May 2003 NREL/EL-500-33963

Wind Turbine Generator System

Safety and Function Test Report

for the

Bergey Excel-S with Gridtek-10 inverter

by

National Wind Technology Center
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401

17 April 2003

Approval By: ____________________ 1 may 2003
Jeroen van Dam, NREL Certification Test Engineer Date

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Approval By: ____________________ 1 may 2003
Charles P. Butterfield, NREL Certification QA manager Date

1.0 Table of Contents

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4.0 Test Objective

The objective of the safety and function test is given in the International Electrotechnical Commission's IEC WT01 [1]:

"The purpose of safety and function testing is to verify that the wind turbine under test displays the behavior predicted in the design and that provisions relating to personnel safety are properly implemented."

The IEC WT01 also states:

"The Certification Body shall verify satisfactory demonstration of the control and protection system functions. In addition, the dynamic behavior of the wind turbine at rated wind speed or above shall be verified by testing if this has not been verified within the scope of the load measurements."

5.0 Background

This test is being conducted as part of the U.S. Department of Energy's Small Wind Turbine Field Verification Project. The primary purpose of this program is to provide consumers, manufacturers, and host site organizations with an independent assessment of the performance and reliability of small U.S. wind turbines. In addition, this test may be used to fulfill the safety and function test requirement identified in IEC WT01 Annex D for wind turbine certification.

The test turbine, located at the National Wind Technology Center's (NWTC's) Site 1.4, is owned by AWS Scientific Inc. This turbine was erected at the NWTC in October 1999.

6.0 Test Turbine

The Bergey Excel-S is a three-bladed upwind wind turbine rated at 10 kW output at 13.0 m/s. It is connected to a Bergey Gridtek-10 inverter, which provides power to the NWTC public service electrical grid.

The Excel uses a permanent magnet alternator to produce three-phase variable frequency output at a nominal 240 volts. The three-phase output is rectified to DC power and then converted to single-phase, 240-volt, 60-Hz AC power in the Gridtek inverter.

The turbine blades are made from pultruded fiberglass. In high wind speeds (greater than about 15.6 m/s), the turbine will turn out of the wind (known as furling) to protect the turbine from overspeeding. Table 1 lists the basic turbine configuration and operational data.

The simulation of grid outages was performed with a new set of blades on the turbine. These new blades result in a smaller rotor diameter and different rotor rotational direction. We determined that the new blades did not have a significant influence on the results of that test.

Table 1: Test Turbine Configuration and Operational Data

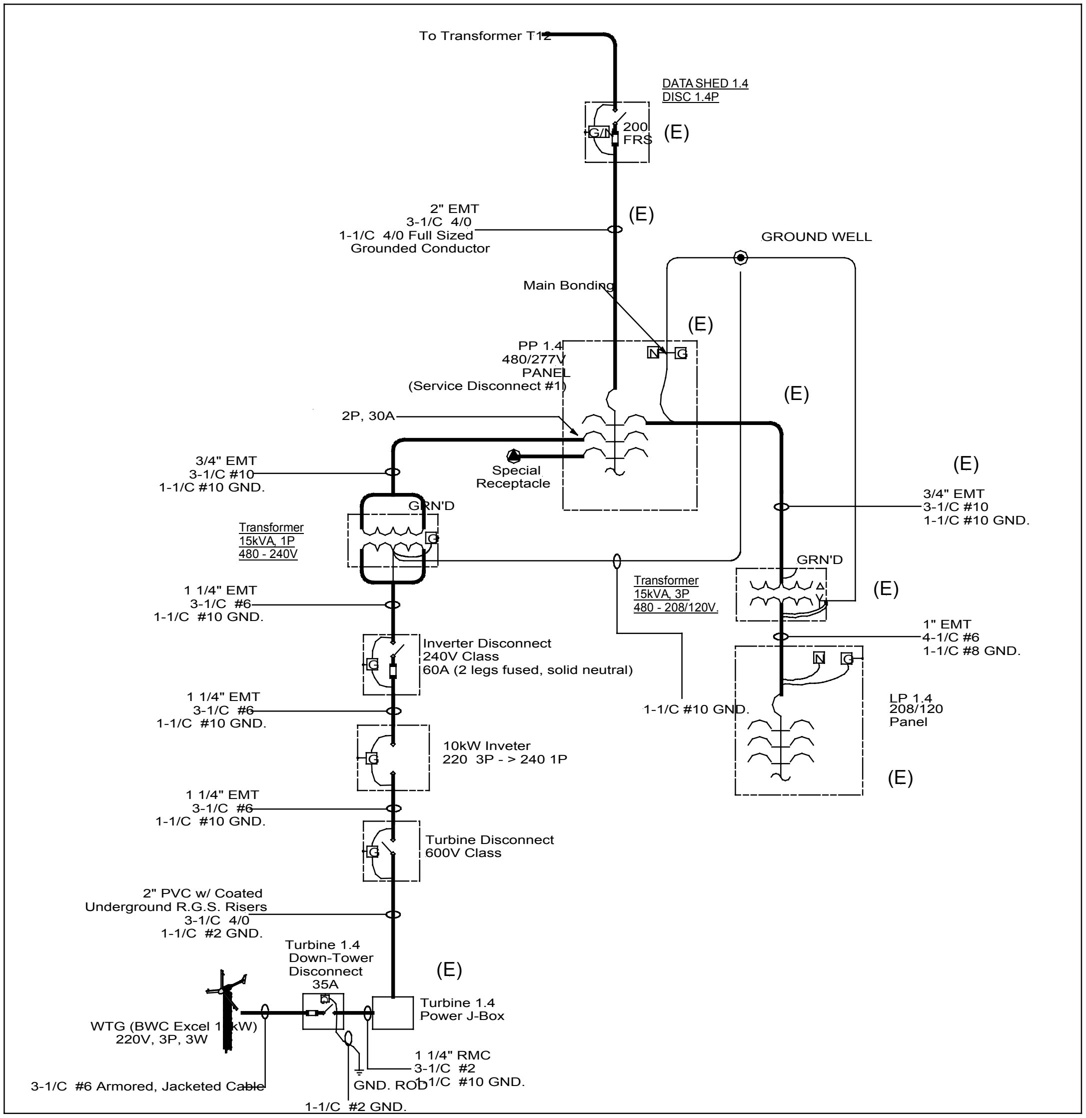
General Configuration:	
Make, Model, Serial Number	Bergey WindPower, Excel, #9900550
Rotation Axis (H/V)	Horizontal
Orientation (upwind/downwind)	Upwind
Number of Blades	3
Rotor Hub Type	Rigid
Rotor Diameter (m)	7.0
Hub Height (m)	37
Performance:	
Rated Electrical Power (kW)	10
Rated Wind Speed (m/s)	13.0
Cut-In Wind Speed (m/s)	3.1
Cut-Out Wind speed (m/s)	none
Rotor:	
Swept Area (m^2)	38.4
Blade Pitch Control	Powerflex®, passive pitch with a pitch weight, with increasing rpm blade flattens
Direction of Rotation	Clockwise viewed from up wind
Rotor Speed	0-400 rpm
Power Regulation (active or passive)	Passive
Tower:	
Type	Bergey guyed lattice
Height (m)	36.5
Control/Electrical System:	
Controller: Make, Type	Bergey Gridtek inverter; serial no. 1
Electrical Output: Voltage	Nominal 240-volt single phase
Yaw System:	
Wind Direction Sensor	Tail vane

Figure 1: The Bergey Excel wind turbine.

6.1. General Electrical Layout

The test configuration consists of the turbine mounted on its tower, a data shed containing the Gridtek inverter and instrumentation, the meteorological tower, and associated wiring and junction boxes. The turbine is installed on a Bergey, 36.5-meter, guyed lattice tower. At the base of the tower is a three-phase fused disconnect. The wire from the base of the tower to the data shed is approximately 20.3 meters of #6 AWG wire. Inside the data shed, there is a disconnect on the turbine side of the inverter and a fused disconnect on the grid side of the inverter. A single-phase 480-240 transformer steps up the voltage to 480 volts. Figure 2 shows the general electrical arrangement.

The electrical interface of the system is the disconnect switch on the grid side of the inverter. The mechanical interface of the system is the bolt connection to the foundation.



Site 1.4 One-Line Electrical Diagram for BWC Installation

Figure 2: General electrical arrangement.

7.0 Test Site

The Bergey Excel wind turbine under test is located at Test Site 1.4 of the NWTC (hereafter referred to as the test site), approximately 8 km south of Boulder, Colorado. The site is located in somewhat complex terrain at an approximate elevation of 1,850 m above sea level. Figure 3 shows a plot plan of the test site with topography lines listed in feet above sea level.

The meteorological tower is a 36.5-m Rohn, 55 G lattice tower located 22.7 m (± 3 diameters) from the test turbine at an azimuth of 292 degrees true.

