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Safety and Function Test Report for the SWIFT Wind Turbine

I. Mendoza and J. Hur
National Renewable Energy Laboratory

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

Technical Report
NREL/TP-5000-57125
January 2013

Contract No. DE-AC36-08GO28308

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Prepared under Task No WE11.0205

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Safety and Function Test Report

for the

SWIFT Wind Turbine

Conducted for

Cascade Engineering
4855 Thirty-Seventh St. SE
Grand Rapids, MI 49512

Conducted by

National Wind Technology Center
National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401

Ismael Mendoza and Jerry Hur

24 September 2012

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Approval By: Arlinda Huskey 08 Jan 2013
Arlinda Huskey, NREL Test Engineer — Date

Review By: 8 January 2013
Jeroen van Dam, NREL Test Engineer — Date

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1. Background

This test was conducted as part of the U.S. Department of Energy's (DOE) Independent Testing project. This project was established to help reduce the barriers of wind energy expansion by providing independent testing results for small turbines. Several turbines were selected for testing at the National Wind Technology Center (NWTC) as a part of the Small Wind Turbine Independent Testing project. Safety and function testing is one of up to five tests that may be performed on the turbines. Other tests include power performance, duration, acoustic noise, and power quality.

The test equipment included a SWIFT wind turbine manufactured by Renewable Devices mounted on a 13.7-meter free-standing monopole tied to the grid through a Kaco Blueplanet 1502x inverter. The turbine was provided by Cascade Engineering of Grand Rapids, Michigan. Cascade Engineering is the North American distributor of the SWIFT turbine and a DOE grant recipient. The system was installed by the NWTC Site Operations group with guidance and assistance from Cascade Engineering.

2. Test Objective

The objectives of this test were to:

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

The National Renewable Energy Laboratory (NREL) does not limit safety and function tests 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 IEC standard, "Wind Turbines—Part 2: Design Requirements for Small Wind Turbines," IEC61400-2, second edition, 2006-03.

3. Description of Test Turbine and Setup

The test turbine was a grid-connected SWIFT wind turbine. The SWIFT is an upwind, 5-bladed with outer ring, side furling turbine with a rated power of 1 kW. Figure 1 shows the test turbine installed at the National Wind Technology Center. Table 1 provides the key descriptive information of the test turbine.

Table 1. Test Turbine Configuration

Turbine manufacturer and address	Renewable Devices Ltd Bush Estate, Penicuik, EH26 0PH Scotland, U.K.
Turbine provider and address	Cascade Engineering 4855 Thirty-Seventh St. SE Grand Rapids, MI 49512
Model name	SWIFT
Production date	May 2010
Serial number	N000780-N
Design nominal voltage at terminals (V_{AC})	240
Maximum current at terminals (A)	10
Design frequency at terminals (Hz)	60
SWT class	II
Design 50-year extreme wind speed, Ve50 (m/s)	59.5
Rotor diameter (m)	2.1 with outer ring*
Hub Height (vertical center of rotor) (m)	14.3*
Tower type	13.7 m (45 ft) freestanding monopole
Rated electrical power (kW)	1
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)	390
Rotor speed range (rpm)	0-450
Fixed or variable pitch	Fixed
Number of Blades	5
Blade Tip Pitch Angle (deg)	6° at the tip
Blade make, type, serial number	Injection molded nano-fiber reinforced polymer, F000648
Description of control system (device & software version)	Kaco Blueplanet 1502x (Software V2.05)

*Measurements verified the rotor diameter and hub height.

The test turbine was located at site 3.1 at the NWTC, which is approximately 8 km south of Boulder, Colorado. The terrain consists of mostly flat terrain with short vegetation. The site has prevailing winds bearing approximately 292 degrees relative to true north.

Figure 2 shows the general electrical arrangement. The wire run from the nacelle at the top of the tower to the point of grid connection at the data shed was approximately 46 meters. The connection was made using #12 American Wire Gauge (AWG) wire for the two power lines and turbine signal, and #6 AWG for ground. The data shed housed the inverter, power instrumentation, disconnect switch, and data acquisition system. The 240 VAC power output from the turbine was connected to a series of insulating step-up transformers that raised the voltage to 13.2 kilovolts, allowing the system to tie to the NWTC grid.

Figure 1: SWIFT test turbine at the NWTC (NREL/PIX 22083)

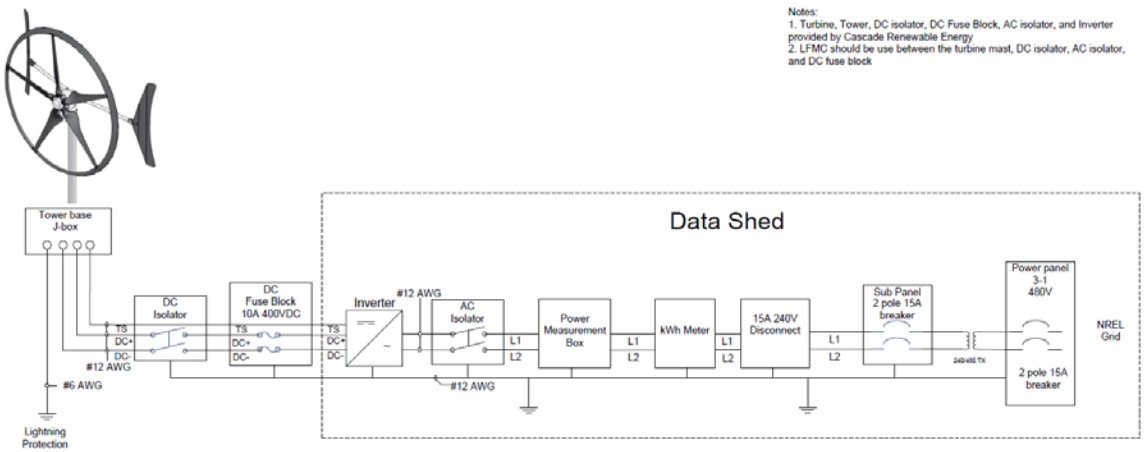

Figure 2: Electrical single-line drawing of SWIFT installation (NREL 2012)

4. Instrumentation

The following parameters were measured in this test: wind speed, electrical power, rotor speed, turbine status, and grid voltage. An indication of turbine status was obtained by measuring the dynamic brake voltage from the turbine controller. The rotor speed was measured using a frequency-to-voltage converter mounted to the side of the turbine that transmitted its output wirelessly to the data acquisition system. The instruments used for these measurements are listed in Table 2. The calibration sheets for the instruments used for this safety and function test are included in Appendix A.

Table 2. Equipment Used in the Safety and Function Test

Instrument	Make and Model	Serial Number	Calibration Due Dates
Power transducer	Secondwind Phaser 5FM-4A20	04607	20 October 2011 7 November 2012
Primary anemometer	Thies, First Class	0609005* 609006	13 October 2011 7 April 2012
Reference anemometer	Met One, 010	W2390	In situ
Rotor speed	Phoenix Contact, MCR-f-UI-DC	32384299	11 November 2012
Data acquisition system	Compact DAQ w/LabView -based data acquisition		
	cDAQ-9172	13AB4F9	
	NI 9229	140DCB9*	29 April 2011
	NI 9217	140A596*	29 April 2011
	NI 9205	140E2BD*	29 April 2011
	NI 9229	14A34EE	22 March 2012
	NI 9217	1494F69	22 March 2012
	NI 9205	1496266	22 March 2012

*Replaced during testing

The DAS modules, power transducer, and primary wind speed anemometer were used beyond the calibration due dates. The initial power measuring module failed its post-test calibration. An investigation was performed on the data acquired but there were no indications that the module failed during the test. It was concluded that it may have been damaged during shipping. This was listed as an exception to our QA system.

5. Procedure

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

5.1. Control and Protection System Functions

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 to occurred, NREL simulated the appropriate input and verified that the control and protection system sensed the condition, and provided indication of an appropriate response. This procedure enabled, for example, all the E-stop functions to be checked without exposing the turbine to multiple, potentially-damaging stops. These checks were 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
5. Normal shutdown
6. Emergency shutdown during operation
7. Behavior upon excessive vibration
8. Behavior upon loss of load

5.2. Personnel Safety Provisions

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

1. Safety instructions
2. Climbing
3. Electrical and grounding system
4. Fire resistance and control
5. Fire extinguisher
6. Emergency stop buttons
7. Lock-out / tag-out provisions
8. Interlock on electrical cabinets
9. Safety signs
10. Unauthorized changing of control settings
11. Lightning protection
12. Presence and functioning of rotor and yaw lock

5.3. Dynamic Behavior

NREL observed the turbine over a wide range of wind speeds. Observations were recorded in the logbook and are reported in the results section of this report. No direct measurements of tower accelerations were taken for this turbine.

6. Results

The results reported here were based on testing conducted from 1 November 2010, when the turbine was commissioned, through 31 March 2012. The turbine controller settings were tested in January 2012. The turbine was decommissioned on 27 June 2012.

6.1. Control and Protection System Functions

The turbine exhibited no unexpected or inherently unsafe behavior during this investigation; however, this did not mean that the turbine is safe under all conditions. NREL limited testing to investigation of single-fault failures and did not investigate failures of “safe life” components. If a second fault were to occur during a critical event, severe results can be expected. Neither NREL nor the IEC turbine-design requirements make judgments on whether such failures are likely or

whether additional features in the control and protection system are needed to protect against such consequences.

6.2. Power Control

Figure 3 shows that the power output of the turbine system was limited in response to high winds. The power curve scatter plot is characteristic of a stall regulated wind turbine, as expected. The turbine had a furling system that limited the amount of power it produced because it began to govern its rotor speed at 10 m/s. Also, in Figure 3 the power curve shows a maximum 1.8-kilowatt instantaneous power. The limit was achieved by the controller applying its dynamic brake if the rotor speed exceeded its safe operating level of 480 revolutions per minute (RPMs). Figure 4 illustrates a time series of the turbine power control behavior during a high-wind event.

6.3. Rotor Speed Control

Rotor speed measurements were taken in January 2012. Figure 5 illustrates how the rotor speed was regulated by the furling system starting at around 10 m/s. The Figure 5 scatter plot also contains the wind speed bin average, 1-minute average, and 1-second maximum and minimum rotor speeds. The rotor average speed always stayed below its operating range maximum of 450 RPMs. The dynamic brake was automatically applied if the rotor speed exceeded the instantaneous safe operating level of 480 RPMs. On 5 January 2012 a high RPM event was recorded, as seen in Figure 5. *As noted in the log book: "The rotor reached a maximum of 489 RPM then immediately applied the break, reducing the rotor speed back to 80 RPMs in 5 seconds."* Figure 4 illustrates a time series of the turbine behavior and how the rotor speed was regulated during a high-wind event. When the turbine was turned off, or experienced a fault or a grid outage, the rotor speed reduced to an idling speed less than 16 RPMs. The idling speed was verified to stay below 16 RPMs even at high-wind speed as seen in Figure 6. Extra precaution needed to be taken when approaching the rotor because it did not stop.

6.4. Yaw Orientation

The SWIFT was an upwind, passive yaw turbine with two tail fins. The unit was equipped with a furling mechanism that engaged during high winds, causing the turbine to turn the rotor perpendicular to the wind. NREL observed this yaw behavior frequently during the test period and compared yaw position with the nearby wind vane's indication of wind direction. Normal yawing behavior was observed under all wind conditions. Winds greater than 2.5 m/s were necessary to begin to orient the turbine to the correct wind direction. The turbine had a dynamic response; during some high winds the rotor was observed to yaw approximately 60 degrees in one second due to its furling mechanism. Extra precaution needs to be taken by personnel when approaching the rotor because the turbine is not equipped with a yaw lock.

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

6.5. Startup

NREL observed that the turbine rotor started spinning whenever winds increased above 2 m/s. The inverter was programed to allow the turbine to couple with the grid when it reached 150 V

(about 170 RPMs). This coupling rotor speed could be achieved at winds averaging 5 m/s. Figure 7 shows the rotor speed versus power production. Figure 8 illustrates a time series of the turbine behavior as the wind increased above cut-in. NREL did not observe any abnormal behavior during any of the startups. NREL observed similar smooth cut-in transitions when the turbine was returned to service after shutdown or a fault had been cleared.

