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Wind Turbine Generator System

Duration Test Report

for the

Bergey Excel-S/60

by

National Wind Technology Center
National Renewable Energy Laboratory
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February 2003

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Approval By: ______________________ 4/2/03
Charles P. Butterfield, NREL Certification QA Manager — Date

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4 Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States government. The test results documented in this report define the characteristics of the test article as configured and under the conditions tested.

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5 Test Objective and Requirements

The objective of this test is to investigate:

- Structural integrity and material degradation (e.g., cracks, deformations, wear)
- Quality of environmental protection of the Bergey Excel wind turbine with Gridtek inverter (e.g., corrosion, failure of paint or seals).

The wind turbine will pass 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 10.2 m/s and above
- 25 hours of power production in winds of 15.3 m/s and above.

Reliable operation means:

- Operational time fraction 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
- Measured energy production within 80% of expected energy production.

6 Background

This test is being conducted as part of the U.S. DOE's Small Wind Turbine Field Verification Program (FVP). The primary purpose of this program is to provide consumers, manufacturers, and host site organizations with an independent assessment of the performance and reliability of small U.S. wind turbines.

The test equipment includes a Bergey Excel wind turbine mounted on a 120-ft lattice tower and a Trace Gridtek 10 inverter. Bergey WindPower Co. in Oklahoma manufactured the turbine, and AWS Scientific installed the system at the National Wind Technology Center (NWTC) with the support of Bergey WindPower.

NREL is currently testing three wind turbines as part of the DOE's Small Turbine Field Verification Program. 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. Additional information on the test turbine, test site, test equipment, and analysis methods can be found in this test plan.

7 Deviations from Test Plan

The following deviations were made from the test plan included in Appendix A:

- The turbine was re-instrumented during the duration test because some of the instruments ran out of calibration. Thus some instruments were different from the list given in the test plan (Appendix A). Changed or re-calibrated instruments are listed in Table 1.

Table 1. Equipment Changed during the Duration Test

Power Transducer and CTs (Inverter Power)	
Make/Model:	OSI, GWV5-001EY24 CT pn 12975
Serial Number (Transducer & CTs):	9101376
Range with CTs:	-13.33 to 13.33 kW/kVar
Calibration Due Date:	15 November 2002
Power Transducer and CTs (WT Watts)	
Make/Model:	OSI, P-143E
Serial Number (Transducer & CTs):	9100896
Range with CTs:	0 to 40 kW
Calibration Due Date:	15 November 2002
Barometric Pressure Sensor	
Make/Model:	Vaisala, PTB101B
Serial Number:	S2830007
Calibration Due Date:	19 November 2002
Atmospheric Temperature Sensor	
Make/Model:	Met One, T-200 RTD
Serial Number:	0464507
Calibration Due Date:	19 November 2002
Frequency Input, Field Configurable Isolator	
Make/Model:	Action Instruments Ultra Slim Pack G478-0001
Serial Number:	B2MCD

- The test plan stated that the test would be continued until an operational time fraction of 90% was obtained. However, NREL did not have funding to continue the testing needed to obtain a higher operational time fraction.
- The dynamic behavior of the turbine has also been observed as part of the duration test.

8 Results

Operation Time

The test turbine system was installed in November 1999 and has operated continuously since then to August 2002. As initially installed, the turbine system produced power and demonstrated power production capability. However, it also suffered from some inverter faults. After several upgrades, the duration test was officially started on March 12, 2001. The duration test was completed on December 31, 2001, after enough data were collected to demonstrate sufficient hours of operation as required by the draft standard (see Appendix B).

Months of Operation

Total time of operation has now exceeded 25 months. The duration test was conducted over a period of 9.5 months from March 12, 2001, to December 31, 2001 (6 months were required).

Hours of Power Production

The hours of power production at any wind speeds:	2,455 hours	(1,500 hours required)
The hours of power production above 1.2*V_{ave} (10.2 m/s):	272 hours	(250 hours required)
The hours of power production above 1.8*V_{ave} (15.3 m/s):	36 hours	(25 hours required)

Thus the turbine exceeded the requirements for hours of power production during the test. Table 2 shows the overall and month-by-month results of the duration test.

Table 2. Monthly and Overall Results of the Bergey Excel-S/60 Duration Test

XL10 Gridtek Duration test	Hours of power production in wind speed above:			Environmental conditions		Operational time fraction					Expected energy		
Month	0 m/s	10.2 m/s	15.3 m/s	max 3-sec gust	TI @ 15 m/s	Tt	Tu	Tn	Te	O [%]	$P_{measured}$	$P_{expected}$	P_{meas}/P_{expect} [%]
Overall	*2455.0*	*271.7*	*35.8*	*43.7*	*17.0*	*7067*	*262.9*	*945.8*	*58.8*	*86.0*	*2839*	*2839*	100
March 2001	50.5	2.8	0.0	30.1	16.7	467	261.8	0.0	0.0	100.0	49	45	107
April 2001	316.7	30.5	4.3	43.7	15.7	720	0.0	35.2	4.6	95.1	366	332	110
May 2001	336.5	31.7	4.5	33.5	16.7	744	0.0	60.2	0.0	91.9	345	338	102
June 2001	300.2	16.5	4.0	34.7	17.5	720	0.3	57.5	0.3	92.0	231	224	103
July 2001	80.7	5.2	2.0	26.6	14.5	744	0.0	559.0	0.0	24.9	54	51	107
August 2001	239.5	11.3	0.7	27.1	14.5	744	0.0	134.0	0.3	82.0	181	195	93
September 2001	281.0	19.8	2.0	26.2	16.9	720	0.0	0.0	2.6	100.0	248	265	93
October 2001	320.2	63.2	11.2	36.3	17.9	744	0.0	76.2	0.0	89.8	527	543	97
November 2001	214.0	17.2	0.3	25.6	14.5	720	0.0	9.2	50.9	98.6	205	202	101
December 2001	315.8	73.5	6.8	41.1	18.3	744	0.7	14.5	0.1	98.0	633	643	98

Operational Time Fraction
The overall operational time fraction of the combined wind turbine system (wind turbine, tower, and inverter) in the total test period was 86%. This does not meet the requirement of 90% operational time fraction. Table 2 and Figure 1 show the operational time fraction per month. NREL has not monitored the operational time fractional of the individual components.

The main reasons for wind turbine system downtime (T_N) during the test period were faults of the inverter: the DC bus overvoltage fault and over-temperature fault. These faults are described in more detail below. The time during which the inverter went into Pause mode was not considered as system downtime.

During the test period, no downtime was attributed to problems with the wind turbine. There was no automatic signal in place to record temporary malfunction of the system uptower. During the test period, lock nuts were installed after some of the nuts loosened on the bolts connecting the guy wires to the equalizer plates. Shortly after the duration test ended, the furl cable broke. Neither of these cases caused any system downtime.

DC Bus Overvoltage (Inverter Fault Code 21)
The occurrence of the DC bus overvoltage is one of the main drivers for the low operational time fraction. In high winds (above ±14 m/s), the inverter went into Pause mode. If this happened several times within a certain time period, the inverter went into the DC bus overvoltage fault. This fault had to be reset manually. Although NREL personnel watched the turbine closely, downtime was unavoidable when this fault happened during nights or weekends. It is not clear whether the DC bus overvoltage fault is caused by a fault of the inverter or caused by interaction between the inverter and the turbine or the inverter and the grid.

Figure 2 shows a scatter plot of measured inverter power versus hub-height wind speed based on 10-second averages. Data points during which the inverter was paused were filtered out. This graph shows that around wind speeds of 18-19 m/s (10-second average), the inverter produces up to 12.5 kW, which is higher than the rated power of the inverter. This high power level could be the cause of the DC bus overvoltage fault.

Over-Temperature Fault (Inverter Fault Code 22)
On July 27, 2001, the inverter was found with this fault on the display. The fault could not be reset, and the main inverter board was changed on August 6, 2001. The period between occurrence of the fault and repair of the inverter was counted as downtime. The cause of this fault has not been identified.