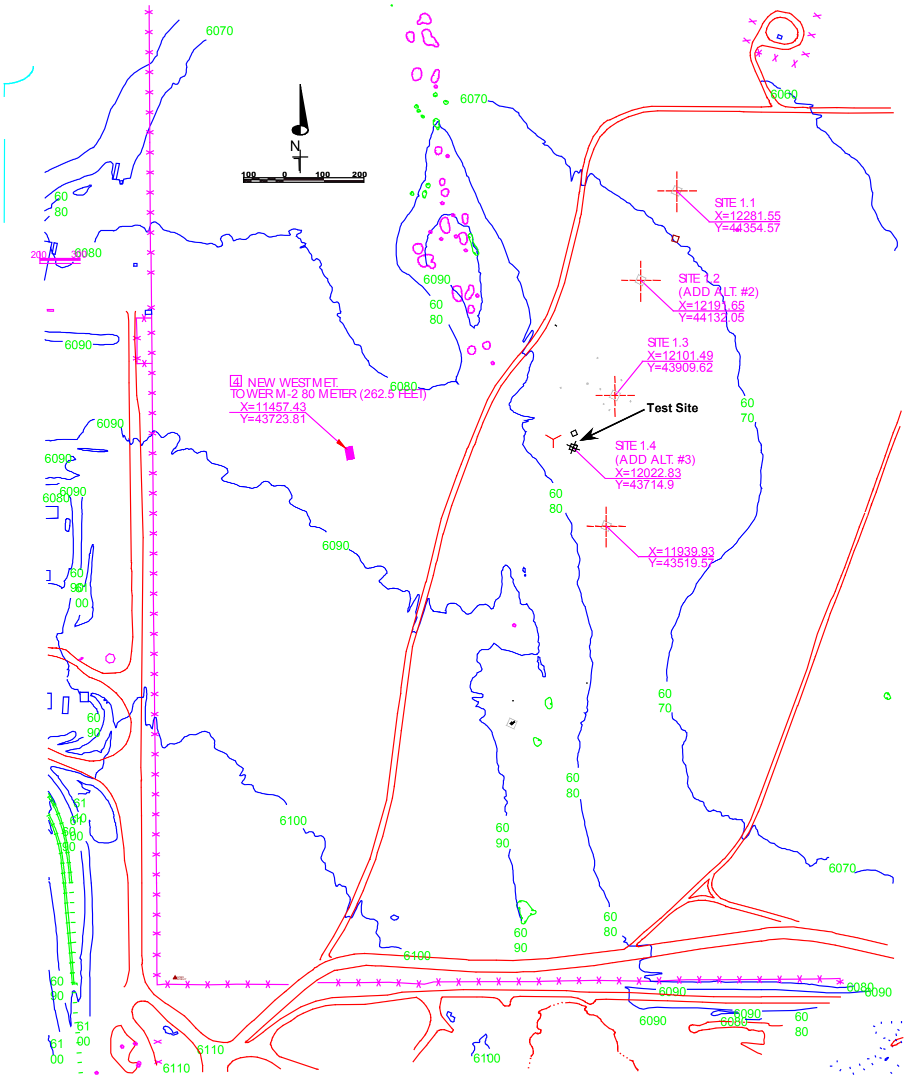


Figure 3: The NWTC test site. The Bergey Excel is located on site 1.4.

8.0 Safety and Function Test

8.1. Overview of Data Acquisition System

The signals measured during the safety and function test are wind speed, inverter power, rotor speed, and the grid connection contactor. The 10-minute statistics based on 1-Hz samples of these channels were stored in the data logger. A higher sampling rate of 10Hz was used for some parts of the safety and function test.

Instrumentation already installed for the duration test and power performance test was used. Table 2 lists the equipment and provides specifications for each of the instruments used, and Figure 4 shows the location of the instruments. As part of the power performance and duration test, the instruments were calibrated and checked for proper functioning after installation.

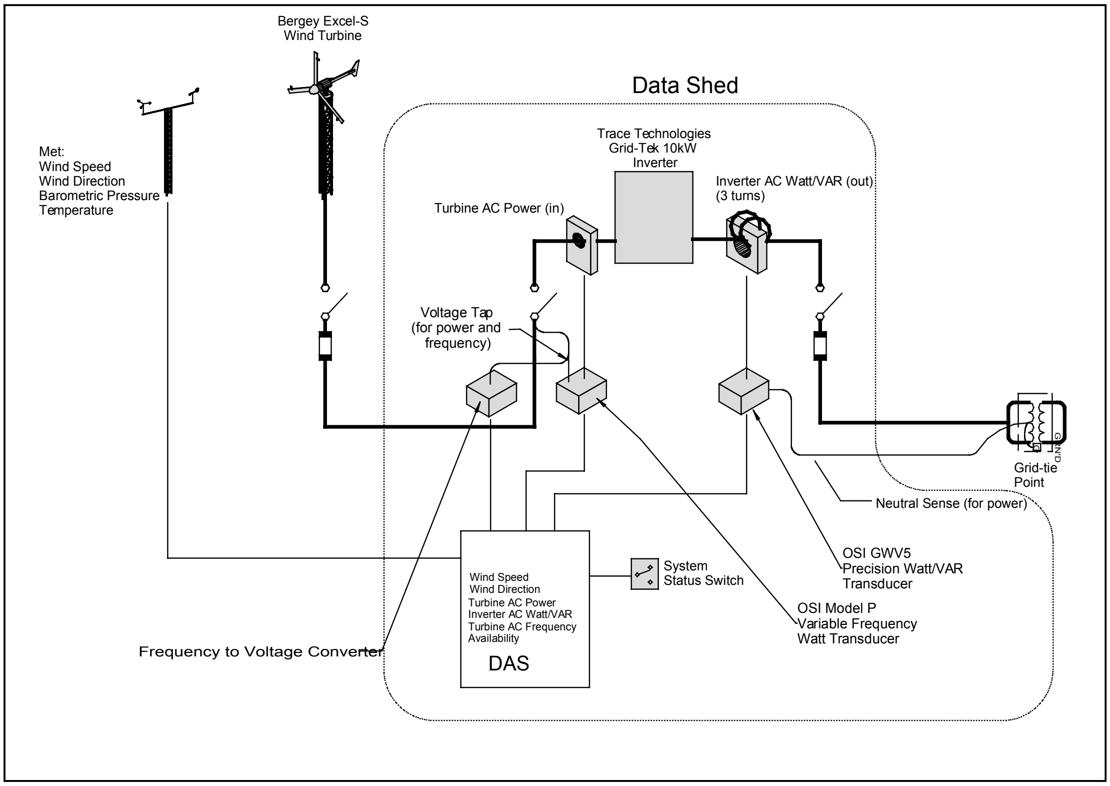


Figure 4: Location of the data acquisition sensors for the test setup.

Table 2: Equipment List for Safety and Function Test

Power Transducer and CTs (Inverter Power)	
Make/Model:	OSI, GWV5-001EY24 CT pn 12975
Serial Number (Transducer & CTs):	9101376
Range with CTs:	-13.33 to 13.33 kW/kVar
Calibration Due Date:	14 September 2001
Power Transducer and CTs (WT Watts)	
Make/Model:	OSI, P-143E
Serial Number (Transducer & CTs):	9100896
Range with CTs:	0 to 40 kW
Calibration Due Date:	14 September 2001
Primary Anemometer	
Make/Model:	Met One, 010C with Aluminum Cups
Serial Number:	Y4397
Calibration Due Date:	20 February 2002
Secondary Anemometer	
Make/Model:	Met One, 010C with Aluminum Cups
Serial Number:	X4233
Calibration Due Date:	20 February 2002

Wind Direction Sensor	
Make/Model:	Met One, 020C with Aluminum Vane
Serial Number:	U1477
Calibration Due Date:	20 February 2002
Barometric Pressure Sensor	
Make/Model:	Vaisala, PTB101B
Serial Number:	T3330002
Calibration Due Date:	19 December 2002
Atmospheric Temperature Sensor	
Make/Model:	Met One, T-200 RTD
Serial Number:	0653393
Calibration Due Date:	12 December 2001
Data Logger	
Make/Model:	Campbell Scientific CR23X
Serial Number:	1214
Calibration Due Date:	31 January 2002
Frequency Input, Field Configurable Isolator	
Make/Model:	Action Instruments Ultra Slim Pack G478-0001
Serial Number:	B2MCD
Voltage Transducer (for rpm)	
Make/Model:	OSI VT7-009X5
Serial Number:	8102964

Some equipment was replaced during the test period or temporarily taken down for re-calibration. Table 3 gives an overview of replacement instruments and re-calibrated instruments.

Table 3: Additional Equipment List for Safety and Function Test

Power Transducer and CTs (Inverter Power)	
Make/Model:	OSI, GWV5-001EY24 CT pn 12975
Serial Number (Transducer & CTs):	9101376
Range with CTs:	-13.33 to 13.33 kW/kVar
Calibration Due Date:	15 November 2002
Power Transducer and CTs (WT Watts)	
Make/Model:	OSI, P-143E
Serial Number (Transducer & CTs):	9100896

Range with CTs:	0 to 40 kW
Calibration Due Date:	15 November 2002
Barometric Pressure Sensor	
Make/Model:	Vaisala, PTB101B
Serial Number:	S2830007
Calibration Due Date:	19 November 2002
Atmospheric Temperature Sensor	
Make/Model:	Met One, T-200 RTD
Serial Number:	0464507
Calibration Due Date:	19 November 2002
Frequency Input, Field Configurable Isolator	
Make/Model:	Action Instruments Ultra Slim Pack G478-0001
Serial Number:	B2MCD

8.2. Test Procedures

Yaw orientation

Observations will be made over time for a range of wind speeds. These observations will be written in the logbook.