6.6. Normal Shutdown

When winds dropped below cut-in, the turbine stopped producing power with no significant change in sound or behavior. The turbine allowed the rotor to freewheel in wind speeds less than cut-in. Figure 9 illustrates a time series of the turbine behavior as the wind decreased below the power production threshold.

This turbine did not have a cut-out wind speed, thus it did not normally shut down in high winds.

6.7. Emergency Shutdown from Any Operating Condition During Operation

The turbine was not equipped with a dedicated emergency stop button. The AC or DC disconnect rotary switches were used to turn off the turbine in case of an emergency (see Figure 10 and Figure 11). Turning any of the rotary switches to the off position immediately disconnected the turbine from the grid and applied the dynamic break by shorting the generator, decreasing the rotor speed to less than 16 RPM in about 9 seconds under any wind conditions. This behavior was consistent with the manual's statement that the system could be shut down at any wind speed. The turbine behavior during the activation of the AC isolation switch can be seen in Figure 6 during the mimic outage performed by NREL. Once the isolator was turned to the off position, the voltage immediately dropped to zero. The grid voltage monitoring also provided another source of turbine availability. The primary source of the availability was based on a controller voltage signal. The signal triggered the dynamic break relay that shorted the generator. Figure 12 illustrates the turbine behavior during the activation of the DC isolation switch. The dynamic break signal had a high reading (5 V) in the DC isolation exercise because the DC isolation switch was hooked up directly to the turbine as seen in Figure 2.

6.8. Behavior Upon Excessive Vibration

A high-wind event and variable wind direction was observed on 16 December 2010 that caused excessive vibration, forcing the turbine to lock down. The turbine immediately disconnected from the grid and applied its dynamic break bringing the rotor to a safe idling speed. The turbine had to be manually reset in order to fully return to a normal operational state, indicating it had locked out for excessive vibration as stated in the owner's manual. The turbine controller did not show any indication when the turbine locked down. The owner's manual instructed the user to observe if there was no change in rotor speed at power-producing wind speeds, thus indicating a lock up. Subsequently, the user was instructed to perform a turbine reset in order to bring the turbine back to normal operation.

6.9. Behavior Upon Loss of Load

In the event of a grid outage or large fluctuations, the SWIFT immediately disconnected from the grid in order to prevent any electric hazards. The controller shorted the generator, reducing the

rotor speed to an idling speed less than 16 RPMs in about 9 seconds. After the grid voltage was reestablished, the turbine inverter performed an internal check that lasted about six minutes. After this check passed, the turbine rotor started to ramp up, depending on wind conditions, and to automatically reconnect and resume normal operation. The turbine inverter was programmed to perform similar daily internal checks, which caused the system to go offline independent of wind conditions.

NREL mimicked a grid outage by opening the disconnect switch between the SWIFT inverter and the electric panel at the 3.1 shed. This test took place on 19 January 2012 in winds of about 9 m/s while the turbine was producing around 900 W. Figure 6 shows a time series of the turbine behavior during the event.

7. Personnel Safety Provisions

The turbine had two separate manuals — an installation manual and owner's manual. The installation manual was used only by trained personnel and was not provided to the turbine owner. The owner's manual states that only trained personnel should service or perform turbine maintenance.

The installation manual focused mainly on structure or building mounting. No hoisting or rigging information was provided for monopole or tower installation. Moreover, the installation manual did not include a safe wind-speed limit for installing the wind turbine or detailed specifications of appropriate personal protective equipment. The installation manual did contain a list of all the required tools and provided equipment needed to install the turbine.

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

- Disengage the load and/or energy sources: The turbine was equipped with a DC and AC isolation switch to remove the turbine from the grid. The owner's manual described how to disconnect the inverter from either the DC or AC supply.
- 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.
- Stop and secure the yaw mechanism: The turbine had no provisions for securing the yaw mechanism.
- Stop and secure the furling system: The turbine had no provisions for securing the furling mechanism.
- Climb tower: The turbine was not equipped with a ladder or other means of climbing the tower.

7.1. Climbing

The turbine tower was not intended for climbing. To service or inspect the turbine, NREL staff used a boom lift.

7.2. Standing Places, Platforms, and Floors

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

7.3. Electrical and Grounding System

The electrical system consisted of wiring from the turbine to a series of isolation switches, then to the inverter, and finally to a dedicated circuit breaker. The grounding system consisted of a ground pole connected to the tower base. Details of the electrical and grounding system were shown in a wiring diagram in the installation manual.

7.4. Fire Resistance and Control

The Kaco Blueplanet 1502x inverters were designed to resist “normal internal temperatures” and, according to the manual, would de-rate to maintain safe internal temperatures. NREL did not evaluate this because the inverter was UL listed as compliant with UL 1741.

The installation manual described the clearance required around each of the system’s components.

7.5. Emergency Stop Button

The turbine was not equipped with an emergency stop button. NREL staff stopped the turbine by opening the disconnect switch. Alternatively the turbine could be stopped by toggling the isolation switches to the off position, as described in the owner’s manual.

7.6. Lock-Out / Tag-Out Provisions

The isolation switches have the capability to lock out the switch in the off position, isolating either the DC or the AC portion of the system.

7.7. Interlock on Electrical Cabinets

There were no interlocks on the inverter enclosure.

7.8. Safety Signs

Neither the turbine nor the controller had any warning signs affixed. NREL personnel labeled the inverter, electrical panels, and disconnects, indicating the hazard and voltage levels of each.

7.9. Unauthorized Changing of Control Settings

There were no readily accessible ways to alter any settings in the inverter without the proper password provided from the inverter manufacturer. For safety purposes only the turbine provider and approved installers could request the password to prevent the end user from modifying the parameters.

7.10. Lighting Protection

The turbine tower and inverter were connected to a ground connection, serving as a diversion path for lightning protection. During the test period no direct or nearby lightning strikes were observed.

7.11. Presence of Rotor and Yaw Lock

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

7.12. Dynamic Behavior

The operation was observed by NREL personnel for at least 5 minutes at wind speeds of approximately 5 m/s, 10 m/s, 15 m/s, and 20 m/s, for a total observation period of at least 1 hour. NREL staff did not measure accelerations directly; however, some slight tower vibration and rattling was observed during high-wind events when the turbine's furling mechanism was engaged. Although vibrations could be felt, and sometimes seen, in the tower, they were not deemed excessive. The turbine did not produce excessive noise, and yaw behavior appeared normal under all conditions.

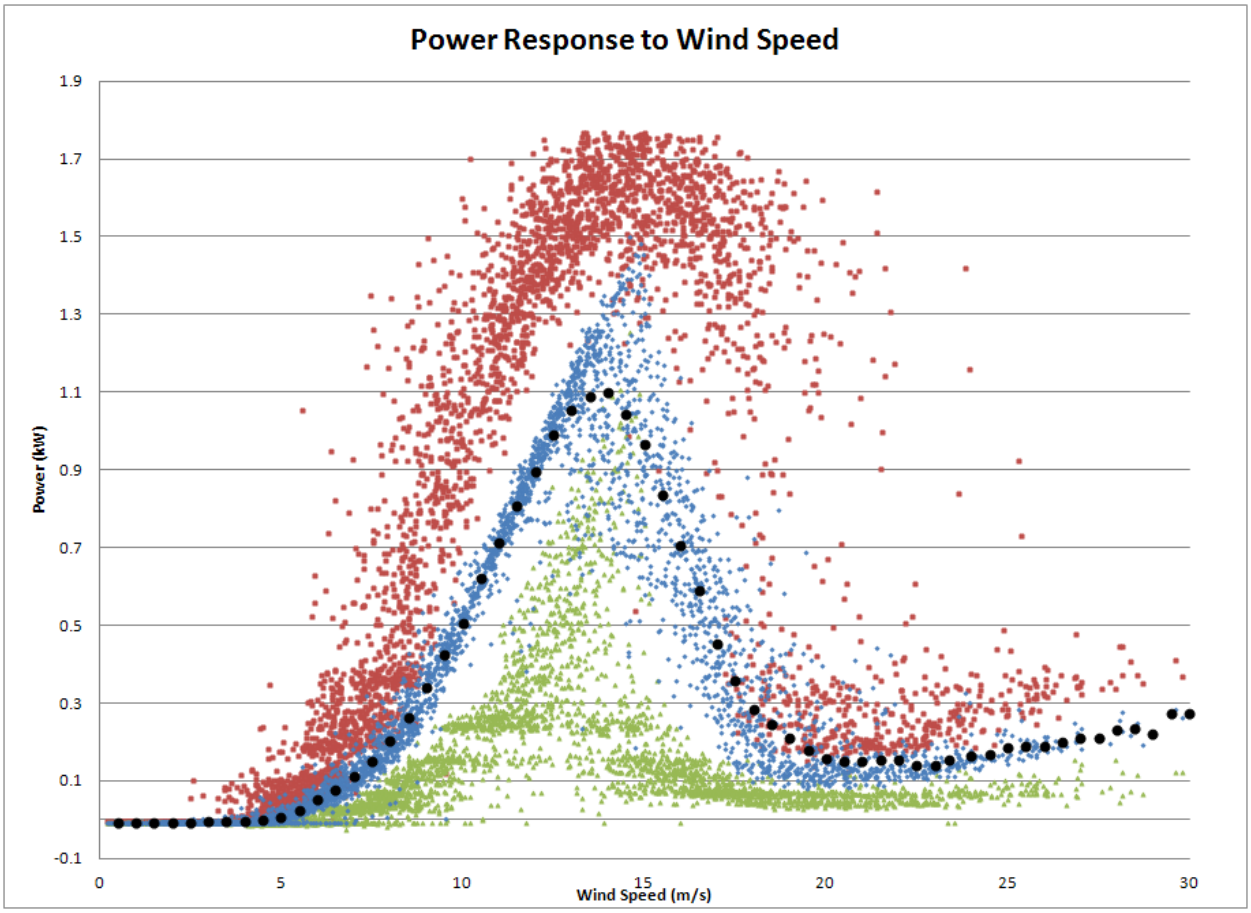

Figure 3: Power response to wind speed, 1-min data (red–maxima, green–minima, blue–average, black–bin average)