The main reasons for excluding time (T_E) in the duration test were:

- Maintenance of data acquisition hardware
- Starting and stopping the turbine to perform noise measurements.

If no reliable measurements were available, the time was classified as Tu. From March 12-23, the counts signal was not working properly; thus no reliable statement on operational time fraction could be made.

Environmental Conditions
As an indication of the environmental conditions during the duration test, the standard asks for reporting of the maximum 3-sec gust and the average turbulence intensity at 15 [m/s]. The maximum recorded 3-sec gust was 43.7 m/s at 2:20 AM on April 7, 2001. The average turbulence intensity at 15 m/s during the duration test was 17.0%.

Power Degradation Checks

Two analysis methods, expected energy ratio and power performance degradation, were used to find any hidden degradation or faults of the turbine that would be reflected in the power performance.

In the expected energy ratio analysis, measured energy is determined from the measured, 10-minute-average power production. Expected energy is determined from the measured, 10-minute-average wind speed. Using that wind speed and the power curve, the "expected" power production is estimated. The expected energy ratio is determined each month by dividing the sum of the measured energy values by the sum of expected energy values. The power curve is obtained from all valid data obtained during the duration test. Therefore the overall energy production ratio is 100%.

The expected energy calculation results are given in Figure 3. Because no clear trend is visible, no hidden defects are expected.

During the power performance degradation analysis, the average power level for certain wind speed bins is plotted as a function of time over the whole test period. This analysis method shows more clearly than the expected energy ratio analysis whether any part of the power curve changes during the test.

Figure 4 shows the power performance degradation plot, which gives the power level in individual wind speed bins for each month. Variations in the power levels are caused by air density variations. Some outliers for the wind speeds above 12 m/s are caused by lack of data points for that particular bin in that month. Using these plots, it was concluded that the power production does not show a clearly increasing or decreasing trend in time; thus there is no reason to expect a hidden fault in the turbine.

Dynamic Behavior

The turbine has been observed over a wide range of wind speeds, mainly during acoustical noise testing or when NWTC personnel visited the site when an inverter fault was suspected. The turbine does not operate at a resonance frequency for long periods of time. The vibrations in the tail, yaw bearing, tower, and guy wires seem normal and should not lead to excessive loads. At high wind speeds, the turbine makes a loud helicopter-like noise which NREL personnel suspect to be blade flutter. When the turbine is shorted, the tower rattles.

Tear-Down Inspection

The turbine's power head was disassembled and inspected. Damage was found on the tail vane and the nacelle cover. The results of the tear-down inspection can be found in Appendix D. The up tower inspection checklist for an inspection that took place on August 6, 2002, can be found in Appendix E. Problems with the guy wires found during an earlier inspection (see test plan) had been solved. We found that grounding of a guy wire broke between the two inspections.

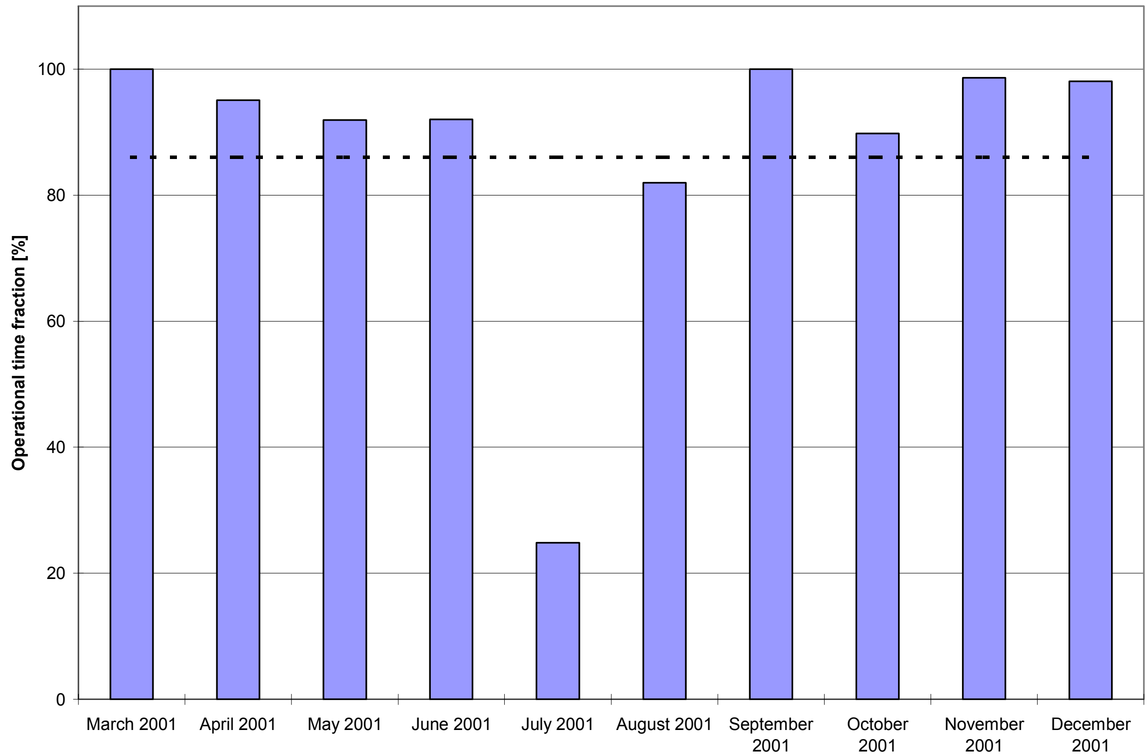

Figure 1. Operational time fraction for each month.

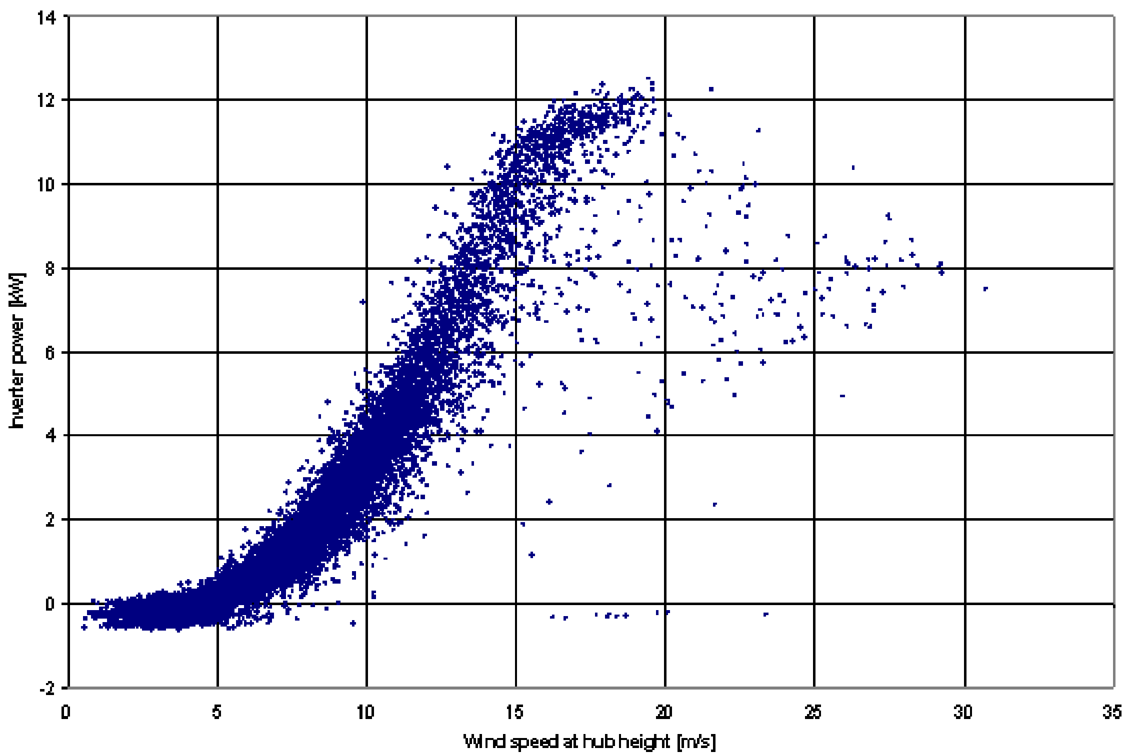

Figure 2. Scatter plot of power versus wind speed (10-second averages).