Start-up and shutdown

The turbine has no start-up or shutdown sequence. During start-up, the turbine is usually spinning unloaded, and the inverter kicks in when there is sufficient wind.

The turbine can be shut down in three ways:

1) The inverter shuts down and lets the turbine run unloaded.
2) The turbine can be manually furled, which should lower the rotor speed.
3) The furled turbine can be shorted to bring it to a stop.

Start-ups and shutdowns will be observed at several wind speeds.

Power production

Power production behavior is recorded as part of the power performance test. Any differences from the expected designed behavior will be reported.

Power and rotor speed limitation

Data will be analyzed from the duration test, and max rpm and power versus wind speed will be plotted. If the furl mechanism works properly, both plots should flatten at the higher wind speeds.

Grid outage

To simulate a grid outage, the switch on the grid side of the inverter will be opened. Rotor speed, wind speed, and power will monitored.

Short loss of grid

The switch on the grid side of the inverter will be opened and closed as quickly as possible. The response of the inverter will be observed.

Loss of load

If the turbine loses connection with the inverter, the turbine will run unloaded. This is normal turbine behavior, which is described under rotor speed limitation.

Unauthorized changing of control settings

The turbine system will be checked to see whether settings can be changed.

Inverter faults

There are several situations in which the inverter goes into a fault condition. If the inverter does go into the faulted condition, it will unload the turbine.

Underwriters Laboratories tested and approved the inverter for the safety impact of the inverter to itself and the safety impact of the inverter to the grid. A UL report describing the functionality tests is available. The two impacts the inverter can have on the turbine—creating a loaded or unloaded turbine—are normal situations for the turbine and do not result in safety concerns. National Renewable Energy Laboratory (NREL) personnel have not repeated the tests done by UL.

Failure in furl system

The control of power and rpm is based on the furl mechanism. In case the furl mechanism fails, the rotor should speed up. A test with locked furl mechanism will be performed if NREL personnel determine that this can be done safely.

Personnel safety:

Fall protection

The Bergey Excel does not have any special provisions for climbing the tower; the lattice is used as a ladder and an anchoring point. There are no anchoring points on the turbine itself. This item is not applicable.

Maintenance

There are no locking devices for the rotor or the yaw mechanism. NREL personnel used a rope to secure the rotor to the tower. This also constrains the yaw movement.

Electrical safety

A visual inspection will be made to determine whether any hazardous situations exist. A qualified electrician will also be asked to look at the electrical system of the turbine.

Lightning protection

Description of the lightning protection for the NWTC installation will be recorded.

9.0 Results

The turbine did not exhibit any unsafe behavior, but it did exhibit behavior that NREL personnel believe is not in accordance with the design.

Yaw orientation

The turbine seems to track the winds fairly well. At higher rotor speeds, the rotor seems to respond less quickly to wind direction changes. Under furled conditions, the tail does not always align with the wind.

Start-up and shutdown

The inverter has been observed under a wide range of wind speeds during start-up. Records of start-up were written down for the dates and times in Table 4. No abnormal behavior was noted on any of these occasions.

Table 4: Logged Start-Ups and Their Wind Speed

Date & Time of Observed Start-Up	Approx. Wind Speed [m/s]
15 June 2001 11:30	9
18 June 2001 15:00	6
6 Aug 2001 15:00	9
27 Sept 2001 16:30	3
15 Oct 2001 8:55	4
22 Oct 2001 15:10	5
23 Oct 2001 8:10	9
24 Oct 2001 9:30	17
24 Oct 2001 16:00	7
31 Oct 2001 14:40	12
1 Nov 2001 9:00	8

Shutdown

The turbine has been furled in several wind speeds. The winch was operated, and the tail folds about 70° out of the wind. Records of furling actions are found in Table 5. No abnormal behavior was noted, except on 21 January when the furl cable broke.

Table 5: Logged Furl Events and Their Wind Speed

Date & Time of Furl Action	Approx. Wind Speed [m/s]
18 June 2001 14:50	6
27 Sept 2001 13:00	5
21 January 2002 13:20	7
8 Feb 2002 18:50	7
13 Feb 2002 12:00	5
18 March 2002 8:50	2
27 March 2002 11:00	20
28 March 2002 13:00	7
1 April 2002 11:20	13

The turbine has been shorted in several wind speeds in order to perform acoustic noise tests at neighboring sites or to measure background noise data at the Bergey Excel turbine. The turbine was furled, after which NREL personnel waited for a lull in the wind. The three phases in the down tower fuse box were then shorted. The highest wind speed at which we successfully tried shorting the turbine was about 8 m/s. NREL personnel would recommend a standardized installation of a short-circuit switch on the turbine or description of a safe short-circuit procedure in the owner’s manual, including the conditions under which it can be safely performed.

Power production

A deviation was observed from the designed behavior expected by NREL. In wind speeds of 13m/s (10-minute average) and above, the inverter enters a paused mode. The higher the wind speed, the more often the inverter will be in pause mode (in which it does not produce power). If the inverter goes into pause mode more than a number of times within a certain time period, the inverter goes into the DC Bus Overvoltage fault, which requires a manual reset. Table 6 gives an overview of faults that NREL personnel encountered during the test period from 12 March 2001 to 17 April 2002.

Table 6: Inverter Faults

Date	Time	Fault	Wind Speed [m/s]	Inverter Software
12 March 2001	22:30	Fault code 21 Bus overvoltage	19	3.02.03.01
7 April 2001	1:30	Fault code 21 Bus overvoltage	23	BG3241B6.io\ 3.02.04.27
6 May 2001	1:50	Fault code 21 Bus overvoltage	18	
13 June 2001	1:00	Fault code 21 Bus overvoltage	25	
8 July 2001	17:00	Fault code 22 Overtemperature	13	
12 October 2001	22:10	Fault code 21 Bus overvoltage	20	13.4.27c?
23 October 2001	4:50	Fault code 21 Bus overvoltage	21	
24 October 2001	10:30	Fault code 21 Bus overvoltage	22	
31 October 2001	12:30	Fault code 21 Bus overvoltage	20	
31 October 2001	15:50	Fault code 21 Bus overvoltage	23	
17 December 2001	6:20	Fault code 21 Bus overvoltage	22	BG324160.IO
27 December 2001	23:20	Fault code 21 Bus overvoltage	21	”
5 January 2002	15:10	Fault code 21 Bus overvoltage	16	”
7 January 2002	19:20	Fault code 21 Bus overvoltage	20	”
12 January 2002	21:20	Fault code 21 Bus overvoltage	21	”
20 January 2002	7:10	Fault code 21 Bus overvoltage	18	”
8 February 2002	16:20	Fault code 21 Bus overvoltage	22	”
8 February 2002	21:10	Fault code 21 Bus overvoltage	23	”
11 February 2002	9:00	Fault code 21 Bus overvoltage	18	”
22 February 2002	7:20	Fault code 21 Bus overvoltage	21	”
3 March 2002	21:20	Fault code 21 Bus overvoltage	22	”
7 March 2002	10:30	Fault code 21 Bus overvoltage	19	”
7 March 2002	11:20	Fault code 21 Bus overvoltage	20	”
7 March 2002	11:30	Fault code 21 Bus overvoltage	20	”
7 March 2002	13:10	Fault code 21 Bus overvoltage	17	”
17 April 2002	15:30	Fault code 22 Overtemperature	14	”

Figure 5 depicts a time series of wind speed, inverter output power, and the number of seconds the inverter was producing power based on 10-second data points. These data were taken on 7 March 2002. Between 9:00 and 11:30, the inverter paused several times and faulted twice. The inverter was reset around 10:40.

