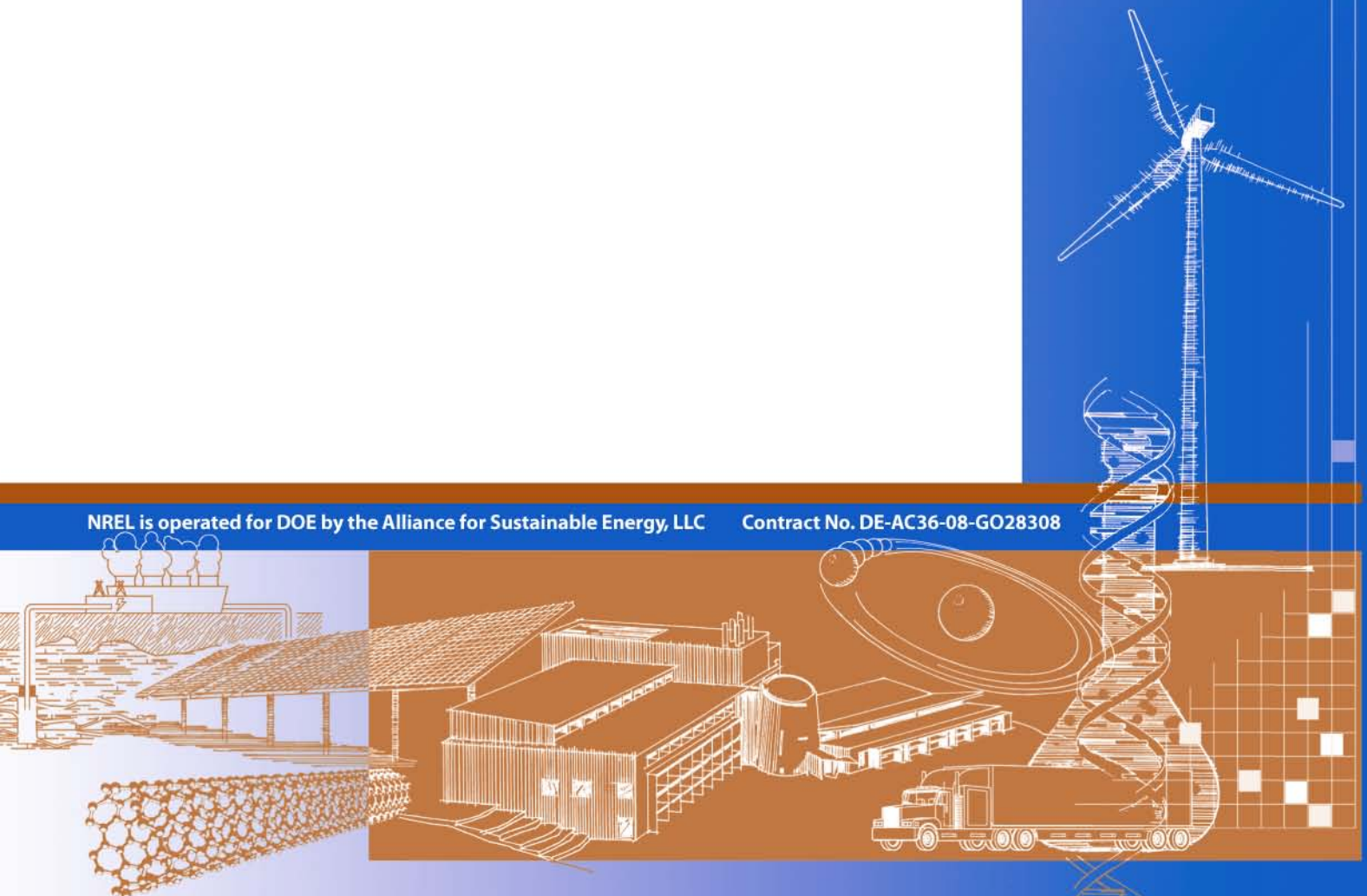
National Renewable Energy Laboratory
A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Innovation for Our Energy Future

Wind Turbine Safety and Function Test Report for the ARE 442 Wind Turbine

J. van Dam, D. Baker, and D. Jager

Technical Report
NREL/TP-500-47030
February 2010



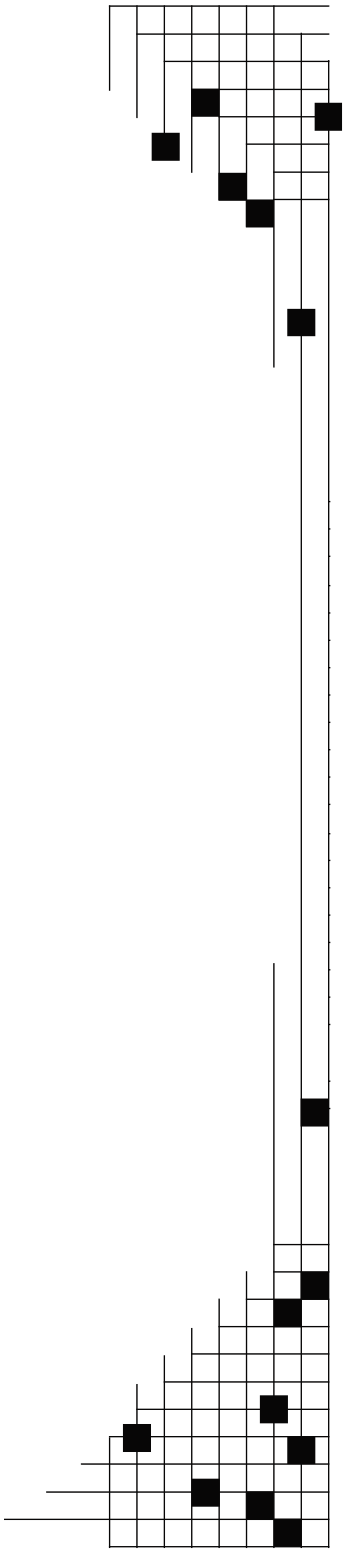
NREL is operated for DOE by the Alliance for Sustainable Energy, LLC Contract No. DE-AC36-08-GO28308

Wind Turbine Safety and Function Test Report for the ARE 442 Wind Turbine

Technical Report
NREL/TP-xxx-xxxxx
Month Year (Arial 12 pt Bold)

J. van Dam, D. Baker, and D. Jager

Prepared under Task No. WE10.2211



National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401-3393
303-275-3000 • www.nrel.gov

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

Contract No. DE-AC36-08-GO28308

NOTICE

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

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.