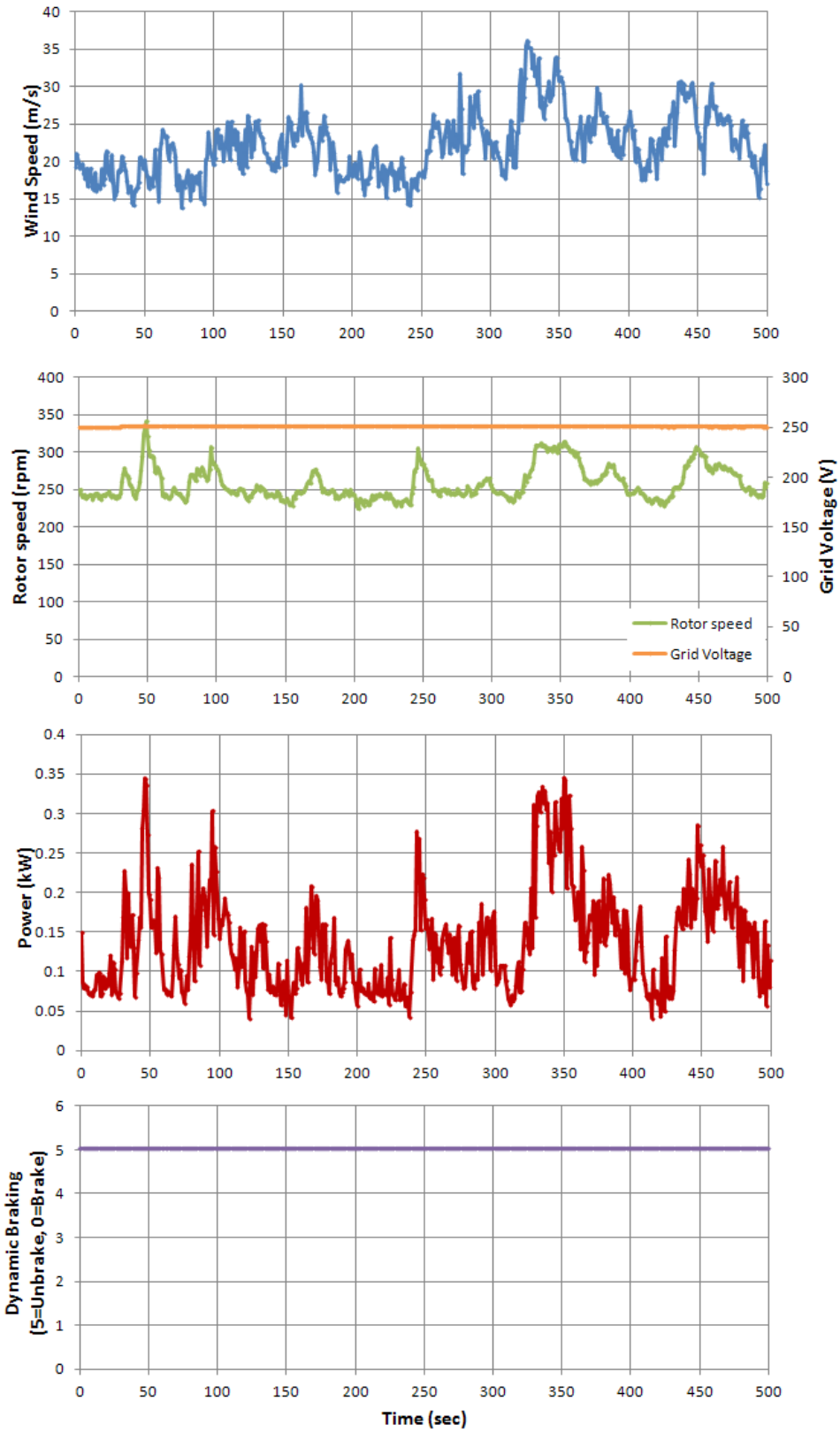

Figure 4: Turbine response during a high-wind event

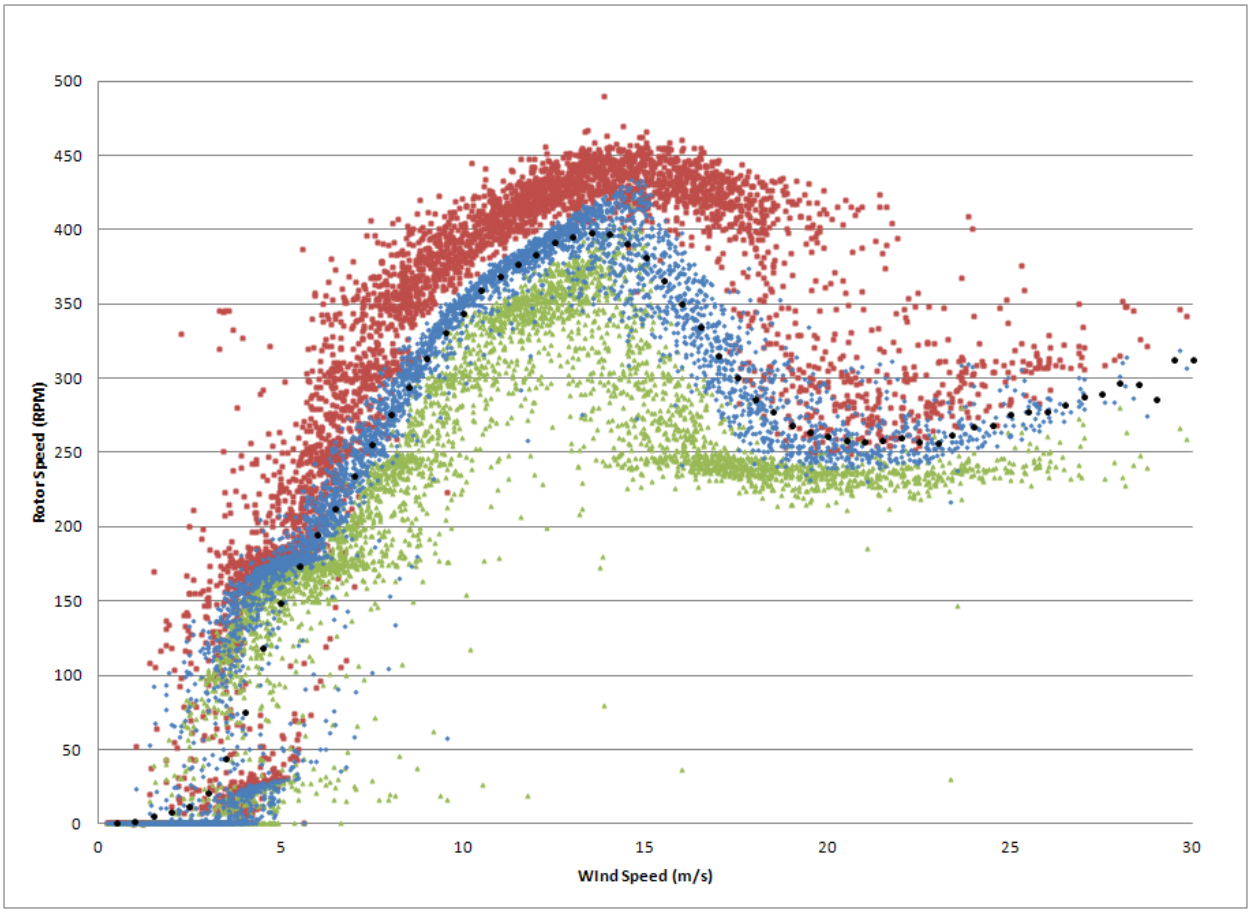

Figure 5: Rotor speed as a function of wind speed, 1-min data (red–maxima, green–minima, blue–average, black–bin average)

