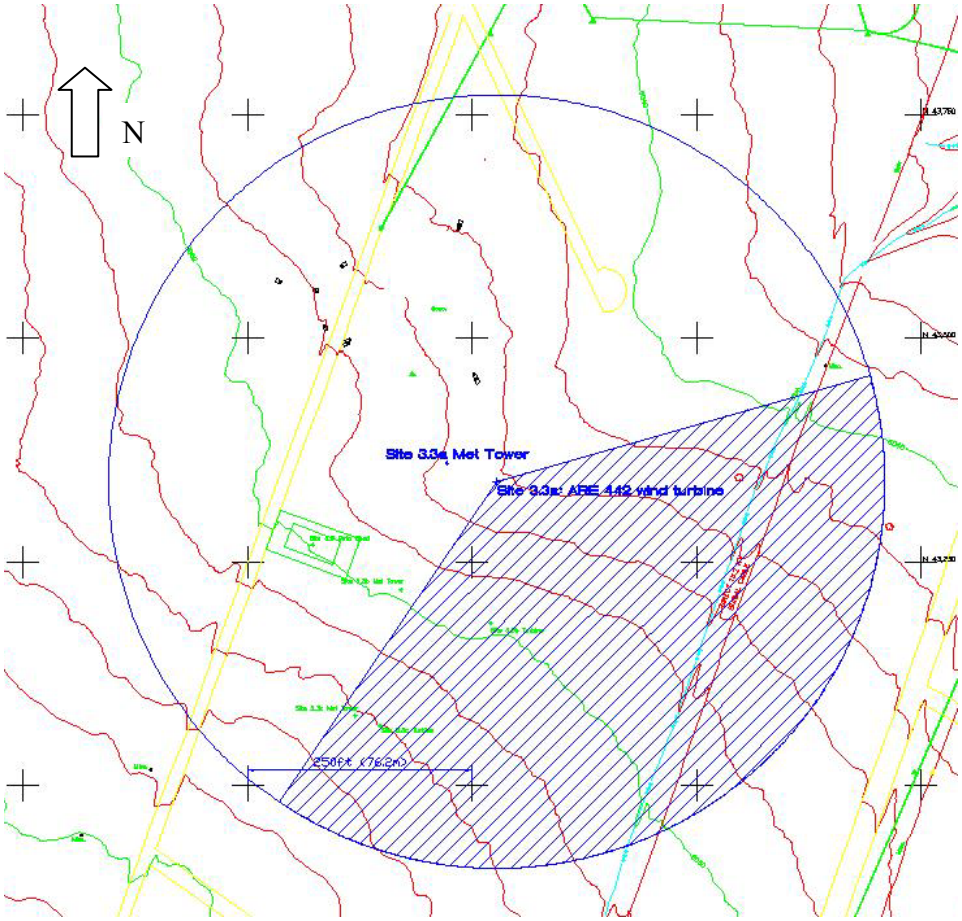

Figure 3. Map of the test site

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.

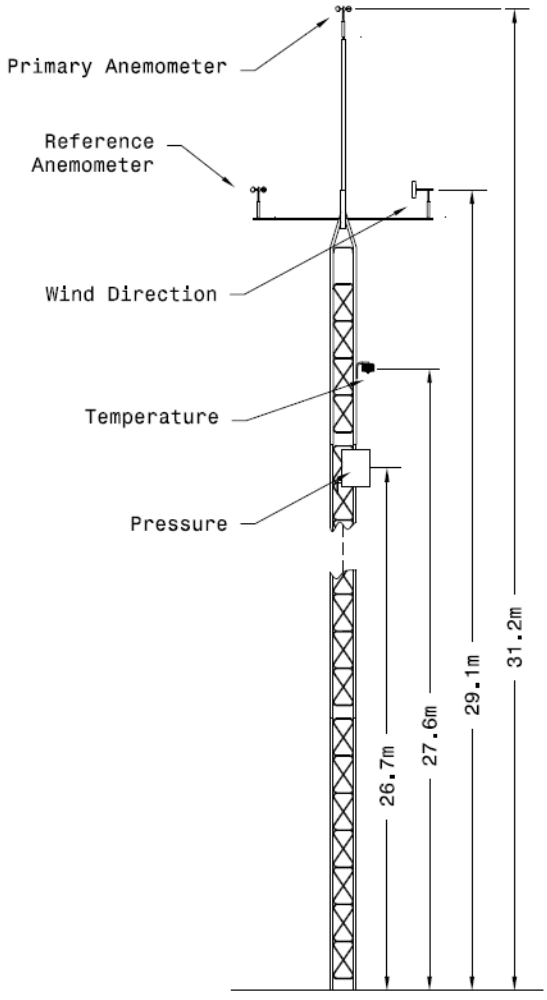

Figure 4. Location of the data acquisition sensors

Table 2. Equipment List for Duration Test

Instrument	Make, Model	Serial Number	Calibration Due Date
Power transducer	Secondwind Phaser 5FM-4A20	02663	28 Apr 2009
Current transducers	OSI 12974	001235408 001235411	Calibrated with power transducer
Primary anemometer	Thies, First Class	0707886 0707888	28 Feb 2009 2 Feb 2010
Reference anemometer	NRG, Max 40	179500049022	In situ
Wind vane	Met One, 020C with aluminum vane	G4706	28 Feb 2009
Pressure sensor	Vaisala, PTB101B	C1020015 T4730007	29 Oct 2008 26 Aug 2009
Temperature sensor	Met One, T-200	0673552 0789020	29 Oct 2008 10 Oct 2009
Precipitation sensor	Campbell Scientific, 237	None	In situ
Data acquisition system	Compact DAQ w/LabView-based data acquisition cDAQ-9172 NI 9229 NI 9217 NI 9205	 12EAE14 12A2037 12C73B4 12ECB77	 31 May 2008 3 Aug 2008 9 Oct 2008

