June 2003 NREL/EL-500-34381

Wind Turbine Generator System

Safety and Function Test Report

(Revision 1)

for the

Southwest Windpower H40 Wind Turbine

by

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

Jeroen van Dam, Hal Link, Mark Meadors, Jerry Bianchi

for

Southwest Windpower
2131 N. First Street
Flagstaff, Arizona 86004

January 20, 2003

Approval By: ____________________ 21 January 2003
Jeroen van Dam, NREL Test Engineer Date

Approval By: ____________________ 21 Jan 03
Hal Link, NREL Certification Test Manager Date

Approval By: ____________________ 1/21/03
Charles P. Butterfield, Certification QA Manager Date

Disclaimer

Table of Contents

1.0 Test Objective

The objective of this test was to evaluate the safety and function characteristics of the Whisper H40 wind turbine. The general requirements of wind turbine safety and function tests are defined in the IEC standard WT01. The testing was conducted in accordance with the National Wind Technology Center (NWTC) Quality Assurance System, including the NWTC Certification Team Certification Quality Manual and the NWTC Certification Team General Quality Manual for the Testing of Wind Turbines, as well as subordinate documents.

This safety and function test was performed as part of the U.S. Department of Energy's (DOE's) Field Verification Program (FVP) for small wind turbines.

2.0 Changes in Revision 1

1. Post-test calibrations have been completed on all instrumentation used for this test. Appendix A is expanded to include the post-test calibration certificates, and the exception to standard practice is removed.
2. Peak power is now quantified.
3. An estimate of peak rotor speed is now provided.

3.0 Description of Test Turbine and Setup

Figure 1 shows the Whisper H40 wind turbine as it was installed at Site 1.3 at the NWTC. The Whisper H40 is a three-bladed, upwind, variable-speed turbine that uses furling for power regulation and overspeed control. The turbine is mounted on a 10-cm (4-in.) tube tower at a hub height of 9.1 m (30 ft). The tilt-down tower is supported by four guy wires and can be easily lowered to ground level for turbine inspection and maintenance.

The turbine uses a direct-drive, permanent magnet, brushless alternator to produce three-phase, variable-frequency, variable-voltage AC power. This "wild AC" power is directed through slip rings in the nacelle to the turbine's EZ Wire controller.

The EZ Wire is a proprietary, silicon-controlled rectifier (SCR) that features turbine control and a dump load. In this test, it was configured to produce 24 volts DC. The voltage is stabilized with four batteries. A Trace sine-wave inverter (model number SW4024) converts the DC power to 120 volts AC and feeds it to the NWTC electrical grid. In case of a utility outage or inverter failure, the resistive dump load dissipates energy from the turbine. A manual switch provides braking for the turbine by disconnecting it from the load and shorting two of the generator leads together. The arrangement of these components is shown in Figure 2.

Table 1 lists configuration and operational data for the Whisper H40.

The Whisper H40 wind turbine was tested at Site 1.3 of the NWTC (hereafter referred to as the test site), approximately 8 km (5 mi) south of Boulder, Colorado. The site is located in somewhat complex terrain at an approximate elevation of 1850 m (6070 ft) above sea level.

Table 1. Test Turbine Configuration and Operational Data

General Configuration:	
Make, model, serial number	World Power Technologies, Whisper H40, 09092256
Rotation axis	Horizontal
Orientation	Upwind
Number of blades	3
Rotor hub type	Rigid
Rotor diameter (m)	2.1
Hub height (m)	9.1
Performance:	
Rated electrical power (kW)	0.9
Rated wind speed (m/s)	12.5
Cut-in wind speed (m/s)	3.4
Rotor:	
Swept area (m^2)	3.6
Cut-in rotational speed (rpm)	300
Maximum rotational speed (rpm)	1,200
Tilt angle (deg)	7
Blade pitch angle (deg)	0 (nonlinear 13^o at root to 1^o at tip)
Direction of rotation	CCW
Overspeed control	Furling
Braking System:	
Electrical brake: make, type, location	Three-phase, short-circuit brake
Yaw System:	
Wind direction sensor	Tail vane
Tower:	
Type	Guyed tube tilt-down
Height (m)	9.1
Control/Electrical System:	
Controller: make, type	EZ Wire system 120 SW4024
Power converter: make, type	Trace
Electrical output: voltage, frequency, number of phases	480 VAC, 60 Hz, 1-phase

Figure 1. Whisper H40 turbine at the NWTC test site.