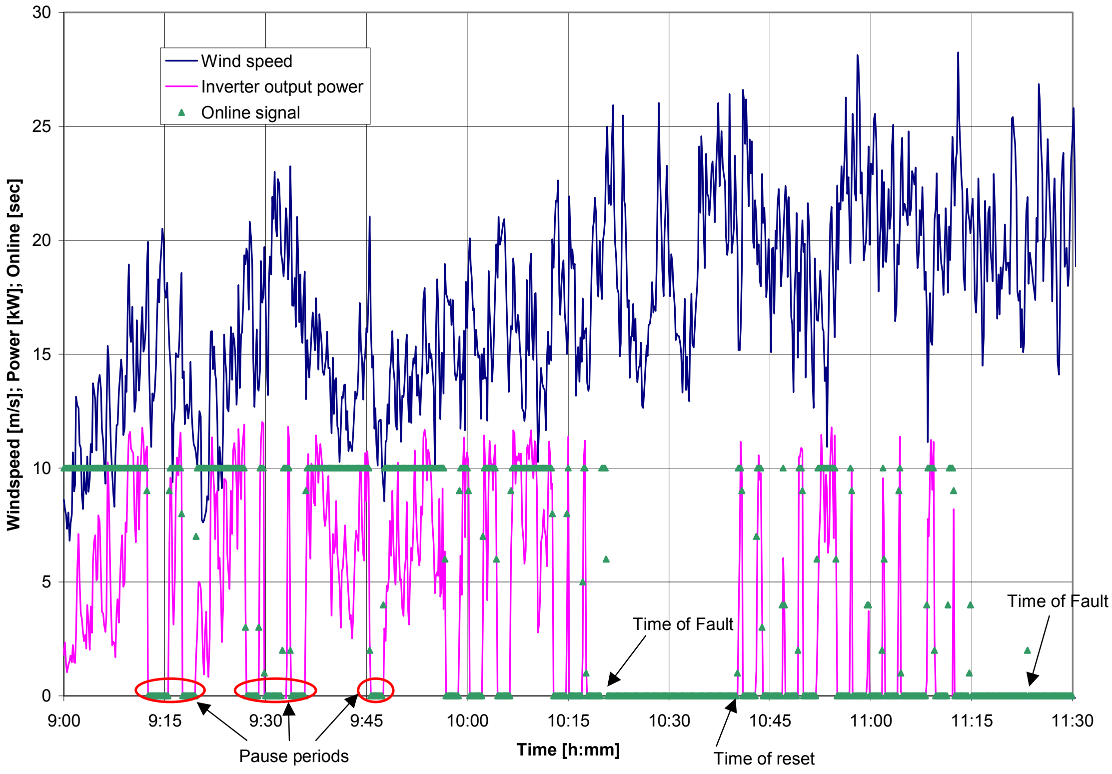


Figure 5: Time series of inverter output power, wind speed, and online signal (10-second data).

The influence of this behavior on the power production is shown in Figure 6. As the wind speed increases above 15m/s, the 10-minute average power decreases. This is caused by the increasing percentage of time the inverter is not producing power.

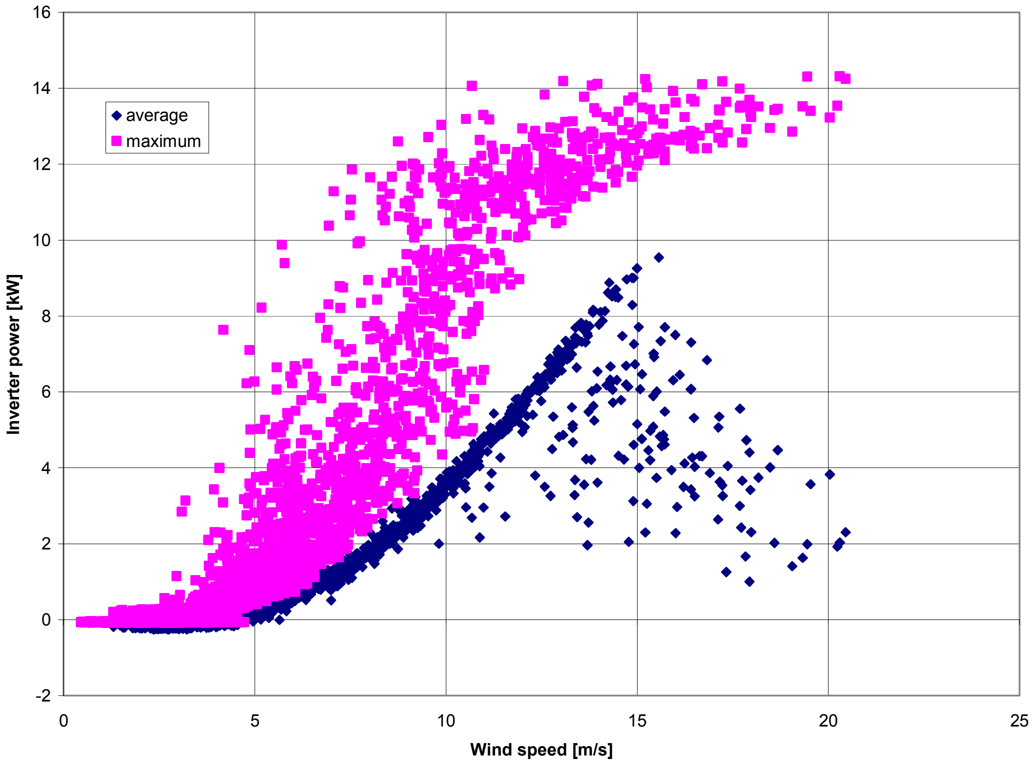


Figure 6: Inverter output power as a function of wind speed.

Figure 7 shows the percentage of time that the inverter was producing power to the grid as a function of wind speed. The line goes through the binned averages at each wind speed. The graph clearly shows that on the lower wind speeds, the inverter switches on and off the grid depending on whether there is enough wind. At higher wind speeds (5-13 m/s), the inverter is online for almost 100% of the time. The graph shows that at even higher wind speeds (>13m/s), the inverter goes offline more often. The scatter above 22 m/s is caused by a lack of data points. The data are from October - December 2001. The level at 80% is caused by 10-minute periods with exactly one pause period (2 minutes) in it.

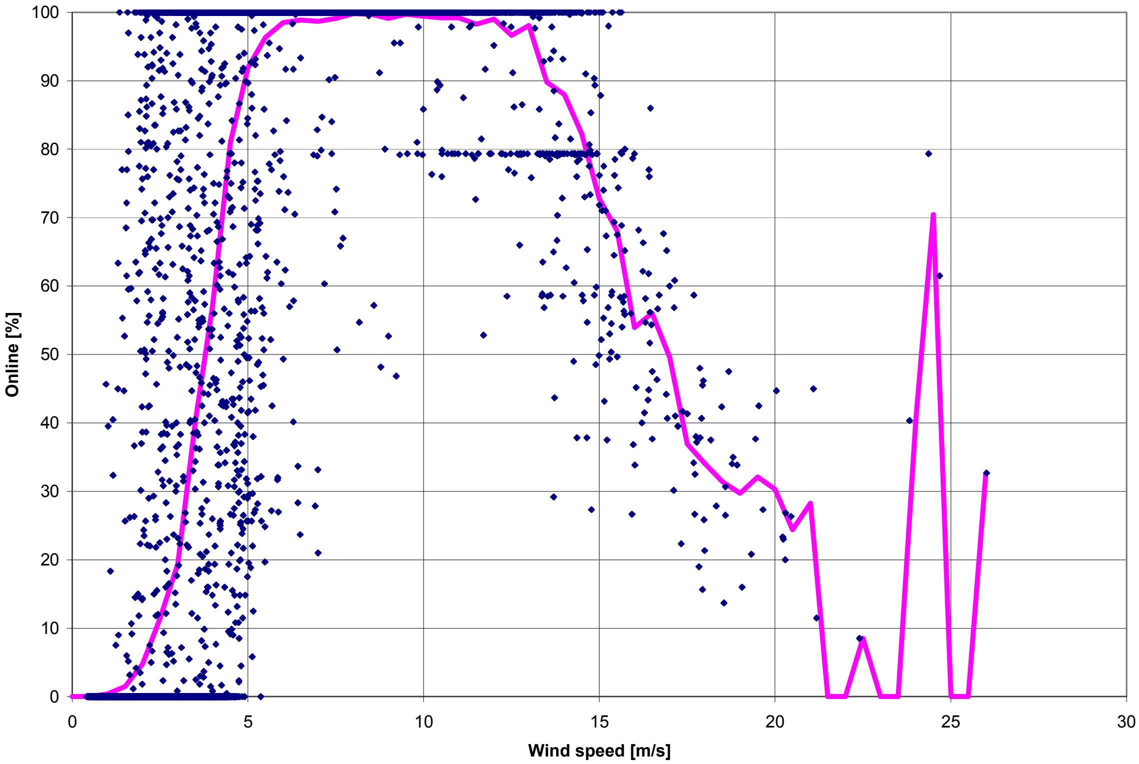


Figure 7: Percentage of time the inverter is online as a function of wind speed.

Power and Rotor Speed Limitation

Power rotor speed and wind speed measurements were taken during the duration test. The 10-minute statistics (average, standard deviation, minimum, and maximum) were stored. Figure 8 shows the 10-minute average rotor speed for the loaded and unloaded turbine. It can be seen that the unloaded rotor spins faster. The data points for the loaded turbine stop at 300 rpm because above that rpm, there are no 10-minute periods in which the turbine stays loaded for the entire 10 minutes. This is caused by the problem described under “power production.”

Also plotted in Figure 8 is the 10-minute maximum rotor speed as a function of wind speed for the *unloaded* turbine. The rotor speed levels off at higher wind speeds and decreases at even higher wind speeds. This is because at medium wind speeds, the turbine goes in and out of furl, and at the high wind speeds, the turbine stays furled for the entire 10 minutes. The highest measured rotor speed is about 610 rpm. The data shown in Figure 8 were measured in the October-December 2001 period.