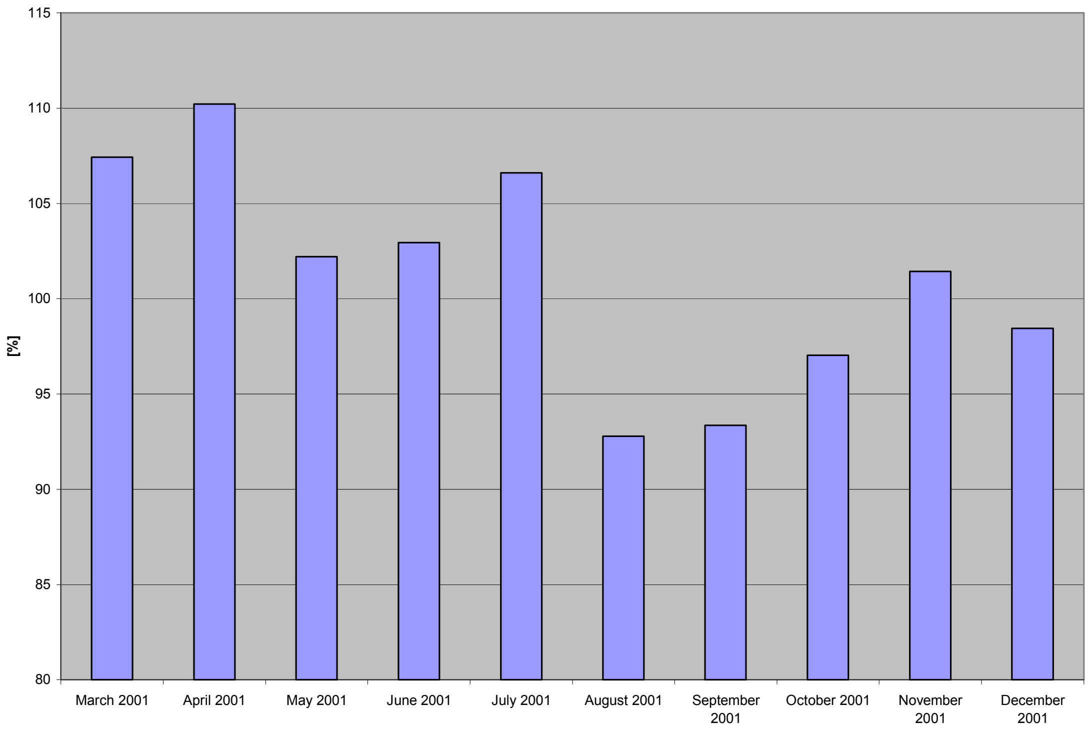

Figure 3. Measured kWh production as a percentage of the expected power production per month.

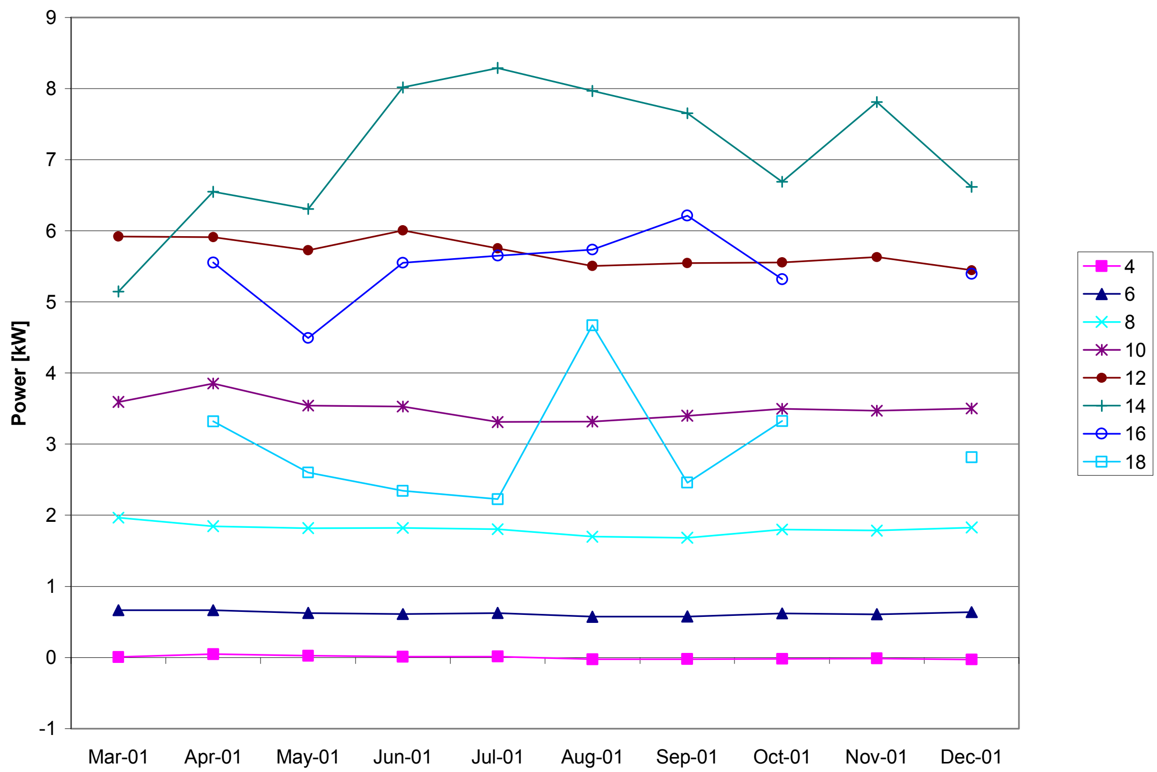

Figure 4. Power level in several wind speed bins (in m/s) as a function of time.

9 Uncertainty

The uncertainty is estimated for the following parameters:

- Hours of power production
- Operational time fraction
- 3-sec gust.

No uncertainty analysis was done for the expected energy and power degradation results. These results were used only to find relative trends, which might indicate hidden faults in the turbine.

Hours of Power Production
For most of the test, NREL did not record the online status of the inverter. Thus we needed to estimate hours of power production based on 10-minute averages of inverter power. We assumed that the turbine was producing power for the whole 10-minute period whenever the average power for that period was larger than zero. This method overestimates time of power production for winds between 4 and 6 m/s. At these wind speeds, the turbine was probably producing power for about half of the time recorded by NREL. At higher wind speeds, the method results in somewhat less of an overestimate. Overall, NREL estimates that the reported time of power production at any wind speed may be 500 hours too high. However, considering that the turbine has been operating for more than 2 years, NREL is confident that the turbine has produced power for many hours in excess of the 1,500 hours required by the draft standard.

For the hours of power production above 10.2 and 15.3 m/s, the uncertainty in the wind speed is assumed to be the dominant factor. Assuming an uncertainty in wind speed of 0.3 m/s leads to an 8% variation in the hours of power production at these wind speeds.

Operational Time Fraction
The total test time is 7,067 hours. Even if the classification of Te and Tn was wrong by 5% (which is a very conservative assumption), the variation in the operational time fraction is less then 1%.

3-Sec Gust
The uncertainties in the wind speed measurements are 0.2 m/s calibration uncertainty, 2% operational characteristics, 0.5% mounting effects, and 3% terrain effects. For the peak recorded 3-sec gust of 43.7 m/s, the uncertainty is 1.3 m/s.