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

	Hours of Power Production Above:			Max Gust	TI @ 15	# Data	T_T	T_U	T_E	T_N	O
Month	0 m/s	10.2 m/s	15.3 m/s	(m/s)	m/s (%)	Points	(hours)	(hours)	(hours)	(hours)	(%)
Overall	3240.6	552.6	156.7	42.9	18.9	325	7249	99.7	214.8	612.0	91.2
Jul 2008	295.8	7.5	0.0	27.8	15.8	3	735	3.1	152.2	0.0	100.0
Aug	286.8	9.5	0.0	26.5	16.9	1	739	26.0	4.0	0.0	100.0
Sep	217.5	8.8	0.7	23.2	13.8	8	687	16.6	5.3	0.3	99.9
Oct	279.7	35.7	6.7	34.0	16.9	13	744	0.9	5.0	9.5	98.7
Nov	156.0	8.2	0.0	34.3	19.5	44	720	0.0	0.1	332.8	53.8
Dec	379.2	131.8	41.8	42.9	18.2	72	744	1.0	10.2	124.2	83.1
Jan 2009	466.5	146.3	44.3	42.9	20.0	93	744	0.7	1.8	79.8	89.2
Feb	389.3	104.5	46.3	39.5	19.7	33	672	4.0	31.7	42.3	93.3
Mar	416.8	68.3	13.2	34.9	18.4	44	744	3.9	1.5	20.3	97.2
Apr	353.0	32.0	3.7	28.4	18.0	14	720	43.5	3.0	2.8	99.6

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 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