THIS REPORT IS PROVIDED "AS IS" AND NEITHER THE GOVERNMENT, ALLIANCE, NREL NOR ANY OF THEIR EMPLOYEES, MAKES ANY WARRANTY, EXPRESS OR IMPLIED, INCLUDING THE WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, OR ASSUMES ANY LEGAL LIABILITY OR RESPONSIBILITY FOR THE ACCURACY, COMPLETENESS, OR USEFULNESS OF ANY SUCH INFORMATION DISCLOSED IN THE REPORT, OR OF ANY APPARATUS, PRODUCT, OR PROCESS DISCLOSED, OR REPRESENTS THAT ITS USE WOULD NOT INFRINGE PRIVATELY OWNED RIGHTS.

Neither Alliance nor the U. S. Government shall be liable for special, consequential or incidental damages. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of the authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof or Alliance.

NREL is a DOE Laboratory, and as an adjunct of the United States government, cannot certify wind turbines. The information in this report is limited to NREL's knowledge and understanding as of this date.

NREL is accredited by the American Association for Laboratory Accreditation (A2LA) and the results shown in this test report have been determined in accordance with the NREL's terms of accreditation unless stated otherwise in the report.

This report shall not be reproduced, except in full, without the written approval of Alliance or successor operator of NREL.

Approval By: _____

Jeroen van Dam, NREL Test Engineer Date

Approval By: _____

Amy Bowen, NREL Test Engineer Date

Table of Contents

List of Figures

List of Tables

Background

This test was conducted as part of the U.S. Department of Energy's (DOE) Independent Testing project. This project was established to help reduce the barriers of wind energy expansion by providing independent testing results for small turbines. In total, four turbines were tested at the National Wind Technology Center (NWTC) as a part of this project. Safety and function testing is one of up to five tests that were performed on the turbines, including power performance, duration, noise, and power quality tests. Test results provide manufacturers with reports that can be used for small wind turbine certification.

The test equipment includes an ARE 442 wind turbine mounted on a 100-ft free-standing lattice tower. The system was installed by the NWTC Site Operations group with guidance and assistance from Abundant Renewable Energy.

Test Objective

The objective of this test is to:

- verify that the test turbine displays the behavior predicted in the design
- determine if provisions relating to personnel safety are properly implemented
- characterize the dynamic behavior of the wind turbine at rated wind speed and above.

NREL does not limit the safety and function test to features described in the wind turbine documentation. NREL also inspects, possibly tests, and reports on features that are required by IEC 61400-2 that may not be described in the wind turbine documentation.

NREL conducted this test in accordance with Section 9.6 of the International Electrotechnical Commission (IEC) standard, Wind Turbines – Part 2: Design requirements for small wind turbines, IEC 61400-2, Second edition, 2006-03.

Description of Test Turbine and Setup

The test turbine was an ARE 442 wind turbine. This turbine is an upwind three-bladed side furling turbine with a rated power of 10kW. Table 1 provides the key descriptive information of the test turbine.

The ARE 442 wind turbine was installed at site 3.3a at the National Wind Technology Center located eight miles south of Boulder, Colorado (Figure 1). The location primarily consists of mostly flat terrain with short vegetation. The test site has prevailing wind, bearing 292 degrees, relative to true north (292°T). For measurements where it is important to accurately measure wind speed, NREL used data obtained when wind direction is between 214°T and 72°T. In this measurement sector, which was established in accordance with IEC 61400-12-1, the influence of terrain and obstructions on the anemometer and turbine is small.

A one line diagram of the turbine system is provided in Figure 2.

Table 1. Test Turbine Configuration

Turbine manufacturer and address	Abundant Renewable Energy 22700 NE Mountain Top Road Newberg OR 97132
Model name	ARE 442
Serial number	Y08-001C
Production date	January 2008
Design nominal voltage at terminals (VAC)	240
Maximum current at terminals (A)	55
Design frequency at terminals (Hz)	60
SWT class	II
Design 50-year extreme wind speed, V_{e50} (m/s)	59.5
Rotor Diameter (m)	7.2
Hub Height (vertical center of rotor) (m)	30.9
Tower Type	Freestanding Lattice Valmont U4.5 x 100’
Rated Electrical Power (kW)	10
Rated Wind Speed (m/s) (lowest wind speed at which turbine produces rated power)	11
Rated rotor speed (rpm) (lowest rotor speed at which turbine produces rated power)	140
Rotor speed range (rpm)	0-160
Fixed or variable pitch	Fixed
Number of Blades	3
Blade Tip Pitch Angle (deg)	0, blade root flat on alternator
Blade make, type, serial number	Aero Energy 089-028, 089-029, 089-030
Description of control system (device & software version)	Combination of side furling with gravity return, VCL 442-HV voltage clamp and Windyboy US6000 inverter software.