Appendix A: Bergey Excel/Gridtek Duration Test Plan

A1

Wind Turbine Generator System

Duration Test Plan

for the

Bergey Excel-S with Gridtek Inverter

by

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February 2003

Approval By: ______________________________ 27 march 2003
Jeroen van Dam, NREL Certification Test Engineer — Date

Approval By: ______________________________ 31 Mar 03
Hal Link, NREL Certification Test Engineer/Manager — Date

Approval By: ______________________________ 4/2/03
Trudy Forsyth, NREL Field Verification Program Leader — 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)
- Quality of environmental protection
- Dynamic behavior of the Bergey Excel turbine with a Gridtek inverter.

The wind turbine will pass the duration test when it has achieved:

- Reliable operation during the test period
- 6 months of operation
- 1,500 hours of power production in winds of any velocity
- 250 hours of power production in winds of 1.2 V_{ave} (10.2 m/s) and above
- 25 hours of power production in winds of 1.8 V_{ave} (15.3 m/s) and above.

Reliable operation is defined as:

- Operational time fraction 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
- No significant degradation in time of produced power at comparable wind speeds.

If there is a major failure of the Bergey Excel, 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 U.S. Department of Energy's Small Wind Turbine Field Verification Program (FVP). The primary purpose of this program is to provide consumers, manufacturers, and host site organizations with an independent assessment of the performance and reliability of small U.S. wind turbines. In addition, this test may be used to fulfill the duration test requirements identified in IEC WT01 Annex E for wind turbine certification.

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

6.0 Test Turbine

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

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

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

Table 1. Test Turbine Configuration and Operational Data

General Configuration:	
Make, Model, Serial Number	Bergey WindPower, Excel, #9900550
Rotation Axis (H/V)	Horizontal
Orientation (upwind/downwind)	Upwind
Number of Blades	3
Rotor Hub Type	Rigid
Rotor Diameter (m)	7.0
Hub Height (m)	37
Performance:	
Rated Electrical Power (kW)	10
Rated Wind Speed (m/s)	13.0
Cut-In Wind Speed (m/s)	3.1
Cut-Out Wind Speed (m/s)	none
Rotor:	
Swept Area (m^2)	38.4
Blade Pitch Control	Powerflex®, passive pitch with a pitch weight, with increasing rpm the blade flattens
Direction of Rotation	Clockwise viewed from upwind
Rotor Speed	0-350 rpm
Power Regulation (active or passive)	Passive
Tower:	
Type	Bergey guyed lattice
Height (m)	36.5
Control/Electrical System:	
Controller: Make, Type	Bergey Gridtek inverter
Electrical Output: Voltage	Nominal 240-volt single phase
Yaw System:	
Wind Direction Sensor	Tail vane

Figure 1. The Bergey Excel wind turbine.

6.1. General Electrical Layout

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

The electrical interface of the system is the disconnect switch on the grid side of the inverter. Thus all faults on the grid side of this switch will be considered external faults. The mechanical interface of the system is the bolt connection to the foundation. Thus failure of the bolts is considered a turbine fault, but failure of the foundation is an external fault.

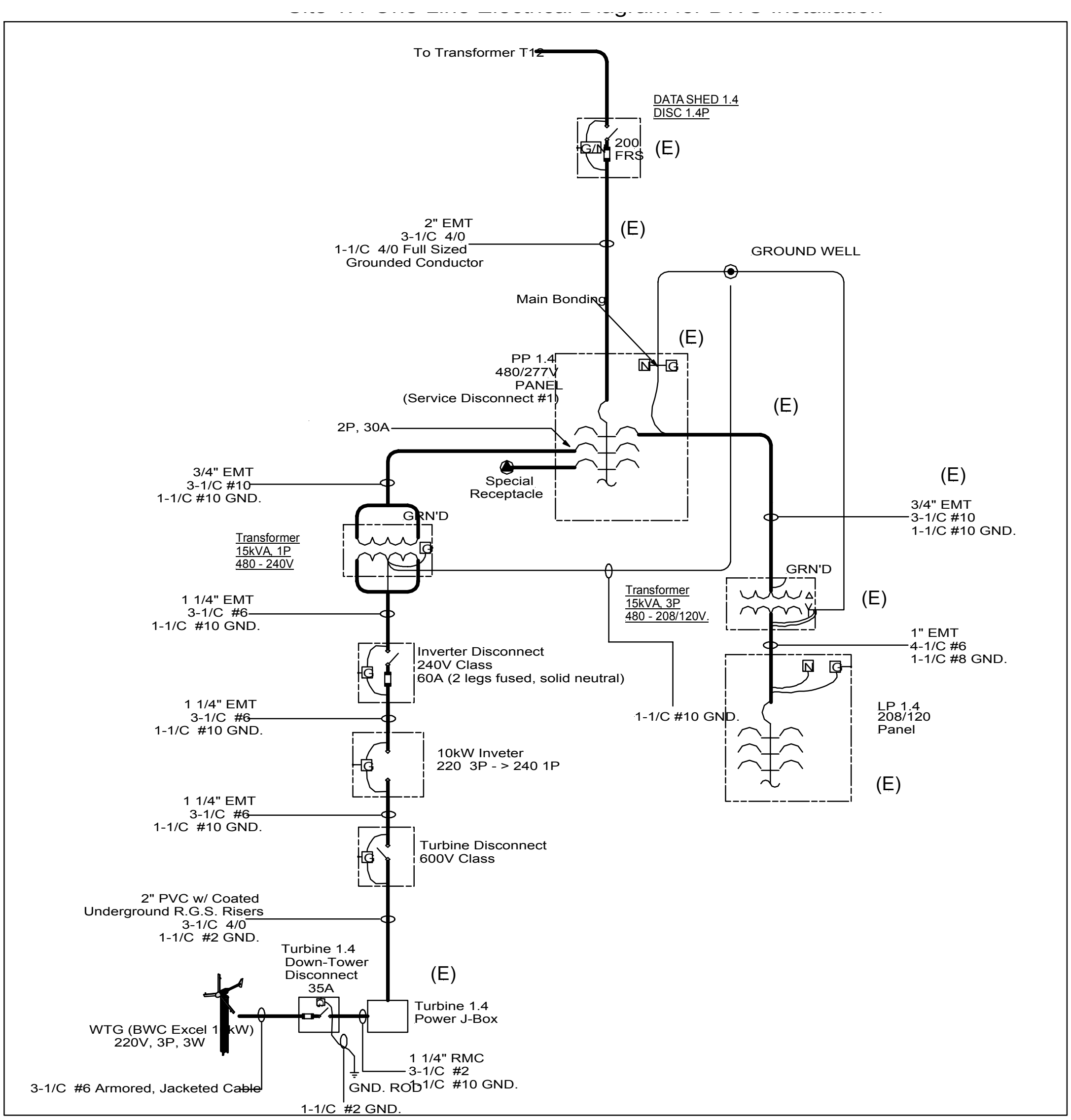


Figure 2. General electrical arrangement.

7.0 Test Site

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

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

For purposes of this test, the allowable measurement sector is 153° to 1° with respect to true north, thus including all westerly winds. The closest operating turbine to the test turbine will be a 900-W Whisper H40 turbine located on a 9.1-m tower. It is located approximately 34.3 m north of the test turbine on site 1.3.