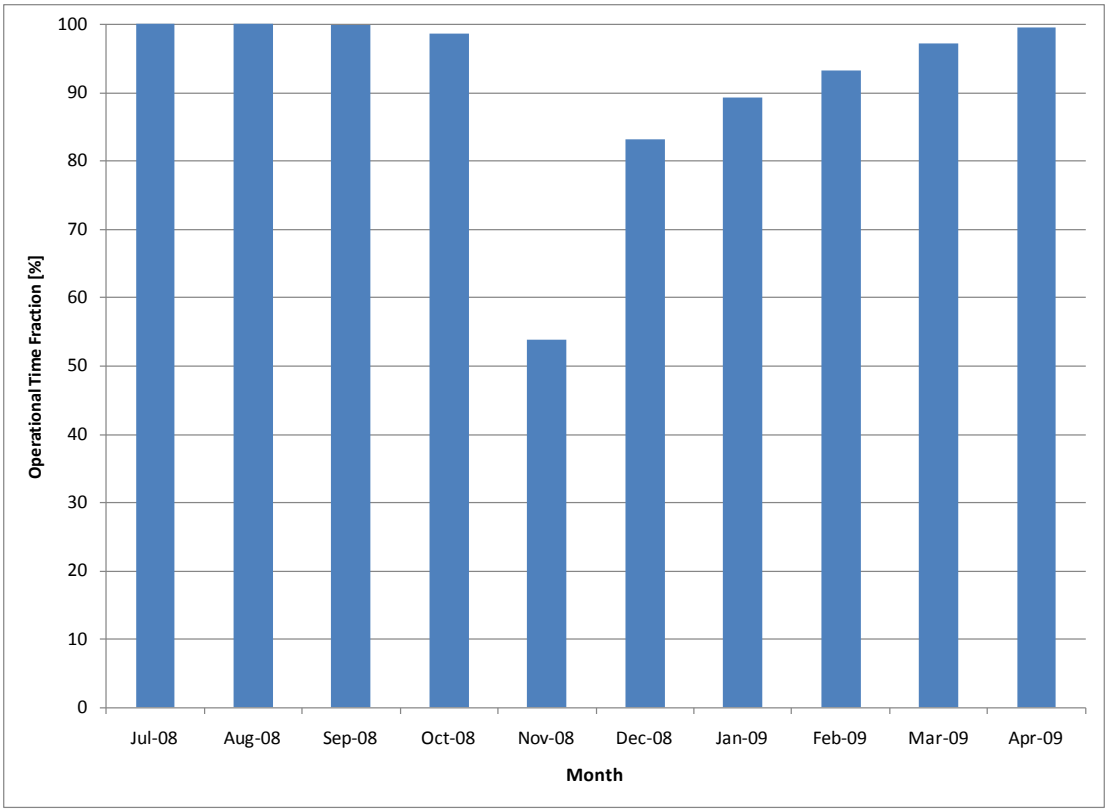

Figure 6. Operational time fraction for each month

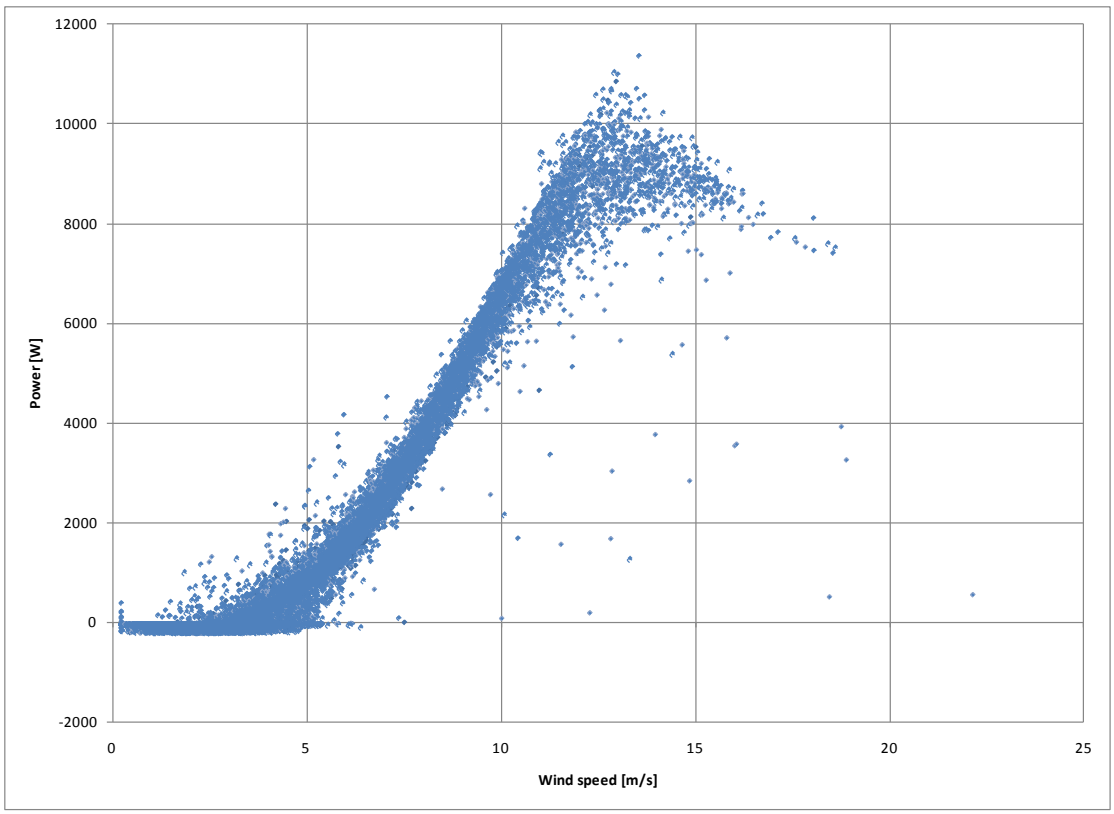

Figure 7. Scatter plot of power versus wind speed (10-minute averages)

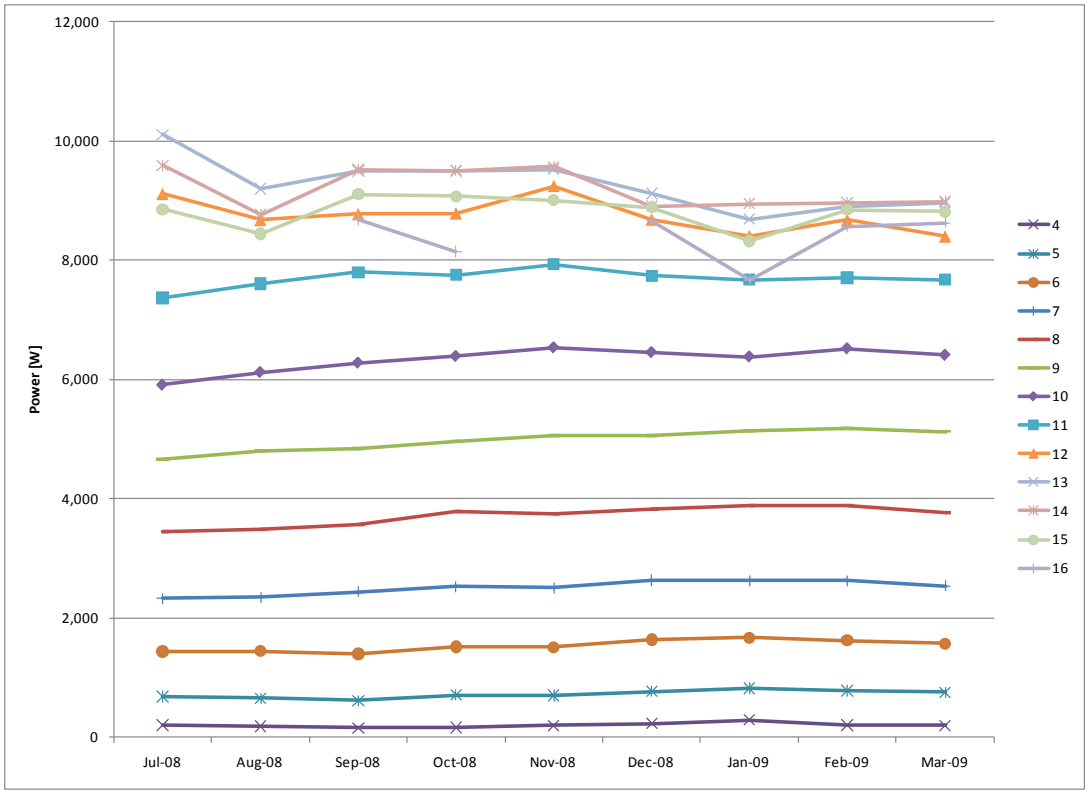

Figure 8. Power level in several wind speed bins (in m/s) as a function of time

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 10.5m/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.

