Wind Turbine Generator System Duration Test Report, Revision 1

for the

Southwest Windpower H40 Wind Turbine

by

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December 24, 2002

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5.0 Revised Contents

After completion of the test report in June, 2001, it was noted that in Table 2, the reported kWh of energy production were incorrectly reported. The correct figures are actually one-sixth of the values originally reported. The corrected values are shown in Table 2 of this report.

Secondly, this report includes the results of the detailed post-test inspection.

6.0 Test Objective and Requirements

The objective of this test is to investigate:

- Structural integrity and material degradation (e.g., cracks, deformations, wear); and
- Quality of environmental protection of the Whisper H40 wind turbine (e.g., corrosion, failure of paint or seals).

The wind turbine will have passed the duration test when it has achieved reliable operation for:

- 6 months of operation
- 3,000 hours of power production in winds of any velocity,
- 250 hours of power production in winds of 10 m/s and above, and
- 25 hours of power production in winds of 15 m/s and above.

Reliable operation means:

- Turbine availability of at least 90%,
- No major failure of the turbine or components in the turbine system,
- No significant wear, corrosion, or damage to turbine components found during periodic inspections or the final turbine inspection, and

- Measured energy production within 80% of expected energy production

7.0 Background

This test is being conducted as part of the Department of Energy's Small Wind Turbine Field Verification Program. 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 US wind turbines. These tests might also be used for turbine certification purposes.

The test equipment included a Whisper H40 wind turbine mounted on a 9.1 meter tip-up tower, an EZ Wire turbine controller, and a Trace power inverter. The Whisper and the EZ Wire were developed by World Power Technologies and are now manufactured Southwest Windpower, Incorporated. The turbine and controller were coupled with a four battery bank and a Trace power inverter, model SW4024. This system was installed at NREL by Windward Engineering.

Currently NREL is testing three wind turbines as part of the DOE's Small Turbine Field Verification Program. As part of these tests, each turbine is subjected to a duration test. Duration testing is currently being defined as part of the IEC/ISO wind turbine certification process for small turbines.

The test plan for the duration test is included as Appendix A to this report. In the test plan additional information can be found on the test turbine, test site, test equipment and analysis methods.

8.0 Instrumentation

Detailed information on the instrumentation used at the beginning of this test is provided in Appendix A. During the test, various instruments were changed because they had reached the end of their calibration period. Appendix B lists the changes that were made and includes the calibration sheets that were not included in the test plan.

9.0 Analysis

The analysis methods described in the test plan were generally used during this test. However, it was noted during the test that all aspects of the instrumentation system did not need to be functioning in order to obtain valid data on some of the parameters being monitored during the test.

A key change was the criteria used for determining time categories for the operational time fraction changed. Originally, the intention was to record time that the turbine was not running by changing the position on a manual switch connected to the data logger. This method and general data logger operation proved to be less reliable than the simple use of a logbook. Therefore the data logger did not have to be functional for the assessment of operational time fraction. Table 1 shows the criteria used for each parameter.

The operational time fraction was determined using the equation in Appendix D. This differs from the equation written in the test plan for availability only by distinguishing between time when the turbine status is unknown from time when the turbine status is known but external conditions, such as a grid outage, cause the time to be excluded.

Table 1. Criteria to quantify test parameters in Whisper H40 duration test

Parameter	DAS Functional *	Turb. Avail	DC Power Functional	Wind Speed	Wind in measure-ment sector	Grid Avail
T_a (available)						
T_e (excluded)						
T_n (non-available)						
T_u (unknown)						
Time of power production at any wind speed	✓	✓	✓ and > 0			✓
Time of power production in winds above 10 m/s	✓	✓	✓ and > 0	> 10		✓
Time of power production in winds above 15 m/s	✓	✓	✓ and > 0	> 15		
Expected energy ratio	✓	✓	✓	✓	✓	✓
Power degradation	✓	✓	✓	✓	✓	✓
3-second gust	✓	✓		✓		

Data acquisition system functional means:

- Recording time in each 10-min period > 595 seconds,
- -40°C < Data logger temperature <80°C, and
- Data logger supply voltage > 11 VDC

10.0 Results

10.1 Operation time

The test turbine was exposed to the environment and produced energy as follows (requirements of the draft standard shown parenthetically). Supporting data are provided in Table 2.

- Total exposure time (> 6 months): 14.7 months from March 10, 2000 through May 31, 2001
- Total operating time (>3000 hrs): 3,107 hours
- Operating time in moderate and high winds (>150 hrs with Vwind > 10 m/s): 312 hours
- Operating time in high winds (>15 hrs with Vwind > 15 m/s): 68 hours
- Maximum 3-sec gust: 41 m/s at 2:30 AM on 7 Apr 01.
- Average turbulence intensity at 15 m/s: Not recorded.

10.2 Operational time fraction

The test turbine exhibited an operational time fraction during the test of 99.98%, which exceeds the requirement of the draft standard of 90%. The only downtime was 1 hour and 40 minutes when the turbine was stopped for repairs to the furling hinge.

10.3 Observations

Three methods were used to determine if the turbine had any significant operational difficulties: periodic inspection, comparison of measured power to expected power, and comparison of power output at various wind speeds.

Periodic inspections revealed one significant problem in March 2001 – the furling mechanism malfunctioned such that the turbine occasionally became stuck in the furled position when it should have returned to the unfurled position. After consulting with the manufacturer, NREL staff cleaned the furling bearing and removed a small amount of metal from the furling joint. This was thought to resolve the problem. However, as noted below, and in observations made after the test period, the problem was seen to reoccur. After the corrective action, the turbine would occasionally get stuck in a partially furled position.

Figure 1 shows the difference between measured and expected power throughout the test period. To generate this figure, NREL calculated expected power based on the measured wind speed and the power that would have been produced if the turbine operated on its power curve. The power curve used for this calculation was based on all the usable data obtained in the test. This figure indicates that the turbine experienced operational difficulties several times during the test period. Some of these correspond closely with the observed furling problem and can be safely attributed to that problem. Other periods may have been associated with the furling problem but may have been due to other problems that were not observed.

Figure 2 shows this similar information on a monthly basis. This graph also shows the loss of production in March 2001. And it shows a seasonal variation. However, it does not show the events in November 2000 and April 2000 where the turbine seems to be having operational problems.

NREL considered but decided not to categorize the low production periods as a turbine fault. The primary reason for this choice was that the cause for the low production periods could not be clearly associated with the furling problem noted above or any other fault condition. Nor were there clear records of how much time the turbine should be considered as faulted.

However, to quantify the effect that this behavior has on overall turbine performance, NREL determined power curves and predicted annual energy production in two ways. First we used all the data obtained during the test period. Then we eliminated data when the measured power level was less than 100 watts below the expected power level. This analysis is documented in the Whisper H40 Power Performance Test Report. We estimate that this behavior would reduce annual energy production by about 5% at a sea-level wind site with a 7 m/s average wind speed.

The comparison of power levels indicates similar behavior. Figure 3 shows significant dips in the 10 m/s power level during November 2000, and March 2001. The 8 m/s power level shows a dip only in March. This could be due to the furling problem becoming worse or some other, unknown problem affecting the turbine in November. There are relatively few data that may have had an effect, but otherwise NREL did not identify the cause for the apparent cyclic variation of 12, 14, and 16 m/s curves.

10.4 Post Test Inspection

The turbine was inspected by sight, sound, and feel at the conclusion of the test to determine if there were any potential problems resulting from operation for over one year. NREL noticed that the furling problem persists as described above. Close inspection indicated that the furling hinge was very tight. NREL investigated during the detailed component inspection and found that the problem was probably due to an overtight set-screw. This condition did not appear to leading to a failure. In fact, with additional wear of the set screw and the shaft surface, the problem with poor furling behaviour might have corrected itself over time.

NREL also noted that the nose cone was cracked and needs to be replaced.

Otherwise NREL noted no cracks in the blades, minor degradation of protective coatings, no corrosion, no oil or grease staining, and no observable “hot spots” in the electrical system. The turbine made no unusual noises. Nor did it exhibit any excessive vibrations. Appendix C lists the items that were inspected.

A detailed inspection involving disassembly of the turbine was conducted on August 9, 2001. It indicated that there was some wear but none that would indicate a premature failure. The most significant problems were:

1) There was a bad connection between one of the wires from the alternator and the slip ring. This would likely have required repair.
2) There was apparent rubbing between the rotor and the stator in the alternator. It is unclear whether this would have resulted in failure during the lifetime of the turbine.

Finally a second Whisper H40 turbine was temporarily installed at the test site in order to perform a thermographic inspection of the electrical system. This inspection was conducted on March 27, 2002 and is reported in Appendix F. That inspection revealed no problems or issues with the electrical system.

Table 2. Duration test data presented by month

Month	Hours of power production in wind speed above:			Operational Time Fraction [hrs]					Expected Energy		
	0 m/s	10 m/s	15 m/s	Tt	Tu	Te	Tn	O [%]	E_{Meas}	E_{Expec}	E_{Meas}/ E_{Expec}
Overall	3,107.3	312.0	68.3	10,737	169.2	15.3	1.7	100.0%	350	350	100.0
Mar-00	200.2	4.2	1.8	512.8	0.0	0.0	0.0	100.0%	20	20	103.3
Apr-00	257.8	35.7	14.8	720.0	15.0	0.0	0.0	100.0%	33	30	108.2
May-00	272.0	19.5	4.0	744.0	0.0	0.0	0.0	100.0%	24	24	101.2
Jun-00	260.5	12.8	0.2	720.0	0.0	0.0	0.0	100.0%	18	18	99.3
Jul-00	198.5	3.0	0.0	744.0	0.0	0.0	0.0	100.0%	8	9	91.3
Aug-00	202.2	6.5	0.2	744.0	0.0	0.0	0.0	100.0%	10	10	95.5
Sep-00	192.5	12.3	1.0	720.0	0.0	0.0	0.0	100.0%	18	19	94.2
Oct-00	77.0	3.3	0.0	744.0	125.3	0.0	0.0	100.0%	7	8	92.7
Nov-00	74.8	15.8	1.0	720.0	28.8	5.7	0.0	100.0%	12	13	93.8
Dec-00	282.7	76.7	31.0	744.0	0.0	0.0	0.0	100.0%	65	62	103.6
Jan-01	219.2	47.3	5.8	744.0	0.0	0.0	0.0	100.0%	43	39	110.7
Feb-01	202.5	20.0	2.2	672.0	0.0	0.0	0.0	100.0%	31	29	107.0
Mar-01	206.7	28.3	2.8	744.0	0.0	0.0	0.0	100.0%	22	28	79.2
Apr-01	220.7	15.8	2.3	720.0	0.0	9.7	1.7	99.8%	20	21	95.3
May-01	240.2	10.7	1.2	744.0	0.0	0.0	0.0	100.0%	18	19	93.7