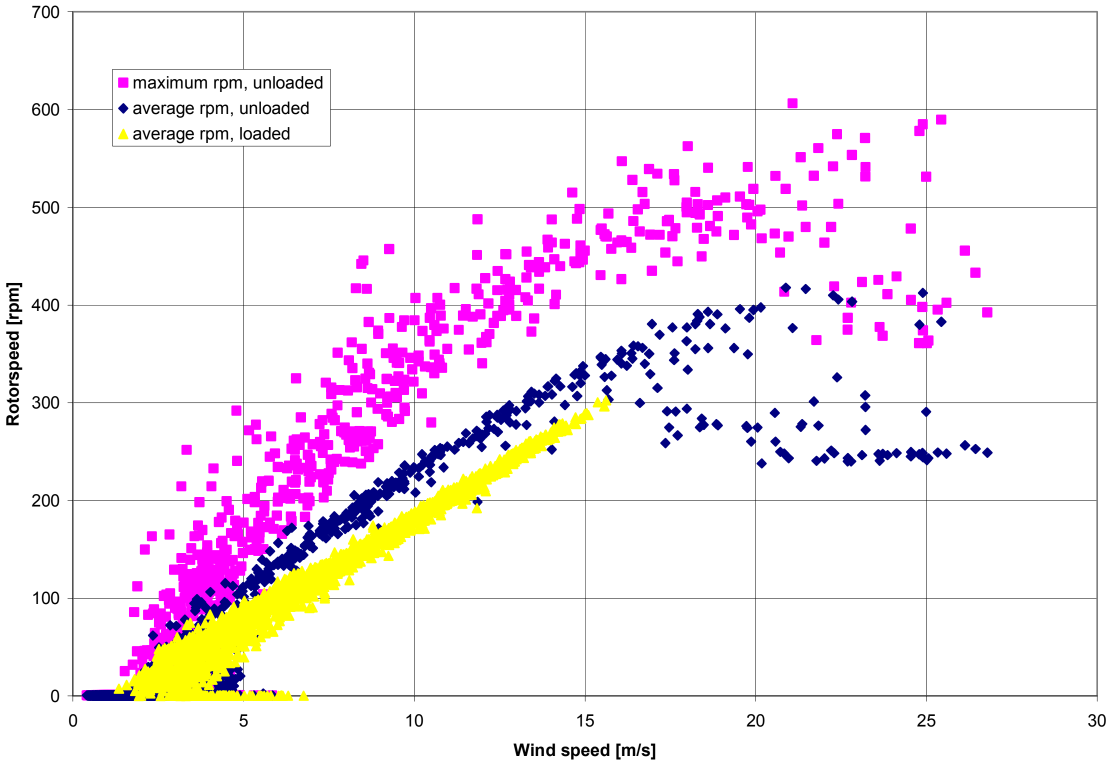


Figure 8: Rotor speed as a function of wind speed (10-minute statistics).

Figure 6 shows 10-minute maximum and 10-minute average inverter output power as a function of wind speed. The data were measured in October 2001. It can be seen that the maximum power within a 10-minute period is limited at about 14 kW. It is not clear whether this power is limited because the inverter cannot produce more or if it is limited by the furling behavior of the turbine.

The 10-minute average power drops after 15 m/s caused by the inverter pauses are described above under “power production.”

Grid Outage

On the afternoon of 26 July 2002, grid outages were simulated to the Gridtek inverter by opening the switch between the inverter and the grid, and 10-Hz measurements were taken of wind speed, power rotor speed, and the online signal. Figure 5 shows a time series with two simulated grid outages (around 14:04 and 14:10). The time series show that the moment the grid is lost, the inverter shuts down and unloads the rotor (compare rpm 14:05-14:06 with rpm around 14:14-14:15). It also shows that the moment the inverter gets back online, the power briefly goes negative, and then it peaks positive and levels off. At the same time the power peaks, the rotor speed decreases.

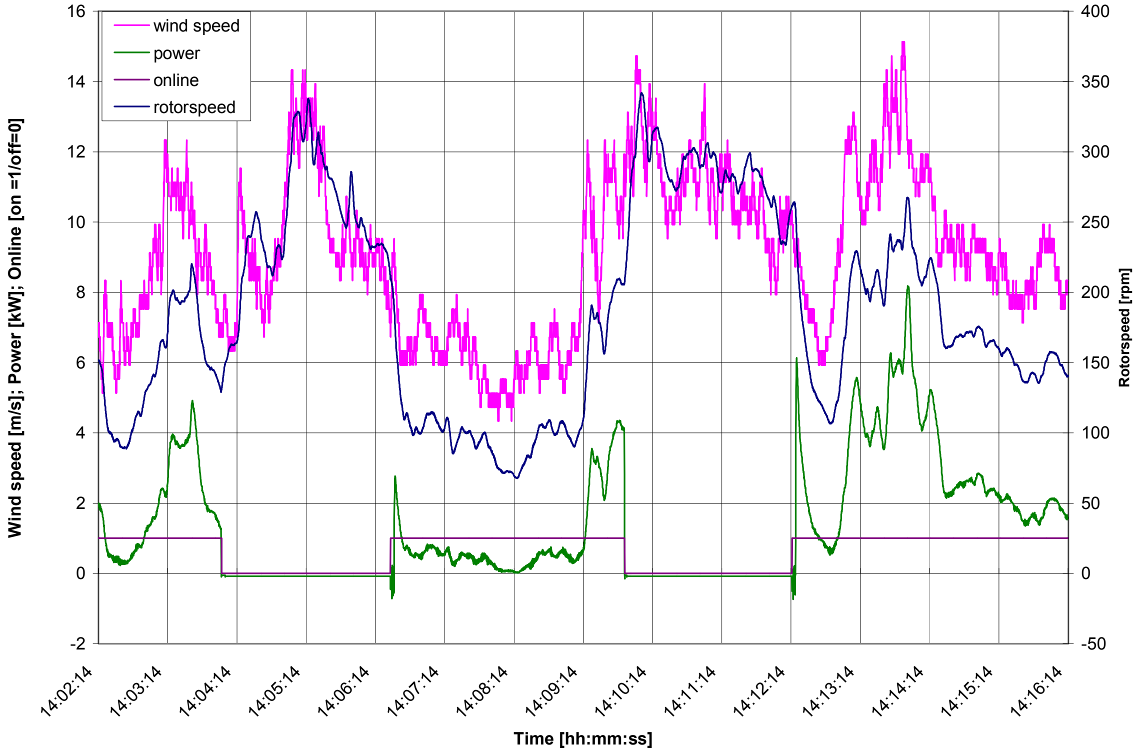


Figure 9: Time series of simulated grid outage.

Short Grid Outage

The switch on the grid side of the inverter was opened and closed as quickly as possible (+/- 0.5s). The inverter shuts down and reboots.

Unauthorized Changing of Control Settings

The turbine has no control settings that can be altered. There is only one button accessible on the outside of the inverter. This is the RESET button, which is used to clear any faults that require a manual reset. This button cannot be used to change any inverter settings.

Electrical Safety

All major electrical components are behind doors that can only be opened with a screwdriver. A sticker on the inverter (Figure 10) gives sufficient warnings for the multiple power sources and in specific capacitors.

WARNING
RISK OF ELECTRICAL SHOCK

DO NOT REMOVE COVER.
NO USER SERVICEABLE
PARTS INSIDE.
STORED ENERGY IN CAPACITOR.
ALLOW AT LEAST 5 MINUTES
AFTER DISCONNECTING ALL
SOURCES OF SUPPLY.
REFER SERVICING TO QUALIFIED SERVICE
PERSONNEL.

BOTH UTILITY AND WIND GENERATOR
VOLTAGE SOURCES ARE TERMINATED
INSIDE THIS EQUIPMENT.
EACH CIRCUIT MUST BE
INDIVIDUALLY DISCONNECTED
BEFORE SERVICING.

WHEN THE WIND GENERATOR
IS ROTATING, IT SUPPLIES
AC VOLTAGE
TO THIS EQUIPMENT.

Figure 10: Warning sticker on the inverter.

A certified electrician checked the turbine installation. It should be noted that most of the electrical installation is owner specific, and safe installation at the NWTC does not automatically mean safe installation for all Bergey Excel turbines. The Gridtek-10 inverter is UL listed under E199356.