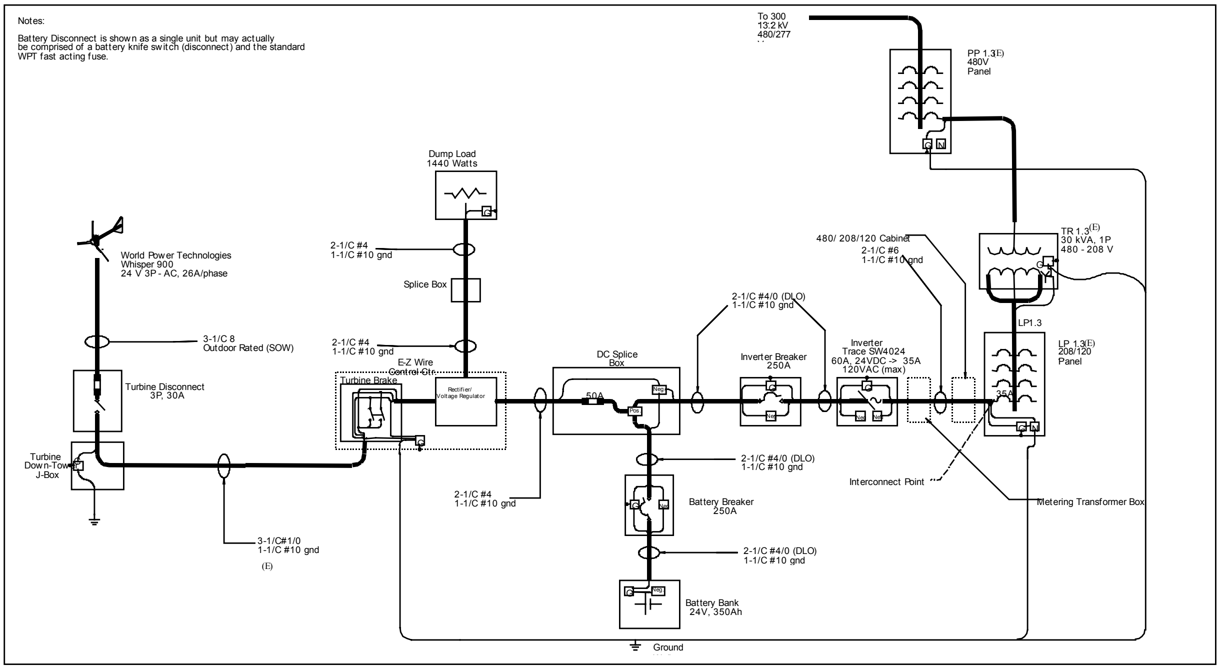


Figure 2. Electrical one-line drawing.

4.0 Instrumentation

The following parameters were measured in this test: wind speed, DC bus voltage, DC bus current, AC power, and rotor speed. In planning for the test, we expected to measure current to the dump load. However, during the test, current to the dump load was not measured. It was determined from heating of the dump load resistors that the dump load function was suitable. The instruments that were used for these measurements are listed in Table 2. The calibration sheets for the instruments used for this safety and function test are included in Appendix A.

Table 2. Equipment List for Safety and Function Test

AC Power Transducer	
Make/model:	OSI, GWV5-001EY24/1
Serial number (power transducer/current transducers):	0010301
Range with CTs:	0 - +/-1
Calibration due date:	1/5/01
Turbine Speed	
Make/model:	Action Pak
Serial number:	B7YSV
CT range:	0-1000 rpm
Calibration due date:	2/18/01
DC Bus Voltage	
Make/model:	OSI VT7-003E

Serial number:	9111995
CT range:	0-50 Vdc
Calibration due date:	1/3/01
DC Bus Current	
Make/model:	OSI CTA212
Serial number:	0010126
CT range:	0-50 Amp
Calibration due date:	1/3/01
Met Anemometer 2/9/2000 to 11/29/2000	
Make/model:	Met One, 010C with aluminum cups
Serial number:	W1231
Calibration due date:	2/9/01
Met tower location:	6.7 m upwind
Met Anemometer 11/29/2000 to 7/30/2001	
Make/model:	Met One, 010C with aluminum cups
Serial number.	W1240
Calibration due date:	4/21/01
Met tower location:	6.7 m upwind
Data Logger 2/15/2000 to 10/4/2000	
Make/model:	Campbell Scientific CR21X
Serial number:	13185
Calibration due date:	Post-calibration on 2/8/2001
Data Logger 10/4/2000 to 7/31/01	
Make/model:	Campbell Scientific CR23X
Serial number:	3099
Calibration due date:	8/30/2001

5.0 Procedure

The requirements for a safety and function test as described in Annex D of IEC WT01 [1] are:

> "The plan for the safety and function tests shall include the critical functions of the control and protection system that require test verification, as described in the design documentation. These critical functions shall at least include:
>
> - emergency shutdown during operation;
> - power and speed control;
> - yaw control (including cable twist);
> - operating vibration levels and excessive vibration protection ;
> - grid loss behaviour;
> - over speed protection at rated wind speed or above; and
> - start-up and shutdown above rated wind speed.
>
> Any additional protection system function that may be activated by component failure or other critical events or operational conditions shall also be tested. This testing may include simulation of the critical event or operational condition. Each test shall be described in the test plan. In many cases, several component failure modes or critical events will lead to similar behaviour of the control and protection system and may be covered by a single test. The Certification Body shall verify that the tests described in the test plan cover all identified critical control and protection system functions."

For the Whisper, this led to a number of tests (procedures can be found in Appendix B).

6.0 Results

The turbine exhibited no unexpected or inherently unsafe behavior. However, this does not mean that the turbine is safe. The tests considered only those conditions in which the turbine control and protection system was expected to maintain the turbine in a safe condition. In some failure modes, such as a failure of the dump load when the grid is not available, the response was expected to result in overcharging, damage, and possible fire in the battery bank. NREL personnel do not judge whether such failures are likely or whether additional features in the control and protection system are needed to protect against such consequences.

Yaw Orientation

Observations have been made of the turbine over the last year, including during acoustic noise tests taken over a wide wind speed range [4–22 m/s (9–49 mph)] and on different dates (January 4 and 25, 2001, and February 5, 2001). No abnormal behavior has been noticed. The wind turbine seems to accurately track the wind.

Power Limitation

DC current and voltage were measured throughout the duration test and the data used to determine the maximum observed and the maximum expected power in winds below 50 m/s (112 mph). Maximum DC power is calculated from the maximum 1-sec measurement of DC current multiplied by the maximum, 1-sec measurement of DC voltage for each 10-minute period. There is some error in this method because maximum current and voltage may have occurred at different times during the 10-minute period. However, DC voltage was maintained very closely by the inverter, so errors are expected to be low. Figure 3 shows a plot of average and maximum 1-sec DC power versus the maximum 1-sec wind speed. The figure indicates that maximum 1-sec power would be limited to less than 1,300 W in winds less than 50 m/s (112 mph).