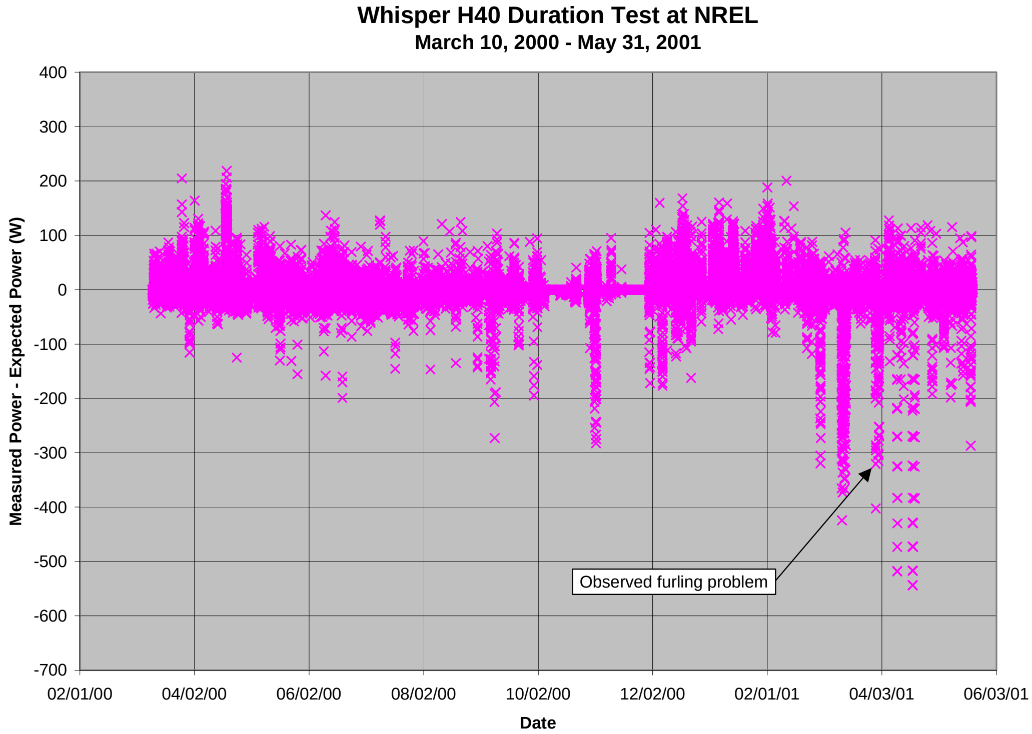

Figure 1. Difference between measured power and expected power

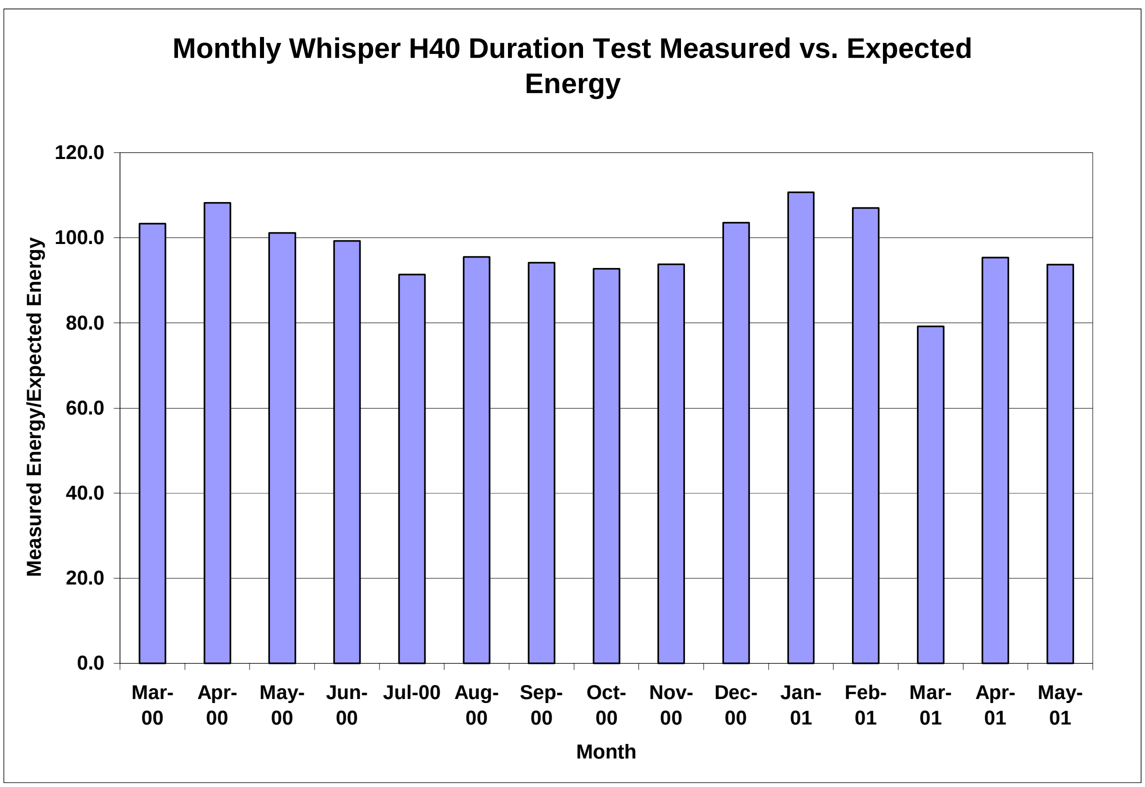

Figure 2. Ratio of measured energy to expected energy

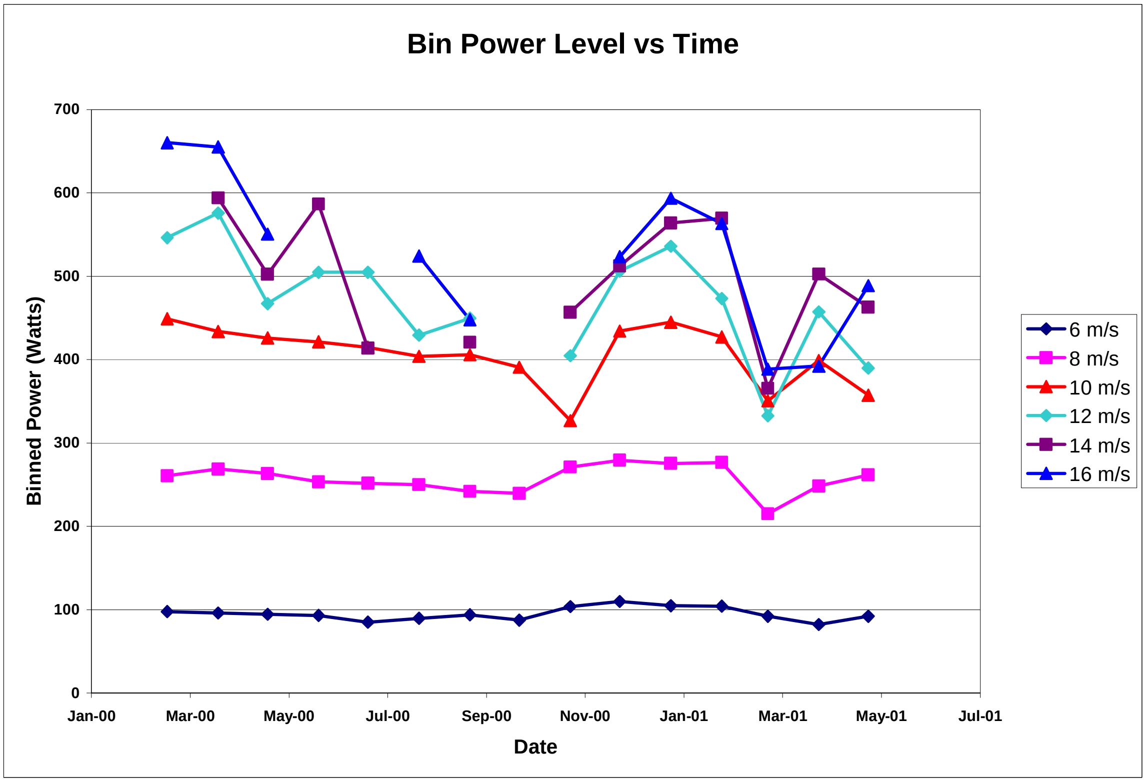

Figure 3. Binned power level at several wind speeds for each month

11.0 Uncertainty

- Operational time fraction
- Turbine operating time
- Peak 3-sec gust

Operational time fraction:
Any data points where the turbine was unavailable for more then 1% of the ten-minute period was counted against the turbine Tn. Thus any uncertainty in this analysis is against the turbine's operational time fraction. In practice, the only time counted as Tn was 1.67 hours during which the turbine was shut down while NREL technicians attempted to fix the unfurling problem. The only time classified as Te were two occasions, totaling 15 hours when the turbine was braked for noise tests on other, nearby turbines. The uncertainty in Te and Tu is zero and thus these do not contribute to any uncertainty in the overall operational time fraction.

Hours of power production:
There were 169 hours classified as Tu concentrated mostly in October and November of 2000. This time represents gaps in the data. During some of this time the turbine was likely to be running. Since October and November are windy months it is reasonable to assume that the wind was higher in the unknown time compared to the whole test period. Conservatively estimating that the distribution during is the same as the test period as a whole, leads to the estimation that during the unknown periods the H40 produced power at any wind speed during an additional 49 hours, 4 hours above 10 m/s and 1 hour above 15 m/s. This leads to the conclusion that the hours of power production presented in this report are an underestimation of 1.5%.

Peak 3-sec gust:

The uncertainty in the 3second gust is driven by the uncertainty in wind speed measurements including anemometer calibration, 0.2 m/s, operational characteristics, 2%, mounting affects, 0.5% and terrain effects, 3%. The maximum 3 –sec gust was found to be 41 m/s which leads to an uncertainty of approximately 1.5 m/s.

12.0 Deviations from test plan

While the duration test was in progress the working group, MT2, which is writing the 2nd edition of the IEC61400-2, changed requirements of the duration test. Where possible these new requirements were used. A copy of the duration section of the draft standard can be found in Appendix D.

Main changes in the description in IEC 61400-2 draft from the description in the IEC61400-22 draft are:

- Availability is renamed "Operational time fraction." This is done to avoid confusion with the availability as defined elsewhere. The names of the different time categories to calculate this are changed to give a better reflection of the reason of classification.
- Instead of the expected energy criteria the new section proposes a power performance degradation. This method plots power level at certain wind speeds as a function of time.
- The hours of power production at any wind speed are doubled from 1500 to 3000 hours. For the H40 test 3000 hours are used.
- Limits for the requirement to operate in moderate and high wind speeds were changed from 10 and 15 m/s to 1.2 and 1.8 times Vave. Vave defines a wind class for which the turbine is designed. For this test 10 m/s and 15 m/s wind speed thresholds were retained. These speeds correspond closely to the thresholds of 10.2 and 15.3 for a Class 2 site.

Other deviations:

- The reference power curve used in the expected energy calculation is the overall power curve measured during the duration test.
- The calibration on most of the instruments expired during the test. A post test calibration was conducted after the conclusion of the test. The turbulence intensity at 15 m/s was not recorded.

Appendix A: Whisper H40 Duration Test Plan

Wind Turbine Generator System
Duration Test Plan

for the

World Power Technology Whisper H40 Turbine

by

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21 June, 2001

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Approval By: Hal Link 28 Jun 01
Hal Link, NREL Certification Test Manager — Date

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4.0 Test Objective

The objective of this test is to investigate:

- Structural integrity and material degradation (corrosion, cracks, deformations); and
- Quality of environmental protection of the World Power Technologies Whisper H40

The wind turbine will have passed the duration test when it has achieved reliable operation for:

- 6 months of operation
- 1,500 hours of power production in winds of any velocity,
- 250 hours of power production in winds of 10 m/s and above, and
- 25 hours of power production in winds of 15 m/s and above.

Reliable operation means:

- Turbine availability of at least 90%,
- No major failure of the turbine or components in the turbine system,
- No significant wear, corrosion, or damage to turbine components found during periodic inspections or the final turbine inspection, and
- Measured energy production within 80% of expected energy production

If there is a major failure of the Whisper H40 then the manufacturer may implement appropriate repairs and the test will be restarted. A major failure on the wind turbine system includes any failure of the system components including blades, charge controller, alternator, yaw bearings, or inverter. A repair of a major failure sets the number of hours of turbine run-time to zero (i.e., the test starts over).

5.0 Background

This test is being conducted as part of the Department of Energy's Small Wind Turbine Field Verification Program. 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 US wind turbines. In addition this test may be used to fulfill the Duration test requirements identified in IEC 61400-2 Annex D for wind turbine certification.

World Power Technologies developed the Whisper H40 wind turbine. The test turbine, located at the National Wind Technology Center's Site 1.3, is owned by Windward Engineering in Spanish Forks, Utah. Currently NREL is testing three wind turbines as part of the DOE's Small Turbine Field Verification Program. As part of these tests, each turbine is subjected to a duration

test as defined under the draft standards, IEC/ISO 61400-22 and IEC/ISO61400-2, Ed 2. These standards are important parts of an international effort to certify robust wind turbines.
In addition to this duration test, the Whisper H40 wind turbine will also be tested to determine its noise and power performance characteristics under the Small Turbine Field Verification Program. After all testing is complete a summary test report will be created which mimics the popular Consumer's Report magazine. This Consumer's Report will not only give the summary of the power curve, annual energy production, teardown inspection summary results, and a summary of any Operations and Maintenance activities done during the test period. This report will also include any educational documentation to enable the novice user to understand the test results.

6.0 Test Turbine

The configuration of the Whisper H40 wind turbine is shown in Figure 1. The turbine is a three-bladed upwind, variable-speed, furling for turbine overspeed control. Rotational energy is converted to electrical power in the nacelle, which contains the permanent magnet alternator, and a brake which shorts one of the electrical wires that runs down the tower.

Figure 1. Overall Configuration of the Test Turbine, the Whisper H40

The permanent magnet alternator produces variable frequency, variable voltage output or 'wild AC'. This electrical output is converted to AC or DC depending on the use of the EZ wire system. The EZ-wire system center has hook up for both the wind turbine, photovoltaic panels, batteries and dump load.

For the duration and power performance tests the EZ-wire system center is connected to 4 batteries, a Trace sine wave inverter model number SW4024 (serial number W14515) and a dump load. The dump load will be used when the batteries are at a full state of charge and there is no connection to the utility grid through the inverter. The wind turbine system is installed on a tube tower at 30 feet high with a 4" outer diameter tube and 4 guy wires. Table 1 lists configuration and operational data for the Whisper H40.

Table 1. Test Turbine Configuration and Operational Data

General Configuration:	
Make, Model, Serial Number	World Power Technologies, Whisper H40 S/N:
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)	1200
Tilt Angle (deg)	7
Blade Pitch Angle (deg)	0 (non-linear 13^o at root to 1^o at tip)
Direction of Rotation	CCW
Overspeed Control	Furling
Braking System:	
Electrical Brake: Make, Type, Location	Electrical single pole
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

The turbine is installed at the National Wind Technology Center, located between Golden and Boulder, Colorado. The test turbine's mechanical interface with its external environment is the boundary between the turbine's foundation and the ground. Any failure of the foundation or tower will be considered a turbine failure.

The test turbine's electrical interface with its external environment is at the turbine side of the isolation switch, LP 1.3. This switch connects the turbine to the utility or isolates it from the utility grid. All wiring between the EZ-wire and the DAS, battery disconnect and DAS relays is considered external to the turbine.

7.0 Test Site

The Whisper H40 wind turbine under test is located at Site 1.3 of the National Wind Technology Center (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 1850 m above sea level. Figure 2 shows the location of the test site relative to Boulder and the front range of the Rocky Mountains, as well as a plot plan of the test site including all obstructions for 20 rotor diameters (with topography lines listed in feet above sea level).

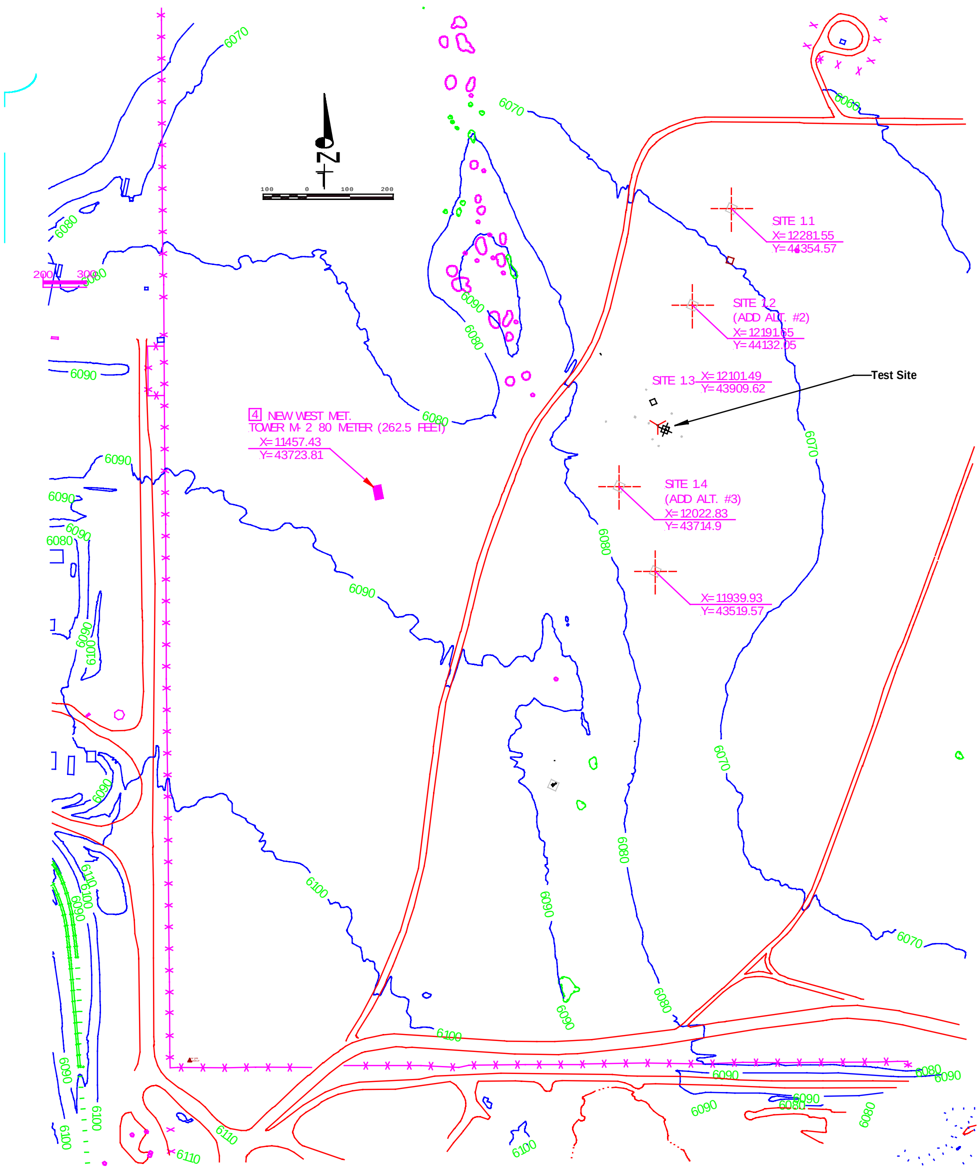


Figure 2. Location and Plot Plan of Whisper H40 Test Site

A switch located outside of the turbine controller building, routes power to the local utility, Public Service Company of Colorado.

The meteorological tower is to be located 22 feet from the test turbine at a bearing of 292^{o} true. This distance is 3 rotor diameters from the test turbine and within the range between 2 and 4 rotor diameters specified in the IEC standard for power performance testing, IEC/ISO61400-12.

For purposes of this test the allowable measurement sector (e.g., the range of wind directions used to determine power performance characteristics) includes westerly and northerly winds between 227^{o} and 359^{o} with respect to true north.

8.0 Duration Test

8.1 Turbine Inspection and Site Commissioning

The turbine will be thoroughly inspected before the beginning of the duration test. The inspection occurs at NREL before the turbine is installed on the tower. The turbine is checked for any defects or signs of damage. This inspection occurs as part of the commissioning of the installed system. In addition to checking the blades for cracks, the system is checked to see that it yaws freely and that the blades spin freely. The commissioning procedure and checklist may be found in Appendix A.

Figure 3 shows the site layout and setup that will handle all the electrical interface hardware as well as the data acquisition hardware. The test turbine's electrical interface with its external environment is at the turbine side of the isolation switch, LP 1.3. This switch connects the turbine to the utility or isolates it from the utility grid. All wiring between the EZ-wire and the DAS, battery disconnect and DAS relays is considered external to the turbine.