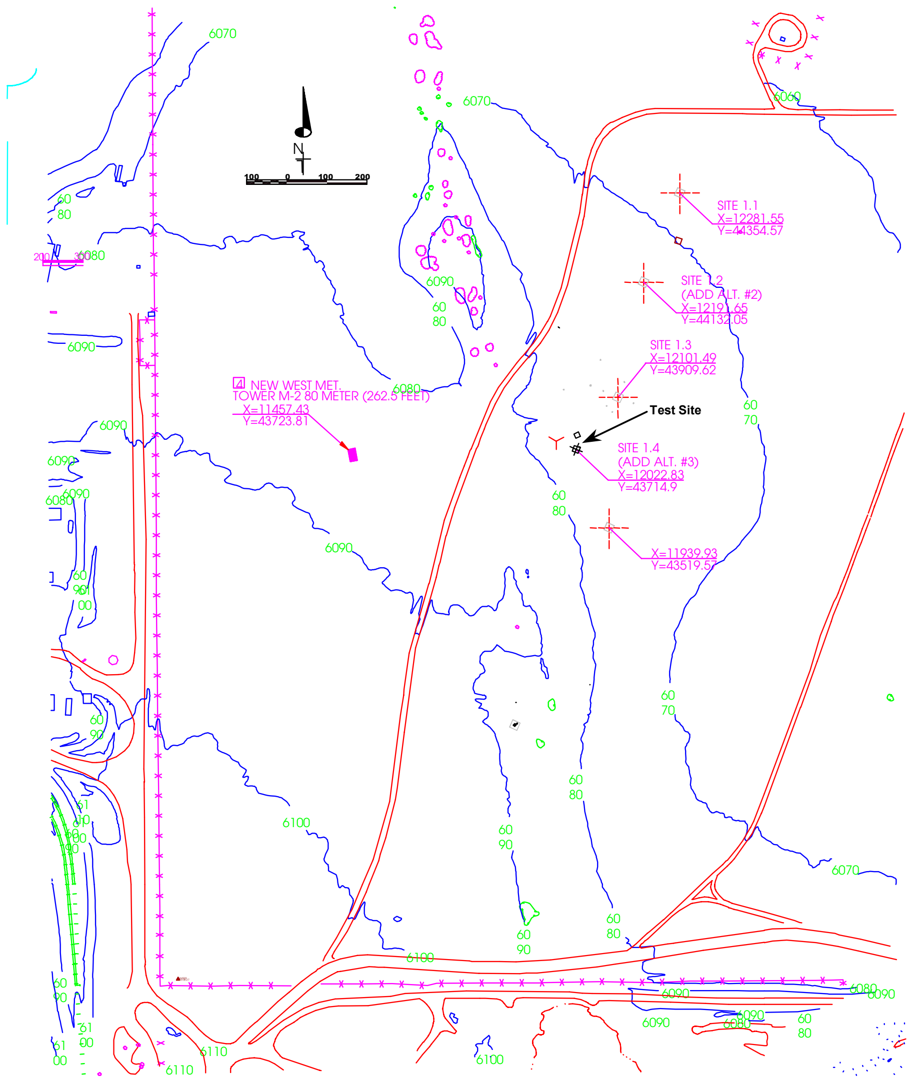


Figure 3. The NWTC test site. The Bergey Excel is located on site 1.4.

8.0 Duration Test

8.1. Overview of Data Acquisition System

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-sec gust during the test period. Availability is further defined in section 9.3. Figure 4 gives the location of the sensors, and Table 2 gives an equipment list that provides the specifications for each of the instruments used.

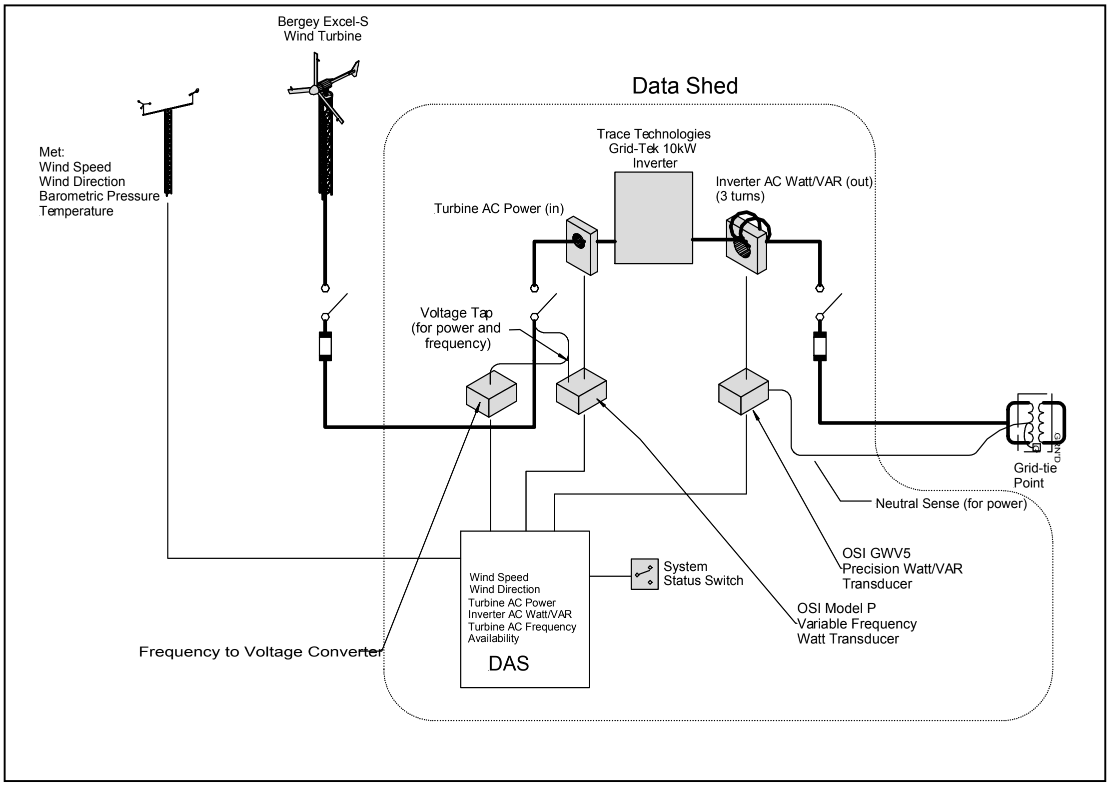


Figure 4. Location of the data acquisition sensors.

Table 2. Equipment List for Duration Test

Power Transducer and CTs (Inverter Power)	
Make/Model:	OSI, GWV5-001EY24 CT pn 12975
Serial Number (Transducer & CTs):	9101376
Range with CTs:	-13.33 to 13.33 kW/kVar
Calibration Due Date:	14 September 2001
Power Transducer and CTs (WT Watts)	
Make/Model:	OSI, P-143E
Serial Number (Transducer & CTs):	9100896
Range with CTs:	0 to 40 kW
Calibration Due Date:	14 September 2001
Primary Anemometer	
Make/Model:	Met One, 010C with Aluminum Cups
Serial Number:	Y4397
Calibration Due Date:	20 February 2002
Secondary Anemometer	
Make/Model:	Met One, 010C with Aluminum Cups
Serial Number:	X4233
Calibration Due Date:	20 February 2002
Wind Direction Sensor	
Make/Model:	Met One, 020C with Aluminum Vane
Serial Number:	U1477
Calibration Due Date:	20 February 2002
Barometric Pressure Sensor	
Make/Model:	Vaisala, PTB101B
Serial Number:	T3330002
Calibration Due Date:	19 December 2002
Atmospheric Temperature Sensor	
Make/Model:	Met One, T-200 RTD
Serial Number:	0653393
Calibration Due Date:	12 December 2001
Datalogger	
Make/Model:	Campbell Scientific CR23X
Serial Number:	1214
Calibration Due Date:	31 January 2002
Frequency Input, Field Configurable Isolator	
Make/Model:	Action Instruments Ultra Slim Pack G478-0001
Serial Number:	B2MCD
Voltage Transducer (for rpm)	
Make/Model:	OSI VT7-009X5
Serial Number:	8102964

8.2. Turbine Inspection and Site Commissioning

An inspection for turbine degradation took place on September 27-28, 2001. The turbine was examined for any defects, signs of damage, and proper functioning. The completed checklist can be found in Appendix B.