Branch #: 5000

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Phaser Power Transducer & 2-CTs DOE #: 02824C

Model # : Phaser-5-F-5A S/N : 02663

Calibration Date: 01/28/2008 Due Date: 01/28/2010

A. Set-Up for Total Real Power Calibration:
A.1. Voltage is applied to phases A&B = 120 V @ 60 Hz.
A.2. Current is applied to n = 5-TURNS through two current transformers that are connected to phases A&B.
A.3. Analog Output-1 is measured across precision resistor = 250 Ω.
A.4. Phaser Full Scale setting = -7.2KW to 7.2KW.

Input Current (AAC)	Input Power (KW)	Analog Output-1 (VDC)
28	6.72	4.790
21	5.04	4.341
14	3.36	3.892
7	1.68	3.444
0	0	2.995
-7	-1.68	2.547
-14	-3.36	2.099
-21	-5.04	1.651
-28	-6.72	1.203

B. Set-Up for Power Factor Calibration:
B.1. Voltage & Current are applied as A.1 & A.2.
B.2. Analog Output-2 is measured across precision resistor = 250 Ω.

Power (KW)	Power Factor	Analog Output-2 (VDC)
6.72	1.0	4.989
"	0.8	4.179
"	0.6	3.377
"	0.4	2.577
"	0.2	1.778

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Figure A.1. Power transducer calibration sheet

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Calibration laboratory for velocity of air flow
Akkreditiert durch die */ accredited by the*
Akkreditierungsstelle des DKD bei der
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Deutsche WindGuard
Wind Tunnel Services GmbH
Varel

Deutscher Akkreditierungs Rat
DAR
DKD-K- 36801

Kalibrierschein
Calibration Certificate

Kalibrierzeichen / *Calibration label*: DKD-K-36801 / 07_2417

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.*	VT07255
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 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.

Stempel / *Seal*: Deutscher Kalibrierdienst DKD-K- 36801
Datum / *Date*: 24.07.2007
Leiter des Kalibrierlaboratoriums / *Head of the calibration laboratory*: Dipl. Phys. D. Westermann
Bearbeiter / *Person in charge*: Tech. Ass. Inf. H. Westermann

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

Figure A.2. Primary anemometer calibration sheet I

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PHYSIKALISCH-TECHNISCHEN BUNDESANSTALT (PTB)

Deutsche WindGuard
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Deutscher Akkreditierungs Rat
DAR
DKD-K- 36801

Kalibrierschein
Calibration Certificate

Kalibrierzeichen
Calibration label
DKD-K-36801
07_2406

Gegenstand *Object*	Cup Anemometer
Hersteller *Manufacturer*	Thies Clima D-37083 Göttingen
Typ *Type*	4.3350.00.000
Fabrikat/Serien-Nr. *Serial number*	Body: 0707888 Cup: 0707888
Auftraggeber *Customer*	Thies Clima D-37083 Göttingen
Auftragsnummer *Order No.*	VT07255
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	3
Datum der Kalibrierung *Date of calibration*	24.07.2007

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Deutscher Kalibrierdienst DKD-K- 36801	24.07.2007	Dipl. Phys. D. Westermann	Tech. Ass. Inf. H. Westermann

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Deutsche WindGuard
Wind Tunnel Services GmbH

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

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

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

Calibration Date: **13-Sep-07**

Report Number: G4706-070913

Page: 1 of 1

Procedure:
NWTC-CT: GI24-000613, Wind Vane Calibration

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

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	020C
Serial Number	**G4706**
Vane Material	Aluminum
Condition	Refurbished

Results:

Slope:	**72.17**	**deg/V**
Offset to boom:	**94.81**	**deg**
Max error:	0.99	deg

Estimated Uncertainty:

Inclinometer Uncertainty (deg)	Total Uncertainty (deg)
0.10	0.57

Traceability:

	Mfg & Model	Serial Number	Cal Date
Inclinometer:	Spi-Tronic	31-038-3	22-Mar-07
Voltmeter:	Fluke743B	6965608	10-May-07