Figure 1. ARE 442 wind turbine at the NWTC test site

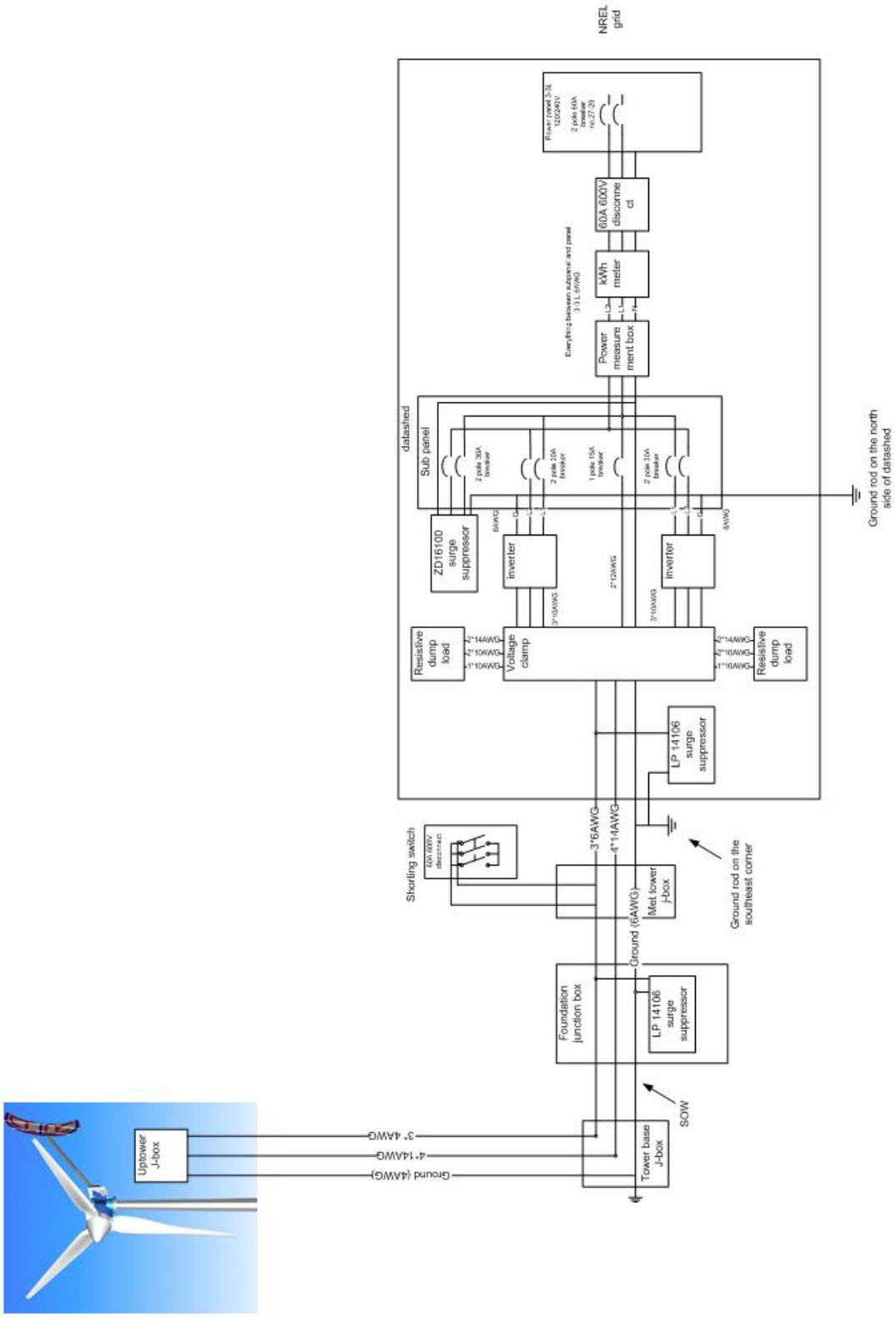


Figure 2. Electrical Drawing of the ARE 442 installation

Instrumentation

The following parameters were measured in this test: wind speed, electrical power, rotor speed, and grid voltage. NREL calculated the rotor speed by measuring the frequency of the wild AC (variable voltage, variable frequency) coming from the alternator.

An indication of turbine status was obtained by measuring the status of the relays that activate the brake resistors up in the yaw head. The signal is zero when the generator is shorted, and five when it is not.

The instruments that were used for these measurements are listed in Table 2. The calibration sheets for the instruments used for this safety and function test are included in Appendix A.

Table 2. Equipment List for Safety and Function Test

Instrument	Make, Model	Serial Number	Calibration Due Date
Power transducer	Secondwind Phaser 5FM-4A20	02663	April 28, 2009
Current transducers	OSI 12974	001235408 001235411	Calibrated with Power transducer, April 28, 2009
Primary anemometer	Thies, First Class	0707886	Feb. 28, 2009
Reference anemometer	NRG, Max 40	179500049022	In situ
Rotor speed	OSI Voltage Transducer VT7-010E-11	08010700	April 28, 2009
Data acquisition system	Compact DAQ w/LabView based data acquisition cDAQ-9172 NI 9229 NI 9217 NI 9205	 12EAE14 12A2037 12C73B4 12ECB77	 May 31, 2008 Aug. 3, 2008 Oct. 9, 2008 Modules calibrated post-test on May 6, 2009, found in compliance

Procedure

Safety and function testing may involve some risk to personnel and to equipment. NREL endeavors to accomplish its tasks with minimal risk by incorporating appropriate controls into testing procedures. This test report documents these controls where they may have had an influence on results obtained.

Control and Protection System Functions

The first part of the test procedure is to assess the control and protection system functions listed below. For each function, NREL provided an input to the existing control and protection system or simulated the external condition. NREL then recorded the response of the turbine.

In the list below, turbine response was observed for each major response category (startup, normal shutdown, emergency shutdown). If faults or other actions caused one of these major responses, NREL simulates the appropriate input and verifies that the control and protection system appropriately a) sensed the condition, and b) provided indication of an appropriate response. This procedure enables, for example, all the E-stop functions to be checked without exposing the turbine to multiple, potentially-damaging stops. These checks are designated by the term "behavior" in the list below.

1. Power control
2. Rotor speed control
3. Yaw orientation
4. Startup
    a. Normal operation – winds rising above cut-in
    b. After maintenance or fault clearance at design wind speed or above
    c. Maintenance of fault conditions at design wind speed or above
5. Normal shutdown
6. Emergency shutdown during operation
7. Behavior upon excessive vibration
8. Behavior upon loss of load
9. Turbine specific checks
    a. Behavior upon over-temperature
    b. Behavior upon loss of load brake or diversion load connection

Personnel Safety Provisions

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

- Safety instructions
- Climbing
- Fire resistance and control
- Fire extinguisher
- Emergency stop buttons
- Lock-out / tag-out provisions
- Interlock on electrical cabinets
- Safety signs
- Unauthorized changing of control settings
- Lightning protection
- Presence and functioning of rotor and yaw lock

Dynamic Behavior

NREL observed the turbine over a wide range of wind speeds. Observations were written in the logbook and are reported in the results section. No direct measurement of accelerations was done for this turbine.