Rotor Speed Limitation

Rotor speed was measured throughout the duration test. However, toward the end of the test, NREL personnel noted that a frequency to voltage transducer used in the measurement system was improperly set. This resulted in the rotor speed signal being clipped at 1,100 rpm, as shown in Figure 4. Thus it was not possible to determine directly whether rotor speed is properly limited by the furling mechanism. However, rotor speed is well correlated with DC power over the range of operation where the signal was not distorted, as shown in Figure 5. Using this correlation and extrapolating this to the highest measured instantaneous power level of approximately 1300 W, NREL personnel estimate that rotor speed does not exceed 1600 rpm in winds below 50 m/s (112 mph). Because of the uncertainty in the correlation of power and rotor speed outside of the observed range of operation, this estimate may not be conservative.

Brake Operation

During the noise tests, the brake was applied several times at different wind speeds. The brake worked in wind speeds up to 6–7 m/s (13.4–15.7 mph). The typical braking procedure involves waiting for a lull in the wind speed (noted by a dip in the produced current) to engage the stop switch, and, if the turbine does not stop directly, releasing the brake to prevent overheating of the alternator. If the dip in the wind speeds lasts, the turbine can be braked at relatively high wind speeds [up to 10 m/s (22.4 mph)]. The Whisper H40 manual indicates that the brake only works in moderate wind speeds when the turbine is not furled. The observed behavior is consistent with the manual.

Grid Outage

On June 25, at wind speeds between 6 and 11 m/s (13.4 and 24.6 mph), the batteries were disconnected and the inverter was shut down. After a minute, the LED on the EZ Wire setting "REGULATING" began switching on and off. After a few minutes, the dump load became hot. The configuration was maintained for 10 minutes, after which the inverter and batteries were connected again. No damage to the dump load was observed.

Battery Disconnect

The batteries were disconnected in winds of 6–11 m/s (13.4–24.6 mph). No change in turbine behavior was heard or otherwise observed. The produced power went to the grid.

Loss of Load

Tests were done with one, two, and three turbine phases disconnected from the EZ Wire. As described above, the measured rpm signal was clipped. In addition, the correlation between rotor speed and power is not applicable to loss-of-load events. Thus, no rpm data can be shown for this test. Observations indicated that under loss of load, the turbine still furled in a manner consistent with its operation under load. However, the blades occasionally fluttered at winds of about 15 m/s (34 mph), indicating that rotor speed was higher than during normal operation.

In addition, after the winds died, the turbine appeared to be stuck in furl (about 20–30° furl angle). This seemed to be related to the furling problem that was observed earlier during the duration test. Up-tower inspection showed excessive friction in the furl bearing. This behavior did not appear to be caused by the loss of load.

Unauthorized Changing of Control Settings

A knob on the front panel of the EZ Wire can be used to set the charge voltage of the batteries. This is used to equalize flooded lead acid batteries. However, turning this knob to high-charge settings might create a danger for gel and agm batteries.

Failure in Furl System

The turbine was locked in an unfurled position using hose clamps. During the measurement period, winds were not high enough to cause the turbine to furl.

Electrical Safety

All major electrical components are behind doors that can only be opened with a screwdriver or other tool. Further stickers warn for high voltages, multiple source, etc.

Lighting Protection

The turbine has no special lightning protection system. In the case of the turbine at the NWTC, the base plate of the tower is grounded, but the tower by itself is not. The guy wires are also not grounded.

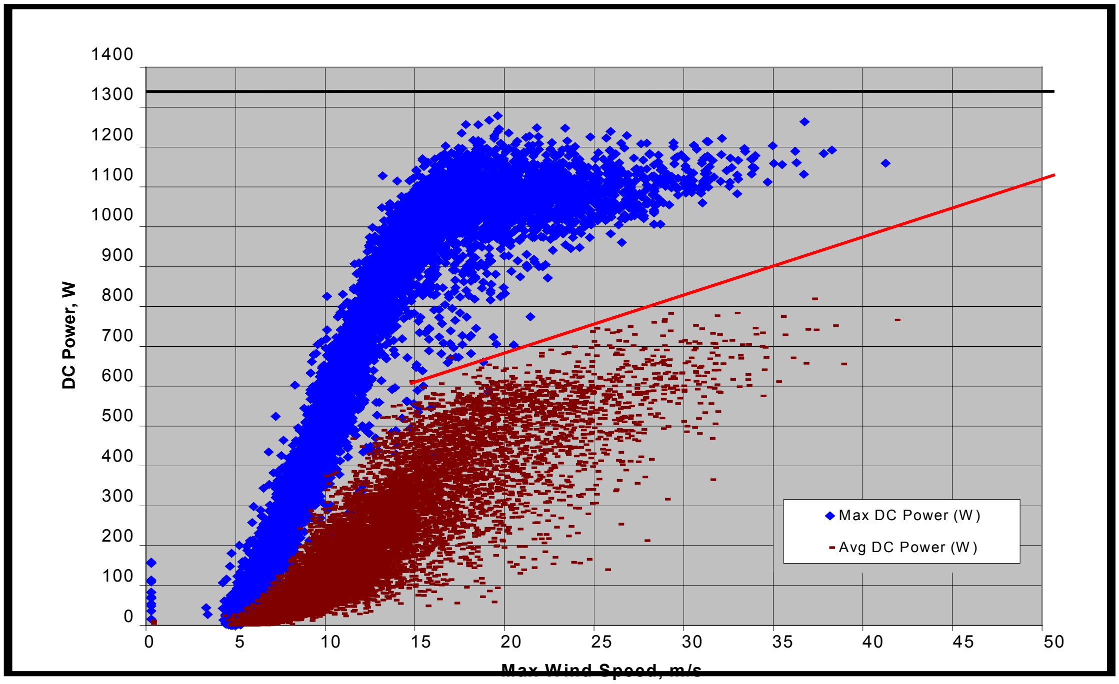


Figure 3. Whisper H40 power response to wind speed.