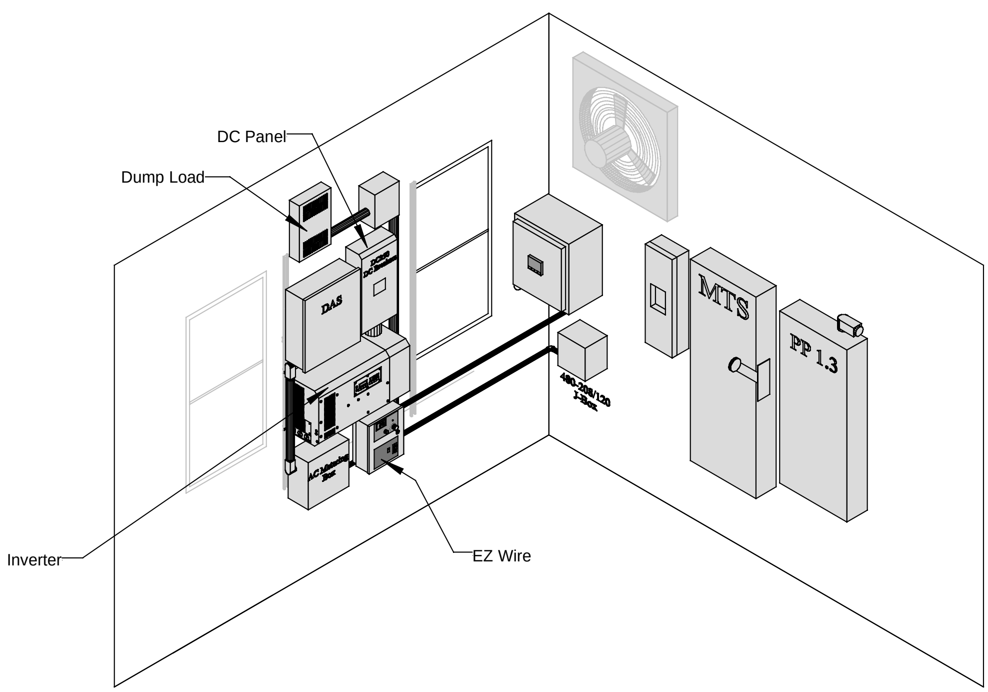


Figure 3. Layout of Site 1.3 Shed

Figure 4 shows a photograph of the actual installation within the Site 1.3 shed.

Figure 4. Photograph of Site 1.3 Electrical Installation

Note that the system batteries are located outside of the shed and within their own containment box for safety reasons. Figure 5 show the battery box (located along the south wall of the Site 1.3 shed) and the provisions made to secure the box in the event of high wind speeds.

Figure 5. Detail of Battery Box Installation

8.2 Test Equipment

Equipment used for duration testing differs only slightly from that used for power performance testing. Normal power performance requires measurements of wind speed, wind direction, turbine power, air temperature, air pressure, precipitation, and overall turbine system availability. For duration testing, NREL added a signal of turbine availability and a small change to the data logger program to record the peak 3-second gust during the test period. Table 2 lists an equipment list that provides the requirements and specifications for each of the instruments used.

Table 2. Equipment List for Duration test

Power Transducer	
Make / model:	OSI, GWV5-001EY24/1
Serial number (Transducer/CTs):	0010301
Range with CTs:	0 - +/-1
Calibration Due Date:	1/5/01
Reactive Power Transducer	
Make / model:	OSI, GWV5-001EY24/2
Serial number (Transducer/CTs):	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 Amps	
Make / model:	OSI CTA212
Serial number:	0010126
CT range:	0-50 Amp
Calibration Due Date:	1/3/01
Battery Amps	
Make / model:	OSI CTA212y42
Serial number:	00125
CT range:	0 - +/-50 Amp
Calibration Due Date:	1/3/01
Met Anemometer	
Make / model:	Met One, 010C with Aluminum Cups
Serial number.	W1231
Calibration Due Date:	2/9/01
Met Tower Location:	22 feet upwind
Secondary Met Anemometer	
Make / model:	Met One, 010C with Aluminum Vane
Serial number:	W1232
Calibration Due Date:	2/9/01
Met Tower Location:	22 feet upwind
Wind Direction Sensor	
Make / model:	Met One, 020C with Aluminum Vane
Serial Number:	P3143
Calibration Due Date:	2/9/01
Met Tower Location:	22 feet upwind
Datalogger	
Make / model:	Campbell Scientific CR23X
Serial number:	13185
Calibration Due Date:	11/23/00

In addition to the instruments listed in Table 2, the duration test requires signals to determine turbine availability. It is important in this test to distinguish clearly between times when external conditions prevent the turbine from operating and when the turbine itself is faulted or otherwise not operating normally. For the Whisper H40 availability is defined in Section 13.0 – Analysis Methods.

If the turbine is turned off to work on instrumentation, it will automatically show up as an external condition, which prevents the turbine from operating and will not count against turbine availability. This is appropriate. However if the turbine is turned off to perform turbine maintenance, then the time should count against turbine availability. In this case, the turbine operator flips the turbine brake switch before turning off the turbine and leaves it off until power has been restored. This will mark the data set with an internal fault and make it easy for the data analyst to attribute time against turbine availability. In addition any action such as turning off power to the turbine or flipping the turbine brake switch requires a log entry with the date, time, person performing the action, and an explanation of the situation.

8.3 Test Preparations

After the instruments have been mounted in the locations detailed in the Electrical one-line drawing shown in Figure 6, the test technician tests their functionality and aligns the wind vane. Functionality tests are conducted in accordance with NREL's quality assurance system. They include comparing data acquisition measurements to independent readings whenever possible, comparing the two anemometer readings, and comparing measurements to theoretical models.

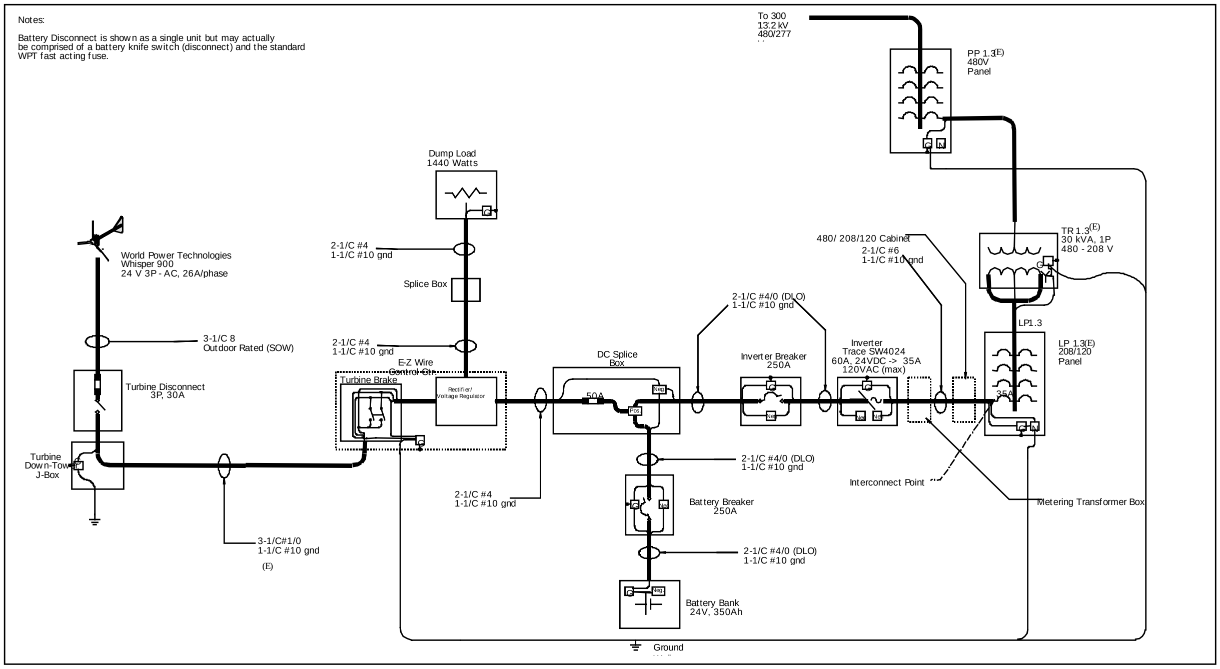


Figure 6. Electrical One-line Drawing

Once the wind direction sensor has been installed and confirmed to be functional, it is oriented so that its readings correspond to degrees from true north. At this site, the vane is first oriented such that it produces a zero-voltage output when pointed approximately east. This places the instrument's 6-degree dead band outside of the allowable measurement sector for power performance measurements.

Next the vane is pointed toward distant landmarks whose directions from the test turbine have been determined from topographical maps. The datalogger readings are compared to the known directions and a suitable calibration offset is determined. This offset is entered into the data logger program and confirmed. Figure 7 shows a graphic depiction of the meteorological tower and its instruments.

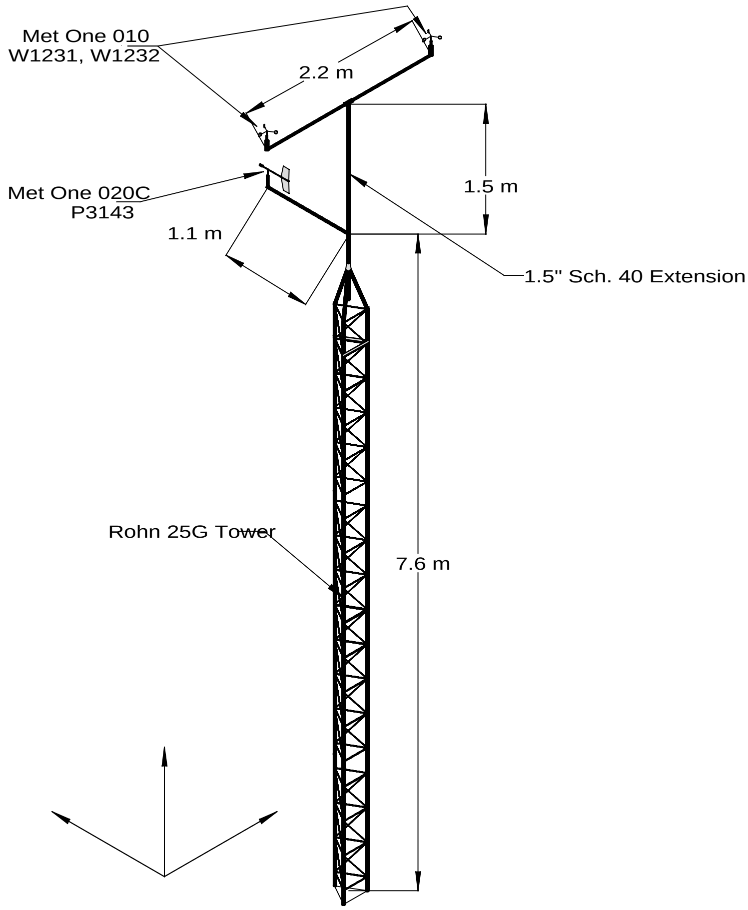


Figure 7. Details of Met Tower

After the in-field checks are completed, the data logger will be run for at least 6 hours. At the start of this time series, the battery charger will be connected to the 120 VAC ground line, and all instruments left to measure and collect data normally. At the end of this time, the Test Analyst will examine the measurements of all instruments to ensure proper operation.

8.4 Measurement Procedures

All instruments will be sampled by the datalogger at a rate of one Hz. The output data will be the ten-minute averages of the data with their standard deviations, minimum and maximum values for the ten minutes also included. For status signals, the datalogger records the percentage of time during each ten-minute period that the signal is high.

On a weekly basis, NREL will transfer data from the data logger to computers at NREL offices using a modem or laptop computer.

NREL personnel will, from ground level, check instruments located on the meteorological tower on a weekly basis. They will note if there are any obvious failures such as broken or missing cups from the anemometers, bent, broken or missing wind vane, misalignment of any sensors and whether 120 VAC power is being provided to the data logger. NREL personnel will also record any unusual occurrences with the turbine or instrumentation in the appropriate logbook inside the turbine control shed.

NREL will analyze the data sets once per week. Using the procedures described in the next section, the Test Analyst will note if any problems have arisen. If so, he/she will notify the Test Engineer. The test will be considered as suspended pending resolution of the problem. The Test Engineer will determine whether data obtained during the period when the problem was active can be used for in the determination of power performance and note whether data are used or not in the test report.

If the test site or turbine changes during the test, the Test Engineer will determine if it is appropriate to continue the test, restart the test, or cancel the test. All such actions will be documented in the test report. The test will continue until the turbine has passed the duration test. If the turbine experiences a major failure or if a significant improvement is desired, the test will be restarted.

8.5 Final Turbine Inspection

At the conclusion of the duration test the test engineer will conduct a detailed inspection of the turbine system. First, the turbine will be inspected on the tower. Then he will disassemble the turbine system and perform a non-destructive tear-down inspection in an NREL laboratory.

9.0 Analysis Methods

9.1 Data Validity Check

NREL uses a spreadsheet to monitor the progress of the test. The spreadsheet enables the test analyst to identify many of the common instrumentation problems such as failed sensors or wiring. It also provides a method to determine whether the turbine is achieving the reliability and time requirements of the test.

After new data are entered into the spreadsheet, the analyst reviews each channel to determine if the signal appears within the expected range and with continued response to conditions. Any problems are immediately noted and investigated before continuing with the analysis below.

9.2 Availability Assignment

Then the analyst investigates the system available signal. If the new data show the system to be unavailable, the analyst reviews the turbine availability signal and the logbook to determine the cause of the downtime. Table 3 lists the operating conditions that may lead to downtime during the test and assigns each condition to either the turbine or to external causes. Turbine faults are counted against turbine availability. Times during which an external fault is present are subtracted from the test time. In this way, external faults neither help nor hurt turbine availability.

Table 3. Fault Condition Assignments

Condition	Turbine	External	No Fault
Grid Fault		X	
Overspeed/Furling	X		
Emergency stop	X		
DAS disable*		X	
Turbine off*		X	

Condition	Turbine	External	No Fault
Turbine in test mode*		X	
Confusion of charge controller	X		

* - This condition is considered an external fault unless the logbook entry indicates that this method was used to stop turbine operation due to a perceived problem with the turbine.

Once faults are properly assigned, the spreadsheet calculates turbine availability using the following equation:

$$A = (Tt - Tn - Tu) / (Tt - Tu) \times 100\%$$

Where:

A is turbine availability, %
Tt is the total time period under consideration, hrs
Ta is the time during which the turbine is known to be available, hrs
Tn is the time during which the turbine known not to be available, hrs
Tu is the time during which the turbine status is unknown or an external fault is present, hrs

9.3 Operating Time Calculation

The spreadsheet calculates the amount of time that the turbine was on line in winds of any speed, in winds of 10 m/s and above and in winds of 15 m/s and above. For the operating time at the higher wind speeds, the calculation attributes 10-minutes of operating time for each 10-minute data set where the average wind speed is greater than or equal to 10 or 15 m/s. These times are compared to the test criteria of 1500 hours, 250 hours, and 25 hours, respectively. Times during which the turbine was on line but not available (e.g., operating in test mode) are not included in these tallies.

9.4 Expected Energy Calculation

Finally the spreadsheet provides a comparison of power performance levels exhibited by the turbine each month. NREL will use the measured data collected to meet the IEC power performance test data requirements. (The details of the IEC power performance test can be found in the Whisper H40 Power Performance Test Plan.) However, a reference power curve was created based on preliminary data. This reference power curve uses the site average air density curve which is documented in the report, “Power Performance Test Report of the AOC 15/50 Wind Turbine,” dated 4/11/00. NREL will use data obtained each month during the duration test to determine if the turbine’s performance is reduced to 80% or less of the reference power curve. This comparison will be made on an energy basis, which has not been corrected for air density.

Expected energy production is the energy that would have been produced if the turbine operated on its reference power curve. For each ten-minute average data point, the spreadsheet determines if the system was available and if winds were from the measurement sector. If so, it:

- rounds the wind speed to the nearest one-half meter per second,
- “looks up” the expected power level for that wind speed from the reference power curve table, and
- calculates the number of kilowatt-hours that the turbine would have produced if it had operated at the reference power level for 10 minutes.