Results

Test results reported here are based on test conducted from June 12, 2008 when the turbine was commissioned through October 2, 2009.

Control and Protection System Functions

The only significant finding is that the rotor speed NREL measured is well above what the manufacturer specified.

NREL limits testing to investigate single-fault failures and has not investigated failures of "safe life" components. If a second fault were to occur during a critical event, severe results can be expected. NREL does not make judgments on whether such failures are likely or whether additional features in the control and protection system are needed to protect against such consequences.

The following is a list of tests that NREL conducted on the ARE 442:

Power control
Figure 3 shows that the power output of the turbine system is limited. This is mainly due to the power output limitations of the inverters. It does not necessarily mean that the turbine itself is limiting power correctly. The measured power curve does not deviate significantly from the published power curve.

Rotor speed control
Rotor speed measurements taken during the test period do not conclusively indicate that the turbine system exhibits control over rotor speed in response to high winds. Figure 4 shows both 10-minute average rotor speed data and maximum and minimum value in each 10 minute period. The maximum and minimum values are based on data samples at 40Hz. The averages appear to be leveling off quite well. However, there is quite a bit of variation in the maxima with no clear trend. Most of the high maxima were measured during periods where the turbine came back online from a faulted condition during high wind conditions. An example of such a high rotor speed event is given in Figure 5.

The manufacturer's expected maximum rotor speed was "above 200 rpm."

Yaw orientation
NREL observed yaw behavior frequently during the test period and compared yaw position with the nearby wind-vane indication of wind direction. We observed normal behavior under all wind conditions. At low wind speeds, the rotor operates at about 40° offset from the prevailing wind direction. This yaw error decreases as the wind speed increases until the turbine furls.

This turbine uses slip rings to transmit power to and from the nacelle to the tower cable. Therefore, droop cable over-twist is not an issue.

Startup
NREL observed that the turbine rotor starts spinning whenever winds increase to about 2 m/s. The turbine controller responds after a wait period during which it checks brake functionality. This is followed by a period during which the controller keeps the rotor speed at a low value until the inverters come on-line. When the inverters are online, the controller releases the rotor to normal operating speed. NREL has observed the turbine starting up over a wide range of wind speeds. NREL has not observed any abnormal behavior during any of the startups. NREL observed similar smooth cut-ins when the turbine was returned to service after shutdown.

Normal Shutdown
When winds drop below cut-in, the rotor gradually slows and stops producing power with no significant change in sound or behavior. This turbine does not have a cut-out wind speed, so normally it does not shut down in high winds.

Emergency shutdown during operation from any operating condition
Physically the emergency shutdown is the same as an automatic shutdown due to a fault.

The turbine safely brings the rotor down to an idling speed under any wind condition. This behavior is consistent with the manual's statement that the system can be shut down at any wind speed.

In addition to the automatic shutdown the controller performed, NREL also performed shutdowns by pushing the stop button on the voltage clamp. The turbine safely brought the rotor down to an idling speed any time this was performed.

Behavior upon excessive vibration

The turbine has no means to sense excessive vibration or to shut down should excessive vibration occur. The IEC turbine design standards require such sensors on large turbines but not on turbines smaller than 200^{m2}.

Behavior upon loss of load

When the inverters sense a grid fault, they disconnect from the grid. The voltage clamp then applies the brake. NREL tested for this by opening the disconnect switch between the ARE subpanel and panel 3-3L. This test took place on November 5, 2008 in winds of about 12 m/s.

The turbine shut down but then never came back online. It was found that the Insulated Gate Bipolar Transistors IGBT's in the voltage clamp had failed. Figure 6 shows the time traces of the event.

A similar event during which the IGBT's failed happened during a real grid outage on June 13th. Both failures happened during winds in which the inverters were producing maximum power and the diversion loads were likely already active.

On July 20, 2009, the loss of load simulation was repeated in low winds (6m/s). The turbine did not sustain any damage from this test. (Figure 7)

Turbine specific checks

Over temperature

This turbine system has provisions to monitor temperature in the voltage clamp and in the diversion loads. Should those components become too hot, the turbine shuts down, initiates a 5-minute cool down period, and waits until all temperatures are below their set point. On December 5, 2008, independent temperature readings were taken during high winds. At the time, an over-temperature fault occurred. NREL measured the temperature at the top of one of the diversion loads to be 72.7°C. The temperature in the voltage clamp enclosure was 41.2°. At that time, the ambient temperature in the data shed was 34.4°C.

Load brake resistor failure simulation

Upon startup of the turbine, the voltage clamp checks to see if the diversion loads and brake resistors are properly installed. To test this function, NREL disconnected the DL2+ wire inside the voltage clamp. The turbine went through the startup sequence, allowing the rotor to rotate slowly. It then faulted to a Load/Brake Resistor test fault as indicated by the red and green LED both being steady on.

Personnel Safety Provisions

Safety Instructions

The turbine operator's manual provides few safety instructions for installation, operation, and maintenance. The turbine does not require trained personnel for maintenance or servicing so no warning of this nature is required on the manual's cover.

The Owners manual covers assembly of the turbine but not the actual installation of the turbine system. NREL asked and received a separate document describing the installation procedure including hoisting and rigging information.