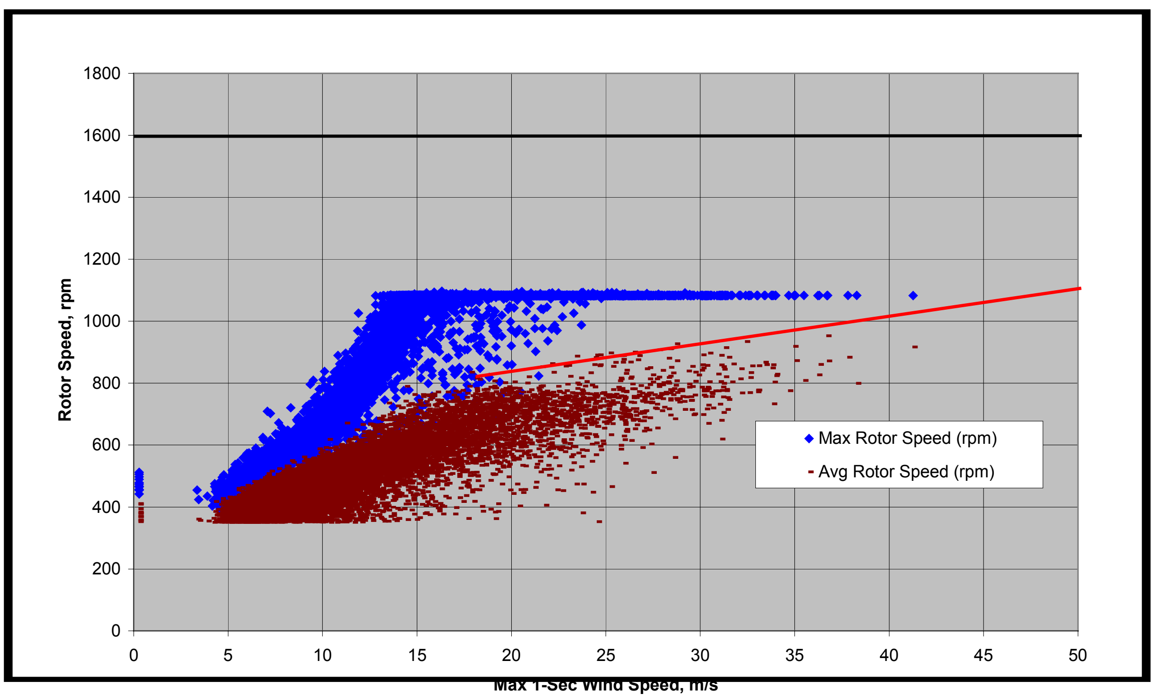


Figure 4. Whisper H40 rotor speed response to wind speed.

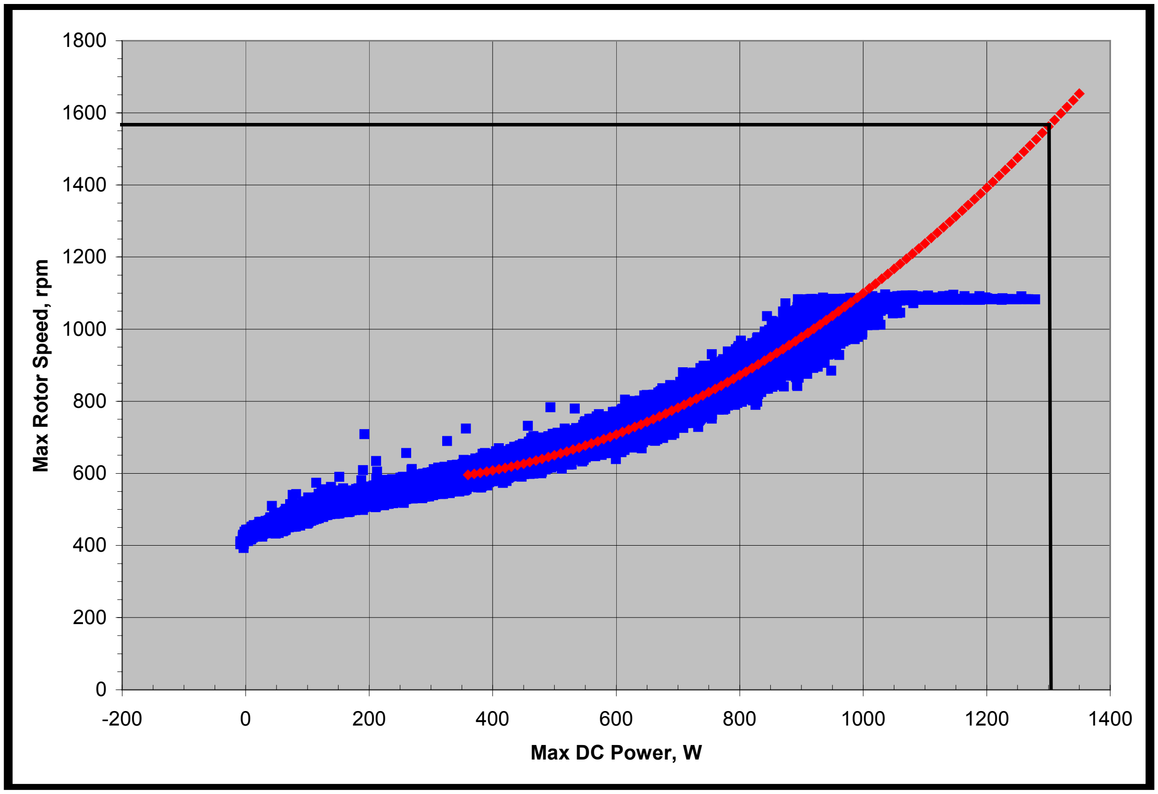


Figure 5. Relationship of Whisper H40 rotor speed to power.