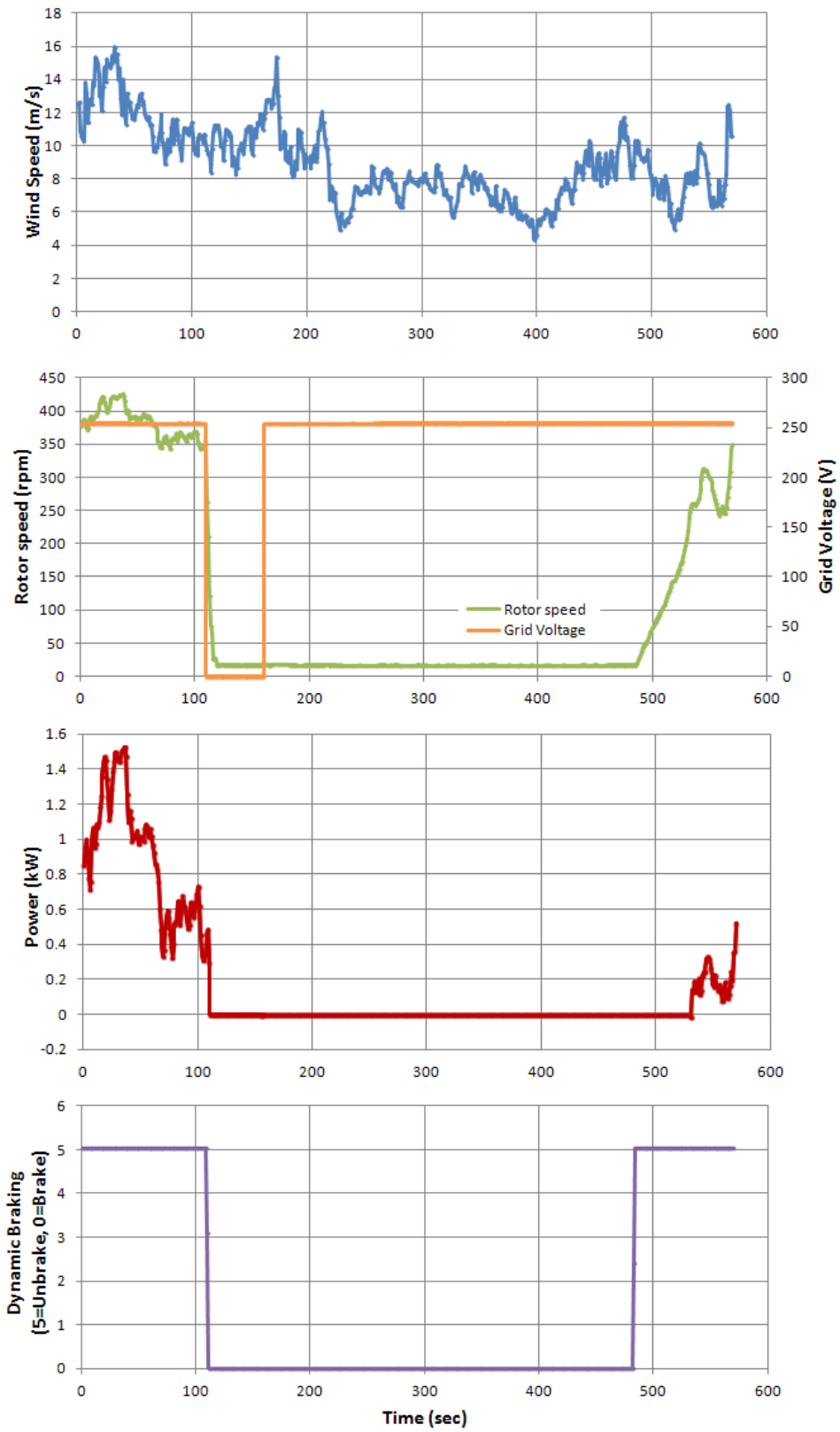

Figure 6: Turbine response during a simulated grid outage

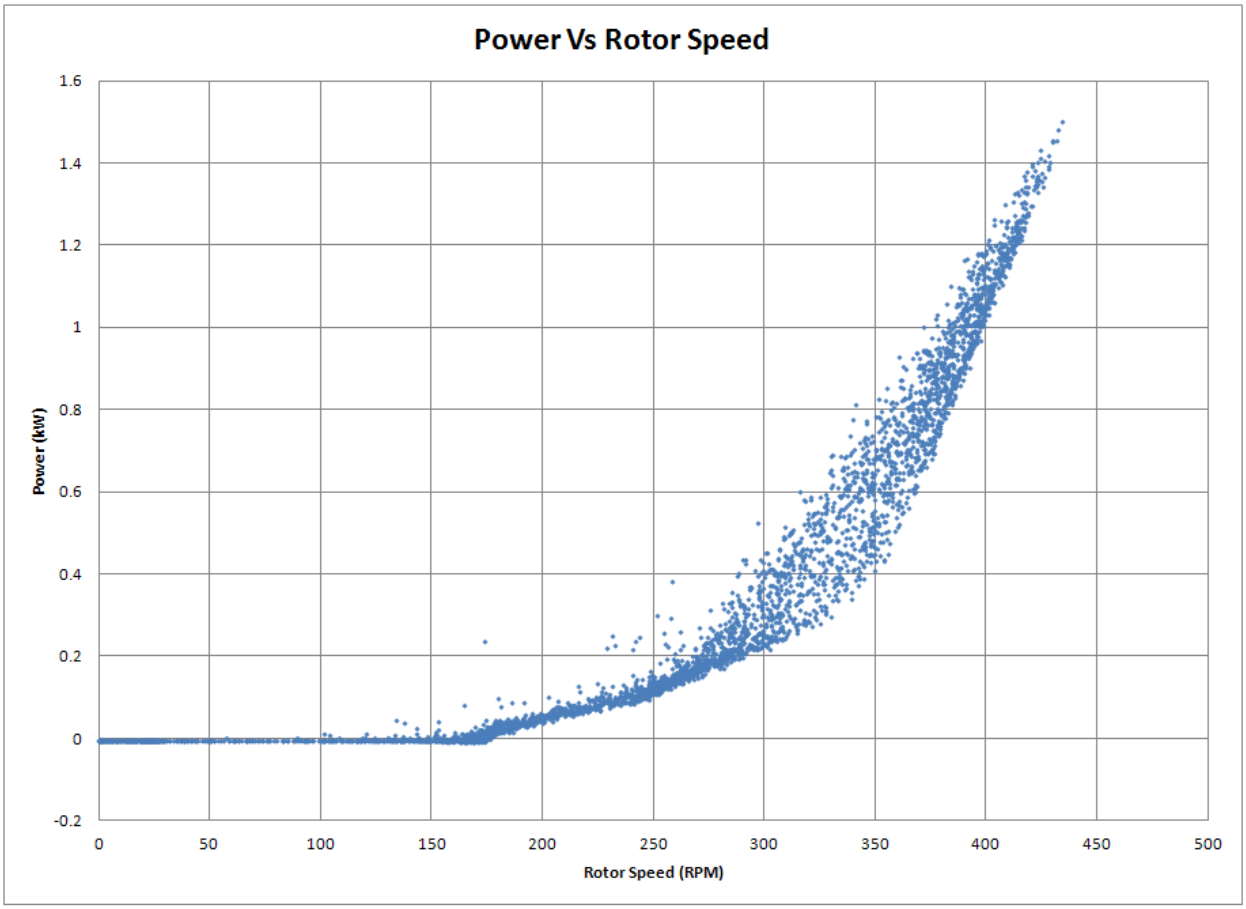

Figure 7: Power as a function of rotor speed

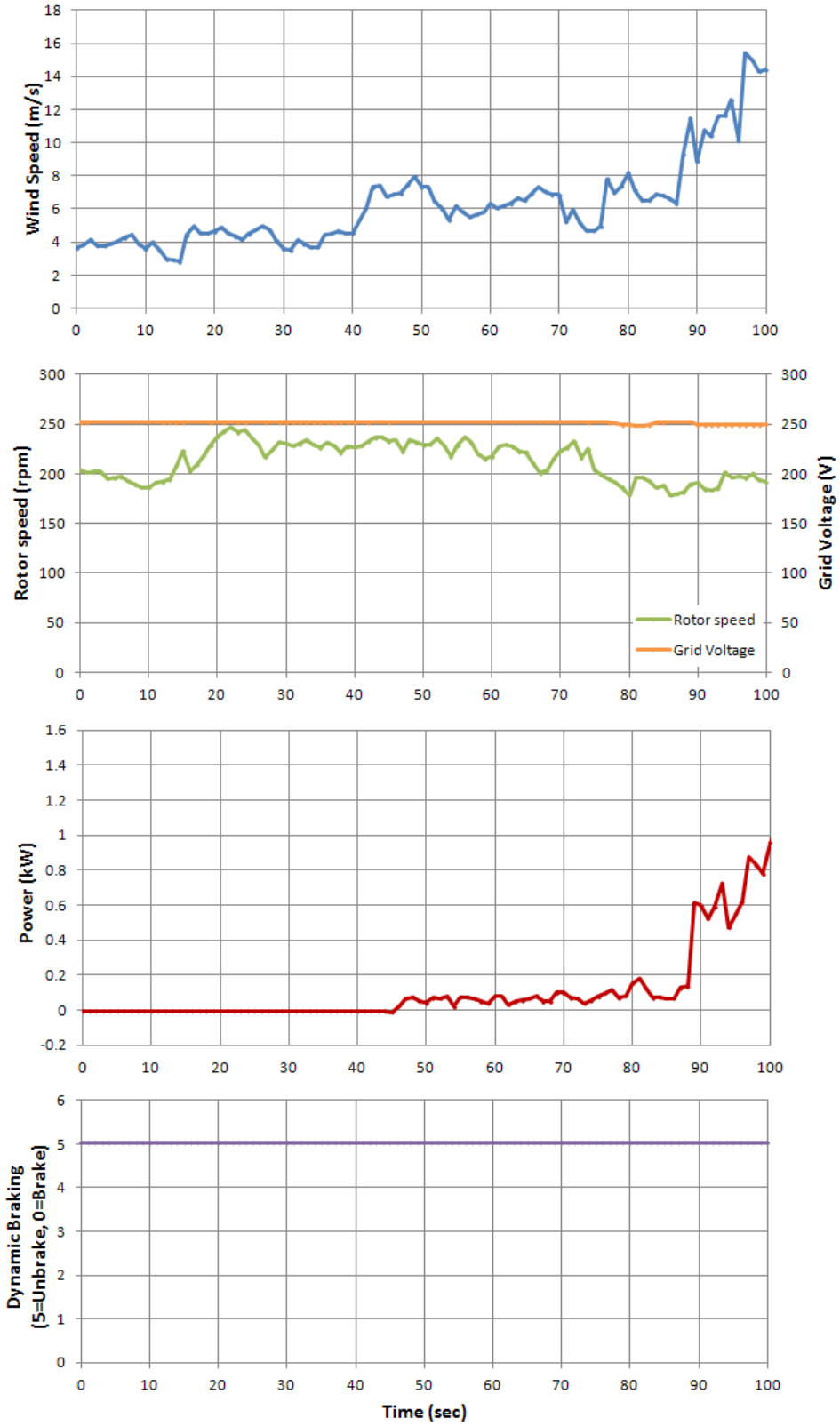

Figure 8: Normal startup in wind speeds increasing beyond cut-in

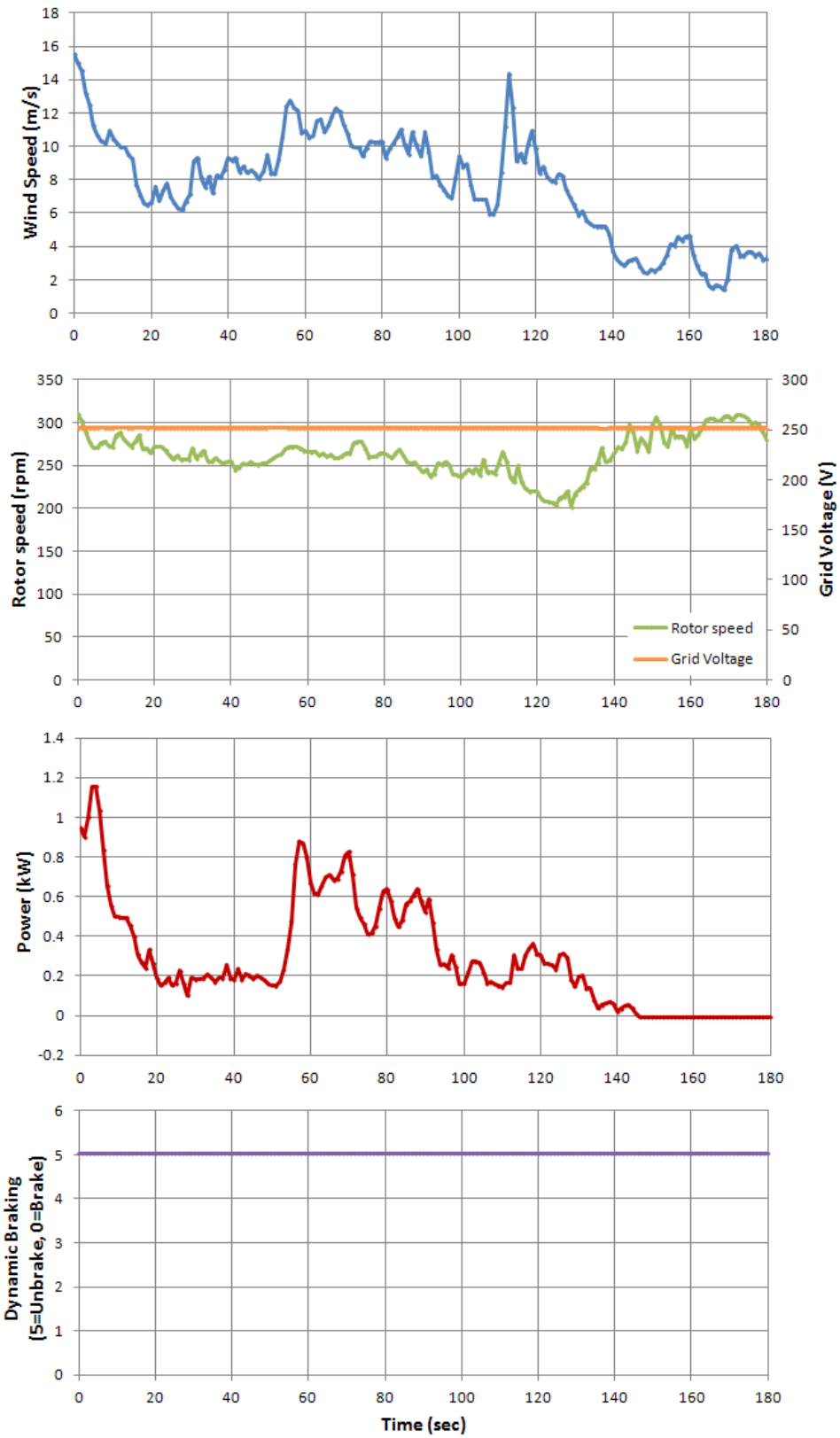

Figure 9: Normal shutdown in wind speeds decreasing below cut-in

Figure 10: DC isolation switch
Source: NREL 2012

Figure 11: AC isolation switch
Source: NREL 2012

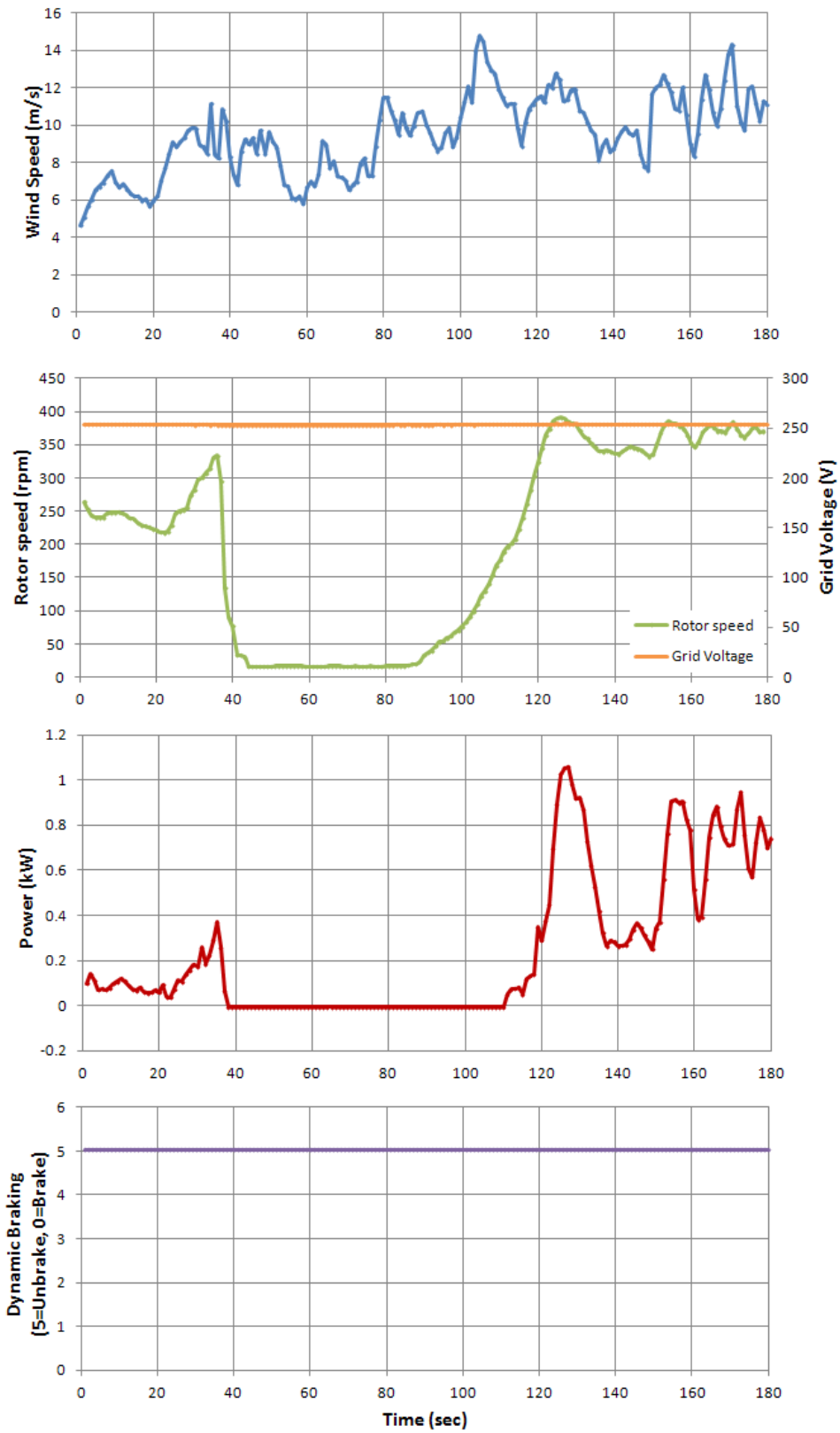

Figure 12: Turbine response during the application of the DC isolation

8. Exceptions

8.1. Exceptions to the Standard

No exceptions to the standard occurred.