8.3. Instrumentation Check

After the instruments have been mounted in the locations detailed in Figure 4, the test technician tests their functionality and aligns the wind vane using distant landmarks to set 0° toward true north. 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. After the in-field checks are completed, the test engineer closely examines the first 6 hours of collected data to ensure proper operation of all instruments.

8.4. Measurement Procedures

All instruments will be sampled by the datalogger at a rate of 1 Hz. The output data will be the 10-minute statistics: the average, standard deviation, minimum, and maximum values. For status signals, the datalogger records the percentage of time during each 10-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 whether 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 engineer will note if any problems have arisen. If so 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 in the determination of power performance and note whether data are used in the test report.

If the test site or turbine changes during the test, the test engineer will determine whether 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.

Maintenance procedures for the turbine, as outlined in the owner's manual, will occur approximately 30 days after the installation and after any severe windstorms. All maintenance activities will be clearly documented in the logbook.

When the turbine is furled for a routine inspection or any other reason not associated with turbine operation (e.g., data logger change or routine maintenance), the three-way availability switch will be put in the "DAS fault" position, and this will be indicated in the logbook. This time period will not enter into the turbine availability calculation. For the purpose of duration testing, the turbine will be considered to be unavailable if it is not operational due to any problems associated with the wind turbine system. This will include any problems with the turbine on the tower, the fuse, or the inverter.

The dynamic behavior will be assessed visually at several wind speeds during the test period. NREL personnel will observe the turbine for a few minutes, feel the guy wires and the tower, and listen for any unusual turbine noises. A note will be made in the logbook, including an indication of the wind speed at the time of observation.

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 the turbine system will be disassembled and a non-destructive tear-down inspection will be performed in an NREL laboratory.

The test engineer will document the turbine condition using a checklist and photographs. He will note any changes in the turbine as compared to when it was commissioned. For example, blades will be checked for cracks, turbine yaw will be checked, all turbine fasteners will be checked, the fuse will be checked, and the grounding for the turbine will be checked. Any deviations from the expected condition will be documented in the final report.

9.0 Analysis Methods

9.1. File Structure

NREL uses three Excel™ spreadsheets to analyze duration test data. Every week, the Campbell data file is added to a "raw data" spreadsheet. This spreadsheet is used to make sure there is no overlap between data files and make sure that no time stamps are missing. If the data file format has changed, the columns are put in those columns where the monthly spreadsheet expects them to be.

Every month, data is copied from the "raw data" file into a monthly analysis file. First a manual check of the signals is performed. After the data has been classified as valid or invalid, the automatic processing takes place. Finally, the logbook is used to check the correct availability classification.

The monthly results are linked to an "overall results" spreadsheet. The power degradation and expected energy plots are made, and the overall results for the whole test period are calculated.

9.2. Data Validity Checks

Flat spots, spikes, or clipping of data can be noticed by plotting time series of the average, standard deviation, minimum, and maximum of the signals. Scatter plots of power vs. wind speed, 3-sec gust vs. maximum wind speed, and rpm vs. wind speed are useful in spotting outliers, which may indicate something wrong with the turbine or the data acquisition system.

9.3. Data Processing

There are several parts of the analysis for which a data point can be used. Table 3 lists conditions under which a data point qualifies for a certain part of the analysis.

Table 3. Conditions Under Which a Data Point Can Be Used for Parts of the Analysis

Part of the Analysis	Data Acquisition System Functional *)	Power	Wind Speed	System Avail	WD in Meas. Sector	3-Sec Gust
Power production at any wind speed	✓	>0		✓		
Power production above 10 m/s	✓	>0	>10.2	✓		
Power production above 15 m/s	✓	>0	>15.3	✓		
Expected energy	✓	✓	✓	=1.0	✓	
Power degradation	✓	✓	✓	=1.0	✓	
Average TI at 15 m/s	✓		14.5 > WS > 15.5		✓	
Max 3-sec gust	✓		✓			✓

*) Data acquisition system functional means: -40°C<T_{air}<80°C and $V_{logger\ battery}$>11 [Volt]
✓ means that after a visual check that channel was found to operate normal.

Hours of Power Production

The spreadsheet calculates the amount of power production time based on a positive current flow to the utility grid. The spreadsheet accrues the total recording time, total turbine power production time, production time in winds at or above 1.2 V_{ave} (10.2 m/s), and production time in winds at or above 1.8 V_{ave} (15.3 m/s).

Power Degradation and Expected Energy Ratio

For the power degradation and expected energy ratio, two power curves are made. The monthly power curve is linked to the "overall results" spreadsheet in which the power levels are plotted against time and an overall power curve for the whole test period is derived.

For the expected energy ratio, the overall power curve is used to determine an expected power level based on the measured wind speed. Once per month, the measured power levels are integrated to calculate measured energy and the expected power levels are integrated to calculate expected energy. The ratio of measured energy over expected energy is the expected energy ratio.

Operational Time Fraction

The operational time fraction is defined as follows:

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

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.

A three-position switch will be mounted in the data shed. Normally the switch is in the Available position. If the turbine is shut down because of reasons that cannot be counted against the turbine (e.g., DAS maintenance, shutdown because of noise test), the switch will be moved to the DAS Fault position. If the turbine is shut down because of a turbine fault, the switch will be put in the Turbine Fault position.

To classify time as T_A, T_E, T_U, or T_N, a combination of signals is used:

- Availability. This channel tracks the percentage of time for which the three-way switch was in the turbine fault position.
- Counts. This channel counts the number of 1-Hz samples in a 10-minute average. The channel does not count if the three-way switch is put in either Turbine Fault or DAS Fault.
- Inverter fault. This signal watches the orange and red LED in the inverter, which indicate an inverter fault or pause.

These channels are used in the combination given in Figure 5. After the spreadsheet has automatically applied the criteria from Figure 5, the analyst uses the logbook to override the spreadsheet if needed.

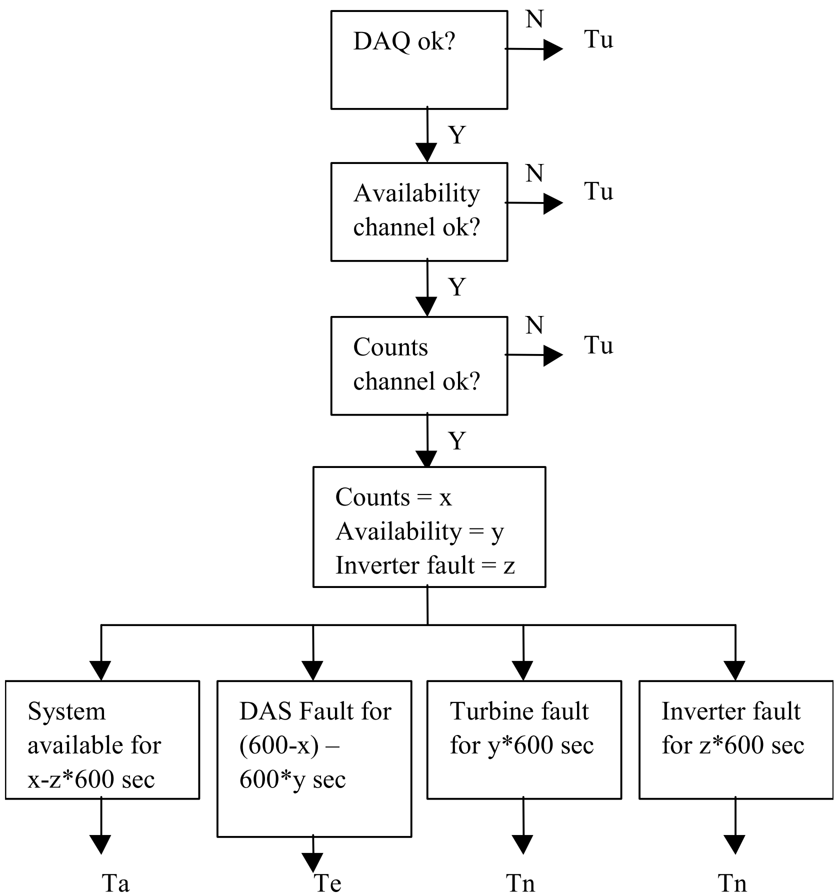


Figure 5. Classification of time for operational time fraction.