The spreadsheet adds all of the 10-minute, expected energy values to obtain a monthly, expected energy value.

The spreadsheet applies the same availability and wind direction criteria to determine when data are used in the calculation of measured energy production. In this case the spreadsheet adds the valid 10-minute power levels as measured with the power transducer and divides by six (10-minute periods in an hour) to obtain the monthly, measured energy value. The spreadsheet will calculate the expected energy ratio as the monthly measured energy value divided by the monthly expected energy value.

9.5 Uncertainty Analysis

Some uncertainty is expected in the measurement of the following parameters:

- turbine availability
- turbine operating time
- peak 3-sec gust
- expected energy ratios.

The major contribution to uncertainty in measured turbine availability is the amount of time during an outage that should be attributed to the turbine as opposed to external conditions. In most cases this assignment should be straightforward. However, some occasions may arise in which the assignment is somewhat arbitrary and subject to the judgement of the test engineer. If as much as 24 hours of time fall into this category, then the final uncertainty will be on the order of one percent.

Turbine operating time will be accurately monitored by the datalogger. If the logger is accurate to one-half second and the turbine experiences 750 on/off cycles during the test, the operating time in any winds will be measured within a 0.1 hours. For 250 hours of operation in winds greater than or equal to 10 m/s, the turbine may see 125 on/off cycles and the uncertainty will be about one minute. And the uncertainty for winds above 15 m/s will be about 0.1 minutes. These uncertainty estimates include the assumption that the wind speed distribution, on average, is equal and symmetrical for average wind speeds close to the cut-off levels of 10 and 15 m/s. Thus the time that winds are less than 15 m/s during a 10-minute data set in which the average wind speed is 16 m/s is assumed to be equal to the amount of time that winds are greater than 15 m/s during a 10-minute data set in which the average wind speed is 14 m/s.

The peak 3-second gust will be driven by the uncertainty in wind speed measurements including anemometer calibration, 0.2 m/s, operational characteristics, 2%, mounting affects, 0.5% and terrain effects, 3%. If the peak 3-sec gust is 40 m/s, the uncertainty will be approximately 1.5 m/s.

The anticipated uncertainty in expected energy ratio accounts for the uncertainty in measuring wind speed and power, as well as the uncertainty associated with not accounting for air temperature and pressure. Air density distribution contributes approximately 4% to the power variations. And the average wind speed for this site was found to be 5 m/s. Another consideration was that anemometer calibration, mounting, and site effects are unchanged from month-to-month so their contributions to uncertainty in expected energy production were zero. Overall, the uncertainty in expected energy ratio is estimated to be on the order of 8%. This figure will be revised using actual data for the final report on this test.

10.0 Reporting

10.1 Progress Reports

NREL will submit progress report to NREL management periodically. This report will summarize:

- status of the test (number of hours of data obtained and number of wind bins with 30 minutes of data)
- anticipated completion date
- if a problem is present, the status of its resolution.

10.2 Final Report

When the turbine has met the requirements of the duration test, NREL will produce a test report. This report will document:

- total test time,
- turbine availability during the test,
- turbine operating time under any wind speed, in winds greater than or equal to 10 m/s, in winds greater than or equal to 15 m/s,
- the peak 3-sec gust recorded during the test,
- the cause and resolution of any significant downtime or failures,
- monthly expected energy ratios,
- a summary of the post-test inspection,
- this Test Plan as an Appendix, and
- changes, if any, to this Test Plan.

11.0 Exceptions to Standard Practice

Power performance instrumentation deviates from the IEC standard as follows:

1. The power transducer was not tested for compliance with IEC 688.
2. The current transformers were not tested for compliance with IEC 185.

12.0 Roles and Responsibilities

Table 4 lists the planned test team, and identifies roles and responsibilities for each team member.

Table 4. Roles of Test Participants

Test Team Title	Name	Employer	Role(s)
NWTC-CT Manager	Hal Link	NREL	NREL approval of test plan.
Test Engineer	Trudy Forsyth	NREL	Overall test management and responsibility. Customer contact person. Authorization for any deviations from planned test procedures. Supervision of performance test set-up, checkout, and conduct. Periodic review of test data. Review and report test results. Primary point of contact between CTG and the test site manager.
Test Technician	Gerry Bianchi	NREL	Selection of instruments Installation and checkout of test equipment Implementation of corrective actions for problems
Test Analyst	Charles Newcomb/Tony Jimenez	NREL	Download and store test data Analyze test data Identify problems based on data analysis results Provide test engineer with updates on test progress Provide tables and graphs of results test reports Assist in writing test report
Site Manager	Trudy Forsyth	NREL	Supervise operation and maintenance of test turbine. Responsible for ensuring safety of personnel and equipment at test site. Reports any change in turbine configuration

13.0 References

1. Wind Turbine Generator Systems, Part 12: Wind Turbine Power Performance Testing, IEC 88/XX/FDIS, Project 1400-12, International Electrotechnical Commission, Netherlands, 1997.
2. Draft Wind Turbine Certification, IEC 88/60/RVN, 61400-22, International Electrotechnical Commission, Netherlands, 1999.
3. Wind Turbine Generator Systems – Part 2:Safety of Small Wind Turbines, IEC 88/53/FDIS, 61400-2, International Electrotechnical Commission, Netherlands, 1995-12-15.

Appendix A: Commissioning Procedure and Checklist

Commissioning Procedure for Whisper 900 Grid-Connected Wind Turbine Generator at Site 1.3

12/16/99

1.0 Introduction

NREL will perform an acceptance test for the Whisper 900 to ensure proper installation and operation of the system prior to certification testing. This test will include, but not be limited to, an inspection of the wind generator installation, the tower, all electrical connections and fusing, the furling mechanism for the wind turbine, the inverter for the system, the electrical connections throughout the system, and a safety inspection of the system. NREL staff will not do anything that will alter the long-term reliability or performance of the system during the acceptance test. NREL staff will not change any system set points without direct involvement of the vendor.

2.0 Documentation Review

NREL will review the Owner's Manual for the project to ensure adequacy. The manual should include a complete set of schematics, technical specifications, operating instructions, emergency procedures, maintenance procedures, and warranty information.

A final set of as-built drawings must be provided. These shall include electrical, mechanical, and physical drawings.

3.0 Visual Inspection

The system will be visually inspected for safety and compliance with accepted installation practices. Any deviation from the as-built will be noted. All fuses, circuit breakers, disconnects and wires will be inspected and their current ratings and type will be verified and compared to the 1-line electrical diagram. The grounding system will be inspected. The turbine mounting and all turbine fasteners will be inspected.

4.0 Wind Turbine Generator Visual Inspection (No wind needed)
- 4.1 Check wind turbine towers
  - 4.1.1 Guy wire tensions
  - 4.1.2 Guy anchors
  - 4.1.3 All fasteners
- 4.2 Visually inspect wind turbine on tower
  - 4.2.1 Note any misalignment in blade rotation
  - 4.2.2 Note any unusual yaw behavior
- 4.3 Inspect wind turbine grounding
  - 4.3.1 Inspect lightning arrestor installation
  - 4.3.2 Verify that ground rod at turbine tower base has appropriate ground surface contact
- 4.4 Inspect all wind turbine electrical connections

5.0 Wind Turbine Generator Operation

5.1 Test wind turbine voltage under no load. Open turbine disconnect in data shed 1.3 and measure turbine voltage under no load with multi-meter (write down voltage).

5.2 Test wind turbine current output and voltage under load with multi-meter and current clamp (write down current ouput).

6.0 Inverter Visual Inspection

6.1 Inspect all inverter electrical connections to the input and output of the inverter. Check fusing on input to inverter. Check fusing on inverter disconnect.

6.2 Check inverter wiring to single phase transformer and from transformer to AC power panel 1.3. Verify all breaker sizes.

7.0 Inverter Operation

7.1 Inverter output – Measure the inverter voltage, current, and frequency under typical load conditions with a multi-meter. Note any variation from the specifications.

7.2 With turbine operating, push the re-set button on the inverter and observe the inverter to disconnect and the reconnect to the grid.

Commissioning Checklist

Date: 12/16/99 Conducted by: Trudy Forsyth

Task		Recorded Observation
Wind Turbine Generator:		
Verify fuse size in down-tower turbine disconnect 1.3		
Inspect guy wires and anchors for installation power vendor's specifications		
Verify that turbine blades spin freely		
Verify that turbine yaws freely		
Visually inspect wind turbine generator blades for any cracks or deviations from normal		
Inspect tower grounding		
Check open circuit voltage of turbine		
Check current from turbine under load		
Check voltage from turbine under load		
Verify 30 amp turbine disconnect		
Verify DC bus voltage regulation		
Verify dump load configuration		
Verify 24V turbine		
Verify EZ-Wire voltage configuration		
Verify voltage tap fuse		
Verify 250A battery breaker		
Verify system bonding (according to drawing)		
Verify conductor sizing (tower - #8 or better)		
Verify tower cable is outdoor rated and sunlight resistant		
Verify EZ-Wire brake		
Verify 35 amp breaker size in power panel 1.3		
Verify 30A disconnect at LP 1.3		
Inverter		
Verify all wire sized per as-built drawing		
Verify installation of 250 amp fuse in inverter disconnect		
Verify that all system disconnects and enclosures are		

bonded and grounded		
Verify 25- amp disconnect on input to inverter		
Measure the inverter current under load		
Measure the inverter voltage under load		
Measure the inverter frequency under load		
Verify inverter re-connects after LP 1.3 breaker is tripped		
Verify anti-islanding for inverter (throw 480 power panel disconnect and isolate from grid)		
Verify inverter will respond to battery low-voltage cut-out		
Other		
Windward Engineering approves one-line electrical design		
Review final as-built drawings for system installation and verify that drawings and installation are in agreement		

8.0 Acceptance of Commissioning Procedures

The installation of the Whisper 900 Grid-Connected Wind Turbine Generator at Site 1.3 has been reviewed and is in conformance with the commissioning procedures above. As a result, we hereby agree that this installation has been completed satisfactorily and approve that the turbine system is ready for field verification testing.

________________________________ __________

Dean Davis Date
Project Leader
Windward Engineering

________________________________ __________

Gerry Bianchi Date
Master Research Technician
NREL, NWTC

________________________________ __________

Trudy Forsyth Date
Project Manager
National Renewable Energy Laboratory

________________________________ __________

Hal Link Date
Certification Project Manager
National Renewable Energy Laboratory

Appendix B: Instrumentation Used during Test

Power Transducer	
Make / model:	OSI, GWV5-001EY24/1
Serial number (Transducer/CTs):	0010301
Range with CTs:	0 - +/-1
Calibration Due Date:	1/5/01
Reactive Power Transducer	
Make / model:	OSI, GWV5-001EY24/2
Serial number (Transducer/CTs):	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 Amps	
Make / model:	OSI CTA212
Serial number:	0010126
CT range:	0-50 Amp
Calibration Due Date:	1/3/01
Battery Amps	
Make / model:	OSI CTA212y42
Serial number:	00125
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 meters upwind
Met Anemometer 11/29/2000 to current	
Make / model:	Met One, 010C with Aluminum Cups
Serial number.	W1240
Calibration Due Date:	4/21/01
Met Tower Location:	6.7 meters upwind
Secondary Met Anemometer	
Make / model:	Met One, 010C with Aluminum Vane
Serial number:	W1232
Calibration Due Date:	2/9/01
Met Tower Location:	6.7 meters upwind
Wind Direction Sensor	
Make / model:	Met One, 020C with Aluminum Vane

Serial Number:	P3143
Calibration Due Date:	2/9/01
Met Tower Location:	6.7 meters upwind
Pressure Sensor (from AOC 15/50) 10/14/99 to 11/21/2000	
Make / model:	Vaisala, PTB101B
Serial Number:	T4730007
Calibration Due Date:	6/2/2000
Instrument Location:	Site 1.1 meteorological tower at 22 meters height
Pressure Sensor (from Bergey XL10) 10/20/99 to 8/24/00	
Make / model:	Vaisala, PTB101B
Serial Number:	T4830002
Calibration Due Date:	10/20/2000
Instrument Location:	Site 1.4 meteorological tower at 33.5 meters height
Pressure Sensor (from Bergey XL10) 2/20/01 to current	
Make / model:	Vaisala, PTB101B
Serial Number:	T3330002
Calibration Due Date:	12/19/2001
Instrument Location:	Site 1.4 meteorological tower at 33.5 meters height
Temperature Sensor (from AOC 15/50) 10/14/99 to 11/21/2000	
Make / model:	Met One, T-200
Serial Number:	0653394
Calibration Due Date:	10/20/2000
Instrument Location:	Site 1.1 meteorological tower at 22 meters height
Temperature Sensor (from Bergey XL10) 10/20/99 – 8/24/00	
Make / model:	Met One, T-200
Serial Number:	0602931
Calibration Due Date:	10/20/2000
Instrument Location:	Site 1.4 meteorological tower at 33.5 meters height
Temperature Sensor (from Bergey XL10) 2/20/01 – current	
Make / model:	Met One, T-200
Serial Number:	0653393
Calibration Due Date:	12/12/01
Instrument Location:	Site 1.4 meteorological tower at 33.5 meters height
Datalogger 2/15/2000 to 10/4/2000	
Make / model:	Campbell Scientific CR21X
Serial number:	13185
Calibration Due Date:	Post-calibration on 2/8/2001
Datalogger 10/4/2000 to current	
Make / model:	Campbell Scientific CR23X
Serial number:	3099
Calibration Due Date:	8/30/2001

Power Transducer
Serial number: 0010301

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. [redacted] 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

Wind Vane

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	x 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

Current Signal Conditioner
Serial number: 0010124/0010126

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) 777-4511

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

Pressure Sensor
Serial number: T4730007

Branch #: 5000 | sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Signal Conditioner | DOE #: 02750C

Model # : CTA212Y42 | S/N : 0010125

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)				
	-50	1	1.034	1.001	± 0.025
	-25	2	2.021	1.995	"
	0	3	3.030	2.998	"
	25	4	4.029	3.998	"
	50	5	5.040	5.005	"

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

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

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

Page: 1 of 1

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:

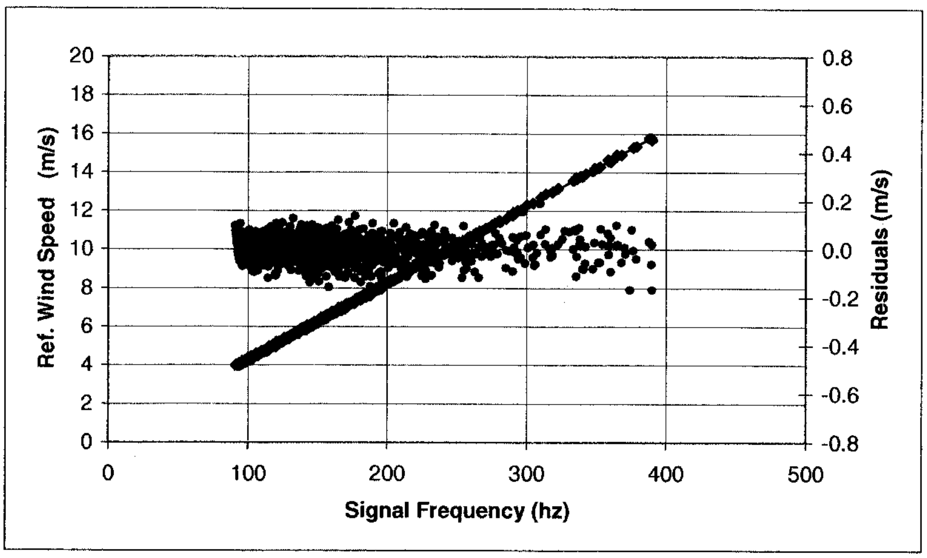
Vwind	Cres Uncer	Total Uncert:
4 - 5 m/s	0.080	0.092
5 - 10 m/s	0.080	0.092
10 - 15 m/s	0.100	0.110