7.0 Exceptions

None.

8.0 References

[1] IEC WT 01 "IEC System for Conformity Testing and Certification of Wind Turbines – Rules and Procedures" First Edition; 2001-04, International Electrotechnical Committee.

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 GWV5-001EY37 COMPANY NREL

SERIAL NO. 0010301 PO# J BIANCHI OSI PO# 48881 RMA# NA

DATE 1-5-00

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	432	10-5-99	8-5-00
KEITHLEY	177	229477	7-15-99	1-5-00

ABOVE EQUIPMENT IS TRACEABLE TO:

MFG	MODEL	S/N	CAL. DATE	DUE DATE	REPORT NO.
ROTEK	800A	432	10-5-99	8-5-00	20981
ROTEK	710	115	12-20-99	5-20-00	21054

TEMP. 72°F

HUM. 55%

OHIO SEMITRONICS, INC.
Company

Quality Assurance

Dwg. #A-7003-02

THE LEADER IN POWER MEASUREMENT

Branch #: 5000

sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Transducer

DOE #: 02747C

Model # : GWV5-001EY37

S/N : 0010301

Calibration Date: 08/09/2001

Due Date: 08/09/2003

Input Voltage @60 Hz	Input Power (Watt) @60 Hz	Output Nominal Voltage (VDC)	Measured Output Volt (VDC)		(X)Mfr. Specs. OR ( )Data only (VDC)
			AS Found	AS Left	
Watt TEST					
	Watt				
100 V	-1000	0.8	0.7935	0.7982	± 0.0036
"	-500	1.6	1.5912	1.5990	± 0.0052
"	0	2.4	2.3937	2.4008	± 0.0068
"	500	3.2	3.1956	3.2008	± 0.0084
"	1000	4.0	3.9968	4.0006	± 0.0100
VAR TEST					
	VAR				
100 V	-1000	1	0.9929	1.0008	± 0.0045
"	0	3	2.9909	2.9983	± 0.0085
"	1000	5	4.9878	4.9993	± 0.0125

Notes:

1. Uncertainty of nominal values is ± 0.06% of reading with traceability to NIST
2. Calibration was performed at 23°C and 40% RH

Tested By: Reda

Date : 08/09/2001

Frequency Converter Calibration

Date Calibrated:	2/18/2000
Report No:	F-to-V B2MCD 000218
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:	Mark Meadors
Frequency Source:	Fluke Documenting Process Calibrator, Model 743B
S/N:	6965608
Calibrated by:	Instrument Repair Labs
Date:	10/12/1999
Cal Due:	10/12/2000
Voltage Measurement:	Campbell Scientific Model 23X Datalogger
S/N:	1214
Calibrated by:	Campbell Scientific
Date:	2/7/2001
Cal Due:	2/7/2002
Device(s) calibrated:	Ultra Slim Pack Frequency Input, Field Configurable Isolator
Model:	G478-0001
S/N:	B7YSV
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
	48.1	rpm/mv	Sensitivity Factor for Campbell
	240.5	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

			RPM - to - Voltage Conversion 10-pole alternator 12 rpm/hz
Calibration Factors:			
Slope:	0.0208	mV/hz	**0.24952** mV/rpm
Offset:	-20.700	hz	**-248.39** rpm

OHIO SEMITRONICS, INC.

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

CERTIFICATE OF COMPLIANCE

MODEL VT7-003E COMPANY NREL

SERIAL NO. 9111995 PO# J BIANCHI OSI PO# 48881 RMA# NA

DATE 1-3-00

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	710	115	12-20-99	5-20-00
KEITHLEY	177	229477	7-15-99	1-15-00

ABOVE EQUIPMENT IS TRACEABLE TO:

MFG	MODEL	S/N	CAL. DATE	DUE DATE	REPORT NO.
ROTEK	710	115	12-20-99	5-20-00	21054

TEMP. 72°F

HUM. 63%

OHIO SEMITRONICS, INC.
Company

Quality Assurance

Dwg. #A-7003-02

THE LEADER IN POWER MEASUREMENT

Branch #: 5000

sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Transducer

DOE #: 02748C

Model # : VT7-003E

S/N : 9111995

Calibration Date: 08/09/2001

Due Date: 08/09/2003

No	Function Tested	Nominal Output Voltage (VDC)	Measured Output (VDC)		(X)Mfr. Specs. OR ( )Data only (VDC)
			As Found	As Left	
*	DC Voltage (VDC)				
	0	1	0.9970	Same	± 0.0125
	25	3	2.9990	"	"
	50	5	5.0000	"	"

Notes:

1. Uncertainty of nominal values is ± 20 ppm with traceability to NIST
2. Calibration was performed at 23°C and 40% RH

Tested By: Reda

Date : 08/09/2001

OHIO SEMITRONICS, INC.