8.2. Exceptions to NWTC Quality Assurance System

The DAS modules, power transducer, and primary wind speed anemometer were used beyond the calibration due dates. The initial power-measuring module failed its post-test calibration. The calibration agency reported that no signal output could be read for that channel as specified in the post-calibration report. An investigation was performed on the data acquired but there were no indications that the module failed during the test. The power reading versus wind speed relationship between both modules stayed consistent throughout the test, as seen in Figure 13. When the module was returned from calibration, some loose parts could be heard that were not present previously. It was concluded that damage may have occurred during shipping. The power transducer and anemometer were found to be in compliance within the Standard specifications. The calibration sheets of the post-test calibrations are included in Appendix A.

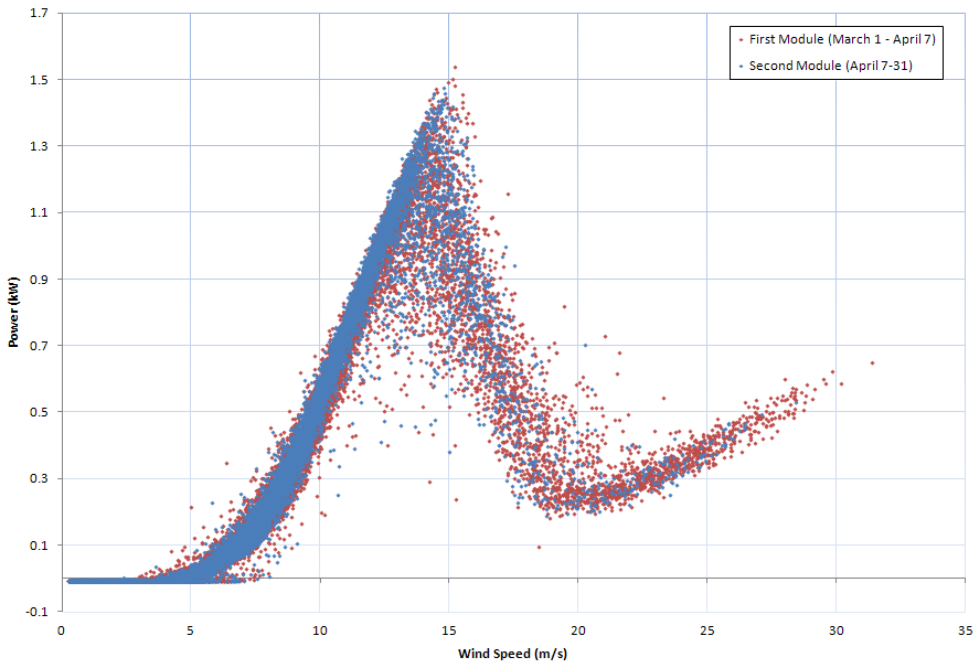

Figure 13: Power vs. wind speed scatter plot comparison (1- min average)

Appendix A — Equipment Calibration Sheets

Power

Branch #: 5000

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Phaser Power Transducer — DOE #: 03503C

Model # : Phaser-5-485-4A 20 — S/N : 04607

Calibration Date: 10/20/2010 — Due Date: 10/20/2012

A. Set-Up for Power Calibration:
A.1. Voltage is applied to phases A&B = 120 V @ 60 Hz.
A.2. Current is applied to phases A&B.
A.3. Analog Output-1 is measured across precision resistor = 250 Ω.

Calibrator Output		Transducer Input/Output		
Current (AAC)	Power 2*V*I (W)	Input Current (AAC)	Input Power 2*n*V*I (W)	Analog Output-1 (VDC)
-9	-2160	N/A	N/A	.997
-8	-1920	"	"	1.078
-6	-1440	"	"	1.557
-4	-960	"	"	2.037
-2	-480	"	"	2.516
-1	-240	"	"	2.754
0	0	"	"	2.994
1	240	"	"	3.234
2	480	"	"	3.473
4	960	"	"	3.953
6	1440	"	"	4.432
8	1920	"	"	4.911
9	2160	"	"	4.991

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Figure A1: Power transducer calibration sheet I, installed 20 October 2010 to 24 October 2011

B. Set-Up for Power Factor Calibration:
B.1. Voltage @120VAC and Current @ 4A @ 60Hz
B.2. Analog Output-2 is measured across precision resistor = 250 Ω.

Calibrator Output		Analog Output-2 (VDC)
Current (AAC)	Power Factor	
4	1	4.994
4	0.75	3.990
4	0.5	2.990
4	0.25	1.990
4	0.0	1.010

C. Set-Up for Total Harmonic Distortion (THD) Calibration:
C.1. Voltage & Current are applied as A.1 & A.2.
C.2. Analog Output-3 is set for Current THD
C.3. Analog Output-3 is measured across precision resistor = 250 Ω.

Current THD (%)	Analog Output-3 (VDC)
0	.999
10	1.395
20	1.796
30	2.191

D. Set-Up for A to B Voltage Measurement:
D.1. Voltage is applied as listed below @ 60Hz
D.3. Analog Output-4 is measured across precision resistor = 250 Ω.

Calibrator Output	Analog Output-4 (VDC)
0V	2.996
80V	3.611
160V	4.226
240V	4.680

Page 2 of 3

Figure A2: Power transducer calibration sheet II, installed 20 October 2010 to 24 October 2011

Notes:
- Calibration was performed using instruments that are traceable to NIST, DOE# 126410 and 01886C.
- Calibration was performed at temperature = 24 °C, ± 1 °C, and relative humidity =45%, ± 10%.
- Uncertainty of nominal values is ± 0.15% of reading.

Calibrated By: P. Morse

Date: 10/20/2010

Approved By : Reda

Date: 10/20/2010

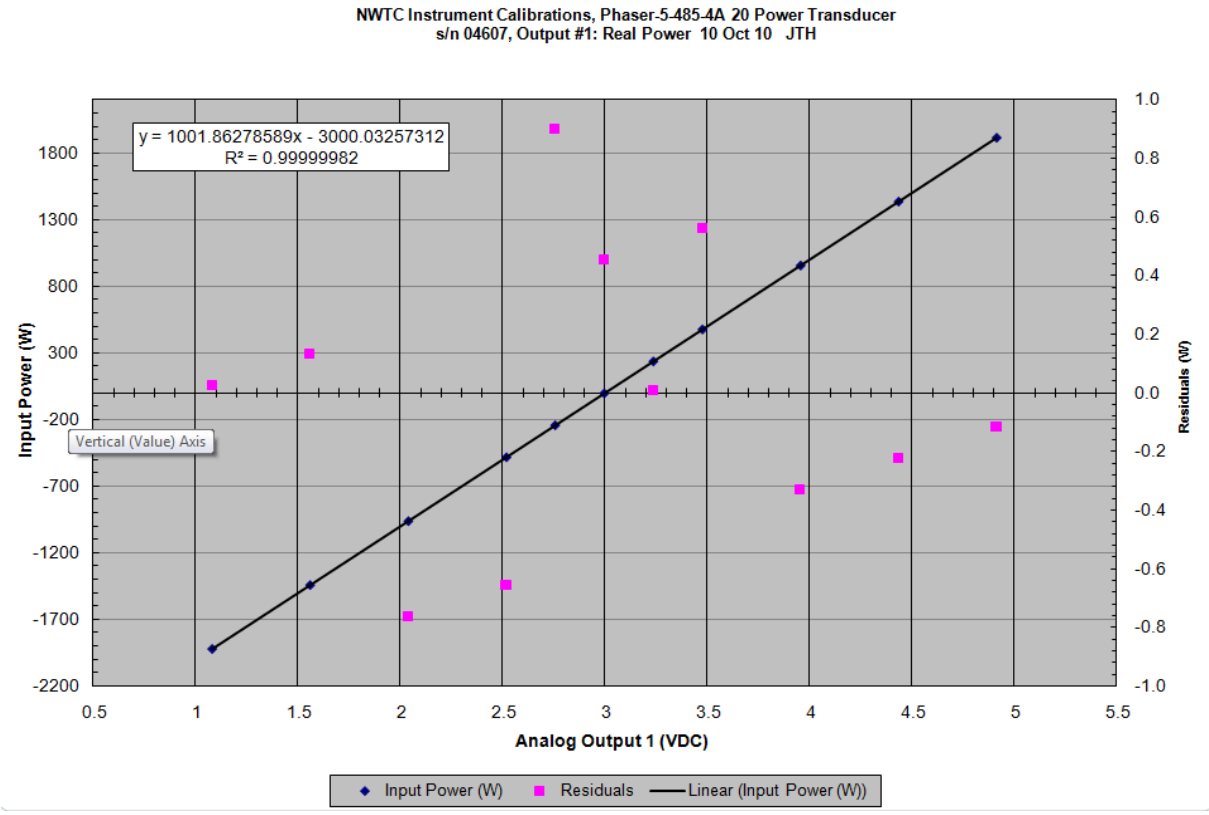

Figure A3: Power transducer calibration sheet III, installed 20 October 2010 to 24 October 2011

Branch #: 5000

Page 1 of 2

NREL METROLOGY LABORATORY

TEST REPORT

Test Instrument:	Phaser Power Transducer	DOE #:	03503C
Model #:	Phaser-5-485-4A20	S/N:	04607
Calibration Date:	7/20/2012	Date Due:	7/20/2013

Test No.	Function Tested	Nominal Input	Measured Output at 250 Ohm (DCV)		( ) Mfr Specs (X)Data Only
			As Found	As Left	
1.	Analog Output 1: Power in Watt applied to Phase A&B with 120V @ 60 Hz				
		-1920	1.078		
		-1440	1.557		
		-960	2.037		
		-480	2.516		
		0	2.994		
		480	3.473		
		960	3.953		
		1440	4.432		
		1920	4.911		
2.	Analog Output 2: Power Factor at 960 W @ A&B with 120V @ 60 Hz				
		1	4.994		
		0.75	3.99		
		0.5	2.99		
		0.25	1.99		
		0	1.005		
3.	Analog Output 3: THD for current in % at 960 W @ A&B with 120V @ 60 Hz				
		0	0.999		
		10	1.395		
		20	1.796		
		30	2.195		
		40	2.599		
		50	3.001		
		60	3.399		
		70	3.793		
4.	Analog Output 4: Voltage in volts between A&B @ 60 Hz				
		0	2.996		
		80	3.611		
		160	4.226		
		240	4.682		

Figure A4: Power transducer calibration sheet I, installed 8 November 2011 to 18 July 2011

Branch #: 5000

Page 2 of 2

Notes:

- Calibration was performed using instruments that are traceable to NIST: DOE# 126410 and 01886C
- Calibration was performed at a temperature of 23°C and Relative Humidity of 39%
- Expanded uncertainity of the nominal value is ± 0.15% of Reading, with k=2