NREL checked the manual to determine if the safety instructions addressed requirements in the IEC small turbine design standard and found the following:

1. Disengage the load and/or energy sources: The voltage clamp has instructions indicating that it should only be opened after the stop button has been pushed. The inverter manuals describe how to disconnect the inverters from both the DC and AC connections.
2. Stop and secure the rotor: NREL found an explanation on how to slow down the rotor but no provision was found on how to stop it completely.
3. Stop and secure the yaw mechanism: The turbine has no provisions for securing the yaw mechanism.
4. Stop and secure the furling system: The turbine has no provisions for securing the furl mechanism.
5. Climb tower: The tower came with a TUF TUG safety climb system. It included a manual with instructions for safe climbing.

Climbing

NREL personnel climbed the turbine using the supplied TUF TUG fall protection system. On one side of the tower, additional horizontal braces are installed to form a ladder. Climbing the tower was found to be fairly easy. The main issue was getting to a working position at the top of the climbing system. There are no recommendations in the owner's manual about transferring from the fall protection cable to a working position on the turbine and the climbing system ends before reaching a position high enough to work on the turbine. There are no obvious or clearly identified tie off points other then the tab on top of the turbine behind the rotor, which is difficult to reach when still holding on to the side of the ladder. Another issue is preventing the turbine from yawing while in the process of getting into a working position. NREL recommends inserting some language into the manual describing how to safely tie off a blade to the tower to prevent rotor rotation and yaw movement.

Fire resistance and control
The Windyboy inverters are designed to resist "normal internal temperatures" and according to the manual will de-rate to maintain safe internal temperatures. NREL did not evaluate this since the inverter is UL listed as compliant with UL 1741.

The voltage clamp has a temperature sensor which will shut the turbine down once the temperature exceeds a threshold. The dump load is enclosed in a fire-resistant, metal enclosure. It has temperature sensors installed in the top of the enclosures. If the temperature exceeds the limits, the turbine will shut down.

The turbine Owner's Manual describes the clearance required around each of the system's components.

Fire extinguisher
NREL provided a fire extinguisher in the building that housed the voltage clamp, diversion loads, and inverters. The manufacturer does not provide fire extinguishers or recommend that they be installed.

Emergency Stop Button
The turbine has an emergency stop button on the voltage clamp (Figure 8) for use in manual turbine shutdown.

Lock-out / tag-out provisions
NREL provided a lockable switch between the grid and the subpanel that was connected to the voltage clamp and the inverters (Figure 9). The manufacturer does not provide this equipment or recommend that this type of equipment be installed. Nor does the manufacturer provide procedures for de-energization of the turbine system.

Interlock on electrical cabinets
The voltage clamp does not have an interlock on the cabinet. However, there is a warning label and instructions on the door. A hex key is needed to open the cabinet.

Safety signs
1. The voltage clamp has a label warning of high voltage and instructions on how to safely open the enclosure. (Figure 10)
2. The diversion loads did not have any warning signs. NREL added a sign stating "Caution hot surface do not touch."
3. The TUF TUG safety system has a tag on the cable at the base of the tower. (Figure 11)
4. NREL added labels indicating the voltage levels on all enclosures, electrical panels, and disconnects.

Unauthorized changing of control settings
There are no readily accessible ways to alter any settings in the voltage clamp. The inverter settings can be changed if the directions in the manual are followed. The inverter must be opened to do so.

Lighting Protection

The turbine was purchased with the lightning protection package. This is normally an add-on that has to be purchased separately. It consists of three surge suppressors. One at the tower base, one on the voltage clamp, and one on the sub-panel as indicated in Figure 2. During the test period, no direct or nearby lightning strikes were observed.

In addition to the surge suppressors, the turbine base is grounded and a ground wire runs in the trench back to the data shed to a second ground rod. No Ufer ground was specified for the foundation itself.

Presence of rotor and yaw lock

There is no rotor lock or yaw lock present on the turbine.

Dynamic Behavior

NREL observed operation throughout the test period in wind speeds ranging from dead calm to winds in excess of 25 m/s. The total observation time exceeded the required one hour. NREL did not measure accelerations directly. NREL noted that the turbine displayed no excessive vibrations. The turbine did not produce any significant differences in noise levels. Tail movement and yaw behavior appeared normal under all conditions.

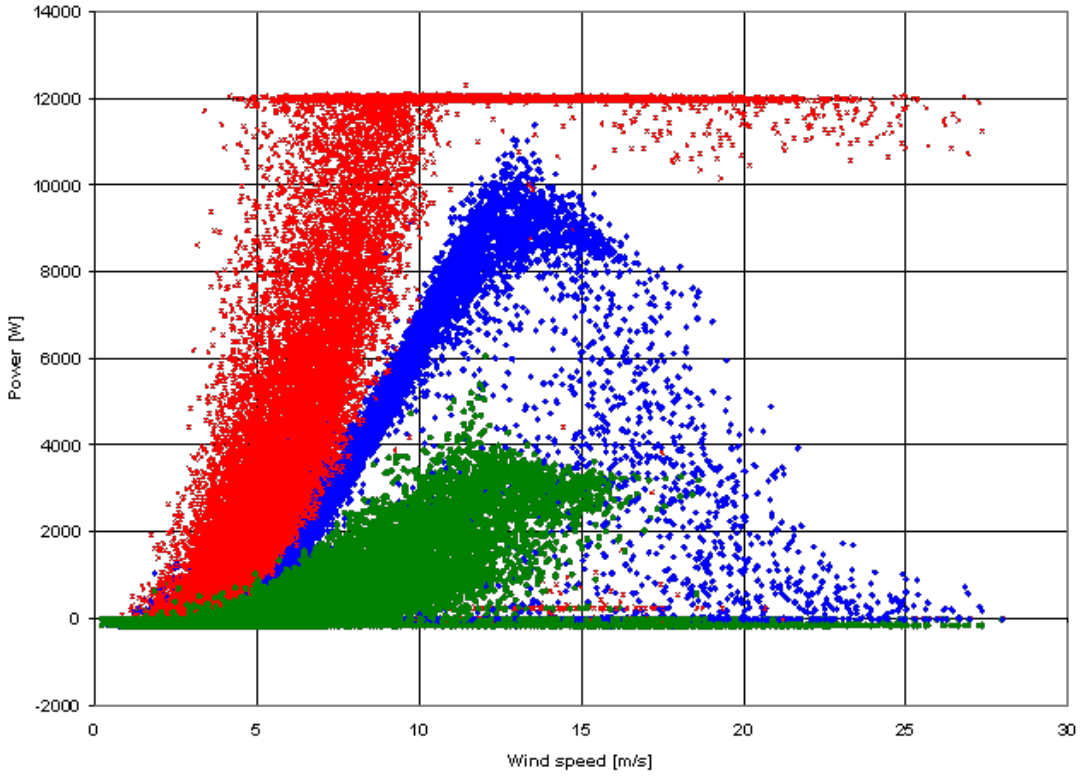


Figure 3. Power response to wind speed (red- maxima, green - minima, blue -average)