9.4. Uncertainty

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

- Operational time fraction
- Hours of power production
- Peak 3-sec gust.

The major contribution to uncertainty in measured turbine availability is the amount of time during which data were lost. In general, similar operation can be assumed in the periods in which data were lost.

The uncertainty in the hours of power production above a certain wind speed is influenced by the uncertainty in the wind speed measurements. Another source of uncertainty is the time when data were lost. NREL will quantify this uncertainty by assuming that the wind speed distribution during periods of lost data is comparable to the distribution measured when data are valid.

The peak 3-sec gust will be driven by the uncertainty in wind speed measurements, including anemometer calibration, 0.2 m/s; operational characteristics, 2%; mounting effects, 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.

10.0 Reporting

10.1. Progress Reports

The test engineer will compile a progress report every month. This report will summarize:

- Status of the test
  - Number of hours of data obtained for wind turbine generation and percentage to completion (defined as number of generating hours/1500)
  - Number of turbine generation hours with winds ≥ 10.2 m/s (10-minute average)
  - Number of turbine generating hours with winds ≥ 15.3 m/s (10-minute average)
  - Maximum 3-sec gust over the whole test period
  - Average TI at 15 m/s
- Anticipated completion date based on typical wind patterns and 100% availability
- If a problem is present, a description of the problem and the status of its resolution. Digital pictures will be used to capture specific details whenever possible.

This report will be sent to the field verification program leader, the test technician, and the certification test manager.

10.2. Unusual Occurrence Report

In addition to the reporting described above, NREL will record any unusual occurrences with the turbine and document them in the final report.

10.3. Final Report

After the test has been completed, NREL will document the test results in a test report. The test report will include this test plan and:

- A statement indicating whether the turbine has passed or failed the test
- Total number of hours of data obtained for wind turbine power generation and a breakdown of the hours into three battery-operating voltage ranges; number of turbine generation hours with winds ≥ 10.2 m/s (10-minute average); number of turbine generating hours with winds ≥ 15.3 m/s (10-minute average)

- Calculation of turbine operational time fraction for the test period
- Maximum 3-sec wind speed and average turbulence intensity at 15 m/s for the test period
- A power degradation plot and expected energy plot
- Compilation of the important entries into the duration test logbook with summary of all observations, including unusual occurrences and description of any potential problems (digital pictures will be used as appropriate)
- Copies of the signed commissioning checklist and the final turbine inspection
- Any exceptions to this test plan
- Data collection dates including any excluded times due to equipment failure.

11.0 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)
Certification Test Manager	Hal Link	NREL	Approves test plan
Test Engineer	Jeroen van Dam	NREL	Manages and is responsible for test Serves as customer contact person Authorizes any deviations from planned test procedures Supervises performance test set-up, checkout, and conduct Analyzes test data Identifies problems based on data analysis results Reports test results Serves as primary point of contact between CTG and the test site manager
Test Technician	Mark Meadors	NREL	Selects instruments Installs and checks test equipment Downloads and stores test data Implements corrective actions for problems
Turbine Maintenance Technician	Scott Wilde	NREL	Maintains test turbine in accordance with manufacturer's recommendations Records all maintenance activities or observations in test log

12.0 References

1. IEC WT01 (2001-04), International Electrotechnical Commission (IEC), IEC System for Conformity Testing and Certification of Wind Turbines - Rules and Procedures.
2. IEC 61400-2 (1996-04), International Electrotechnical Commission (IEC), Wind Turbine Generator Systems - Part 2: Safety of Small Wind Turbines.

APPENDIX A: Instrument Calibration Sheets

OHIO SEMITRONICS, INC.

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

CERTIFICATE OF COMPLIANCE

MODEL P-143E COMPANY N.R.E.L. NATIONAL WIND TECH.

SERIAL NO. 9100896 PO# M MEADORS OSI PO# NA RMA# 12322

DATE 9-13-00

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

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

EQUIPMENT USED:

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

ABOVE EQUIPMENT IS TRACEABLE TO:

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

TEMP. 73°F

HUM. 69%

OHIO SEMITRONICS, INC.
Company

Quality Assurance

Dwg. #A-7003-02

THE LEADER IN POWER MEASUREMENT

OHIO SEMITRONICS, INC.

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

CERTIFICATE OF COMPLIANCE

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

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

DATE 9-13-00

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

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

EQUIPMENT USED:

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

ABOVE EQUIPMENT IS TRACEABLE TO:

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

TEMP. 73°F

HUM. 69%

OHIO SEMITRONICS, INC.
Company

Quality Assurance

Dwg. #A-7003-02

THE LEADER IN POWER MEASUREMENT

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

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

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

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

DEWI Anemometer Calibration

Calibration No.	**1103_00**
Object	**Cup Anemometer**
Manufacturer	**Met One Instruments USA**
Type	**010C-1**
Serial number	**Y4397**
Cup number	**Y4397**
Customer	**NREL Golden, Colorado**
Date	**12/14/00**
Remarks	**no**

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

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

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

Wilhelmshaven, 14.12.2000

i.V. Dipl. Phys. D. Westermann

DEWI · Deutsches Windenergie-Institut · German Wind Energy Institute · measnet

i.A. Dipl. Ing. K. Junior

DEWI Calibration No. 1103_00

MET ONE INSTRUMENTS INC.

TEST CERTIFICATION

SENSOR MODEL # 010 B/(C) SERIAL NO. X 4233

SALES ORDER # 986992 CUSTOMER NREL

TEST DATE 1/17/01 TESTED BY Mark Russell

PO NUMBER V159

Room Temperature 20°C Room Humidity 30%

TEST STANDARDS:

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

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

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

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

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

Wind Vane Calibration Report

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

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

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

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

Report Number: U1477-000614

Page: 1 of 1

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

Deviations from procedure: None

Item Calibrated:

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

Results:

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

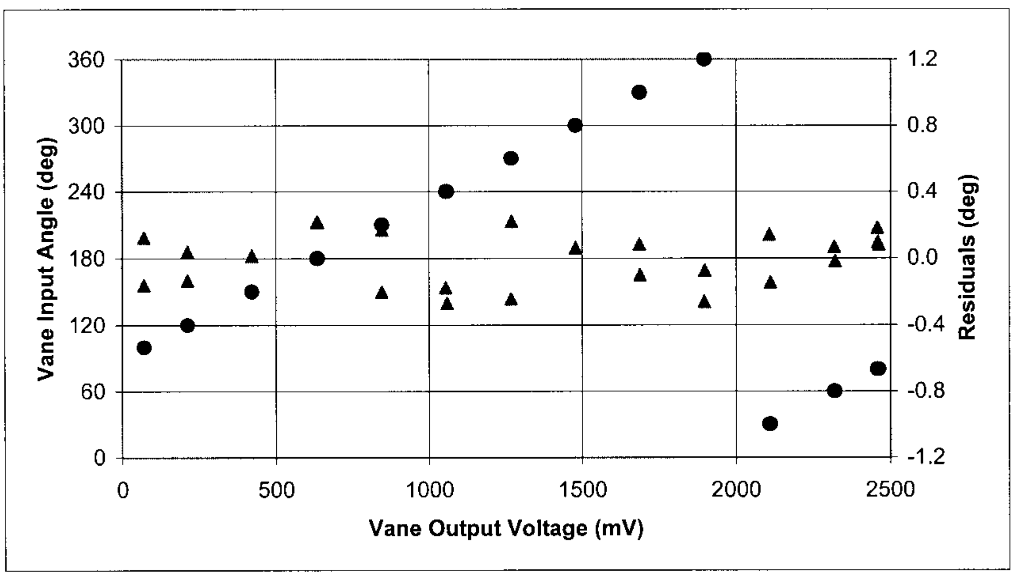
Estimated Uncertainty:

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

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

Calibration by: Mark Meadors (signature) Mark Meadors

Date 6/14/00



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Calibration Certificate

INSTRUMENT REPAIR LABS INC.