4242 REYNOLDS DRIVE • HILLIARD, OHIO 43026
Telephone (614) 777-1005 FAX (614) 777-4611

CERTIFICATE OF COMPLIANCE

MODEL CTL-51/50-CTA212 COMPANY NREL

SERIAL NO. 0010124-0010126 PO# J BIANCHI OSI PO# 48881 RMA# NA

DATE 1-3-00

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
EMPRO	100Amps/100mV	107	5-28-99	5-28-00
KEITHLEY	179A	253342	6-22-99	12-22-99
KEITHLEY	179	23461	7-28-99	1-28-00
KEITHLEY	179	20585	7-21-99	1-21-00

ABOVE EQUIPMENT IS TRACEABLE TO:

MFG	MODEL	S/N	CAL. DATE	DUE DATE	REPORT NO.
ROTEK	710	115	12-20-99	5-20-00	21054
EMPRO	200 Amps/50 mV	99	11-8-99	11-8-00	62209

TEMP. 72°F

HUM. 63%

OHIO SEMITRONICS, INC.
Company

Quality Assurance

Dwg. #A-7003-02

THE LEADER IN POWER MEASUREMENT

Branch #: 5000

Sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Signal Conditioner

DOE #: 02749C

Model # : CTA212

S/N : 0010126

Calibration Date: 08/09/2001

Due Date: 08/09/2003

No	Function Tested	Nominal Output Voltage (VDC)	Measured Output (VDC)		(X)Mfr. Specs. OR ( )Data only (VDC)
			As Found	As Left	
*	DC Current (ADC)				
	0	1	0.990	1.001	± 0.025 .01
	25	3	2.978	2.997	* .022
	50	5	4.971	5.000	* .029

Notes:

1. Uncertainty of nominal values is ± 0.1% of reading with traceability to NIST
2. Calibration was performed at 23°C and 40% RH

Tested By: Reda

Date : 08/09/2001

Serial number: W1231

Anemometer 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
Side-by-Side Anemometer Calibration Facility

Dates of Calibration:
Test Start: 24-Aug-99
Test End: **29-Nov-99**
Report: 29-Nov-99

Report Number: CR-anno-99-4-T1

Page: 1 of 1

Procedure:
NWTC-CT: GI21-98237, Field Calibrate Anemometers

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	010C
Cup Serial Number	**W1231**
Cup Material	Aluminum
Condition	Refurbished: 2 June 99

Deviations from procedure:
Limited wind speeds to under 16 m/s
Allowed ref annos to agree within 2% (vs 0.2%)

Results:

Slope:	**0.03982**	m/s/hertz
Offset:	**0.3100**	m/s

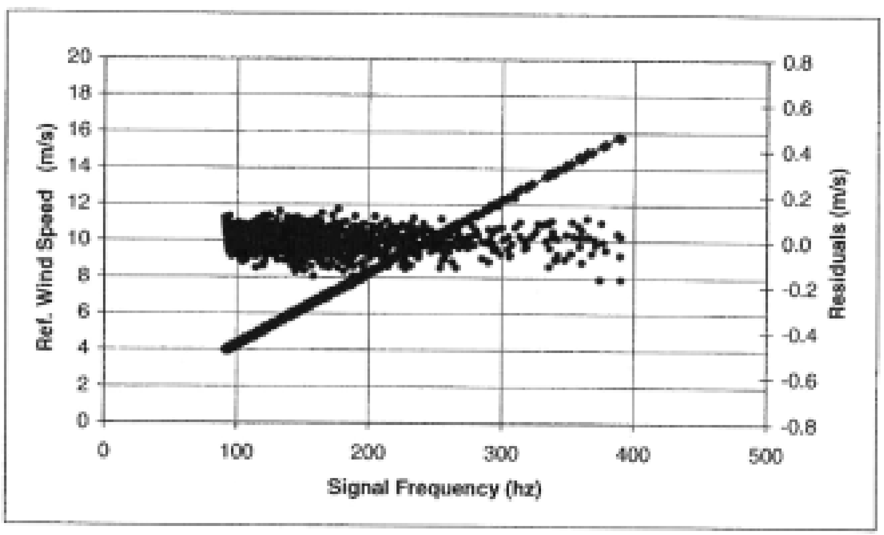
Estimated Uncertainty:

Vwind	Cres Uncer	Total Uncert:
4 - 5 m/s	0.080	0.092
5 - 10 m/s	0.080	0.092
10 - 15 m/s	0.100	0.110

Traceability:

Reference Cup:	Met One, 010C, s/n: U1195
Calibrated by:	CRES, Pikermi, Greece
Calibration date:	2-Mar-99

Approved: ________ 23/Nov 99
Hal Link Date



Serial number: W1240

Anemometer 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
Side-by-Side Anemometer Calibration Facility

Dates of Calibration:
Test Start: 23-Dec-99
Test End: 10-Jan-00
Report: 10-Jan-00

Report Number: CR-anno-99-5-T4

Page: 1 of 1

Procedure:
NWTC-CT: GI21-96237, Field Calibrate Anemometers

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	010C
Cup Serial Number	**W1240**
Cup Material	Aluminum
Condition	Refurbished: 5 May 99

Deviations from procedure:
Limited wind speeds to under 16 m/s
Allowed ref annos to agree within 2% (vs 0.2%)

Results:

Slope:	**0.04092**	m/s/hertz
Offset:	**0.3288**	

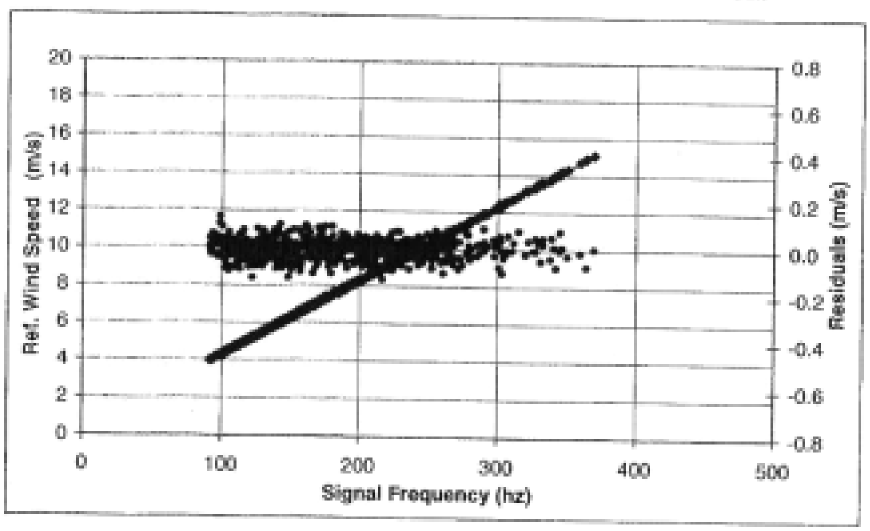
Estimated Uncertainty:

Vwind	Cres Uncer	Total Uncert
4 - 5 m/s	0.080	0.090
5 - 10 m/s	0.080	0.090
10 - 15 m/s	0.100	0.109

Traceability:

Reference Cup:	Met One, 010C, s/n: T2351
Calibrated by:	CRES, Pikermi, Greece
Calibration date:	2-Mar-99

Approved: Hal Link (signature) — Date: 10 Jan 00



CAMPBELL SCIENTIFIC, INC.

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

21X Calibration Report

Datalogger Type: 21X **Serial Number:** 13185 **RMA#: 3059** **Contract #:**

When Received, this instrument was found as follows:

In Tolerance: X
Out of tolerance
Operational failure: (No incoming tolerance declared)

		Single Ended measurements		Differential measurements	
Range	Input	Before	After	Before	After
5	-5000mv	-4997.1	-4997.6	-5000.0	-5000.4
5	5000mv	4999.4	4999.9	5001.3	5001.5
4	500mv	500.05	500.13	500.11	500.16
3	50mv	50.004	50.004	50.005	50.005
2	15mv	15.000	14.999	15.002	15.002
1	5mv	4.9991	4.9985	4.9996	4.9997
1	-5mV	-4.9982	-4.9975	-4.9995	-4.9998

Note: X = Out of tolerance

Time Clock Deviation (PPM)	Before	After
	-12	-19

Test Details..

Test Doc/Rev.: PRC23A Rev/24 Temperature: 22.5 C RH: 9.1

Calibrated By: [signature]

Name: S. Palmer Title: Customer Service Technician

Calibration equipment used: (NIST traceable through certified documents on fil

	Make/ Model#	S/N	NIST#
Voltage Source:	DATA PRECISION 8200	A014824	10598
Frequency source	OSCILATEK TXCO/112	196319	01411WWVB
RTD Ref.:	ROSEMONT-ADSR544	150171	1285

CSI certifies the above instrument meets or exceeds published specifications and has been calibrate using standards and instruments whose accuracies are traceable to the National Institute of Standards and Technology, an accepted value of a natural physical constant or a ratio calibration technique. The measurement uncertainty of the calibration process exceeds a 4:1 accuracy ratio. The policies and procedures at this calibration facility comply with ISO-9001.

Calibration date: Thursday, February 08, 2001
Calibration due: Friday, February 08, 2002

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: MS 3911

1617 COLE BLVD

GOLDEN CO

Contract/PO #:

RMA #: 4492

Log Option: 2

Model: CR23X-4M

Serial Number: 3099

Test Panel Loc. 2

CSI Calibration Number: 20781

Calibration Procedures: TST10517B R1 PRC32A R8 TST10517C R17 PRC33A R 1

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: 10/30/01 Manufacturer's suggested recalibration date: 10/30/02

Report of Calibration Standards Used

Make/ Model	SN	Cal Due Date	NIST reference
DP 8200	A014824	9/8/02	A014824
CSI Oscillator	196319	5/18/02	196319

CSI 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 Technology, an accepted value of a natural physical constant or a ratio calibration technique. The collective measurement uncertainty of the calibration process exceeds a 4:1 ratio. The policies and procedures at this calibration facility comply with ISO-9001. The calibration of this instrument was performed in accordance with CSI's Quality Assurance program.

Quality Control Manager responsible for content of certificate: Clint Howell

Remarks:

Based on Report option, some fields are intentionally left blank.

Instrument Data Report

Analog Inputs

Log Option: 2 S/N 3099

Range	Input (mV)	Tolerance (mV)	Single-Ended (Full Scale) Before (mV)	Single-Ended (Full Scale) After (mV)	Differential Before (mV)	Differential After (mV)	Temp (C)
5	5000	+-2.5	5000.3	5000.3	4999.7	5000.0	24.1
5	-5000	+-2.5	-4999.5	-5000.1	-4999.9	-5000.2	24.1
4	1000	+-0.5			999.98	1000.00	24.1
3	200	+-0.1			199.99	200.01	24.1
2	50	+-0.025			49.996	50.000	24.1
1	10	+-0.005			10.000	10.001	24.1
1	-10	+-0.005			-10.000	-10.000	24.1
5	5000	+-5		4996.8		4996.2	-25
5	5000	+-5		5001.1		5000.9	50
5	5000	+-7.5		4996.6		4997.7	-40
5	5000	+-7.5		5001.0		5001.1	80

Quiescent System Power

Tolerance Max (ma)	As Received (mA)	As Returned (mA)	Temp (C)
2.5	1.29	1.23	24.1

Real-Time Clock

Tolerance (min/month)	As Received (min/month)	As Returned (min/month)	Temp (C)
+-1.33 min	-0.1	0.0	24.1
+-1.33 min		-0.2	-25
+-1.33 min		-0.4	50
+-2.66 min		-0.5	-40
+-2.66 min		-0.6	80

Note: an "*" with data indicates out of tolerance; an "*" without data indicates operational failure.