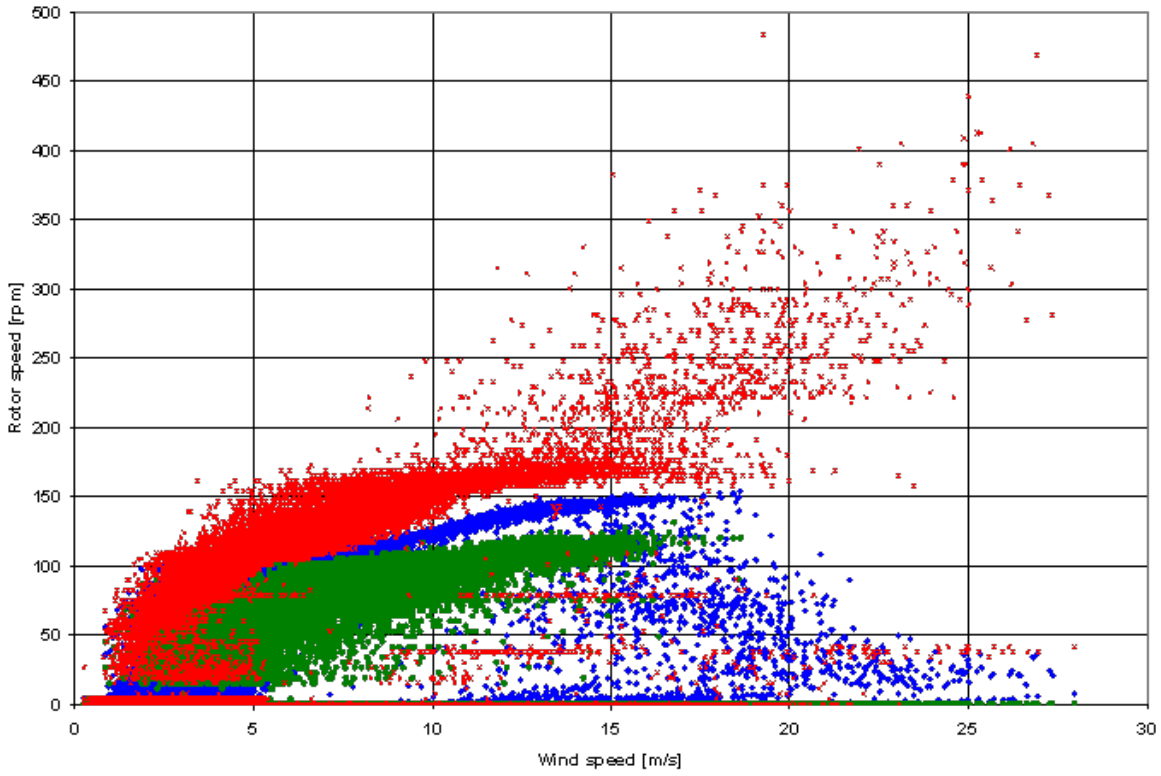


Figure 4. Rotor speed response to wind speed (red- maxima, green - minima, blue -average)