Traceability:

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

Approved: Hal Link
Hal Link

29Nov99
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: GI21-98237, 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:	**0.04002**	m/s/hertz
Offset:	**0.3288**	

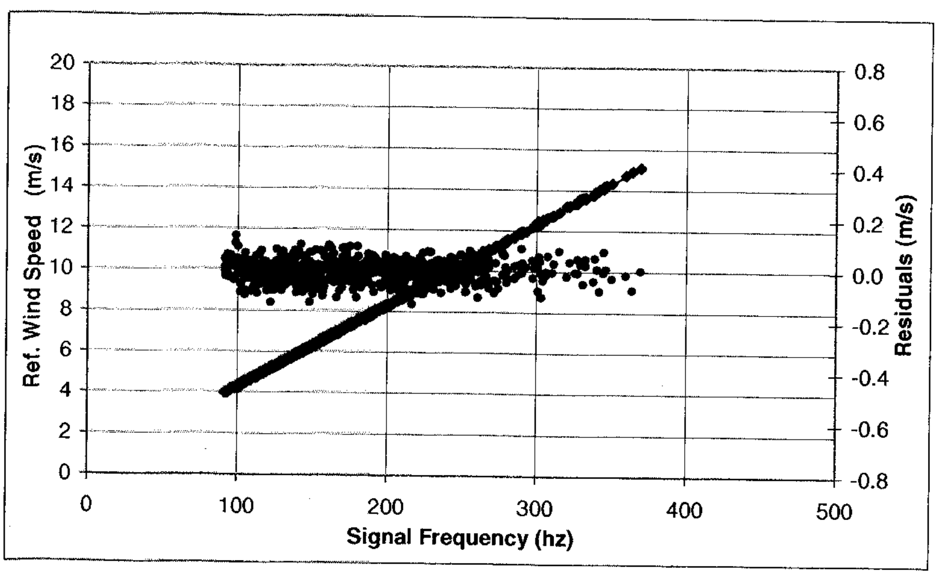
Estimated Uncertainty:

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 — 10 Jan 00
Hal Link — Date



Met One Anemometer

Serial number: P3143

Refurbishment

MET ONE INSTRUMENTS INC.
NIST Test Certification

Model Model 020 B/C W/D Serial No. P3143 DATE 10/14/99

Job Number 994226 Customer NREL

PO Number VISA Tested by [signature]

Room Temperature 72° Room Relative Humidity 51%

NIST Test Standards:

DMM Keithley 197A Ser 490833 Calibrated 2-11-99

FREQUENCY HP 5316B Ser 3005A07041 Calibrated 9-17-99

TEMPERATURE M.O.I. Model 062 Ser K8749 Calibrated 4-9-99

BAROMETRIC PRESSURE M.O.I. 090D-STD Ser P6676 Calibrated 4-7-99

TEST	EXPECTED	AS REC'D	ERROR	AS CALIB	ERROR	SPEC	NOTES
Torque	<0.09in oz	<.09	Pass/Fail	<.09	Pass/Fail	<0.09in oz	
Gap Noise	<1.0V		Pass/Fail		Pass/Fail		

CALIBRATION

TEST	EXPECTED	AS REC'D	ERROR	AS CALIB	ERROR	SPEC	NOTES
10°	0.070V	.077	+.007	.057	-.020	±0.021V	
90°	0.625V	.641	+.016	.608	-.017	±0.021V	
180°	1.250V	1.289	+.039	1.244	-.006	±0.021V	
270°	1.875V	1.869	-.006	1.881	+.006	±0.021V	
350°	2.431V	2.521	+.090	2.448	+.017	±0.021V	
2.5 V Ref	2.500V	2.556	+.056	2.500	-0-	±0.003V	

Document 020-96 (service) 4/95

Voltage Transducer
Serial number: 9111995

INSTRUMENT REPAIR LABS INC.

Certificate of Calibration

COMPANY NAME: National Renewable Energy Lab
CERTIFICATION #: 990505117
CALIBRATION LOCATION: IRL Depot

MANUFACTURER	MODEL NUMBER	P.O. NUMBER
Vaisala	PTB101B	
SERIAL NUMBER	**CALIBRATION ID #**	**CUSTOMER ID #**
T4730007	40050	

RECEIVED	[X] Within Tolerance [ ] Out Of Tolerance	[ ] Operational Failure [ ] Physical Damage
RETURNED	[X] Within Tolerance [ ] Other ______	[ ] Limited ______
CALIBRATION	Due 06/02/2000	
STANDARD(S)	Used ME3 DR1 FL8	
CALIBRATION PROCEDURE USED	MFGR Cal Procedure	

Instrument Repair Labs, Inc. does hereby certify 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 Z540, MIL-STD-45662A, FDA GMP 820.61 and ISO Guide 25. The calibration environment was 70°F +/- 5°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: Ronald Horton
DATE CALIBRATED: 06/02/99
QUALITY MANAGER: BILL HEDRICK

TÜV CERT CERTIFIED TO ISO 9002 INSTRUMENT REPAIR LABS ISO 9002 • CERT NO. 12 100 5851

2100 W. 6th Ave. • Broomfield, CO 80020
(303) 469-5375 or (800) 345-6140 FAX (303) 469-5378

page 1 of 2 Form 07, Rev. 03, 3-26-98

Temperature Sensor
Serial number: 0653394

Serial number: T4830002

INSTRUMENT REPAIR LABS INC.

Certificate of Calibration

COMPANY NAME: National Renewable Energy Lab
CERTIFICATION #: 990505116
CALIBRATION LOCATION: IRL Depot

MANUFACTURER	MODEL NUMBER	P.O. NUMBER
Vaisala	PTB101B	
SERIAL NUMBER	**CALIBRATION ID #**	**CUSTOMER ID #**
T4830002	40051	

RECEIVED	☒ Within Tolerance ☐ Out Of Tolerance	☐ Operational Failure ☐ Physical Damage
RETURNED	☒ Within Tolerance ☐ Other	☐ Limited
CALIBRATION	Due 06/02/2000	
STANDARD(S)	Used DR1 ME3 FL8	
CALIBRATION PROCEDURE USED	MFGR Cal Procedure	

Instrument Repair Labs, Inc. does hereby certify 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 Z540, MIL-STD-45662A, FDA GMP 820.61 and ISO Guide 25. The calibration environment was 70°F ± 5°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: Ronald Horton
DATE CALIBRATED: 06/02/99
QUALITY MANAGER: BILL HEDRICK

TÜV CERT CERTIFIED TO ISO 9002 INSTRUMENT REPAIR LABS ISO 9002 • CERT NO. 12 100 5851

2100 W. 6th Ave. • Broomfield, CO 80020
(303) 469-5375 or (800) 345-6140 FAX (303) 469-5378

page 1 of 2

Form 07, Rev. 03, 3-26-98

Temperature Sensor
Serial number: 0602931

Serial number: T3330002

CEESI

LABORATORY/OFFICE:
54043 County Rd. 37
Nunn, Colo. 80648
Phone: 970-897-2711
FAX: 970-897-2710

COLORADO ENGINEERING EXPERIMENT STATION, INC.

CALIBRATION OF A VAISALA ABSOLUTE PRESSURE TRANSMITTER
MODEL NO.: PTB101B **SERIAL NO.: T3330002**
FOR: INSTRUMENT REPAIR LABS **PURCHASE ORDER NO.: 017853**

CERTIFICATE OF CALIBRATION

The calibrations identified by CEESI files:

00CG-030

were performed using standards that are traceable to the National Institute of Standards and Technology

These calibrations were performed in accordance with the current revision of PROC-010 and MIL-STD-45662A.

The pressure measurement uncertainty is estimated to be: ± 0.14 hPa of reading, to 95% confidence.

These calibrations were: ☑ as found
☑ as left

Calibrated by: [signature]
John Reiner

[signature]
Quality Assurance

[signature]
On behalf of Colorado Engineering Experiment Station Inc.

Temperature Sensor
Serial number: 0653393

HART SCIENTIFIC, INC.
METROLOGY LABORATORY
799 East Utah Valley Drive
American Fork, Utah 84003-9775

REPORT OF CALIBRATION

INTERNATIONAL TEMPERATURE SCALE OF 1990

Platinum Resistance Thermometer
Model No: T200
Serial No: 0653394

Submitted By:
Instrument Repair Labs
Broomfield, CO 80020

This Platinum Resistance Thermometer (PRT) was calibrated by comparison to a laboratory standard SPRT via a Precision DC Thermometer at a constant current of 1.0 mA. The procedure followed is based on the technical information contained in NIST Technical Note 1265, "Guidelines for Realizing the International Temperature Scale of 1990 (ITS-90)" pertaining to secondary PRT's.The following comparison points and their uncertainties (k=2) were used to calibrate the thermometer. This calibration is traceable to NIST or natural physical constants and is in compliance with ANSI/NCSL Z540 - 1 and MIL-STD 45662A.

COMPARISON POINT NOMINAL	COMPARISON POINT ACTUAL	MEASURED RESISTANCE	MEASUREMENT UNCERTAINTY
-38.834 °C	-38.83724°C	84.67680	0.008°C
0.010 °C	0.01294°C	99.96670	0.005°C
156.599 °C	156.6047°C	159.76850	0.008°C
231.928 °C	231.9799°C	187.53810	0.009°C

The calibration data were fitted by the method of least squares to obtain the following values for the resistance at the triple point of water (RTPW) and the coefficients of the pertinent deviation functions of the ITS-90. The attached interpolation tables were generated using these values.

ITS=90 Coefficients: Rtpw = 99.9655282 ohms

a5 = -1.9295598 E-02　　b5 = -8.5532591 E-04
a9 = -1.9393385 E-02　　b9 = 3.4495763 E-05

STANDARDS USED

Description	Manufacturer	Model No.	Serial No.	Due Date
Thermometer, 1ppm Super	Hart Scientific	1590	8C030	07/03/1999
Standard Platinum Resistance Thermometer	Hart Scientific	5680	5-1001	10/06/1999

Laboratory Environment:
Temperature: 23°C
Humidity: 34%
Procedure: HSC106
Calibration Date: 04/09/1999
Calibration Due: 04/08/2000
PO Number: 015878
Report Number: 932248

Calibration Performed by:
Michael Coleman
(801) 763-1600

Approved by:
Thomas J. Wiandt
(801) 763-1600

Pressure Sensor

HART SCIENTIFIC, INC.
METROLOGY LABORATORY
799 East Utah Valley Drive
American Fork, Utah 84003-9775

REPORT OF CALIBRATION

INTERNATIONAL TEMPERATURE SCALE OF 1990

Platinum Resistance Thermometer
Model No: T200
Serial No: 0602931

Submitted By:
Instrument Repair Labs
Broomfield, CO 80020

This Platinum Resistance Thermometer (PRT) was calibrated by comparison to a laboratory standard SPRT via a Precision DC Thermometer at a constant current of 1.0 mA. The procedure followed is based on the technical information contained in NIST Technical Note 1265, "Guidelines for Realizing the International Temperature Scale of 1990 (ITS-90)" pertaining to secondary PRT's.The following comparison points and their uncertainties (k=2) were used to calibrate the thermometer. This calibration is traceable to NIST or natural physical constants and is in compliance with ANSI/NCSL Z540 - 1 and MIL-STD 45662A.

COMPARISON POINT		MEASURED	MEASUREMENT
NOMINAL	ACTUAL	RESISTANCE	UNCERTAINTY
-38.834 °C	-38.83724°C	84.68600	0.008°C
0.010 °C	0.01294°C	100.01520	0.005°C
156.599 °C	156.6047°C	159.81340	0.008°C
231.928 °C	231.9799°C	187.55370	0.009°C

The calibration data were fitted by the method of least squares to obtain the following values for the resistance at the triple point of water (RTPW) and the coefficients of the pertinent deviation functions of the ITS-90. The attached interpolation tables were generated using these values.

ITS-90 Coefficients: Rtpw = 100.0140277 a5 = -1.8451497 E-02 b5 = -8.5217786 E-03
a9 = -1.9255452 E-02 b9 = -1.1259971 E-03

STANDARDS USED

Description	Manufacturer	Model No.	Serial No.	Due Date
Thermometer, 1ppm Super	Hart Scientific	1590	8C030	07/03/1999
Standard Platinum Resistance Thermometer	Hart Scientific	5680	5-1001	10/06/1999

Laboratory Environment:
Temperature: 23°C
Humidity: 34%
Procedure: HSC106
Calibration Date: 04/09/1999
Calibration Due: 04/08/2000
PO Number: 015878
Report Number: 932245

Calibration Performed by:
Michael Coleman
(801) 763-1600

Approved by:
Thomas J. Wiandt
(801) 763-1600

Pressure Sensor

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 ℃	94.131 Ω	-14.97 ℃	0.03 ℃
2	100.00 Ω	0.0 ℃	100.017 Ω	0.04 ℃	0.04 ℃
3	105.85 Ω	15.0 ℃	105.872 Ω	15.06 ℃	0.06 ℃
4	111.67 Ω	30.0 ℃	111.704 Ω	30.09 ℃	0.09 ℃
5	117.47 Ω	45.0 ℃	117.506 Ω	45.09 ℃	0.09 ℃

Notes:

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

Checked By: Reda

Date : 12/12/2000

Campbell Datalogger
Serial Number: 13185

3033847097 NREL NWTC VILLAGE PT 128 P02 JUN 28 '01 10:07

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: 22.5C 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

Met One Anemometer

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		4998.8		4998.2	-25
5	5000	+-5		5001.1		5000.9	50
5	5000	+-7.5		4998.6		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*

T. KENDALL

Title: Electronic Technician

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

Page 2 of 2

Appendix C: Up-tower Turbine Inspection Checklist

As part of the assessment of component wear and durability, the turbine is inspected on its tower at the conclusion of the duration test. This checklist documents the findings of that inspection.

Conducted by: Jeroen van Dam Date: 27 June 2001

Task	Comments / findings:
Wind Turbine Generator:	
1. With the turbine braked the rotor should turbine should turn with strong resistance	The rotor still spins quite easily
2. Visually inspect the rotor blades for any cracks or deviations from normal.	No cracks found in the blades, there are some small chips missing from the leading and trailing edge.
3. Manually spin the rotor, this should be easy and smooth.	Rotor spins smooth and easy without any shocks
4. Check the main bearing for play	The main bearing has a little play in it, and should be inspected in the tear down inspection
5. Manually yaw the turbine, this should be smooth without shocks.	Yawing is smooth and light
6. Check the yaw bearing for play	The yaw bearing has some play in it and should be inspected in the tear down inspection.
7. Manually furl the turbine, this should be smooth without shocks. Turbine should completely unfurl after release. Check the furl bearing for play.	Furling is not smooth and takes quite some force. Also the turbine does not unfurl from any position. This needs attention in the tear down inspection.
8. Check all fasteners for presence and torque. All should be present and should be have a reasonable torque (hand tight) a) blade connection bolts (12*) (torque: +/-8 Ft-lbs) b) hub to tail connection (2*) c) tail boom to tail vane (2*)	All fasteners are present and seem to have the right torque.

Task	Comments / findings:
9. d) tower to tower insert (6*)	
10. Check windings and magnet of generator as far as they are visible	No de-coloring of windings visible, no magnet chips found, all looks as should be as far as visible.
11. Check the slip rings for any debris and wear.	No visible wear or damage
12. Check the turbine for any oil, grease, cracks corrosion, wear.	No oil, grease found. Some minor corrosion spots found on tail boom, magnet can and tower. None serious. The nose cone is cracked and will need replacement. The magnet can might have caused some wear on the top casting, this needs further attention in the tear down inspection
13. Listen to the wind turbine in several wind speeds	On June 25,2001 the turbine produced power at wind speed up to 10 m/s. No strange noises were observed.
14. Check the turbine for vibration by looking at it and feeling the tower.	The turbine was observed on June 25, 2001 in wind speeds between 2,5 and 15 m/s. No major vibrations were observed by looking at the tower and no major vibrations were felt in the tower.
15. Other remarks:	None

Appendix D: Draft IEC Standard

As of the date of this report, the following text is being considered for inclusion in Edition 2 of the IEC Standard, IEC 61400-2, "Wind Turbine Generator Systems -- Part 2: Safety of Small Wind Turbines."