Calibration by: Mark Meadors — 13-Sep-07 Date

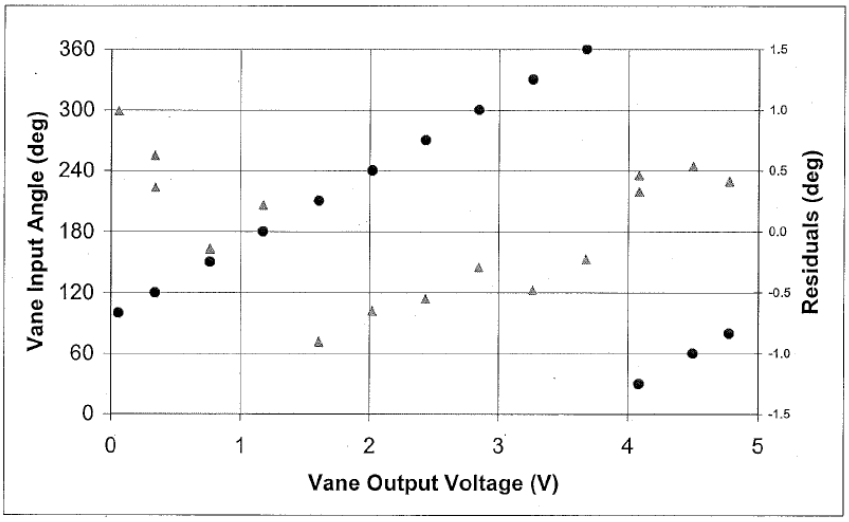

Figure A.4. Wind vane calibration report

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: RTD Probe DOE #: 03507C

Model # : 78N01N00N04 S/N : 0673552

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

No	Nominal Values		Measured Values		
	Nominal Resistance /	Equivalent Temperature /	Measured Resistance /	Equivalent Temperature /	Temperature Error /
1	96.09 Ω	-10 °C	96.082 Ω	-10.02 °C	0.02 °C
2	100.00 Ω	0 °C	100.002 Ω	0.01 °C	-0.01 °C
3	103.90 Ω	10 °C	103.906 Ω	10.02 °C	-0.02 °C
4	107.79 Ω	20 °C	107.780 Ω	19.97 °C	-0.03 °C
5	111.67 Ω	30 °C	111.678 Ω	30.02 °C	-0.02 °C
6	115.54 Ω	40 °C	115.548 Ω	40.02 °C	-0.02 °C

Notes:

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

Calibrated by: Reda QA by: Bev

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

Figure A.5. RTD-Probe calibration sheet I

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: RTD-Probe DOE #: 03722C

Model # : 78N01N00N S/N : 0789020

Calibration Date: 10/10/2008 Due Date: 10/10/2009

No	Function Tested	Nominal Value (°C)	Measured Values (Ω)		( )Mfr. Specs. OR (X)Data only
			AS Found	AS Left	
*	Temperature:	0	99.96	Same	
		25	109.68	"	
		50	119.32	"	
	Notes: - Calibration was performed using instruments that are traceable to NIST. DOE#s 124272, 108603, and 108604. - Calibration was performed at temperature = 23 °C and relative humidity = 38. - Uncertainty of Nominal Values = ± 0.03 °C, k = 2.				

Tested By: Reda

Date : 10/10/2008

Figure A.6. RTD-Probe calibration sheet II

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Pressure Transmitter DOE #: 03508C

Model # : PTB101B S/N : C1020015

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

No	Function Tested	Nominal Value (kPa)	Measured Output Voltage (VDC)		( )Mfr. Specs. OR (X)Data only (mb)
			As Found	As Left	
*	Absolute Pressure				
		65	0.274		
		70	0.547		
		75	0.818		
		80	1.091		
		85	1.362		
		90	1.634		
		95	1.905		
		100	2.177		
		105	2.450		
	Notes: 1. Expanded Uncertainty of the nominal value is ± 0.2 kPa, with k = 2. 2. Calibration was performed at 23°C and 37% RH. 3. Calibration was performed using standards that are traceable to NIST. DOE numbers: 02625C, 02727C, and 02301C.				

Calibrated By: Reda
Date: 10/29/2007

QA By: Bev
Date: 10/29/2007

Figure A.7. Pressure transmitter calibration sheet

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Pressure Transmitter DOE #: 02795C

Model # : PTB101B S/N : T4730007

Calibration Date: 08/26/2008 Due Date: 08/26/2009

No	Function Tested	Nominal Value (kPa)	Measured Output Voltage (VDC)		( )Mfr. Specs. OR (X)Data only (mb)
			As Found	As Left	
*	Absolute Pressure				
		65	0.287	Same	
		70	0.560	"	
		75	0.832	"	
		80	1.105	"	
		85	1.377	"	
		90	1.648	"	
		95	1.921	"	
		100	2.194	"	
		105	2.467	"	
	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: Reda
Date: 08/26/2008

QA By: Bev
Date: 08/26/2008

Figure A.8. Pressure transmitter calibration sheet II

NATIONAL INSTRUMENTS

Certificate of Calibration

Board Information:
Serial Number: 12C73B4
NI Part Number: 192547D-01
Description: NI 9217

Certificate Information:
Certificate Number: 786529
Date Printed: 05-JAN-09

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,

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

NATIONAL INSTRUMENTS

Certificate of Calibration

Board Information:
Serial Number: 12A2037
NI Part Number: 192580D-02
Description: NI 9229

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

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

Ambient Temperature: 22 °C
Relative Humidity: 50 %

National Instruments certifies that at the time of manufacture, the above product was calibrated in accordance with applicable National Instruments procedures. These procedures are in compliance with relevant clauses of ISO 9001 and are designed to assure that the product listed above meets or exceeds National Instruments specifications.