Calibrated By: Reda
Date: 7/20/2012

Approved By: Preston
Date: 7/20/2012

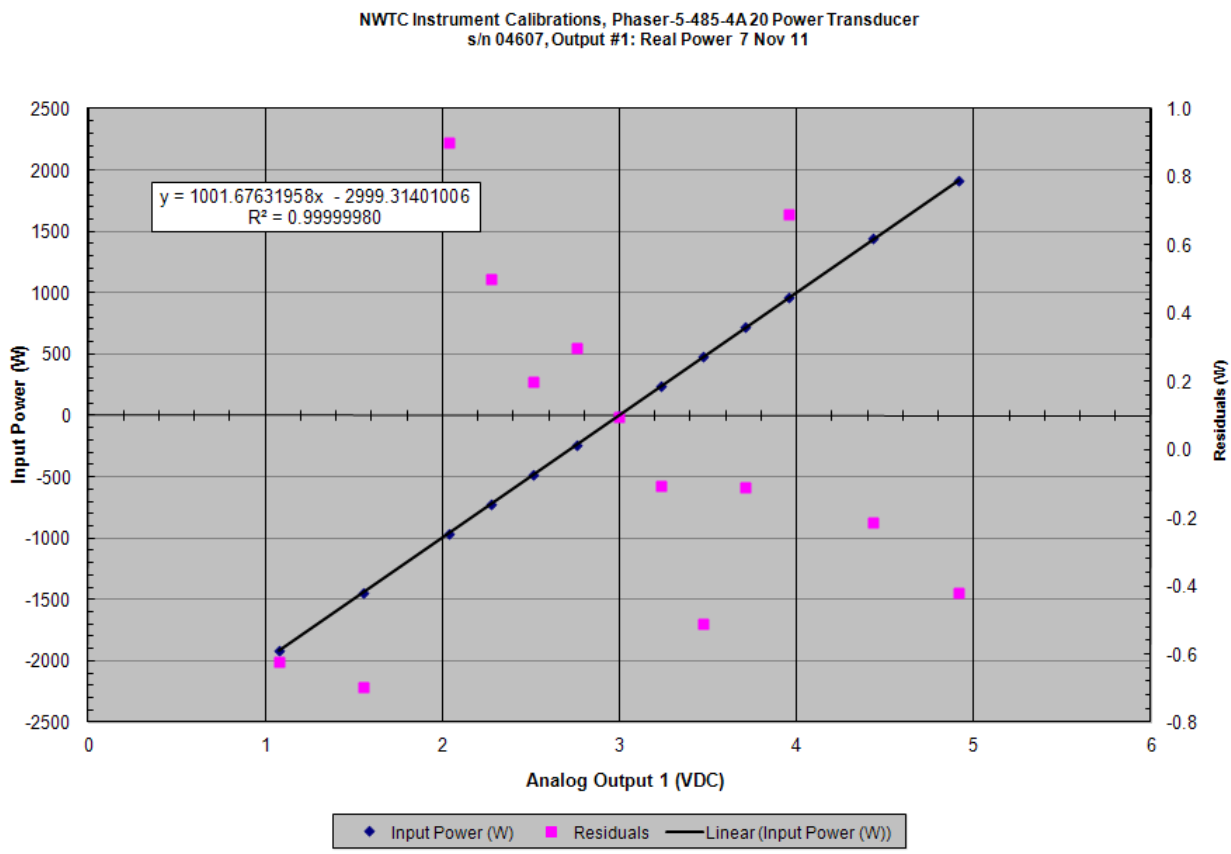

Figure A5: Power transducer calibration sheet II, installed 8 November 2011 to 18 July 2011

Wind Speed

Svend Ole Hansen ApS

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WIND ENGINEERING FLUID DYNAMICS

CERTIFICATE FOR CALIBRATION OF CUP ANEMOMETER

Certificate number: 09.02.3130 **Date of issue:** June 15, 2009

Type: Thies 4.3351.10.000 **Serial number:** 0609005

Manufacturer: ADOLF THIES GmbH & Co.KG, Hauptstrasse 76, 37083 Göttingen, Germany

Client: Sky Power Int'l LLC, 250 Sawdust Road, 29657-8521 Liberty SC, USA

Anemometer received: June 11, 2009 **Anemometer calibrated:** June 13, 2009

Calibrated by: jj **Calibration procedure:** IEC 61400-12-1, MEASNET

Certificate prepared and approved by: Calibration engineer, soh Svend Ole Hansen

Calibration equation obtained: v [m/s] = 0.04629 · f [Hz] + 0.22635

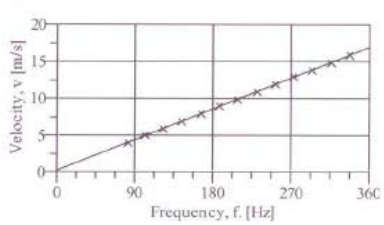
Standard uncertainty, slope: 0.00130 **Standard uncertainty, offset:** 0.05929

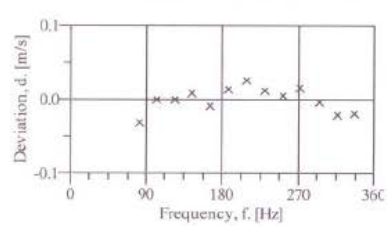
Covariance: -0.0000008 (m/s)²/Hz **Coefficient of correlation:** $\rho = 0.999991$

Absolute maximum deviation: -0.031 m/s at 3.985 m/s

Barometric pressure: 1005.0 hPa **Relative humidity:** 24.1%

Succession	Velocity pressure, q. [Pa]	Temperature in wind tunnel [°C]	Temperature in control room [°C]	Wind velocity, v. [m/s]	Frequency, f. [Hz]	Deviation, d. [m/s]	Uncertainty u_c (k=2) [m/s]
2	9.06	32.2	23.4	3.985	81.8814	-0.031	0.029
4	13.97	32.0	23.3	4.946	101.9395	0.001	0.033
6	20.07	31.9	23.3	5.927	123.1528	0.000	0.038
8	27.33	31.8	23.3	6.916	144.3130	0.009	0.044
10	35.69	31.7	23.3	7.901	165.9900	-0.009	0.049
12	45.23	31.7	23.2	8.893	186.9321	0.014	0.055
13-last	56.17	31.6	23.2	9.910	208.6317	0.027	0.062
11	67.93	31.7	23.2	10.900	230.3216	0.012	0.068
9	80.42	31.8	23.3	11.861	251.2567	0.004	0.074
7	94.41	31.9	23.3	12.854	272.4533	0.016	0.080
5	109.58	32.0	23.3	13.851	294.3993	-0.003	0.086
3	125.70	32.1	23.3	14.837	316.0953	-0.021	0.092
1-first	142.80	32.4	23.4	15.821	337.2985	-0.018	0.099





Page 1 of 2

ilac-MRA DANAK CAL Reg.nr. 452 Accreditation to ISO 17025 measnet

Figure A6: Primary anemometer calibration, (first Page) installed 13 October 2010 to 7 April 2011

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WIND ENGINEERING FLUID DYNAMICS

CERTIFICATE FOR CALIBRATION OF CUP ANEMOMETER

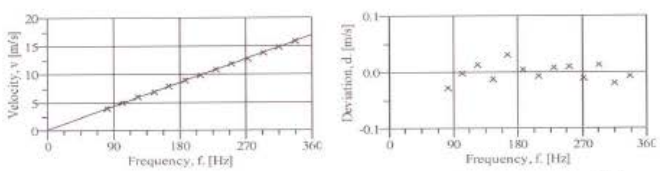
Certificate number: 09.02.3131 **Date of issue:** June 15, 2009
Type: Thies 4.3351.10.000 **Serial number:** 0609006
Manufacturer: ADOLF THIES GmbH & Co.KG, Hauptstrasse 76, 37083 Göttingen, Germany
Client: Sky Power Int'l LLC, 250 Sawdust Road, 29657-8521 Liberty SC, USA

Anemometer received: June 11, 2009 **Anemometer calibrated:** June 13, 2009
Calibrated by: jj **Calibration procedure:** IEC 61400-12-1, MEASNET
Certificate prepared and approved by: Calibration engineer, soh

Calibration equation obtained: v [m/s] = 0.04630 · f [Hz] + 0.22992
Standard uncertainty, slope: 0.00126 **Standard uncertainty, offset:** 0.05660
Covariance: -0.0000007 (m/s)²/Hz **Coefficient of correlation:** $\rho = 0.999991$
Absolute maximum deviation: 0.032 m/s at 7.911 m/s

Barometric pressure: 1005.4 hPa **Relative humidity:** 24.1%

Succession	Velocity pressure, q. [Pa]	Temperature in wind tunnel [°C]	Temperature in control room [°C]	Wind velocity, v. [m/s]	Frequency, f. [Hz]	Deviation, d. [m/s]	Uncertainty u_v (k=2) [m/s]
2	9.03	32.3	23.3	3.978	81.5163	-0.027	0.029
4	14.04	32.1	23.2	4.958	102.1571	-0.002	0.033
6	20.23	32.0	23.2	5.950	123.2216	0.014	0.038
8	27.39	31.9	23.2	6.923	144.8197	-0.013	0.044
10	35.79	31.8	23.2	7.911	165.2051	0.032	0.050
12	45.41	31.8	23.2	8.910	187.3624	0.005	0.056
13-last	56.18	31.7	23.1	9.911	209.1977	-0.006	0.062
11	67.73	31.8	23.2	10.884	229.8895	0.009	0.068
9	80.53	31.9	23.2	11.869	251.1191	0.011	0.074
7	94.07	32.0	23.2	12.830	272.3620	-0.011	0.080
5	109.65	32.1	23.2	13.855	293.9411	0.014	0.086
3	125.49	32.2	23.3	14.825	315.6078	-0.019	0.092
1-first	143.09	32.4	23.3	15.838	337.2206	-0.007	0.099



Page 1 of 2

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Figure A7: Primary anemometer calibration, (first page) installed 7 April 2011 to 27 June 2012

DOE # 043900

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WIND ENGINEERING FLUID DYNAMICS

CERTIFICATE FOR CALIBRATION OF CUP ANEMOMETER

Certificate number: 12.02.6727 **Date of issue:** August 24, 2012

Type: Thies 4.3351.10.000 **Serial number:** 0609006

Manufacturer: ADOLF THIES GmbH & Co.KG, Hauptstrasse 76, 37083 Göttingen, Germany

Client: National Renewable Energy Lab, 1617 Cole Boulevard, Golden, Colorado 80401-3393, USA

Anemometer received: August 13, 2012 **Anemometer calibrated:** August 23, 2012

Calibrated by: asj **Calibration procedure:** IEC 61400-12-1, MEASNET

Certificate prepared by: ca **Approved by:** Calibration engineer, ml

Calibration equation obtained: $v\,[m/s] = 0.04654 \cdot f\,[Hz] + 0.15404$

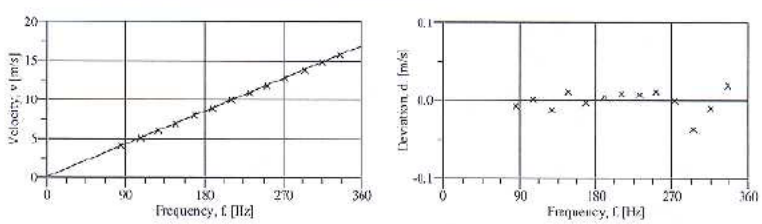
Standard uncertainty, slope: 0.00114 **Standard uncertainty, offset:** 0.07713

Covariance: -0.0000006 $(m/s)^2/Hz$ **Coefficient of correlation:** $\rho = 0.999993$

Absolute maximum deviation: -0.036 m/s at 13.844 m/s

Barometric pressure: 1009.3 hPa **Relative humidity:** 27.6%

Succession	Velocity pressure, q. [Pa]	Temperature in wind tunnel [°C]	Temperature in control room [°C]	Wind velocity, v. [m/s]	Frequency, f. [Hz]	Deviation, d. [m/s]	Uncertainty u_c (k=2) [m/s]
2	9.65	33.4	25.5	4.112	85.1908	-0.007	0.021
4	14.95	33.3	25.5	5.119	106.6331	0.002	0.025
6	21.07	33.1	25.4	6.075	127.4800	-0.012	0.029
8	28.26	33.1	25.4	7.035	147.5747	0.012	0.033
10	36.34	33.0	25.4	7.977	168.1495	-0.003	0.037
12	45.88	33.0	25.4	8.962	189.1365	0.005	0.042
13-last	56.70	32.9	25.4	9.963	210.5526	0.009	0.046
11	68.46	33.0	25.4	10.948	231.7626	0.007	0.051
9	80.56	33.1	25.4	11.878	251.6408	0.012	0.055
7	94.56	33.1	25.4	12.870	273.2038	0.000	0.059
5	109.38	33.2	25.4	13.844	294.9135	-0.036	0.064
3	125.53	33.4	25.5	14.833	315.5930	-0.009	0.068
1-first	141.94	33.6	25.5	15.780	335.3141	0.020	0.073



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Page 1 of 2

Figure A8: Primary anemometer post-test calibration, (first page) installed 7 April 2011 to 27 June 2012

Rotor Speed

Frequency to Voltage Device Calibration

Calibration Laboratory:
National Wind Technology Center - Cert. Team
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401

Item Calibrated:
Mfgr: Phoenix Contact
Model: MCR-f-UI-DC
Serial No: **32384299**
Condition: good

Calibration Location:
National Wind Technology Center
Certification Laboratory

Cal Date: November 1, 2011

Results:
Slope: **1.00054** Hz/V
Offset: **0.00280** Hz
Max Error: 0.00112 Hz

Calibrated for:
Viryd CS8 Horizontal Axis Wind Turbine

Procedure:
CI11 F-to-V Device Calibration Method_091209
Deviations:

Certificate Number / File Name:
F-to-V Cal, Phoenix Contact 67472901 111003

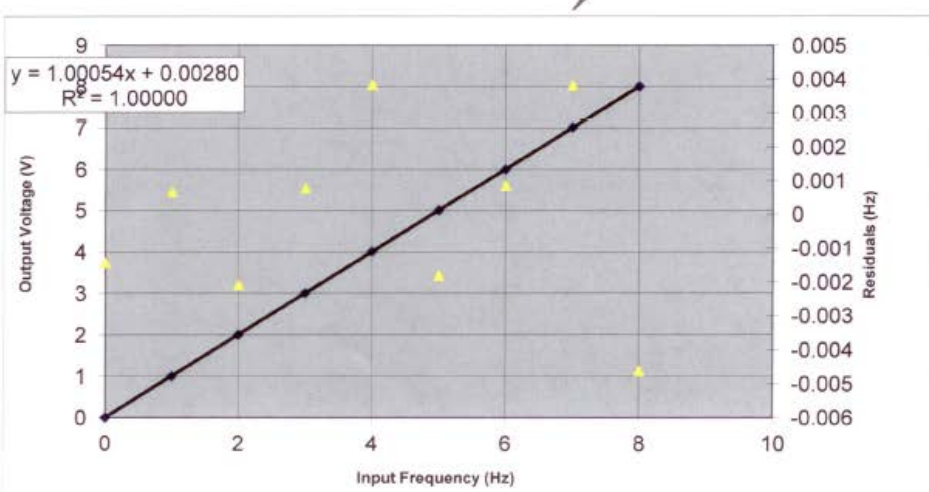
Frequency Input Device:
Fluke Documenting Process Calibrator, Model 743B
s/n: 6865614
Last Calibration: NREL Calibration Lab, 9/12/2011

Voltage Measurement Device:
Fluke Documenting Process Calibrator, Model 743B
s/n: 6865614
Last Calibration: NREL Calibration Lab, 9/12/2011

I-to-V Resistor
Not Used, output in Volts

The standard used in this calibration is traceable to the National Institute of Standards and Technology (NIST). Measurement uncertainty for this calibration was determined in accordance with the ISO "Guide to the Expression of Uncertainty in Measurement." It is based upon a 95% confidence level (coverage factor = 2).

Mark Murphy — Date 11/2/11



F-to-V Cal, Phoenix Contact 32384299 111101.xls — Page 1 of 2

Figure A9: Phoenix Contact, MCR-f-UI-DC calibration sheet I, installed 11 November 2011 to 7 February 2012

DAS

Davis Calibration

ACCREDITED CALIBRATION

Certificate of Calibration

4111865

Certificate Page 1 of 1

Instrument Identification

Company ID: 120205
NREL
METROLOGY LAB / BEV KAY
16253 DENVER WEST PARKWAY
GOLDEN, CO, 80401

PO Number: CC-BEVERLY KAY

Instrument ID: **04074C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CHANNEL, ±60 V, 24-BIT SIMULTANEOUS ANALOG INPUT

Model Number: NI 9229
Serial Number: 140A596

Accuracy: Mfr Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025 WITH UNCERTAINTIES
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: NATIONAL INSTRUMENTS CAL EXECUTIVE REV 3.3.2

Technician: COREY CLAXTON
Cal Date 29Apr2010
Cal Due Date: 29Apr2011
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 58.0 %

Remarks: *CALIBRATED WITH DATA, REFER TO ATTACHED DATA FOR BEFORE AND AFTER READINGS.*

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 9001:2008 by Eagle Registrations (certificate # 3046). Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994 (R2002), ISO 10012:2003, 10CFR50 ApprB, and 10CFR21.

ISO/IEC 17025-2005 accredited calibrations are per ACLASS certificate # AC-1187 within the scope for which the lab is accredited.
When uncertainty measurement calculations have been calculated per customer request, reported condition statements do not take into account uncertainty of measurement.
All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.

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

Approved By: COREY CLAXTON
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
4047816	15-0048	MULTIFUNCTION CALIBRATOR	5700A	07Apr2010	06Jul2010

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

Figure A10: NI 9229 data acquisition module calibration sheet I, installed 20 October 2010 to 7 April 2011

Davis Calibration

ACCREDITED CALIBRATION

Certificate of Calibration

4111821

Certificate Page 1 of 1

Instrument Identification

Company ID: 120205
NREL
METROLOGY LAB / BEV KAY
16253 DENVER WEST PARKWAY
GOLDEN, CO, 80401

PO Number: CC-BEVERLY KAY

Instrument ID: **04072C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CH 100 OHM 24-BIT RTD ANALOG INPUT

Model Number: NI 9217
Serial Number: 140DCB9

Accuracy: Mfr. Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025 WITH UNCERTAINTIES
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: NATIONAL INSTRUMENTS CAL EXECUTIVE REV 3.3.2

Technician: COREY CLAXTON
Cal Date 29Apr2010
Cal Due Date: 29Apr2011
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 58.0 %

Remarks: *CALIBRATED WITH DATA, REFER TO ATTACHED DATA FOR BEFORE AND AFTER READINGS.*

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 9001:2008 by Eagle Registrations (certificate # 3046). Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994 (R2002), 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.
When uncertainty measurement calculations have been calculated per customer request, reported condition statements do not take into account uncertainty of measurement.
All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.
This certificate shall not be reproduced except in full, without written consent of Davis Calibration Laboratory.

Approved By: COREY CLAXTON
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
4085286	15-0060	DIGITAL MULTIMETER (GOLDEN CAL)	3458A OPT 002	15Apr2010	14Jul2010

Figure A11: NI 9217 data acquisition module calibration sheet I, installed 20 October 2010 to 7 April 2011

Davis Calibration

ACLASS ACCREDITED CALIBRATION

Certificate of Calibration

4111826

Certificate Page 1 of 1

Instrument Identification

Company ID: 120205
NREL
METROLOGY LAB / BEV KAY
16253 DENVER WEST PARKWAY
GOLDEN, CO, 80401

PO Number: CC-BEVERLY KAY

Instrument ID: **04071C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 32-CH ±200 MV TO ±10 V, 16-BIT, 250 KS/S ANALOG INPUT MODULE

Model Number: NI 9205
Serial Number: 140E2BD

Accuracy: Mfr Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025 WITH UNCERTAINTIES
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: NATIONAL INSTRUMENTS CAL EXECUTIVE REV 3.3.2

Technician: COREY CLAXTON
Cal Date 29Apr2010
Cal Due Date: 29Apr2011
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 58.0 %

Remarks: *CALIBRATED WITH DATA, REFER TO ATTACHED DATA FOR BEFORE AND AFTER READINGS.*

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 9001:2008 by Eagle Registrations (certificate # 3046). Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994 (R2002), 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.
When uncertainty measurement calculations have been calculated per customer request, reported condition statements do not take into account uncertainty of measurement.
All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.
This certificate shall not be reproduced except in full, without written consent of Davis Calibration Laboratory.

Approved By: COREY CLAXTON
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
4047816	15-0048	MULTIFUNCTION CALIBRATOR	5700A	07Apr2010	06Jul2010

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

Figure A12: NI 9205 data acquisition module calibration sheet I, installed 20 October 2010 to 7 April 2011

Tektronix
Service Solutions

ACLASS ACCREDITED
CALIBRATION
AC-1187

5100145516
Maintenance Record
5557968
Certificate Page 1 of 1

Instrument Identification

Company ID: 000031
TEKTRONIX-DENVER
Andrew Beckerdite
8020 SOUTHPARK CIRCLE
SUITE 300
LITTLETON, CO 80120

PO Number: FIFO

Instrument ID: **51-2050769**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CHANNEL, ±60 V, 24-BIT SIMULTANEOUS ANALOG INPUT
Model Number: NI 9229
Serial Number: 140A596

Accuracy: Mfr Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025 WITH UNCERTAINTIES
As Found Condition: FUNCTIONAL FAILURE
As Left Condition: LEFT AS FOUND
Procedure: NATIONAL INSTRUMENTS CAL EXECUTIVE 3.4.1

Technician: COREY CLAXTON
Service Date 10Oct2011
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 39.0 %

Remarks: *Unit failed calibration on channel ai0. Opened unit and found that input transfromers on all channels have been lifted from circuit board and are hanging by the circuit traces. Unit needs to be sent to National Instruments for repair.*

Tektronix Service Solutions certifies the performance of this instrument has been verified using equipment of known accuracy which are traceable to National Metrology Institutes (NIST, NPL, PTB) which are traceable to the International System of Units (SI), derived from ratio type measurements, compared to reference materials or recognized consensus standards. The policies and procedures used comply with ISO17025:2005.
Reported uncertainties represent expanded uncertainties expressed at approximately the 95% confidence level using a coverage of k=2. The certificate and associated attachments relate only to the metrological quantities presented in this report. No representation is made about the long term stability of this unit; any number of factors may influence the calibration that may cause the unit to drift out of specification before the calibration interval has expired.
This certificate shall not be reproduced, except in full, without the written consent of Tektronix Service Solutions.

Approved By: COREY CLAXTON
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Manufacturer	Model	Cal Date	Date Due
5327332	15-0271	MULTIFUNCTION CALIBRATOR	FLUKE	5700A	21Jul2011	19Oct2011

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

Figure A13: NI 9229 data acquisition module post-test calibration sheet I, installed 20 October 2010 to 7 April 2011

Tektronix
Service Solutions

ACLASS ACCREDITED CALIBRATION

Certificate of Calibration

4976419

Certificate Page 1 of 1

Instrument Identification

Company ID: 600168
NATIONAL RENEWABLE ENERGY LABORATORY

16253 DENVER WEST PARKWAY
GOLDEN , CO 80401

PO Number: CC-BKAY

Instrument ID: **04171C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CH 100 OHM 24-BIT RTD ANALOG INPUT

Model Number: NI 9217
Serial Number: 1494F69

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 3.4

Remarks: *Reference attached Calibration Data.*

Technician: WAYNE GETCHELL
Cal Date 22Mar2011
Cal Due Date: 22Mar2012
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.

Tektronix Service Solutions is registered to ISO 9001:2008. Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994 (R2002), ISO 10012-2003, 10CFR50 Appdx. and 10CFR21.

ISO/IEC 17025-2005 accredited calibrations are per ACLASS certificate # AC-1187 within the scope for which the lab is accredited.
When uncertainty measurement calculations have been calculated per customer request, reported condition statements do not take into account uncertainty of measurement.
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: WAYNE GETCHELL
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
4587476	15-0020	DECADE RESISTOR	1433-F	26Oct2010	26Oct2011
4176293	A144598	DMM	3458A	24May2010	24May2011

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Figure A14: NI 9217 data acquisition module post-test calibration sheet I, installed 20 October 2010 to 7 April 2011

Tektronix
Service Solutions

ACLASS ACCREDITED CALIBRATION

Certificate of Calibration

4976401

Certificate Page 1 of 1

Instrument Identification

Company ID: 600168
NATIONAL RENEWABLE ENERGY LABORATORY

16253 DENVER WEST PARKWAY
GOLDEN , CO 80401

PO Number: CC-BKAY

Instrument ID: **04170C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 32-CH ±200 MV TO ±10 V, 16-BIT, 250 KS/S ANALOG INPUT MODULE

Model Number: NI 9205
Serial Number: 1496266

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 3.4

Technician: WAYNE GETCHELL
Cal Date 22Mar2011
Cal Due Date: 22Mar2012
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 47.0 %

Remarks: *Reference attached Calibration Data.*

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.

Tektronix Service Solutions is registered to ISO 9001:2008. Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994 (R2002), ISO 10012:2003, 10CFR50 AppB, and 10CFR21.

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

When uncertainty measurement calculations have been calculated per customer request, reported condition statements do not take into account uncertainty of measurement.

All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.

This certificate shall not be reproduced except in full, without written consent of Tektronix Service Solutions.