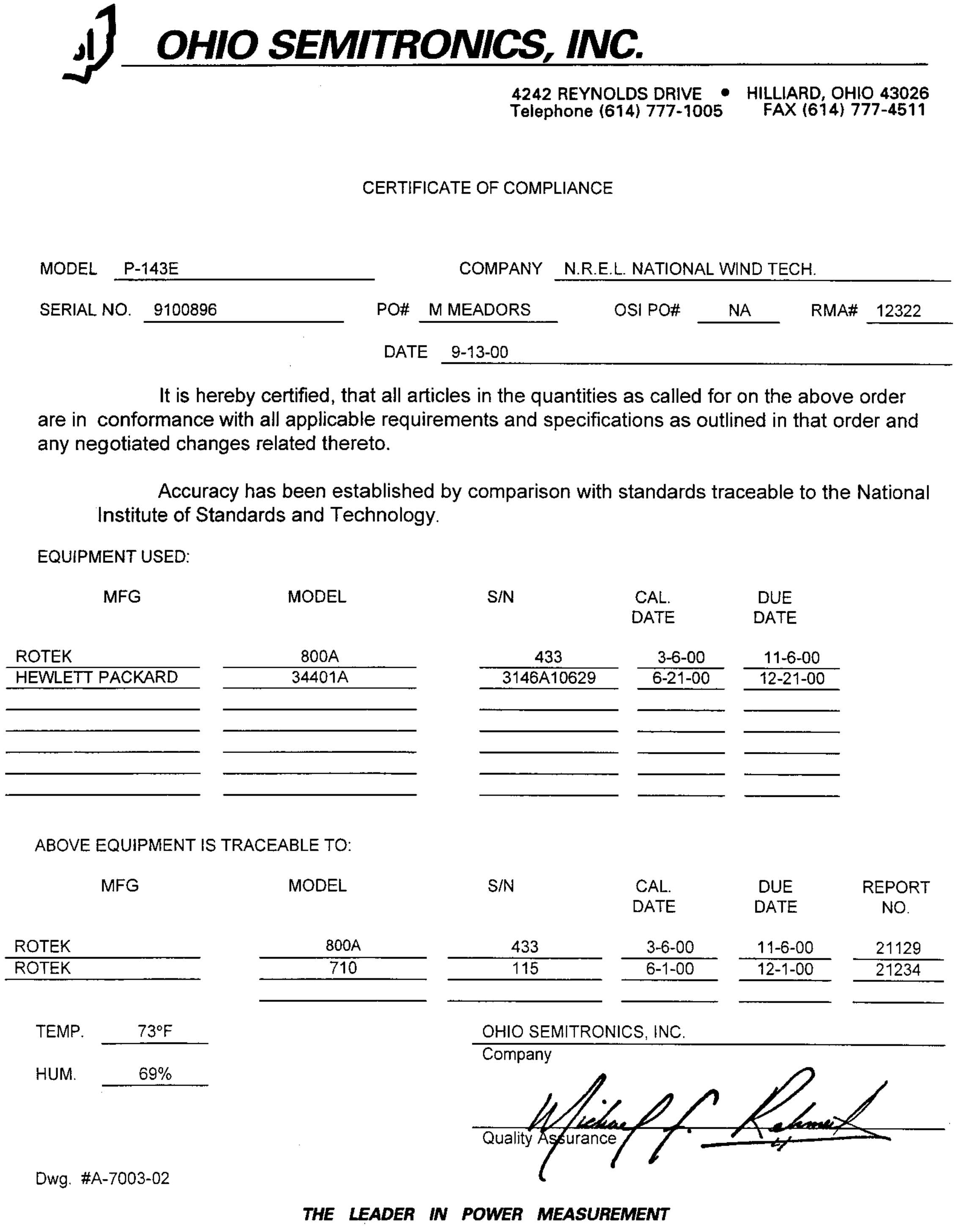
Lightning Protection

All guy wires are connected to the ground at all three anchoring points. The tower is connected to a metal frame, which is grounded. The three phases are protected by a surge protection device in the down tower switchbox.

10.0 References

1. IEC WT01 (2001-04), International Electrotechnical Commission (IEC), IEC System for Conformity Testing and Certification of Wind Turbines - Rules and Procedures.

APPENDIX A: Instrument Calibration Sheets



OHIO SEMITRONICS, INC.

4242 REYNOLDS DRIVE • HILLIARD, OHIO 43026
Telephone (614) 777-1005 FAX (614) 777-4511

CERTIFICATE OF COMPLIANCE

MODEL P-143E
COMPANY N.R.E.L. NATIONAL WIND TECH.
SERIAL NO. 9100896
PO# M MEADORS
OSI PO# NA
RMA# 12322
DATE 9-13-00

It is hereby certified, that all articles in the quantities as called for on the above order are in conformance with all applicable requirements and specifications as outlined in that order and any negotiated changes related thereto.

Accuracy has been established by comparison with standards traceable to the National Institute of Standards and Technology.

EQUIPMENT USED:

MFG	MODEL	S/N	CAL. DATE	DUE DATE
ROTEK	800A	433	3-6-00	11-6-00
HEWLETT PACKARD	34401A	3146A10629	6-21-00	12-21-00

ABOVE EQUIPMENT IS TRACEABLE TO:

MFG	MODEL	S/N	CAL. DATE	DUE DATE	REPORT NO.
ROTEK	800A	433	3-6-00	11-6-00	21129
ROTEK	710	115	6-1-00	12-1-00	21234

TEMP. 73°F
HUM. 69%

OHIO SEMITRONICS, INC.
Company

Quality Assurance

Dwg. #A-7003-02

THE LEADER IN POWER MEASUREMENT

OHIO SEMITRONICS, INC.

4242 REYNOLDS DRIVE • HILLIARD, OHIO 43026
Telephone (614) 777-1005 FAX (614) 777-4511

CERTIFICATE OF COMPLIANCE

MODEL GWV5-001EY24 COMPANY N.R.E.L. NATIONAL WIND TECH.

SERIAL NO. 9101376 PO# M MEADORS OSI PO# NA RMA# 12322

DATE 9-13-00

It is hereby certified, that all articles in the quantities as called for on the above order are in conformance with all applicable requirements and specifications as outlined in that order and any negotiated changes related thereto.

Accuracy has been established by comparison with standards traceable to the National Institute of Standards and Technology.

EQUIPMENT USED:

MFG	MODEL	S/N	CAL. DATE	DUE DATE
ROTEK	800A	433	3-6-00	11-6-00
HEWLETT PACKARD	34401A	3146A10629	6-21-00	12-12-00
HEWLETT PACKARD	34401A	3146A58150	7-27-00	12-27-00

ABOVE EQUIPMENT IS TRACEABLE TO:

MFG	MODEL	S/N	CAL. DATE	DUE DATE	REPORT NO.
ROTEK	800A	433	3-6-00	11-6-00	21129
ROTEK	710	115	6-1-00	12-1-00	21234

TEMP. 73°F

HUM. 69%

OHIO SEMITRONICS, INC.
Company

Quality Assurance

Dwg. #A-7003-02

THE LEADER IN POWER MEASUREMENT

Deutsches Windenergie - Institut
GmbH
Ebertstr. 96
D-26382 Wilhelmshaven
Tel. 49 4421 48080
Fax. 49 4421 4808 43

Test laboratory according to DIN EN 45.001
accredited by the DAP
Deutsches Akkreditierungssystem
Prüfwesen GmbH

Deutscher
Akkreditierungs
Rat
DAP-P-02.394-00-92-01

Member of MEASNET
International Network for Harmonised and
Recognised Measurements in Wind Energy

DEWI Anemometer Calibration

Calibration No. **1103_00**
Object **Cup Anemometer**

Manufacturer **Met One Instruments**
USA

Type **010C-1**

Serial number **Y4397**
Cup number **Y4397**

Customer **NREL**
Golden, Colorado

Date **12/14/00**

Remarks **no**

This calibration certificate documents that the measured physical values frequency, voltage, air pressure, air temperature and difference pressure in the airflow are traceable to national standards.
The determination of the wind velocity follows to ISO 3966 1977 *Measurement of fluid flow in closed conduits [2]* and *MEASNET Cup Anemometer Calibration Procedure [1].*

The presented results are valid only for the described anemometer and the measuring conditions.

This calibration report includes 3 pages (plus appendix). It is not permitted to publish this document partly without permission of DEWI. The test result documented in this report relates only to the item tested. The user has to recalibrate the anemometer at appropriate intervals.

Wilhelmshaven, 14.12.2000

i.V. Dipl. Phys. D. Westermann

i.A. Dipl. Ing. K. Junior

MET ONE INSTRUMENTS INC.

TEST CERTIFICATION

SENSOR MODEL # 010 B/[✓ C]

SERIAL NO. X 4233

SALES ORDER # 986992

CUSTOMER NREL

TEST DATE 1/17/01

TESTED BY Mark Russell

PO NUMBER Visa

Room Temperature 70°C

Room Humidity 30%

TEST STANDARDS:

DMM KEITHLEY 197A Ser 490833 CALIBRATED 2/17/00

FREQUENCY HP 5245L Ser 71616181 CALIBRATED 2/17/00

TEMPERATURE M.O.I. Model 062 Ser N8823 Calibrated 4/17/00

RELATIVE HUMIDITY Vaisala Model HMP35A Ser 460410 Calibrated 9/15/00

TEST	AS FOUND	ERROR	AS LEFT	ERROR	SPEC.
Torque	<0003	[✓ pass]/fail	<.003	[✓ pass]/fail	<0.003 inoz
Output 300rpm	200.3 Hz	+0.3 Hz	199.9	-0.1	200 +/- 1.7Hz

Wind Vane Calibration Report

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

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

Calibration Location:
National Wind Technology Center
Room 123, Industrial Users Facility

Calibration Date: **14-Jun-00**

Report Number: U1477-000614

Page: 1 of 1

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

Deviations from procedure: None

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	020C
Serial Number	**U1477**
Vane Material	Aluminum
Condition	Refurbished

Results:

Slope:	**0.1424**	deg/mv
Offset to boom:	**89.7**	deg
Max error:	0.2	deg

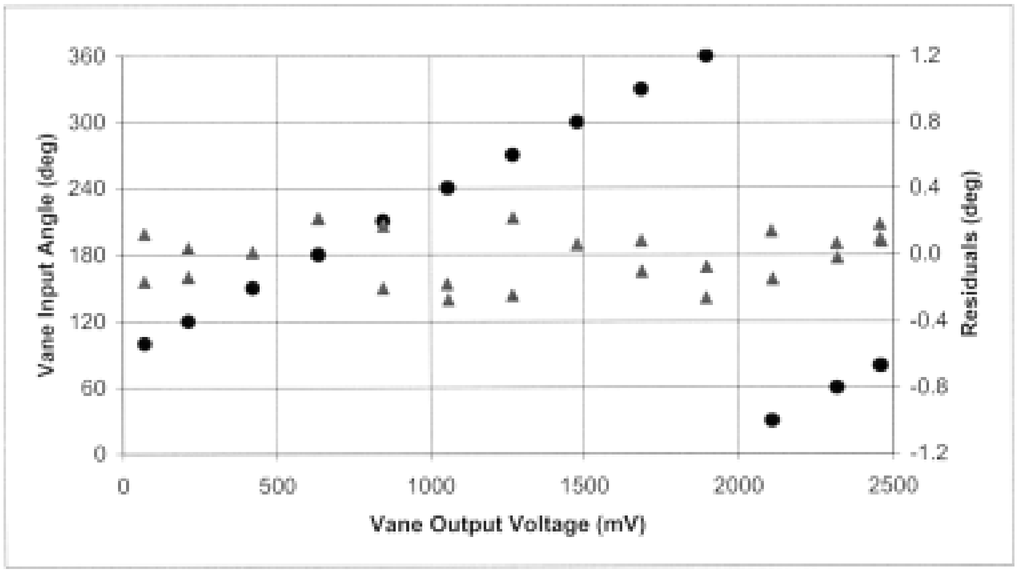
Estimated Uncertainty:

Inclinometer Uncertainty (deg)	Total Uncertainty (deg)
0.10	0.27

Traceability:	Mfg & Model	Serial Number	Cal Date
Inclinometer	Lucas DP45	82860032	20-Jan-00
Voltmeter:	CR10X	X08210	25-Feb-00

Calibration by: Mark Meadors
Mark Meadors

6/14/00
Date



Calibration Certificate

INSTRUMENT REPAIR LABS INC.

2100A West 6th Avenue
Broomfield, CO 80020
PH: 303/469-5375 or 800/345-6140, FX: 303/469-5378

Company Name: National Renewable Energy Lab
Certification#: 001128059
Calibration Location: Subcontractor
Customer's P.O. Number:
Received Status: In Tolerance
Returned Status: In Tolerance
Procedure Used: MFGR Cal Procedure
Calibration Date: 12/19/2000
Standards Used: Subcontracted - See attached
Calibration Remarks: Calibrated by CEESI, reference certificate
Description: Absolute Pressure Transducer

MFG: Vaisala
Model: PTB101B
SN: T3330002
Barcode: 17816
Cust ID:
Temp: 72 F
RH: 35 %
Rec. Cal. Due: 12/19/2001

It is Instrument Repair Labs, Inc. opinion that the above listed instrument meets or exceeds all manufacturer's or agreed upon local specifications. The instrument has been calibrated using standards whose accuracies are traceable to N.I.S.T. within the limitation of their calibration services, or have been derived from accepted values of natural physical constants. Our "Calibration System Requirements" satisfy ANSI/NCSL Z-540, MIL-STD 45662A, FDA GMP 820.61 and ISO/IEC 17025. The calibration environment was 70 Deg F, +/- 5 Deg F and <70% RH unless otherwise noted. This report is not to be reproduced, except in full, without the written approval of Instrument Repair Labs' Quality Manager.

CERTIFIED BY: **Subcont. -Cal**
QUALITY MANAGER: **Bill Hedrick**

Date Printed: **12/26/2000**
Time Printed: **11:22:04**

Instrument Repair Labs, is certified to ISO 9002 by TUV Management Service. Our ANSI-RAB certificate registration number is: 950-98-0218, and is valid until April 30, 2001.

Form 07, Rev. 06, 10/10/2000

Branch #: 5000 **sheet: 1 of: 1**

NREL METROLOGY LABORATORY

Test Report

Test Instrument: RTD Probe **DOE #: 02683C**

Model # : N/A **S/N : 0653393**

Calibration Date: 12/12/2000 **Due Date: 12/12/2001**

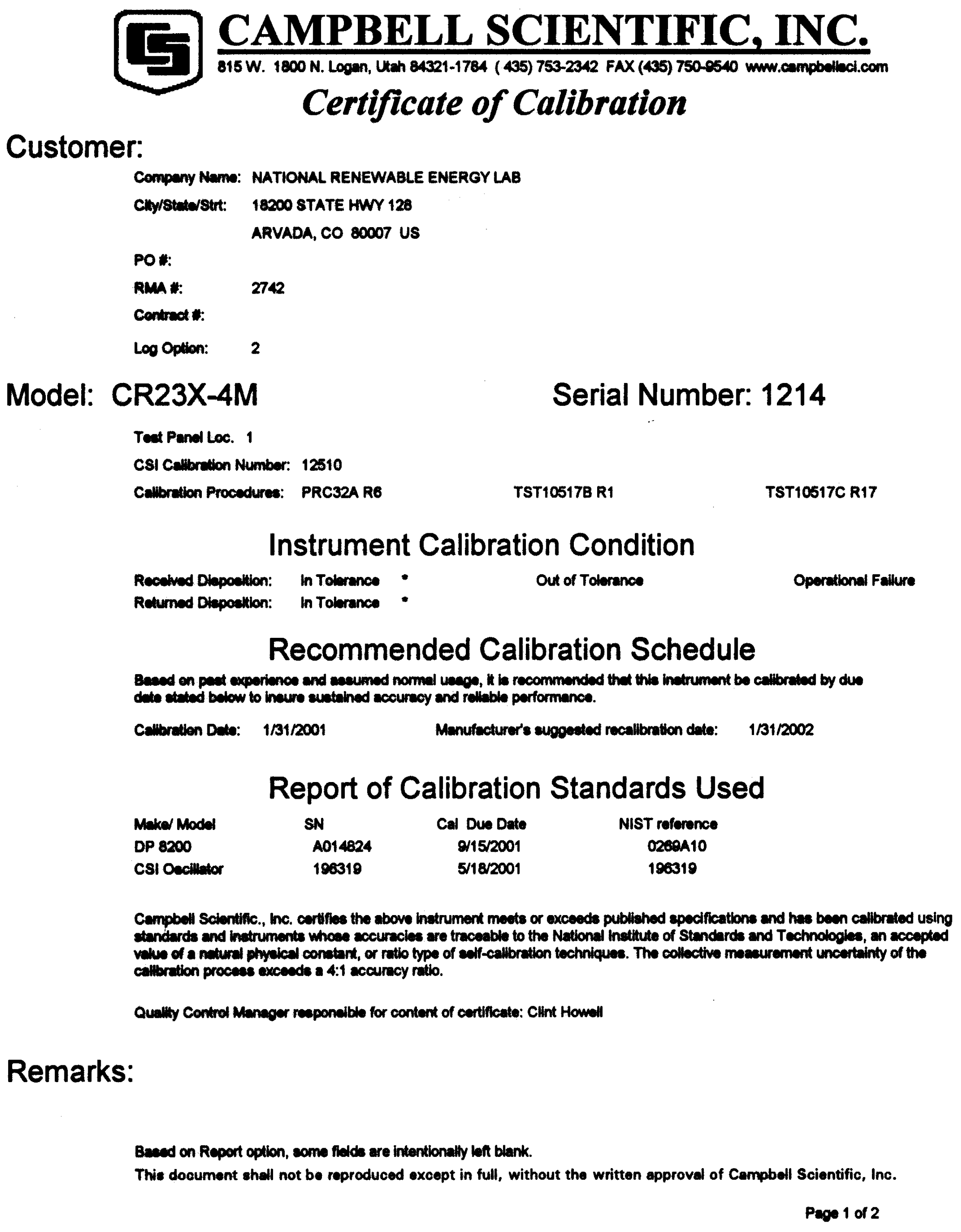
Nu	Nominal Values		Measured Values		
	Nominal Resistance	Equivalent Temperature	Measured Resistance	Equivalent Temperature	Temperature Error(M-N)
1	94.12 Ω	-15 °C	94.131 Ω	-14.97 °C	0.03 °C
2	100.00 Ω	0.0 °C	100.017 Ω	0.04 °C	0.04 °C
3	105.85 Ω	15.0 °C	105.872 Ω	15.06 °C	0.06 °C
4	111.67 Ω	30.0 °C	111.704 Ω	30.09 °C	0.09 °C
5	117.47 Ω	45.0 °C	117.506 Ω	45.09 °C	0.09 °C

Notes:

1. Total Uncertainty of Nominal Values = ±0.03 °C
2. Calibration was performed at 23 °C and 30% RH
3. Resistance is measured using 3-wire technique

Checked By: Reda

Date : 12/12/2000



CAMPBELL SCIENTIFIC, INC.