National Instruments further certifies that the measurements standards and instruments used during the calibration of this product are traceable to National and/or International Standards administered by NIST or Euromet members or are derived from accepted values of natural physical constants.

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

The information shown on this certificate applies only to the instrument identified above and the certificate may not be reproduced, except in full, without prior written consent by National Instruments.

For questions or comments, please contact National Instruments Technical Support.

NI Hungary Software és
Hardware Gyártó Kft.
4031 Debrecen, Határ út
1/A.
HUNGARY

Signed,

Andrew Krupp
Quality Director

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

Figure A.10. NI 9229 data acquisition module calibration sheet I

NATIONAL INSTRUMENTS

Certificate of Calibration

Board Information:
Serial Number: 12ECB77
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
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.11. NI 9205 data acquisition module calibration sheet I

Davis Calibration

ACCREDITED CALIBRATION

Certificate of Calibration

3214191

Instrument Identification

Company ID: 229037
NATIONAL INSTRUMENTS

PO Number: 337683

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

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

Accuracy: Mfr Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: NATIONAL INSTRUMENTS CAL EXECUTIVE REV 3.3.1
Remarks: *Reference attached Data.*

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

The instrument on this certification has been calibrated against standards traceable to the National Institute of Standards and Technology (NIST) or other recognized national metrology institutes, derived from ratio type measurements, or compared to nationally or internationally recognized consensus standards.

A test uncertainty ratio (T.U.R.) of 4:1 [K=2, approx. 95% Confidence Level] was maintained unless otherwise stated.

Davis Calibration Laboratory is certified to ISO 9001:2000 by Eagle Registrations (certificate # 3046). Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994, ISO 10012:2003, 10CFR50 AppxB, and 10CFR21.

ISO/IEC 17025-2005 accredited calibrations are per ACLASS certificate # AC-1187 within the scope for which the lab is accredited. All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.

Approved By: VICTOR PENA
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
3143038	15-0271	MULTIFUNCTION CALIBRATOR	5700A	15Apr2009	14Jul2009

Figure A.12. NI 9229 data acquisition module calibration sheet II

Davis Calibration

ACCREDITED CALIBRATION

Certificate of Calibration

3214178

Instrument Identification

Company ID: 229037
NATIONAL INSTRUMENTS

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

PO Number: 337683

Instrument ID: **12C73B4**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CH 100 OHM 24-BIT RTD ANALOG INPUT

Model Number: NI 9217
Serial Number: 12C73B4

Accuracy: Mfr. Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: CAL EXEC 3.3.1 CAL EXEC 3.3.1

Remarks: *Reference attached data.*

Technician: WAYNE GETCHELL
Cal Date 06May2009
Cal Due Date: 06May2010
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 46.0 %

The instrument on this certification has been calibrated against standards traceable to the National Institute of Standards and Technology (NIST) or other recognized national metrology institutes, derived from ratio type measurements, or compared to nationally or internationally recognized consensus standards.

A test uncertainty ratio (T.U.R.) of 4:1 [K=2, approx. 95% Confidence Level] was maintained unless otherwise stated.

Davis Calibration Laboratory is certified to ISO 9001:2000 by Eagle Registrations (certificate # 3046). Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994, ISO 10012:2003, 10CFR50 AppxB, and 10CFR21.

ISO/IEC 17025-2005 accredited calibrations are per ACLASS certificate # AC-1187 within the scope for which the lab is accredited. All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.

Approved By: VICTOR PENA
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
3078982	15-0011	DECADE RESISTOR	DB52	24Mar2009	24Mar2010
3004176	15-0060	DIGITAL MULTIMETER (GOLDEN CAL)	3458A OPT 002	17Feb2009	17May2009

Figure A.13. NI 9217 data acquisition module calibration sheet II

Davis Calibration

ACCREDITED CALIBRATION

Certificate of Calibration

3214150

Instrument Identification

Company ID: 229037
NATIONAL INSTRUMENTS

PO Number: 337683

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

Instrument ID: **12ECB77**
Model Number: NI 9205
Manufacturer: NATIONAL INSTRUMENTS
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 06May2009
Cal Due Date: 06May2010
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 47.0 %

The instrument on this certification has been calibrated against standards traceable to the National Institute of Standards and Technology (NIST) or other recognized national metrology institutes, derived from ratio type measurements, or compared to nationally or internationally recognized consensus standards.

A test uncertainty ratio (T.U.R.) of 4:1 [K=2, approx. 95% Confidence Level] was maintained unless otherwise stated.

Davis Calibration Laboratory is certified to ISO 9001:2000 by Eagle Registrations (certificate # 3046). Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994, ISO 10012:2003, 10CFR50 AppxB, and 10CFR21.

ISO/IEC 17025-2005 accredited calibrations are per ACLASS certificate # AC-1187 within the scope for which the lab is accredited.
All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.