Approved By: WAYNE GETCHELL
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
4837275	15-0048	MULTIFUNCTION CALIBRATOR	5700A	03Feb2011	04May2011

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Figure A15: NI 9205 data acquisition module post–test calibration sheet I, installed 20 October 2010 to 7 April 2011

Tektronix
Service Solutions

ACLASS ACCREDITED CALIBRATION

Certificate of Calibration

4976433

Certificate Page 1 of 1

Instrument Identification

Company ID: 600168
NATIONAL RENEWABLE ENERGY LABORATORY

PO Number: CC-BKAY

16253 DENVER WEST PARKWAY
GOLDEN , CO 80401

Instrument ID: **04169C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CHANNEL, ±60 V, 24-BIT SIMULTANEOUS ANALOG INPUT

Model Number: NI 9229
Serial Number: 14A34EE

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 3.4
Remarks: *Reference attached Calibration Data.*

Technician: WAYNE GETCHELL
Cal Date 22Mar2011
Cal Due Date: 22Mar2012
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.

Tektronix Service Solutions is registered to ISO 9001:2008. Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994 (R2002), ISO 10012:2003, 10CFR50 AppendB, and 10CFR21.

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

When uncertainty measurement calculations have been calculated per customer request, reported condition statements do not take into account uncertainty of measurement.

All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.

This certificate shall not be reproduced except in full, without written consent of Tektronix Service Solutions.

Approved By: WAYNE GETCHELL
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
4837275	15-0048	MULTIFUNCTION CALIBRATOR	5700A	03Feb2011	04May2011

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Figure A16: NI 9229 data acquisition module calibration sheet I, installed 7 April 2011to 27 June 2012

Tektronix
Service Solutions

ACLASS ACCREDITED CALIBRATION

Certificate of Calibration

4976419

Certificate Page 1 of 1

Instrument Identification

Company ID: 600168
NATIONAL RENEWABLE ENERGY LABORATORY

16253 DENVER WEST PARKWAY
GOLDEN , CO 80401

PO Number: CC-BKAY

Instrument ID: **04171C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CH 100 OHM 24-BIT RTD ANALOG INPUT

Model Number: NI 9217
Serial Number: 1494F69

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 3.4

Technician: WAYNE GETCHELL
Cal Date 22Mar2011
Cal Due Date: 22Mar2012
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 47.0 %

Remarks: *Reference attached Calibration Data.*

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.

Tektronix Service Solutions is registered to ISO 9001:2008. Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994 (R2002), ISO 10012-2003, 10CFR50 Appxdx, and 10CFR21.

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

When uncertainty measurement calculations have been calculated per customer request, reported condition statements do not take into account uncertainty of measurement.

All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.

This certificate shall not be reproduced except in full, without written consent of Tektronix Service Solutions.

Approved By: WAYNE GETCHELL
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
4587476	15-0020	DECADE RESISTOR	1433-F	26Oct2010	26Oct2011
4176293	A144598	DMM	3458A	24May2010	24May2011

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Figure A17: NI 9217 data acquisition module calibration sheet I, installed 7 April 2011to 27 June 2012

Tektronix
Service Solutions

ACLASS ACCREDITED CALIBRATION

Certificate of Calibration

4976401

Certificate Page 1 of 1

Instrument Identification

Company ID: 600168
NATIONAL RENEWABLE ENERGY LABORATORY

PO Number: CC-BKAY

16253 DENVER WEST PARKWAY
GOLDEN , CO 80401

Instrument ID: **04170C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 32-CH ±200 MV TO ±10 V, 16-BIT, 250 KS/S ANALOG INPUT MODULE

Model Number: NI 9205
Serial Number: 1496266

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 3.4

Technician: WAYNE GETCHELL
Cal Date 22Mar2011
Cal Due Date: 22Mar2012
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 47.0 %

Remarks: *Reference attached Calibration Data.*

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.

Tektronix Service Solutions is registered to ISO 9001:2008. Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994 (R2002), ISO 10012:2003, 10CFR50 Appx B, and 10CFR21.

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

When uncertainty measurement calculations have been calculated per customer request, reported condition statements do not take into account uncertainty of measurement.

All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.

This certificate shall not be reproduced except in full, without written consent of Tektronix Service Solutions.

Approved By: WAYNE GETCHELL
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
4837275	15-0048	MULTIFUNCTION CALIBRATOR	5700A	03Feb2011	04May2011

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Figure A18: NI 9205 data acquisition module calibration sheet I, installed 7 April 2011to 27 June 2012

Dynamic Technology, Inc.

A Trescal Company

17025 Accredited Certificate of Calibration

Certificate #: *2261870002* *F*

ILAC-MRA ACCREDITED

Calibration Laboratory
Certificate # 2516.01

Acct #:	101320	**Manufacturer:**	National Instruments
Customer:	National Renewable Energy Laboratory	**Model:**	9229
Shipper #:	1892577	**Description:**	4 Channel Analog Input Module
Address:	16253 Denver West Parkway Golden, CO, 80401	**Serial Number:**	14A34EE
Contact:	NI RMA	**Asset Number:**	14A34EE
PO #:		**Barcode:**	

As Received	As Returned	Action Taken		
In Tolerance X	In Tolerance X	Full Calibration X	**Cal Date:**	08/16/2012
Out of Tolerance	Out of Tolerance	Special Calibration	**Due Date:**	08/16/2013
Malfunctioning	Malfunctioning	Open Verification	**Temperature:**	73.60 deg. F
Operational	Operational	Adjusted	**Humidity:**	47.00 %
Damaged	N/A	Repaired	**Baro. Press.:**	
N/A		Charted	**Procedure:**	DCN 09375
		Returned As Is	**Reference:**	manufacturer's manual

Incoming Remarks:
Dimensionally inspected. Calibration sticker in vinyl bag

Technical Remarks:

Calibration Standards Utilized

Cert. #	Manufacturer	Model #	Description	Cal Date	Due Date
2250250103	Fluke	5700A	Multifunction Calibrator	08/10/2012	11/10/2012

The above identified unit was calibrated in our laboratory at the address shown below.

This report applies only to the item(s) identified above and shall not be reproduced, except in full, without the written approval of Dynamic Technology, Inc. This unit has been calibrated using standards with a Test Uncertainty Ratio (TUR) of greater than 4:1 approximating a 95% confidence level with a coverage factor of 2 unless otherwise noted above or as stated on the Report of Calibration. The calibration was performed using reference standards traceable to the SI through NIST or other recognized national laboratory, accepted fundamental or natural physical constants, ratio type of calibration, or by comparison to consensus standards. Dynamic Technology's calibration program is compliant with

ISO/IEC 17025:2005, ANSI/NCSL Z540-1-1994, ANSI/NCSL Z540-3-2006, MIL-STD-45662A, MIL-HDBK-52011

Dynamic Technology warrants all materials and labor performed for ninety (90) days unless specified under a separate agreement.

* Any number of factors may affect the calibration item's drift out of tolerance before the interval has expired.

Technician Name/Date Andrew Bash, 08/16/2012 Signature QA Approved:

3201 West Royal Lane, Suite 150, Irving, TX 75063 (214) 723-5600 FAX (214) 723-5601

Page 1 of 1

Figure A19: NI 9229 data acquisition module post-test calibration sheet I, installed 7 April 2011 to 27 June 2012

Dynamic Technology, Inc.

A Trescal Company

17025 Accredited Certificate of Calibration

Certificate #: *2261870001* *F*

ilac-MRA ACCREDITED Calibration Laboratory Certificate #: 2249.01

Acct #:	101320	**Manufacturer:**	National Instruments
Customer:	National Renewable Energy Laboratory	**Model:**	9205
Shipper #:	1892577	**Description:**	32 Channel Analog Input Module
Address:	16253 Denver West Parkway Golden, CO, 80401	**Serial Number:**	1496266
Contact:	NI RMA	**Asset Number:**	1496266
PO #:		**Barcode:**	

As Received	As Returned	Action Taken		
In Tolerance X	In Tolerance X	Full Calibration X	**Cal Date:**	08/16/2012
Out of Tolerance	Out of Tolerance	Special Calibration	**Due Date:**	08/16/2014
Malfunctioning	Malfunctioning	Oper. Verification	**Temperature:**	73.00 deg. F
Operational	Operational	Adjusted X	**Humidity:**	47.00 %
Damaged	N/A	Repaired	**Baro. Press.:**	
N/A		Charted	**Procedure:**	DCN 09381
		Returned As Is	**Reference:**	manufacturer's manual

Incoming Remarks:
Domestic accredited Calibration
sub-weed bag

Technical Remarks:

Calibration Standards Utilized

Cert. #	Manufacturer	Model #	Description	Cal Date	Due Date
2256250103	Fluke	5700A	Multifunction Calibrator	08/10/2012	11/10/2012

The above identified unit was calibrated in our laboratory at the address shown below.

This report applies only to the item(s) identified above and shall not be reproduced, except in full, without the written approval of Dynamic Technology, Inc. The calibration standards have uncertainties with a Test Uncertainty Ratio (TUR) of greater than 4:1 (approximately 4.6:1) and are traceable to the SI through NIST or other recognized national laboratory, accepted fundamental or natural physical constants, ratio type of calibration, or by consensus standards. Dynamic Technology's calibration program is in compliance with:

ISO/IEC 17025:2005, ANSI/NCSL Z540-1-1994, ANSI/NCSL Z540-3-2006, MIL-STD-45662A, ISO 9001:2015

Dynamic Technology warrants all material and labor performed for sixty (60) days unless covered under a separate policy.

* Any number of factors may cause the calibrated item to drift out of tolerance before the interval has expired.

Technician Name/Date: Andrew Bush, 08/15/2012 Signatory QA Approved

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Page 1 of 1

Figure A20: NI 9217 data acquisition module post-test calibration sheet I, installed 7 April 2011 to 27 June 2012

Dynamic Technology, Inc.

A Trescal Company

17025 Accredited Certificate of Calibration

Certificate #: *2261870003* *F*

ilac-MRA ACCREDITED Calibration Laboratory Certificate # 2516.01

Asset #:	101320	**Manufacturer:**	National Instruments
Customer:	National Renewable Energy Laboratory	**Model:**	9217
Shipper #:	1892577	**Description:**	4 Channel 100ohm RTD Analog Input M
Address:	16253 Denver West Parkway Golden, CO, 80401	**Serial Number:**	1494F69
Contact:	NI RMA	**Asset Number:**	1494F69
PO #:		**Barcode:**	

As Received	As Returned	Action Taken		
In Tolerance X	In Tolerance X	Full Calibration X	**Cal Date:**	08/15/2012
Out of Tolerance	Out of Tolerance	Special Calibration	**Due Date:**	08/15/2013
Malfunctioning	Malfunctioning	Oper. Verification	**Temperature:**	72.50 deg. F
Operational	Operational	Adjusted	**Humidity:**	51.00 %
Damaged	N/A	Repaired	**Baro. Press.:**	
N/A		Cleaned	**Procedure:**	DCN 09480
		Returned As Is	**Reference:**	manufacturer's manual

Incoming Remarks:

Domestic accredited Calibration
sealed in end bag

Technical Remarks:

Calibration Standards Utilized

Cert. #	Manufacturer	Model #	Description	Cal Date	Due Date
2067190010	LSI	RS925	Decade Resistance Standard	01/05/2012	01/05/2013
2182620007	Agilent Technologi	3458A	DMM	05/23/2012	08/23/2012

The above identified unit was calibrated in our laboratory at the address shown below.

This report applies only to the item(s) identified above and shall not be reproduced, except in full, without the written consent of Dynamic Technology, Inc. This unit has been calibrated within standards with a Test Uncertainty Ratio (TUR) of greater than 4:1 upon entering a 95% confidence level with a coverage factor of k=2 unless otherwise noted above or in accordance the Report of Calibration. The calibration was performed using references traceable to the SI through NIST or other recognized national laboratory, accepted fundamental or natural physical constants, ratio type of calibration, or by comparison to consensus standards. Dynamic Technology's calibration program is in compliance with:

ISO/IEC 17025:2005, ANSI/NCSL Z540-1-1994, ANSI/NCSL Z540-3-2006, MIL-STD-45662A, MIL-HDBK-52.

Dynamic Technology warrants all external and inter-performed calibrations for ninety (90) days unless covered under a separate policy.

* Any number of factors may cause the calibrated item to drift out of tolerance before the recommended period.

Technician Name/Date: Andrew Busla, 08/15/2012 Signatory: W. Taylor QA Approved:

3201 West Royal Lane, Suite 150, Irving, TX 75063 (214) 723-5600 FAX (214) 723-5601

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Figure A21: NI 9205 data acquisition module post-test calibration sheet I, installed 7 April 2011 to 27 June 2012