9.4 Duration Testing

The purpose of the test is to investigate:
1. Structural integrity and material degradation (corrosion, cracks, deformations);
2. Quality of environmental protection of the wind turbine.
3. The dynamic behavior of the turbine

During the duration test, test procedures shall be implemented to determine if and when the test turbine successfully meets the following test criteria.
The wind turbine will have passed the duration test when it has achieved:
1. reliable operation during the test period,
2. 6 months of operation,
3. 3000 hours of power production in winds of any velocity,
4. 250 hours of power production in winds of 1,2 V_{ave} and above, and
5. 25 hours of power production in winds of 1,8 V_{ave} and above.

Wind speed is the 10-minute average of 1-sec wind speed samples. The highest 3-sec wind speed shall be recorded and the average turbulence intensity at 15 m/s wind speed during the test shall be derived from recorded wind speeds. These results shall be stated in the test report. Power production means that the turbine is producing positive power as measured by the power transducer at the connection to the grid or battery bank.

9.4.1 Reliable operation

Reliable operation means:
1. Operational time fraction of at least 90%,
2. No major failure of the turbine or components in the turbine system,
3. No significant wear, corrosion, or damage to turbine components found during periodic inspections or the final turbine inspection, and
4. No significant degradation in time of produced power at comparable wind speeds

If the turbine is altered in any way during the test other than to perform scheduled maintenance or for inspections, the test organization will determine if such an alteration has resulted from a major failure or a significant design change. The test organization's judgement shall be noted in the test report. A major failure of the wind turbine system includes any failure of the system components which affect the turbine safety and function including blades, charge controller, alternator, yaw bearings, or inverter.

Significant wear is any wear which, extrapolated to the lifetime of the turbine, would result in unacceptable loss of strength or clearance

9.4.1.1 Operational time fraction

For purposes of this test, operational time fraction is defined as the measure of performance given by the ratio of time a wind turbine shows it normal designed behaviour to the test time time in any evaluation period expressed as a percentage.
Normal designed behaviour includes the following (where applicable):
1. Turbine producing power
2. Automatic start-up and shut-own due to wind speed transitioning across low wind cut-in and high wind cut-out
3. Idling or parked states at wind speeds under V_{cut-in} or above $V_{cut-out}$;
4. Extended time between a normal shutdown (not caused by a failure) and a restart of the turbine (e.g. brake cool cycle, retraction of tip brakes)

The Operation time fraction, O, is given by the following equation:

$$O = \frac{T_T - T_N - T_U - T_E}{T_T - T_U - T_E} \times 100\%$$

where:
T_T is the total time period under consideration,
T_N is the time during which the turbine is known to be non-operational,
T_U is the time during which the turbine status is unknown,
T_E is the time which is excluded in the analysis.

Note that neither the time during which the turbine status is unknown nor the time that is excluded for the analysis count against or in favour of the operational time fraction.

The following conditions shall be considered as turbine faults and shall be part of T_N:
1. Any turbine fault condition indicated by the turbine controller that prevent the turbine from operating
2. Any automatic shutdown of the turbine by its controller due to an indicated fault
3. Manual selection of pause, stop, or test mode that prevents the turbine from operating normally for the purpose of routine maintenance or a perceived fault condition
4. Turbine inspections conducted in accordance with manufacturer's recommendations.
5. Down time due to unwrapping of the droop cable

The following conditions shall be considered as time during which the turbine status is unknown (TU in the equation above):
1. Failure or maintenance of the data acquisition system
2. Lost or unresolvable records of turbine condition.

The following conditions shall be excluded from the test time period and be part of T_E.
1. Turbine inspections conducted as part of this test that are not recommended by the manufacturer (e.g. inspection of data acquisition system)
2. Manual selection of a pause, stop, or test mode that prevents the turbine from operating normally for any purpose other than routine maintenance or a perceived fault condition.
3. Failure of the grid, battery system, inverter or any component external to the turbine system being tested (see below). If these components are considered part of the system this time shall count as T_N.
4. Reduced or no power production due to the turbine control system sensing external conditions outside the designed external conditions.
If a turbine fault is present during one of the above situations, caused during normal external conditions, this time shall count as T_N

The duration test plan shall clearly state which components shall be considered parts of the turbine system and which components shall be considered as external to the turbine. This statement shall consider:
1. The mechanical interface between the turbine and the ground
2. The electrical interface between the turbine and the load
3. The control interface between the turbine and local and/or remote control devices.

In cases where conditions may exist that are not clearly attributable to a turbine fault or an external condition, the test plan shall define to which category such conditions will be attributed. Examples of such conditions are:
1. Inadvertent actuation of tip brakes or furling
2. Confusion of the controller due to voltage transients

The test plan shall describe instrumentation and data logging arrangements that allow for determination and recording of turbine operation status at all times during the duration test.

9.4.1.2 Power production degradation

To check any hidden degradation in the power performance of the turbine the following procedure is part of the duration test.
For each month in the duration test the power levels will be binned by wind speed (bin width 1 m/s). For each wind speed a plot will be made with the binned power levels as a function of time. There should be no clear trend visible when plotting these points in time and fitting a trendline. (slope within 0.9 and 1.1) If there is trend visible, investigation should take place to the cause of that slope.
For battery charging systems points with comparable state of charge should be plotted.
Only data points which are considered normal operation should be used in this analysis.

9.4.2 Dynamic behaviour

The dynamic behaviour of the turbine shall be assessed in order to verify that system natural frequencies do not interfere with operational frequencies. The dynamic behaviour of the turbine shall be observed for at least 1 minute at wind speeds near and above 10, 15 and 20 m/s. Special attention should be paid on tower vibrations, turbine noise, tail movements and yaw behaviour. Assess the dynamic behavior by observation or instrumentation.

Appendix E

Detailed Component Wear and Durability Assessment
Southwest Windpower Whisper H40

NREL performed a component wear and durability assessment after the duration testing was completed on the Southwest Windpower Whisper H40. The purpose of this assessment was to verify that the turbine components have not undergone any excessive wear that would be indicative of a premature turbine failure. The uptower inspection performed at the end of the duration test already gave some indications of wear. These indications were examined in more detail.

The assessment includes an evaluation of: a) the rotor, furl and yaw bearings to assess if there is any irregular wear, b) blades to verify there are no cracks, and c) the circuit boards to verify there are no thermal or electrical signs of fatigue. In addition, the slip rings, stator, turbine nacelle, and tower will be evaluated for any abnormal wear. The procedures are described below.

The assessment was conducted on 9 August 2001 by Jim Adams, Jerri Bianchi, Mark Meadors and Jeroen van Dam.

Task	Comments
1. Blade check Inspect the blades for any cracks, pits or wear.	There is no major wear visible, some minor dents are present in the trailing edge.
2. Rotor assessment Look of any signs of wear, cracks or corrosion on the magnets or the can.	The magnets have been slightly rubbing against the stator. See Figure 1.
3. Stator assessment Look for any signs of wear, heating, check resistance of each of the ten windings	It seems the magnet can has worn a groove in the stator part. (Figure 2), The magnet can misses paint on the area where contact took place (Figure 3) The windings on the downwind side of the stator seem slightly darker then the windings on the upwind side (Figure 4). This might indicate some heating. Areas where the magnets have been rubbing against the stator are clearly visible.
4. Slip ring check Check the slip rings for abnormal wear including breakdown of the insulation between slip rings, wear on rings and brushes including excessive material build-up and misaligned brushes.	For the upper slip ring, there is no contact between the slip ring race and the wire coming from the tower (see Figure 5) The wire in the hole of the slip ring seems to be tinned but it is unclear if the wire has been soldered to the slip ring race (Figure 6 & 7). There either has never been a connection or a very cold solder. Since there is some sign of solder on the brass of the slip ring the assumption is that there has been a connection but this was "poor quality workmanship". One of the wires running from the brush to the nacelle has some insulation damage. (Figure 8)

5. Rotor bearing Dismount he bearings from the turbine and check for abnormal wear, signs of pitting or excessive play in the bearings.	The bearings have been taken out of their housing and seem to be fine. Some metal shavings are found at the shoulder which transmits the thrust force from the last bearing to the housing. There is no sign of wear. So the conclusion is that the housing was not cleaned very well before installation of the bearing. A point of worry is the very small shoulder through which the thrust force is transferred from the shaft to the housing. It only supports the outer race of the bearing on a very small area near the rounding. See Figure 9 & 10
6. Furl bearing Dismount he bearings from the turbine and check for abnormal wear, signs of pitting or excessive play in the bearings.	The furl bearing consists of a pin which turns in a plastic bushing. The whole bearing is kept together by a set-screw which fits in a ~groove?~ of the pin. See Figure 11. During the duration test we had some furl problems so the tear-down focussed on the cause of this furl problem. The plastic bushing is found to be slightly tapered (0.005 in) but seems to be ok. The set screw showed quite some wear (Figure 12) and so did the groove the set-screw fits in (Figure 13). We suspect that by tightening the set-screw too much, the furl bearing got fixed and the friction in the bearing reported earlier was caused by this.
7. Yaw bearing Dismount he bearings from the turbine and check for abnormal wear, signs of pitting or excessive play in the bearings.	The yaw bearing has some play in it, but no more then can be expected from a double row of the type of ball bearings used. The bearings itself seem fine. There is some minor wear found on the yaw axis caused by the bearing seal (Figure 14)
8. Other findings: Check any other components (tail, nacelle body, nose cone, tower insert etc.) for wear, cracks, corrosion, deformation, etc.	As reported earlier the nose cone is cracked and will need replacement. (see Figure 15)

Figure 1: Signs of wear on the magnet can

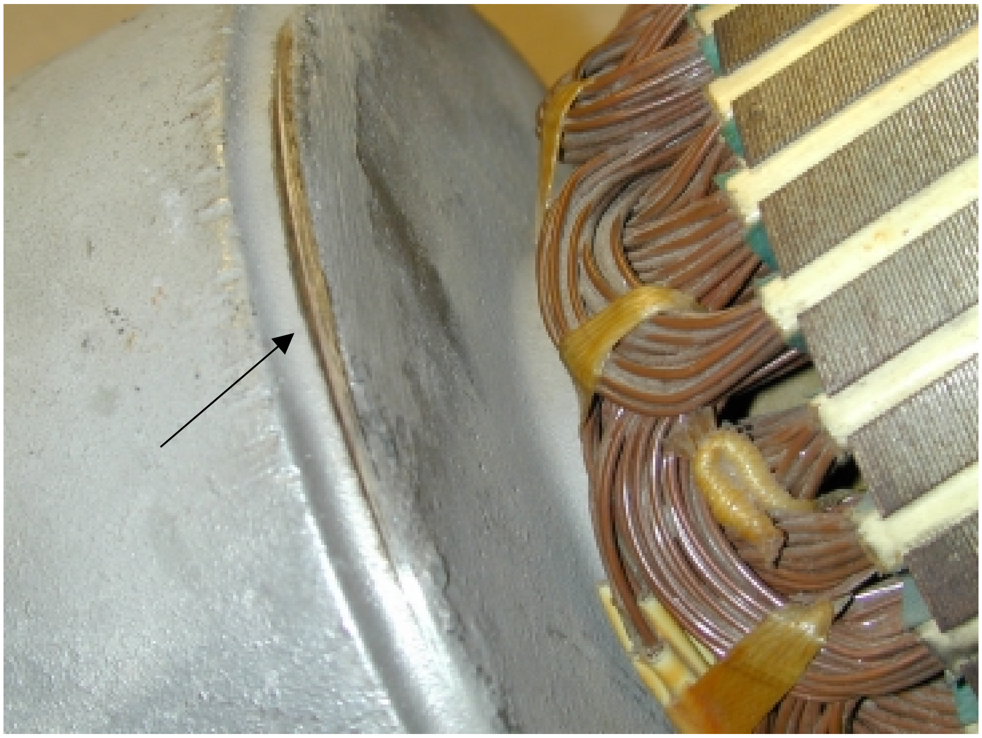


Figure 2: Signs of contact between the magnet can and the static part of the housing.

Figure 3: Wear on the edge of the magnet can

Figure 4: Windings on the downwind side (left) seem slightly decolored compared to the windings on the up wind side (right). Further the brown areas on the left show where the magnets have been rubbing the stator lamination.

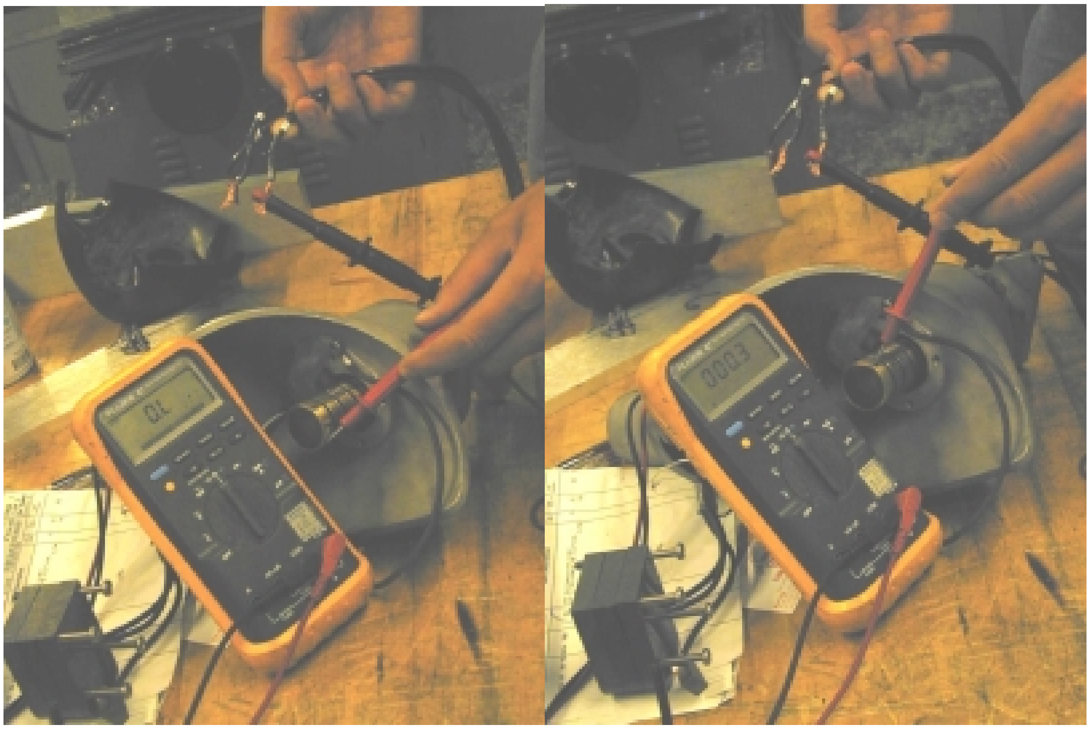


Figure 5: Left: measuring resistance between the slip ring race and the end of the wire, no contact. Right: Measuring resistance between one end of the wire and the wire end in the slip ring hole, connection.