Approved By: VICTOR PENA
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
3143038	15-0271	MULTIFUNCTION CALIBRATOR	5700A	15Apr2009	14Jul2009

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

Date: Conducted by:

Task		Recorded Observation
Wind Turbine Generator:		
Electrical Inspection Completed	✓	
Verify all wire sized per manufacturer drawing and one liner	✓	
Verify 60 amp breaker size in power panel 3.3L	✓	
Visually inspect turbine components for any damage or deviations from normal	✓	
Inspect tower grounding	✓	
Verify tower alignment	✓	
ARE 442 commissioning procedure (chapter 11 in manual) followed for first start up	✓	
Verify freedom from excessive vibration	✓	
Verify that turbine blades spin freely at 8 m/s or above	✓	
Verify absence of excessive noise	✓	
Verify power production to manufacturer's power curve at 8 m/s or above	✓	6700W@9.8 m/s
Verify conductor sizing (tower - #6 or better)	✓	#6 to tower #4 up the tower
Verify RPM signal from controller	✓	
Verify "turbine status" signal from controller	✓	
Measure the frequency under load	✓	59.98 - 60.02 Hz
Measure the current under load	✓	44A @ 10 kW
Measure the voltage under load	✓	247.6 V @ 12kW
Verify manual shutdown from turbine specific disconnect	✓	
Verify manual shutdown from 60 amp breaker function in power panel 3.3	✓	5 m/s
Estop in 20 m/s	✓	

Verify turbine automatically restarts after loss of grid was simulated and reset.		
At least one NREL employee trained		Jeroen D Mark
Review final as-built drawings for system installation and verify that drawings and installation are in agreement		

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.