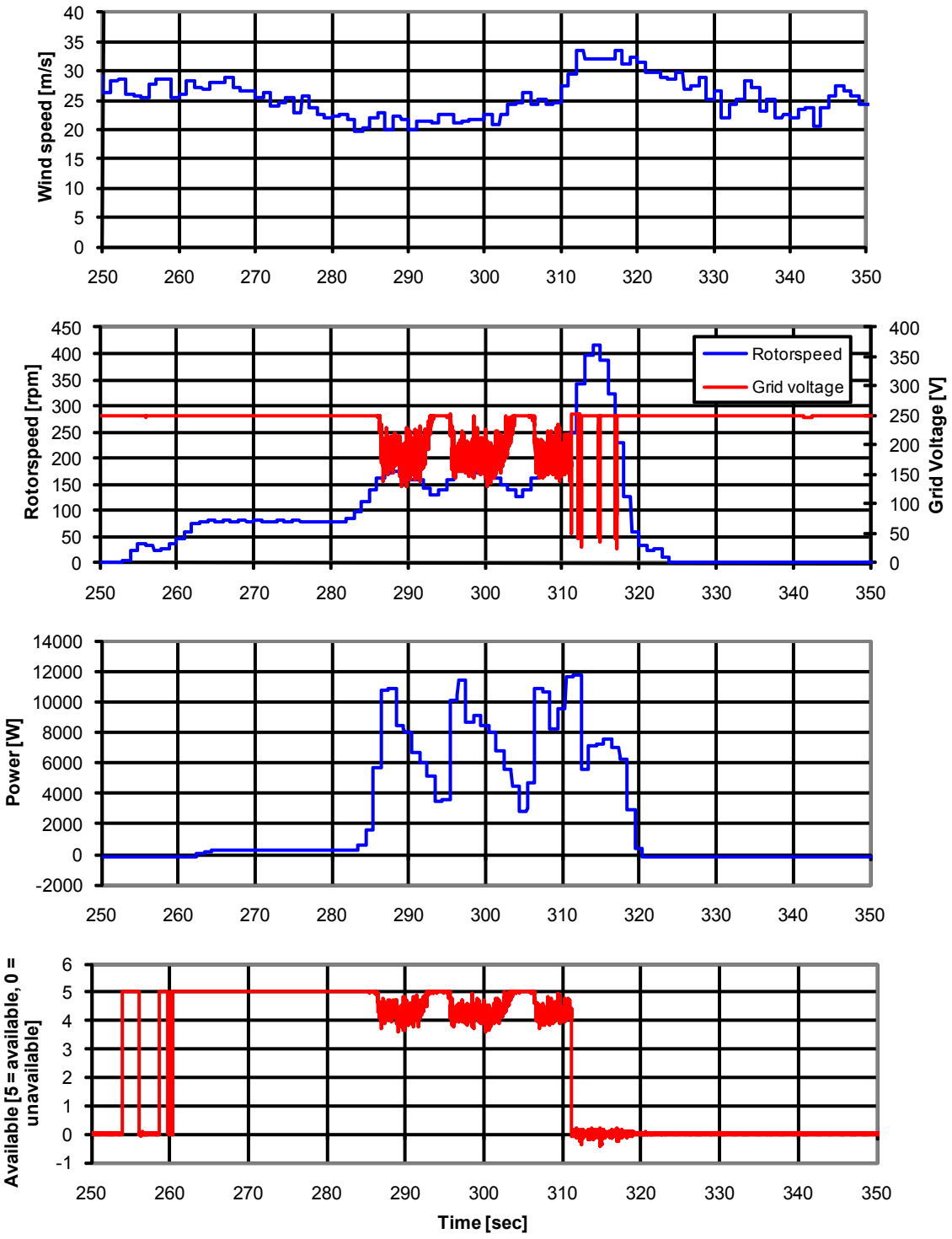


Figure 5. Time series of a high rpm event (datafile ARE081230_001156)

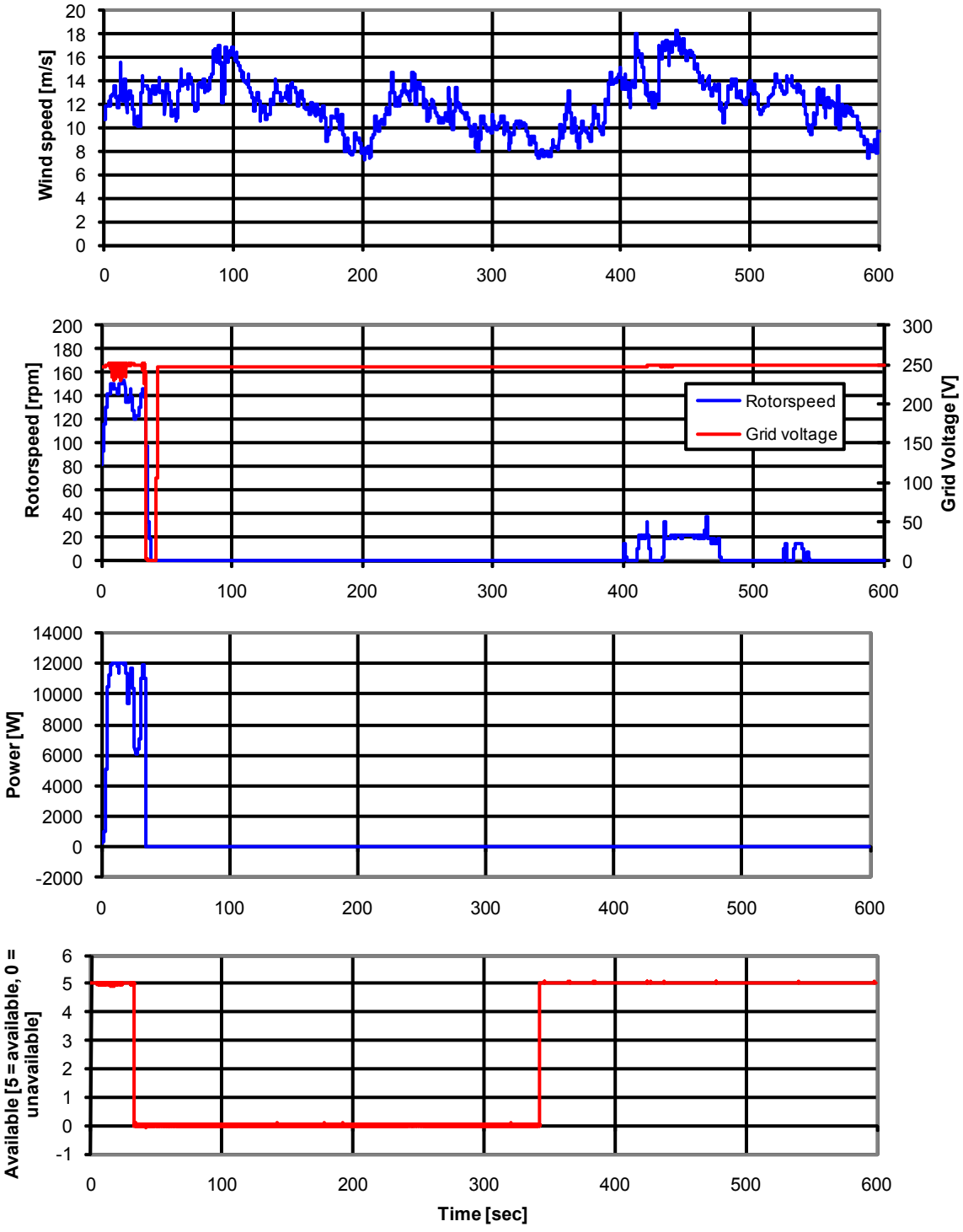


Figure 6. Turbine response during a simulated grid outage -- the IGBT's failed. (datafile ARE081105_144425)