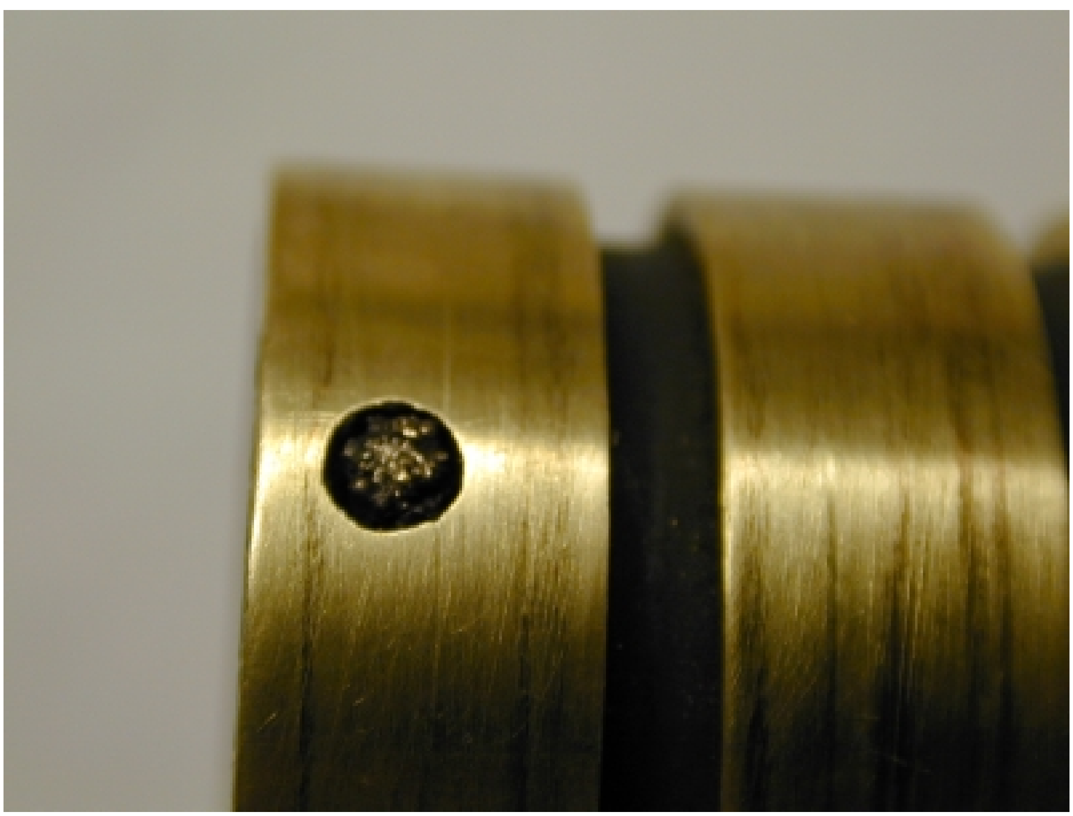


Figure 6: The bad connection between the wire in the slip ring hole and the slip ring race.

Figure 7: As a comparison a good connection on one of the other slip ring channels.

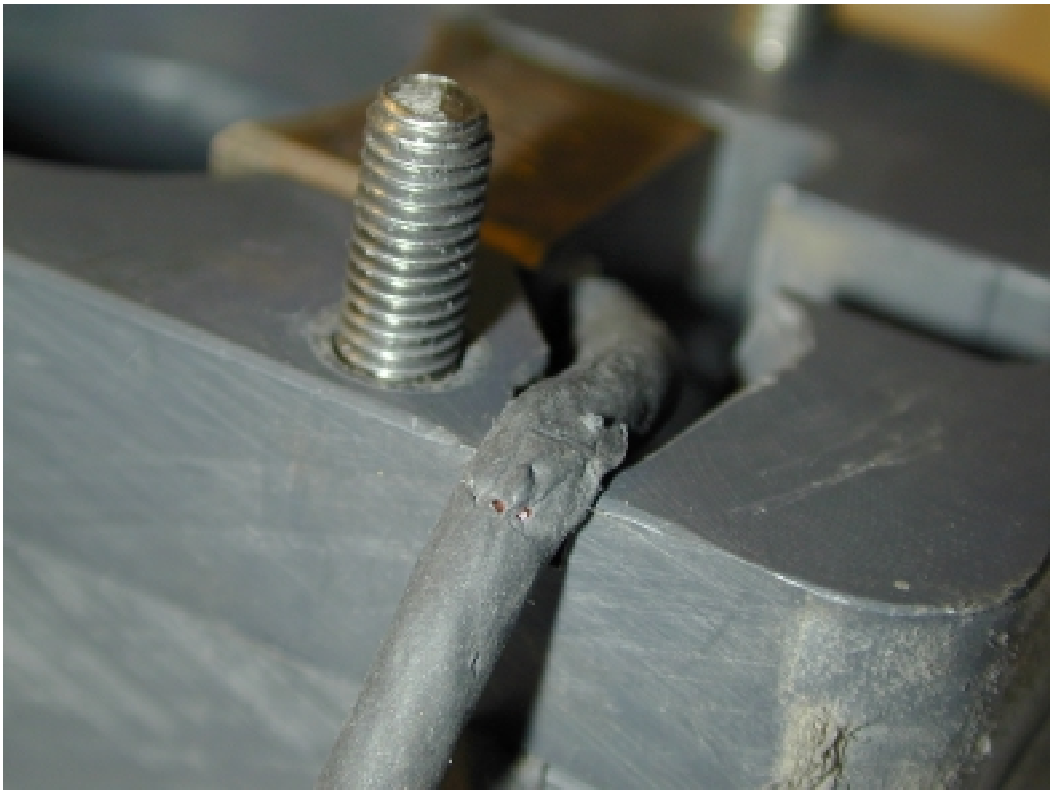


Figure 8: Damaged insulation on one of the wires coming out of the slip ring assembly.

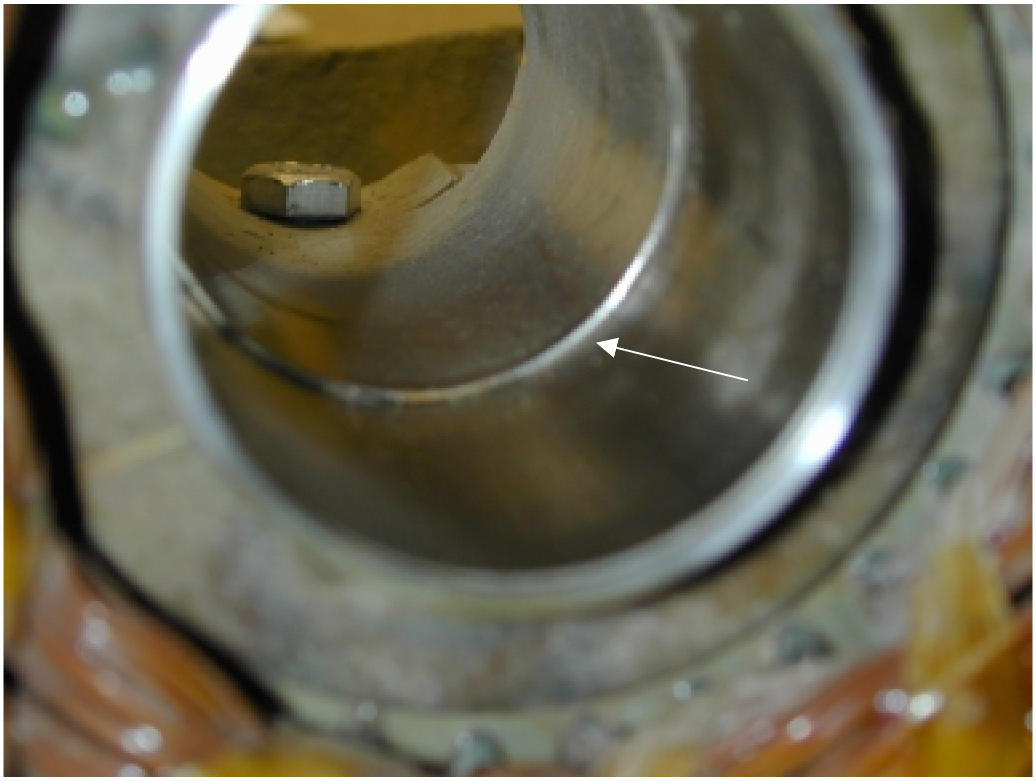


Figure 9: Close up of the shoulder which takes the thrust force from the main bearing to the housing.

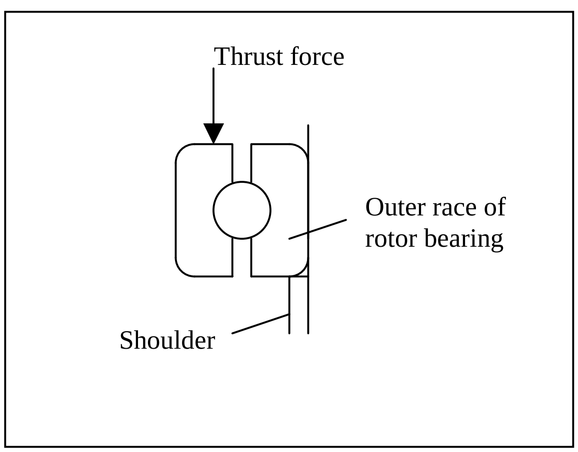


Figure 10: Schematic of the connection between the back rotor bearing and its supporting should.

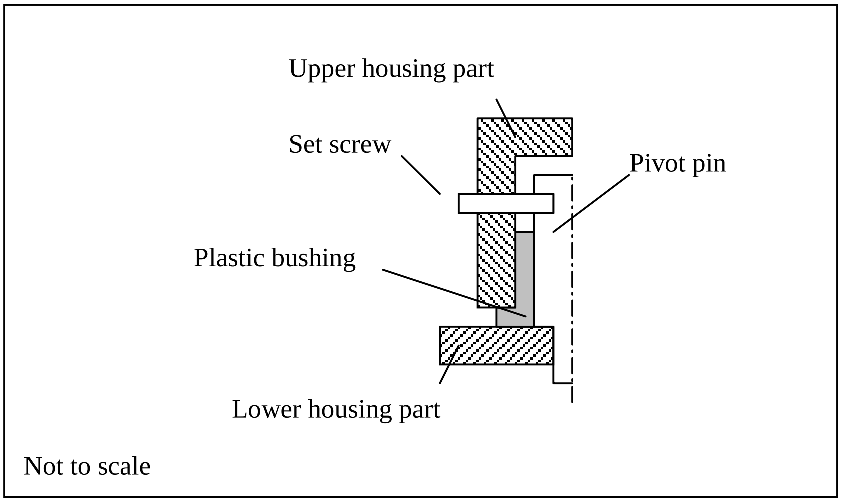


Figure 11: Schematic of the furl bearing. The upper housing part furls with respect to the lower housing part.

Figure 12: The setscrew. Note the wear on the top of the setscrew.

Figure 13: Close up of the groove in the pivot pin. Some wear caused by the setscrew is present.

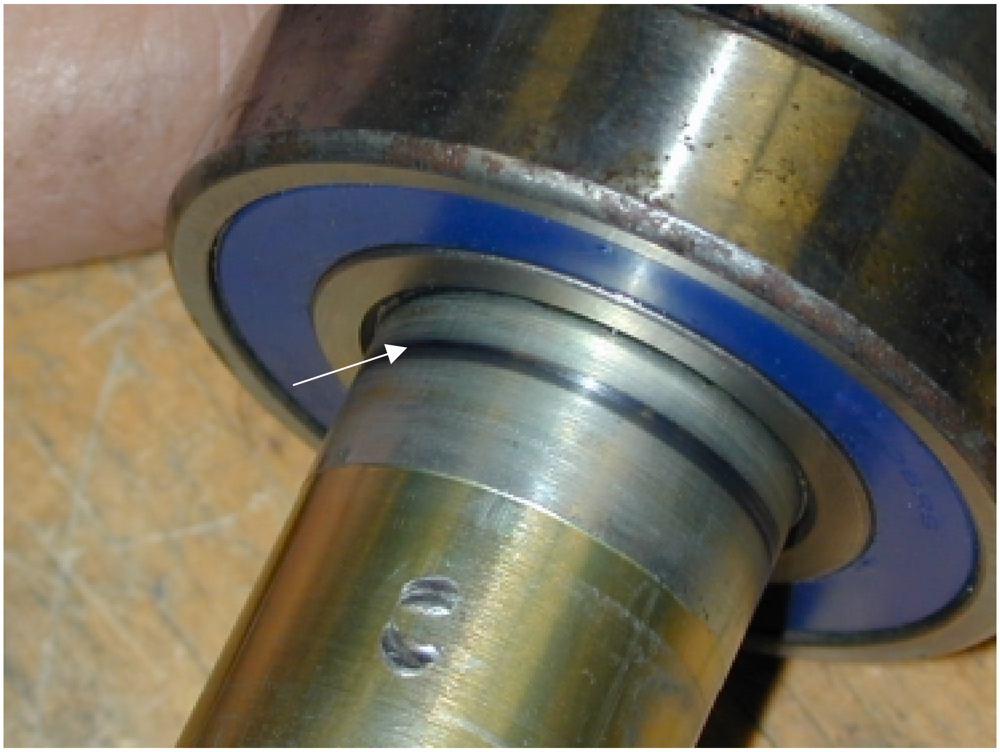


Figure 14: Close-up of the lower yaw bearing. The shining track under the yaw bearing is caused by the bearing seal.

Figure 15: Close up of the nose cone. The holes are use by the fasteners connecting the nose cone to the hub.

Appendix F

Report on the Electrical Inspection of the Whisper H40

General

On March 27, 2002, Jeroen van Dam (NREL) and Mark Rumsey (SNL) inspected the electrical components of Southwest Windpower's Whisper H40. This inspection took place as part of the duration test as carried out under the small turbine Field Verification Program. At the time of the inspection the hub height wind speed was between 15 and 20 m/s. The turbine was not connected to the grid; all the generated energy was dumped into the batteries and dumpload.

There are three main electrical components that are of interest for this inspection: the EZ Wire controller, the battery bank and the dumpload. Since the inverter was not connected to the grid and is an off-the-shelf item, less effort was put into inspecting this component. All components are identified in Figure 1.

Mark Rumsey, with Sandia National Laboratories, used an infrared sensitive camera (Agema ThermoVision 550 Pro) to take thermal images of the Whisper H40 electronics to find possible points of concern. Normal visible-light pictures are shown along with the thermal images to give the reader an idea of what can be seen in the thermal image. (The IR pictures were taken with an emmisivity setting of 0.95. The IR camera is sensitive to electromagnetic energy with wavelengths of 3.6 to 5 micrometers.)

Disclaimer: The infrared camera used in this electrical inspection was not calibrated. Therefore, it is not possible to report accurate definitive (quantitive) temperatures. Temperatures obtained from an infrared image and quoted in this report should be treated as only an estimate of the actual temperature. The various colors showing up in the thermal pictures are dependent on the component emmisivity and thermal reflections off the component; the colors are then calculated into temperatures. Because the electrical inspection was conducted around midday, several of the thermal pictures taken outside were influenced by reflections of sunlight.

Results

A visual inspection of the electrical components did not indicate any problems. No signs of damage overheating or other problems were found.

EZ Wire

The inside of the EZ wire is shown in Figure 2. There are three rectifiers in the upper part of the EZ Wire box. One of the rectifiers seems to be slightly warmer then the other two, as indicated in the thermal image in Figure 3. The two cooler rectifiers (the two on the left) had been replaced by NREL in an attempt to fix a problem that later appeared to be a problem with one of the slip-ring channels. Also note the vertical line of FETs , along the right edge of the box, appear to all be operating at about 130°F (54°C). Figure 4 shows a picture of the cabinet door of the EZ Wire. The two prominent warm areas in the thermal image of the back of the microprocessor board are due to power resistors located on the other side of the board.

Dumpload

The dump load shows up as a hot item, which is not surprising since all the generated power is dumped to this dump load. The outside cover of the dump load remains cool with temperatures close to the ambient temperature.

Battery bank

The battery bank does not show any surprises (Figure 6). The battery bank is normally covered to protect it from the environment. However, to take the thermal images the cover had to be removed which caused solar reflections off the shiny battery posts and connectors. Ignoring the reflections, the battery seems only slightly warmer then ambient.