815 W. 1800 N. Logan, Utah 84321-1784 (435) 753-2342 FAX (435) 750-9540 www.campbellsci.com

Certificate of Calibration

Customer:

Company Name: NATIONAL RENEWABLE ENERGY LAB
City/State/Strt: 18200 STATE HWY 128
ARVADA, CO 80007 US
PO #:
RMA #: 2742
Contract #:

Log Option: 2

Model: CR23X-4M Serial Number: 1214

Test Panel Loc. 1
CSI Calibration Number: 12510
Calibration Procedures: PRC32A R6 TST10517B R1 TST10517C R17

Instrument Calibration Condition

Received Disposition:	In Tolerance *	Out of Tolerance	Operational Failure
Returned Disposition:	In Tolerance *		

Recommended Calibration Schedule

Based on past experience and assumed normal usage, it is recommended that this instrument be calibrated by due date stated below to insure sustained accuracy and reliable performance.

Calibration Date: 1/31/2001 **Manufacturer's suggested recalibration date:** 1/31/2002

Report of Calibration Standards Used

Make/ Model	SN	Cal Due Date	NIST reference
DP 8200	A014824	9/15/2001	0269A10
CSI Oscillator	196319	5/18/2001	196319

Campbell Scientific., Inc. certifies the above instrument meets or exceeds published specifications and has been calibrated using standards and instruments whose accuracies are traceable to the National Institute of Standards and Technologies, an accepted value of a natural physical constant, or ratio type of self-calibration techniques. The collective measurement uncertainty of the calibration process exceeds a 4:1 accuracy ratio.

Quality Control Manager responsible for content of certificate: Clint Howell

Remarks:

Based on Report option, some fields are intentionally left blank.
This document shall not be reproduced except in full, without the written approval of Campbell Scientific, Inc.

Page 1 of 2

Center #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Transducer DOE #: 02792C

Model # : P-143E S/N : 9100896

Calibration Date: 11/15/2001 Due Date: 11/15/2003

Input Voltage @60 Hz (Volt)	Input Power @60 Hz (KWatt)	Output Nominal Voltage (VDC)	Measured Output Volt, @ Watt Terminal (VDC)		(x)Mfr. Specs. OR ( )Data only
			AS Found	AS Left	
200	0	1.0	1.000	Same	± 0.05 VDC
"	4	1.4	1.396	"	"
"	8	1.8	1.796	"	"
"	12	2.2	2.196	"	"
"	16	2.6	2.597	"	"
"	20	3.0	2.999	"	"
"	24	3.4	3.400	"	"
"	28	3.8	3.804	"	"
"	32	4.2	4.205	"	"
"	36	4.6	4.609	"	"
"	40	5	5.012	"	"

Tested By: Reda
Date : 11/15/2001

Branch #: 5000 *sheet: 1 of: 1*

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Transducer *DOE #: 02793C*

Model # : DWV5-001EY24 *S/N : 9101376*

Calibration Date: 11/15/2001 *Due Date: 11/15/2003*

Input Voltage @60 Hz (Volt)	Input Power @60 Hz (K-Watt/VAR)	Output Nominal Voltage (VDC)	Measured Output Volt, @ Watt Terminal (VDC)		(x)Mfr. Specs. OR ( )Data only
			AS Found	AS Left	
1. Watt Test					
100 V	-20	0.8	0.802	Same	± 0.016 VDC
"	-15	1.2	1.99	"	± 0.016 VDC
"	-10	1.6	1.599	"	± 0.016 VDC
"	-5	2	1.999	"	± 0.016 VDC
"	0	2.4	2.399	"	± 0.016 VDC
"	5	2.8	2.799	"	± 0.016 VDC
"	10	3.2	3.200	"	± 0.016 VDC
"	15	3.6	3.600	"	± 0.016 VDC
"	20	4	4.002	"	± 0.016 VDC
1. VAR Test					
100 V	-20.000	1.0000	1.0047	Same	± 0.020 VDC
"	-15.008	1.4992	1.4825	"	± 0.021 VDC
"	-10.001	1.9999	1.9891	"	± 0.022 VDC
"	-5.019	2.4981	2.4943	"	± 0.023 VDC
"	0	3.0000	2.9903	"	± 0.024 VDC
"	5.019	3.5019	3.4970	"	± 0.025 VDC
"	10.001	4.0001	4.0015	"	± 0.026 VDC
"	15.008	4.5008	4.5080	"	± 0.027 VDC
"	20.000	5.0000	5.0170	"	± 0.028 VDC

Tested By: Reda
Date : 11/15/2001

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Pressure Transmitter DOE #: 02794C

Model # : PTB101B S/N : S2830007

Calibration Date: 11/16/2001 Due Date: 11/16/2002

No	Function Tested	Nominal Value (mb)	Measured Values		( )Mfr. Specs. OR (X)Data only (mb)
			Output Voltage (VDC)	Equivalent Pressure (mb)	
*	Absolute Pressure	651.7	0.2815	651.8	
		701.7	0.5538	701.9	
		751.7	0.8266	752.1	
		801.7	1.0987	802.2	
		851.7	1.3712	852.3	
		901.7	1.6424	902.2	
		951.7	1.9152	952.4	
		1001.7	2.1875	1002.5	
		1051.7	2.4601	1052.7	

Note:
Uncertainty of the nominal value is ± 1 mb

Tested By : Reda
Date : 11/16/2001

RTD Calibration Certificate

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

Calibration Location:
National Wind Technology Center
Building 257 room 101-04

Calibrated for:
NWTC - Certification Team

Procedure:
CI02 Calibrate RTD 011129
Deviations: NONE

Item Calibrated:

Mfgr:	Met One Instruments, Inc
Model:	T200
Serial No:	**0464507**
Condition:	good

Cal Date: November 19, 2001

Results:

Slope:	**2.6034**	C/ohm
Offset:	**-260.20**	C
Max Uncert*:	0.65	C

*over temperature range of -20 to +45 C

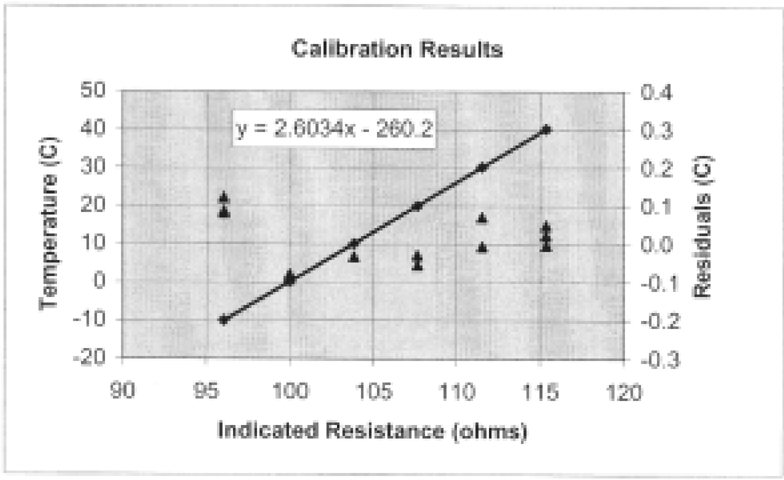
Certificate Number / File Name:
RTD Cal 0464507, 011119.xls

Reference Standard:
Hart Scientific, Model 9102 HDRC Dry-Well Calibrator
Last Calibration: Hart Scientific, 8/28/2001, A182823

Associated Equipment
Campbell Scientific, Model CR23X, Datalogger
Vishay, S102C, 10 kohm Precision Resistor

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 Meadors 19 Nov '01
Mark Meadors Date



Phoenix Contact Universial Frequency Converter Calibration

Date Calibrated: 3/1/01

Report No: F-to-V 0103011

Calibration Laboratory:
National Renewable Energy Laboratory
1617 Cole Blvd
Golden, CO 80401

Cal Location:
National Wind Technology Center
18200 State Hwy 128
Boulder, CO 80303

Technician: Mak Meadors x Mark Meadors

Frequency Source: Fluke Documenting Process Calibrator, Model 743B
S/N: 6965608
Calibrated by: Instrument Repair Labs
Date: 11/14/00
Cal Due: 11/14/01

Voltage Measurement: Campbell Scientific Model 23X Datalogger
S/N: 1214
Calibrated by: Campbell Scientific
Date: 1/13/01
Cal Due: 1/13/02

Device(s) calibrated: Ultra Slim Pack Frequency Input, Field Configurable Isolator
Model: G478-0001
S/N: B2MCD
Calibration Method: GI27 010227, Calibrate frequency to voltage devices

Device Condition: Good

Calibration Uncertainty:

0.1	hertz	Fluke Calibrator for freq: 11<hz<110
0.5	hertz	Fluke Calibrator for freq: 110<hz<1100
5.0	mv	Campbell Datalogger for volt: 0<v<5
3.6	rpm/mv	Sensitivity Factor for Campbell
18.1	rpm	Campbell Uncertainty in rpm

Special Limitations: 0-150 Vac input, 4-20 mA output with 250 ohm, .01%, 0.6 ppm/deg C IR

Calibration Factors:

Slope:	**0.2762**	mV/rpm
Offset:	**-275.737**	rpm
Calibration Uncertainty:	18.1	rpm