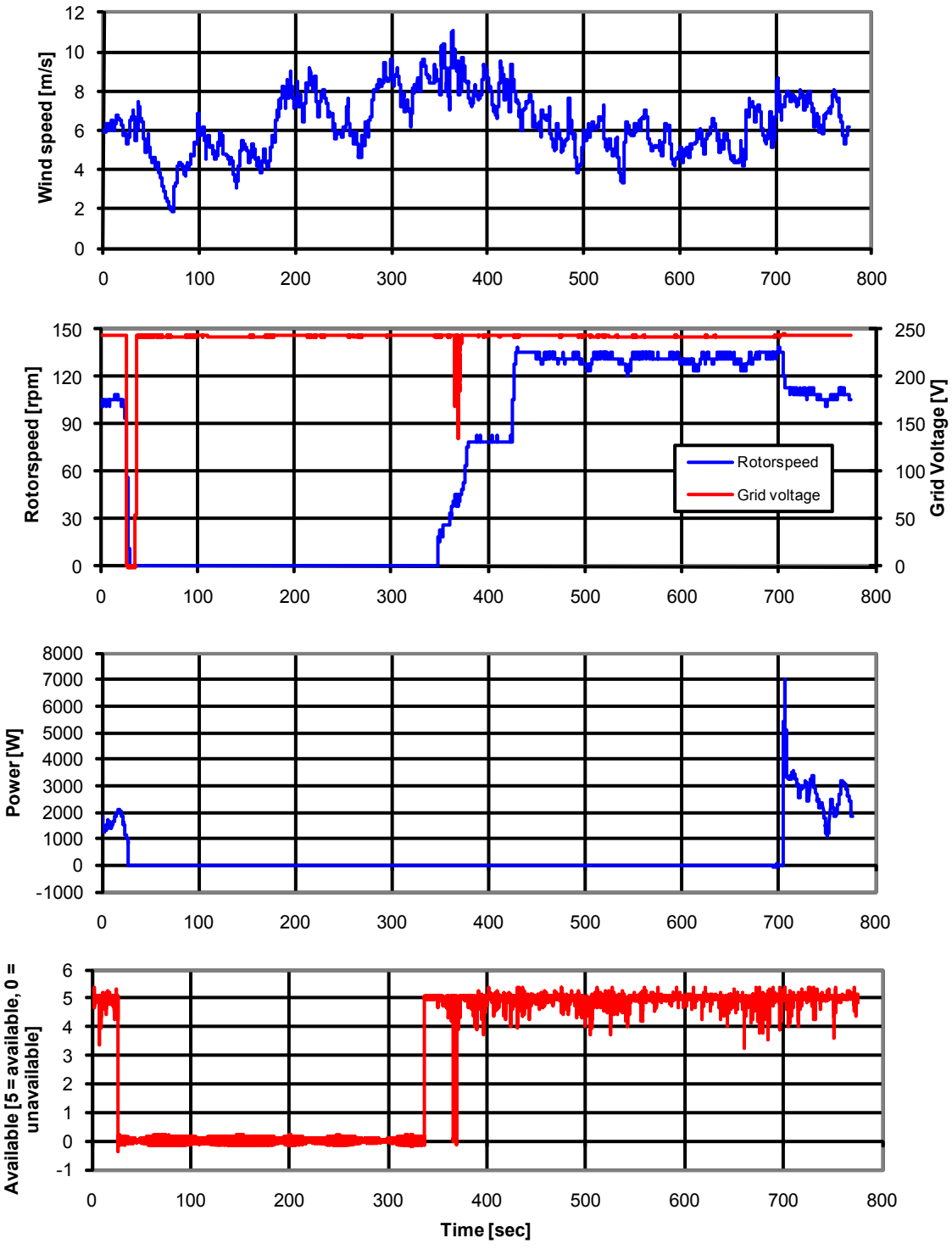


Figure 7. Simulated grid outage in low winds (data file ARE090720_115146)

Figure 8. ARE442 Voltage clamp with e-stop button

Figure 9. ARE 442 disconnect

Figure 10. Safety instructions on the voltage clamp

Figure 11. Safety instruction tag on the TUF TUG climbing system

Deviations and Exceptions

Deviations from the Standard

There were no known exceptions to the Standard for the test.

Exceptions to the NWTC Quality Assurance System

The data acquisition modules were used beyond the calibration due date. The modules were post-test calibrated and found to be in compliance within the specifications. Appendix A includes the post-test calibration sheets.

Appendix A – Instrument Calibration Sheets

Branch #: 5000

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Phaser Power Transducer & 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

Page 1 of 2

Figure A.1. Power transducer calibration sheet

DEUTSCHER KALIBRIERDIENST **DKD**

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

Deutsche WindGuard
Wind Tunnel Services GmbH
Varel

Deutscher Akkreditierungs Rat
DAR
DKD-K- 36801

Kalibrierschein
Calibration Certificate

Kalibrierzeichen / *Calibration label*: DKD-K-36801 **07_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.

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

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

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

Deutsche WindGuard
Wind Tunnel Services GmbH

Figure A.2. Primary anemometer calibration sheet

NATIONAL INSTRUMENTS

Certificate of Calibration

Board Information:
Serial Number: 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.4. NI 9229 data acquisition module calibration sheet I

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.5. NI 9217 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.6. 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.7. 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.8. 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.9. NI 9205 data acquisition module calibration sheet II

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)*
February 2010	Technical Report	

4. TITLE AND SUBTITLE
Wind Turbine Safety and Function 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-500-47030

5e. TASK NUMBER
WE102211

5f. WORK UNIT NUMBER

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

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/TP-500-47030

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

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

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

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

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*

This test was conducted as part of the U.S. Department of Energy's (DOE) Independent Testing project. This project was established to help reduce the barriers of wind energy expansion by providing independent testing results for small turbines. In total, four turbines were tested at the National Wind Technology Center (NWTC) as a part of this project. Safety and function testing is one of up to five tests that were performed on the turbines, including power performance, duration, noise, and power quality tests. Test results provide manufacturers with reports that can be used for small wind turbine certification. The test equipment includes an ARE 442 wind turbine mounted on a 100-ft free-standing lattice tower. The system was installed by the NWTC Site Operations group with guidance and assistance from Abundant Renewable Energy.

15. SUBJECT TERMS
ARE 442 wind turbine; safety and function test; independent testing project; small wind turbines

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