R W Preus — 6/12/08

Robert Preus, Abundant Renewable Energy — Date

6/12/08

Jeroen van Dam, NREL — Date

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

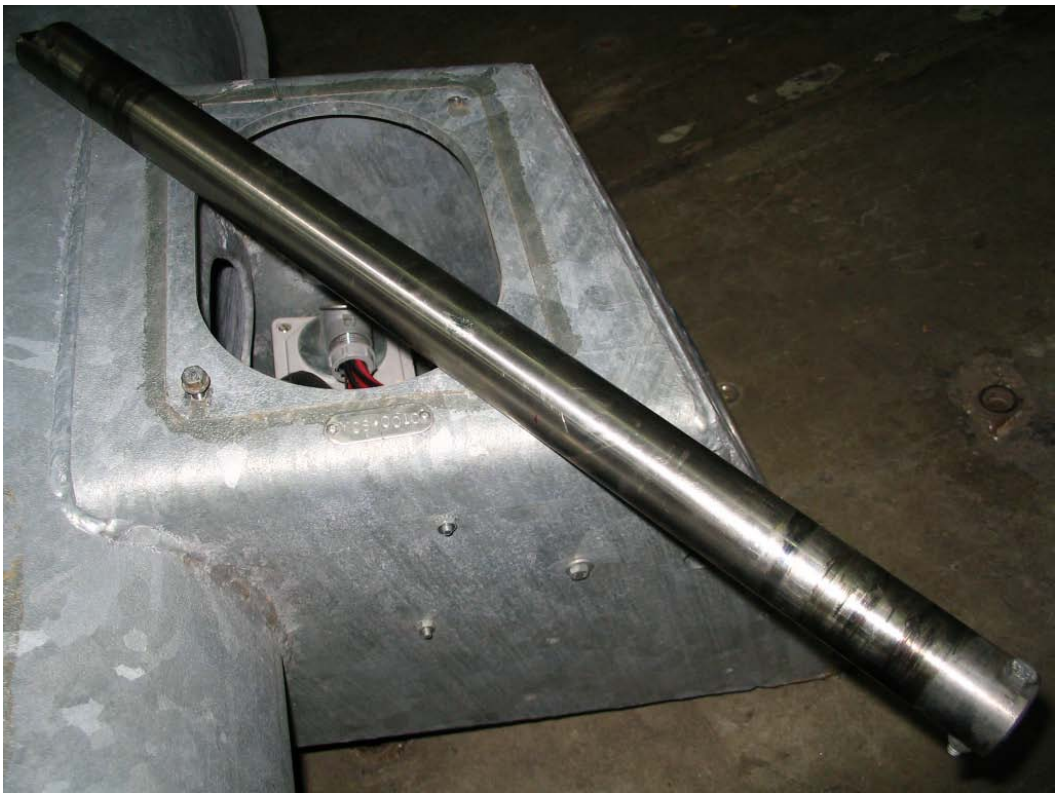

Figure C-15. Tail hinge pin

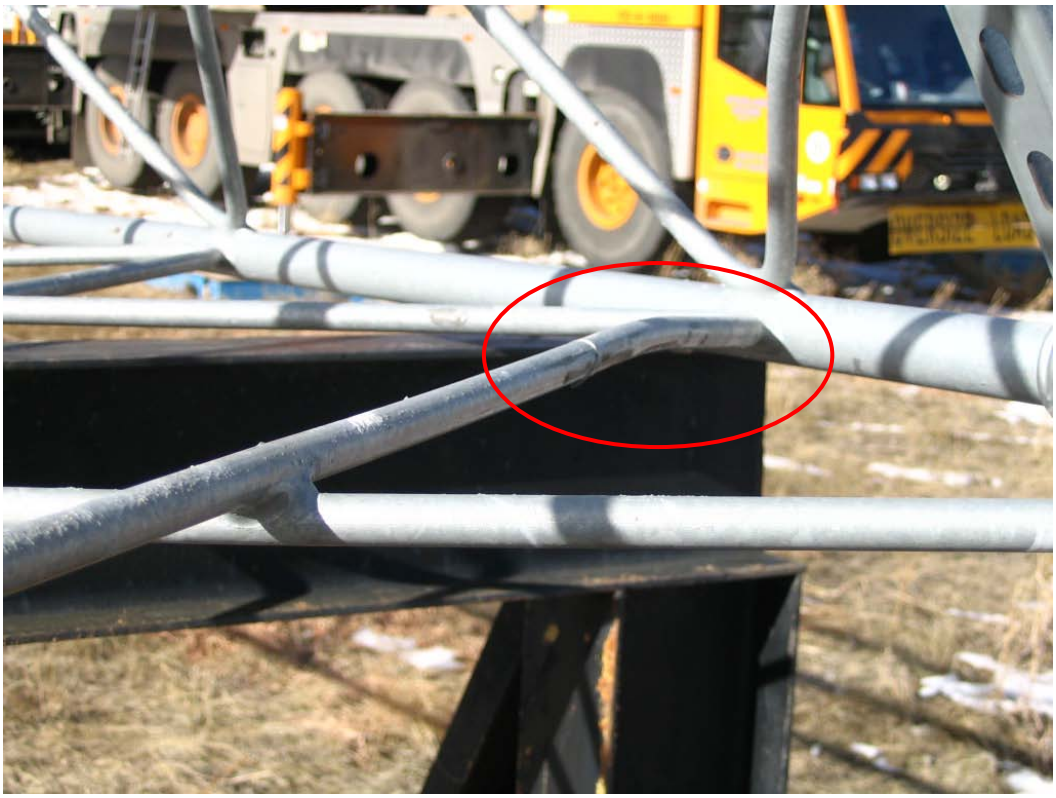

Figure C-16. Bent tower diagonal

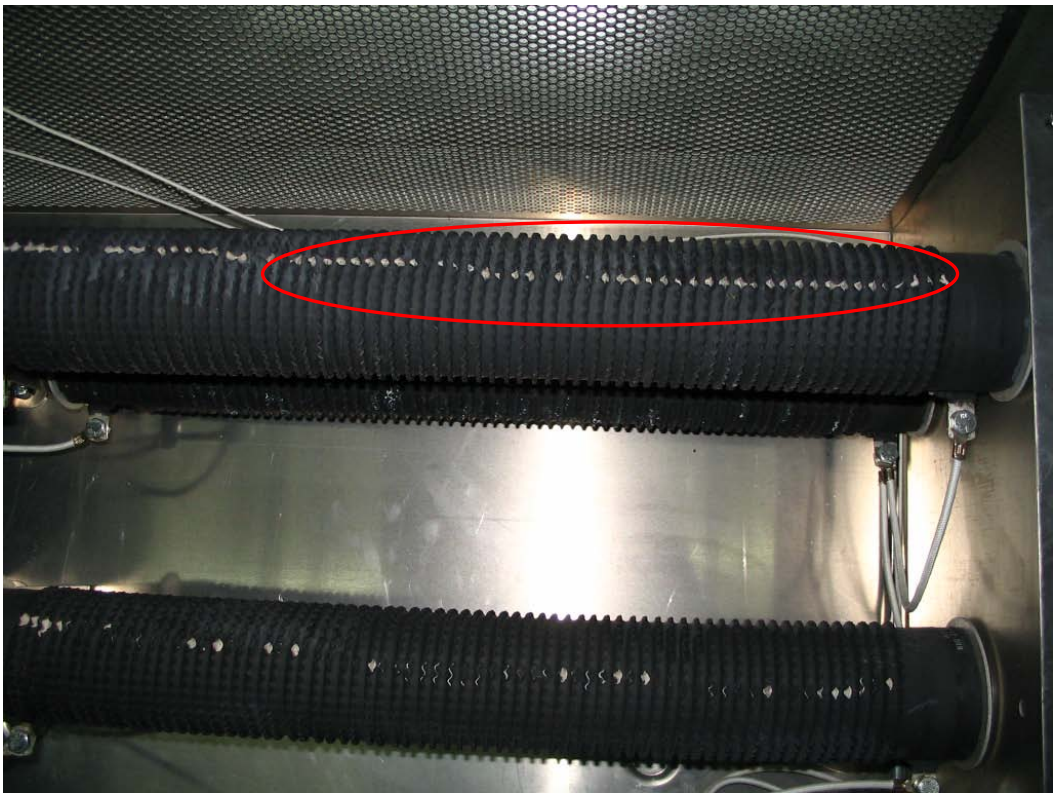

Figure C-17. Chipped coating on diversion loads

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

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

4. TITLE AND SUBTITLE
Wind Turbine Generator System Duration Test Report for the ARE 442 Wind Turbine

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

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
J. van Dam, D. Baker, and D. Jager

5d. PROJECT NUMBER
NREL/TP-500-47203

5e. TASK NUMBER
WE10.2211

5f. WORK UNIT NUMBER

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

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/TP-500-47203

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

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

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

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

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*

This test 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.

15. SUBJECT TERMS
wind turbines; independent testing; duration testing; ARE 442; Abundant Renewable Energy wind turbine

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

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

F1147-E(10/2008)