Laboratory temperature and relative humidity at the time of calibration

Temperature: 24.1 C Relative Humidity: 19.2 %

Functions tested per test document (see page 1):

Analog:
- Excitation Channels
- CAO Channels
- Analog Input ranges over temperature

Frequency:
- Pulse Counters
- Period Averaging

Calibration by: T. Kendall Title: Electronic Technician

T. KENDALL

Based on Report option, some fields are intentionally left blank.

Page 2 of 2

Appendix B: Safety and Function Test Checklist

System safety and function test procedures and checklist for the Whisper H40

The objective of the safety and function test is to verify that the turbine displays the behavior predicted in the design and that provisions relating to personnel safety are properly implemented.
However, this does not mean that the turbine is safe. If it is clear that a certain simulated fault would bring the turbine into an unstable situation, then this was not tested for. The outcome would be predictable. Only issues in which the system is supposed to respond or stay in a safe condition were evaluated. Below is a list of items that will be evaluated for the Whisper H40.

The signals needed for this test are: wind speed, DC voltage, AC power, rpm, and dump load status.

The italic text gives the test procedure.
The Arial text in the boxes is a reproduction of the notes taken during the measurements.

The tests were performed on June 25 and 26, 2001, by Mark Meadors and Jeroen van Dam.

Yaw orientation
Over the year, observations have been made during the acoustic noise tests. These were taken over a wide wind speed range [4–22 m/s (9–49 mph)] on different days. No abnormal behavior was noticed.

Power and rotor speed limitation
Rpm and power data have been measured in the duration test and can be used to check this part of the safety and function test.

Use the duration test data to determine plots of maximum rpm and maximum power as a function of wind speed.

Brake operation
Several braking operations have been performed over the year. That experience will be used to check this part of the safety and function test.

Check logbook for brake entries and indication of wind speeds.

Grid outage
In case of a grid outage, the inverter will go down. The turbine should keep operating normally and the power should go to the batteries. When the batteries are full, the dump load should be switched in. If the grid is reconnected after this has happened, the dump load should switch off and the power should be delivered to the grid.

To test to see if the dump load can handle the maximum power, this test ideally should take place at wind speeds slightly above rated wind speed [10–15 m/s (22.4–33.6 mph)].

We will disconnect the grid on the grid side of the inverter. The expected behavior is that the turbine will operate normally, the inverter will go down, and the power will go to the batteries. After a while, the batteries will be full and power will go to the dump load.

After this, connect the grid again and the dump load should switch off and power should go to the grid.
Signals needed: wind, dump load sensing, and DC bus voltage.
Ideally high winds would be best to see if dump load can handle the maximum power.

Observed behavior: 25 June 2001 A few minutes after the batteries were disconnected and the inverter shut down, the dump load started getting warm. Regulating LED switches on and off. Winds are in range of 6–11 m/s (13.4–24.6 mph).

Battery disconnect
In case the batteries are disconnected, the turbine should continue normal operation. All the power should be delivered to the grid or dump load.

Open the switch to the batteries. Listen to the turbine noise for any significant changes in rpm. Observe the AC power and dump load status.
Signals needed: wind speed, AC power, dump load sense

Observed behavior: 25 June 2001 No change in rpm is audible; winds are around 6 m/s (13.4 mph). At 12:25, the winds reach 10–11 m/s (22.4–24.6 mph) and the turbine starts furling. Power goes to the grid.

Loss of load
In case any of the phases loses its connection to the EZ Wire, the turbine should speed up and the power should decrease. The more phases are disconnected, the higher the rpm and the lower the power (zero for three phases loose).

Pull one of the fuses at the tower bottom. Take measurements of DC power and rpm. Repeat the same measurement for two and three phases loose.

Observed behavior: 25 June 2001: 9:47–10:14 three phases loose. 10:17–10:46 two phases loose. 12:25–13:00 one phase loose. Winds are between 2.5 and 12 m/s (5.6 and 26.8 mph). 14:40 Winds reach 15 m/s (33.6 mph). Pulled three phases loose. Turbine goes into occasional flutter. After the wind dies, the turbine gets stuck in furl twice (20-30° furl angle). 15:13 Reconnected the phases.

Unauthorized changing of control settings
A knob on the front panel of the EZ Wire is used to set charge voltage. A dangerous situation can be created for the batteries by turning this knob to a higher set point.

Failure of furl system
The control of power and rpm is primary based on the furl mechanism. In case the furl mechanism fails, the rotor should speed up and eventually the rotor should come into flutter.

Block the furl mechanism. Tie a rope to the tail of the turbine such that the turbine can be yawed out of the wind in case of an unsafe situation. Start measurements of power and rpm. The wind speed should be reasonably low to start.

Observed behavior: 26 June 2001: Blocked furl mechanism using hose clamps. Waited for winds all day. Removed hose clamps at the end of the day. No high winds have been recorded.

Personnel safety
Electrical safety
The turbine has been checked for electrical safety.

Write down notes on electrical safety: Are enclosures accessible? Can high voltages be touched? Are warning labels present, etc.? All electrical wiring is behind doors that can only be opened with a screwdriver or something similar. Stickers warn for danger. Wires run through conduits.
Make remark about how lightning protection is configured on this turbine. Turbine has no special lightning protection system. The base of the tower is grounded. Measuring the resistance between tower and tower base leads to the conclusion that the tower itself is not grounded. Guy wires are not grounded.

Lowering and raising of the tower

The Whisper H40 as present at the NWTC is equipped with a tilt-down tower. The turbine has been tilted and raised a few times during the test period. According to the people performing this work, no difficulties were encountered and no hazardous situations have occurred.