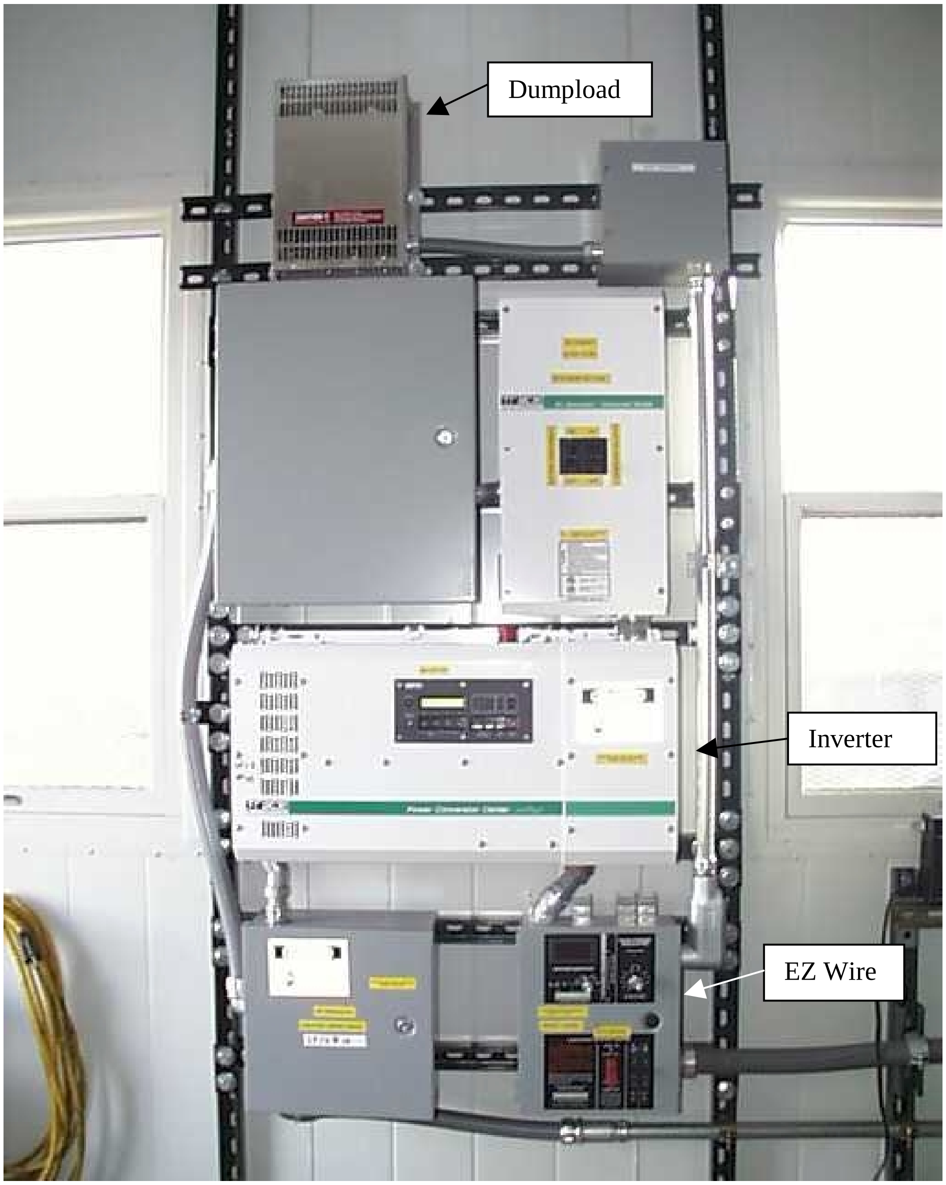


Figure 1: Electrical components of the Whisper H40 setup at the NWTC.

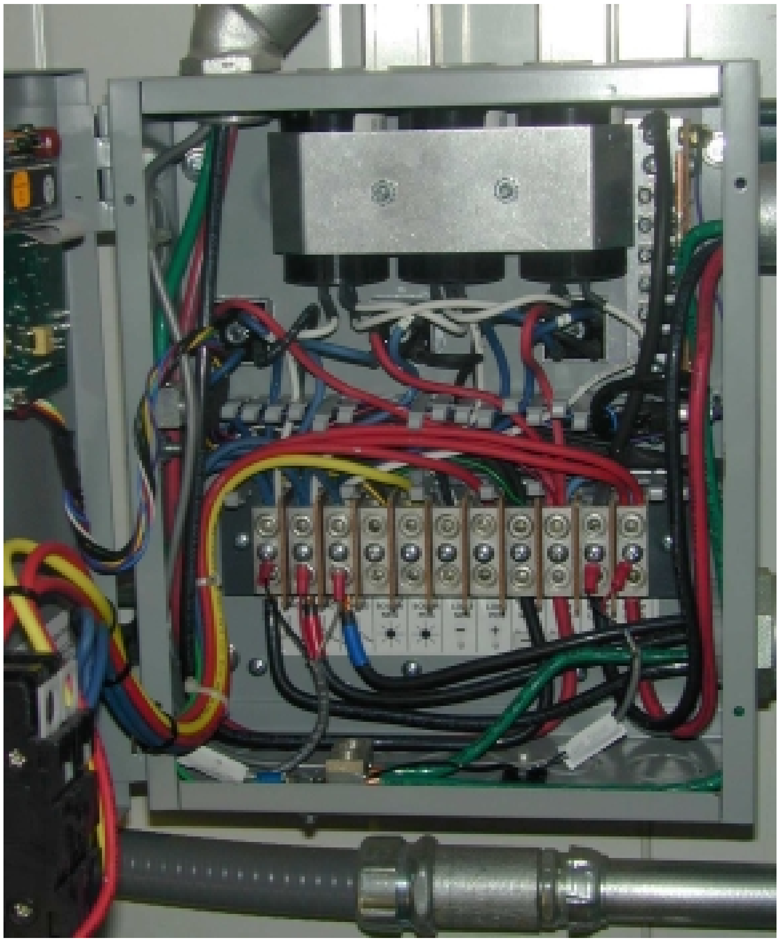


Figure 2: The inside of the EZ Wire.

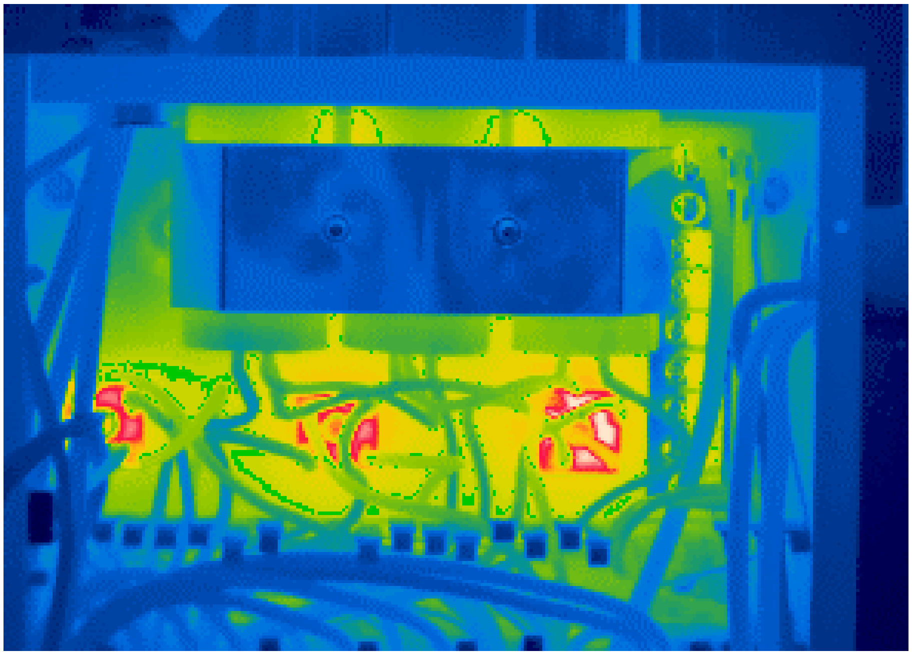


Figure 3: Thermal image of the upper part of the EZ Wire controller, the red color indicates temperatures around 150°F (66°C), the white spots indicate even higher temperatures.

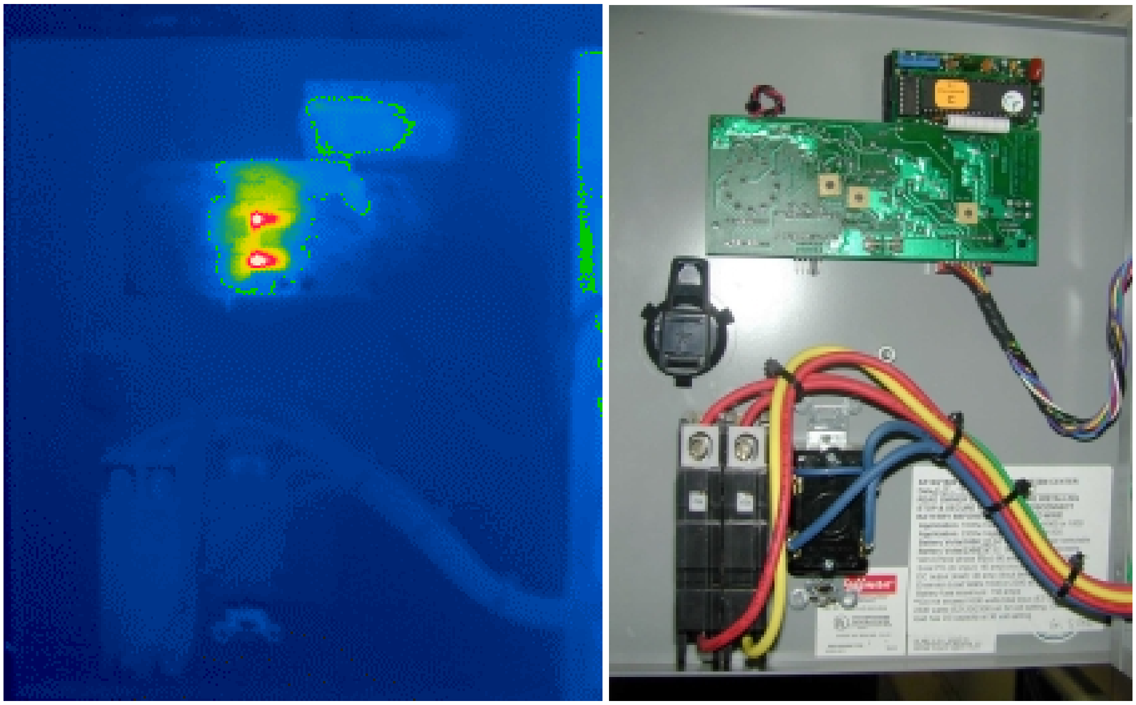


Figure 4: Thermal and normal picture of the cabinet door of the EZ Wire.

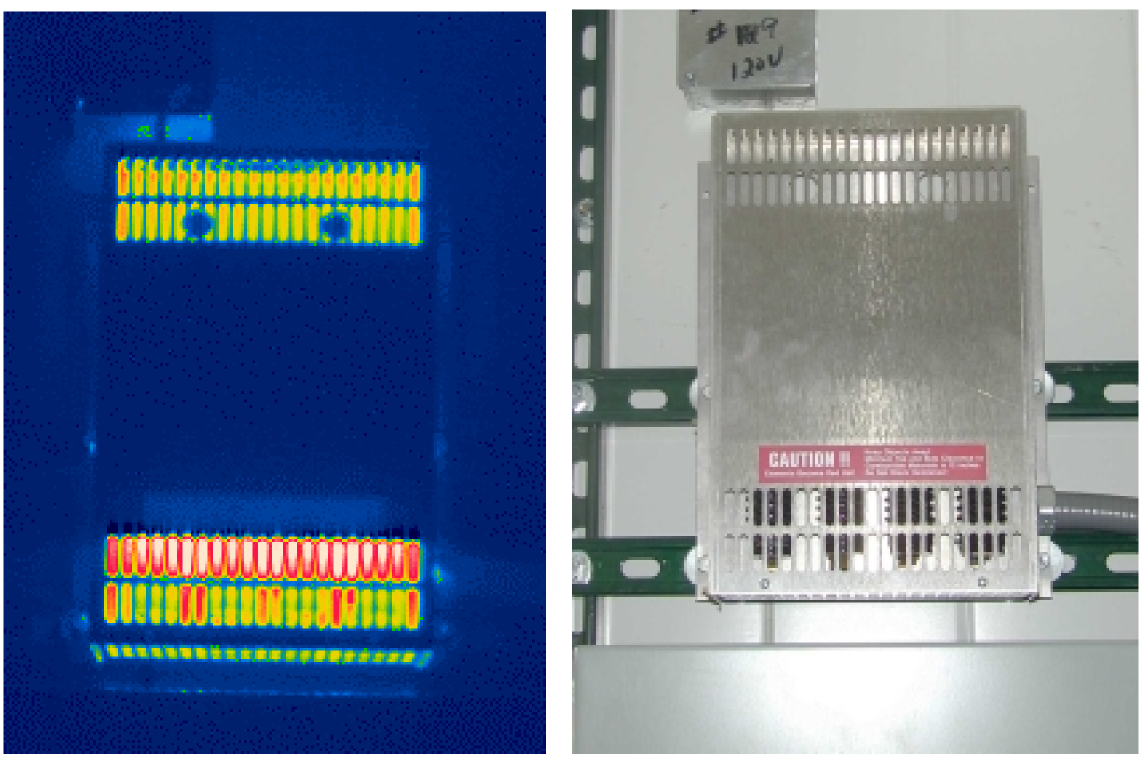


Figure 5: Close up of the dumpload. The temperatures on the outside of the dumpload appear to be on the order of 110°F (43°C). Temperatures on the inside of the dumpload appear to be on the order of 530°F (277°C).

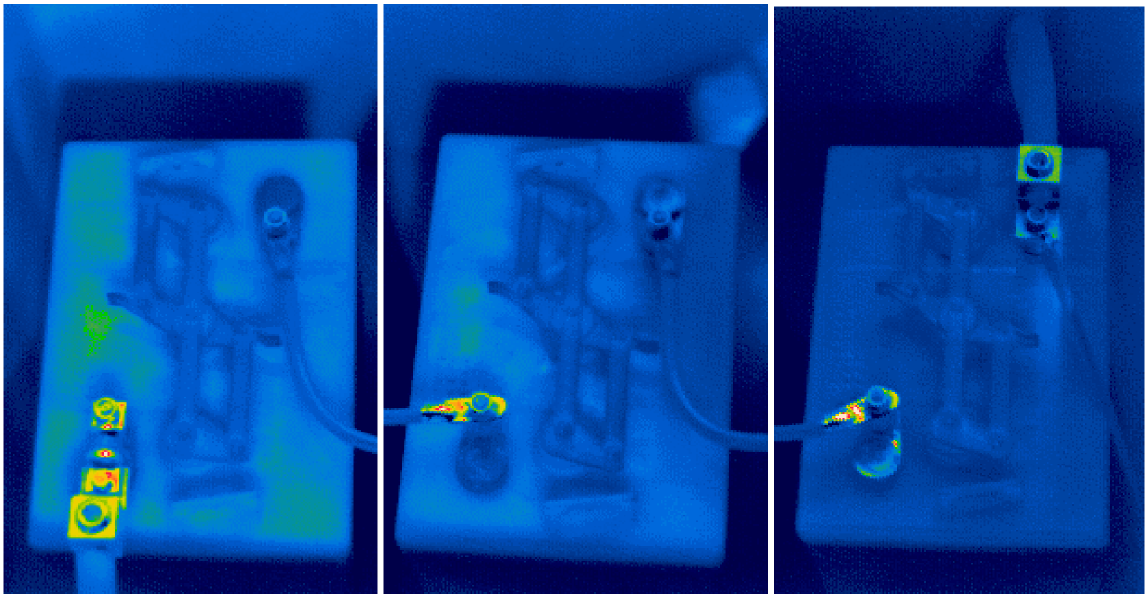


Figure 6: Thermal images of the battery bank.