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

Company Name:	National Renewable Energy Lab	**MFG:**	Vaisala
Certification#:	001128059	**Model:**	PTB101B
Calibration Location:	Subcontractor	**SN:**	T3330002
Customer's P.O. Number:		**Barcode:**	17816
Received Status:	In Tolerance	**Cust ID:**	
Returned Status:	In Tolerance	**Temp:**	72 F
Procedure Used:	MFGR Cal Procedure	**RH:**	35 %
Calibration Date:	12/19/2000	**Rec. Cal. Due:**	12/19/2001
Standards Used:	Subcontracted - See attached		
Calibration Remarks:	Calibrated by CEESI, reference certificate		
Description:	Absolute Pressure Transducer		

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

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

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

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

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

Branch #: 5000 | sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: RTD Probe | DOE #: 02683C

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

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

Nu	Nominal Values		Measured Values		
	Nominal Resistance	Equivalent Temperature	Measured Resistance	Equivalent Temperature	Temperature Error(M-N)
1	94.12 Ω	-15 ℃	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 SCIENTIFIC, INC.

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

Certificate of Calibration

Customer:

Company Name: NATIONAL RENEWABLE ENERGY LAB

City/State/Strt: 18200 STATE HWY 128
ARVADA, CO 80007 US

PO #:

RMA #: 2742

Contract #:

Log Option: 2

Model: CR23X-4M Serial Number: 1214

Test Panel Loc. 1

CSI Calibration Number: 12510

Calibration Procedures: PRC32A R6 TST10517B R1 TST10517C R17

Instrument Calibration Condition

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

Recommended Calibration Schedule

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

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

Report of Calibration Standards Used

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

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

Quality Control Manager responsible for content of certificate: Clint Howell

Remarks:

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

Page 1 of 2

APPENDIX B: Turbine Inspection Checklist for the Bergey Excel

At the conclusion of the duration test, the turbine will undergo a final inspection on the tower before it is taken down and the Component Wear and Durability Assessment is performed. The same inspection will be performed halfway through the duration.

This checklist helps document the state of the turbine at the time of inspection. Small changes in the turbine as compared to when it was originally installed and commissioned should be noted, and any deviations from normal should be further inspected once the turbine is removed from the tower.

Conducted by: Jerry Bianchi, Jeroen van Dam   Date: September 27-28, 2001

The winds on September 27 were around 3-5 m/s, coming from the west. On September 28, the wind speed was below the cut-in wind speed (3 m/s).

Task	Comments/Findings:
1. Inspect each of the anchor points. Ensure that all hardware is secure and the guy wires are properly tensioned. Check to ensure that no strands are broken.	No broken strands found. On the top west guy wire, only one thread turn is visible through the nuts on the clamps (Figure 2). On two of the anchor points, there is no lock nut on the bottom guy wire and the nut is not turned on all the way (S-E and N) (Figures 3, 4 and 5). The tension of the guy wires was checked through the eigenfrequency of the wires as recommended in the installation manual. The observed values are given in Table 1. Figure 1 gives the recommended values. A deviation of 1 second is allowed. All guys, except for the top guys, seem to have too much tension on them.
2. Check the turbine's grounding.	The guy wires are each connected to a ground rod. The tower is grounded to the frame of the electrical boxes located on the side of the foundation. The frame on its turn has a wire going to ground.
3. Furl the turbine and check that the damper restricts the tail's unfurling to a period of at least 3 seconds when the winch cable is rapidly released.	It takes about 5 seconds for the tail to return to normal position. There are some loose strands in the furl cable on the winch. The cable also does not follow a clean path on the winch drum.

Task	Comments/Findings:
4. While climbing the tower, check the following: tower fasteners, any cracks, guy wire attachments, furl cable, and the furl cable swivel.	All tower fasteners are secure. No cracks are visible. No loose strands in the furl cable were noticed. The center guy wire on the western side of the tower does not seem to be properly installed. The wires cross in the second clamp and the dead end is not straight between the two clamps (Figure 6). Some crossbars are bent at the bottom of the tower.
5. With the turbine braked, the rotor should turn with strong resistance. With the brake released, the rotor should spin easily and smoothly.	The turbine phases were shorted in the down tower junction box. The rotation of the rotor was hard but smooth.
6. Visually inspect the rotor blades for: • Cracks (especially near the hub and just past the stiffener) • Condition of the leading edge tape (especially outboard of the pitch weight) • Tip damage.	Only the downwind side of the blades could be inspected from the tower. No cracks were observed. The pitch weights lost their paint cover. The leading edge tape was intact. No dents or damage on the tips was noticed. The leading edge had some insect buildup.
7. Remove the nose cone and check blade nuts (recommended torque is 150 ft-lbs). Check the main bearing for play. Check the seal for integrity and loss of grease.	This was not performed. During removal of the blades with a man basket on a different Bergey Excel, it was found that the required torque is hard to apply. Being suspended from the tower this time, it seemed impossible to put enough torque on the bolts.
8. Manually yaw the turbine—it should be smooth without shocks.	Starting the turbine's yaw is difficult, but once there is some momentum, the yawing continues easily and smoothly.
9. Check the yaw bearing for play.	Due to the weight of the turbine, this was difficult to check. No play was observed (most likely caused by the turbine weight, which caused the bearing to be under a preload).
10. Check the furl bearing for play.	The same is valid as for the yaw bearing.

Task	Comments/Findings:
11. Check fasteners for presence and torque, if possible. All should be present and should have a reasonable torque. Recommended torque for alternator, mainframe connection is 80 ft-lbs.	All fasteners and split pens were present. There were no signs of bolts loosening.
12. Check rear alternator bearing for seal integrity and grease loss.	The seal is intact; no signs of grease loss.
13. Check windings and magnet of generator, as far as they are visible.	Some windings are visible through the louvers in the alternator, but the view is not good enough to make a statement of their condition.
14. Open the nacelle junction box to check electrical wiring.	No signs of damage or wear on the terminal strip. All the connections on the strip were tight (Figure 7).
15. Remove the slip ring cover plate and: • Check brushes for ease of movement in the brush holder • Check slip rings for signs of arcing damage • Check that no grease has leaked from the yaw bearings onto the slip rings • Take pictures.	The wire connection to the slip rings had no damage. The slip ring races had no signs of uneven wear. The races had some lubricant on them (Figure 8).
16. Check the yaw damper. Some leakage around the front seal is OK. Take picture of current state.	The visible parts of the yaw damper looked OK. There were no signs of leakage (Figure 9).
17. Check the furl cable.	The furl cable in the nacelle had no broken strands, and the connection to the tail had no visible cracks or deformation.
18. Check tail boom and fin for cracks or loose hardware.	Seen from the tower, all fasteners were present and no damage was observed on the tail boom and tail vane.
19. Check the turbine for any oil, grease, cracks, corrosion, or wear.	No corrosion visible. The shield of the furl cable had some wear. Since there are no parts near the location of the wear, this must have happened before or during installation. No signs of grease were found. Traces of bird feces were found in the nacelle.

Table 1. Observed Time in Seconds for Guy Wires to Complete 20 Oscillations

Guy Wire:	West		Southeast		North		Recommended
Observation:	1	2	1	2	1	2	+/- 1 sec
Bottom	5.6	5.5	5.6		5.2	5.3	7.5
Middle	7.5	7.5	8.1	8.1	7.4	7.3	10.2
Top	13.4	13.2	13.5	13.7	14.1	14.0	13.8

The measured distance from the tower to the guy wires was 59 ft.

Guy levels are assumed to be 31.4, 71.4, and 108.6 ft.

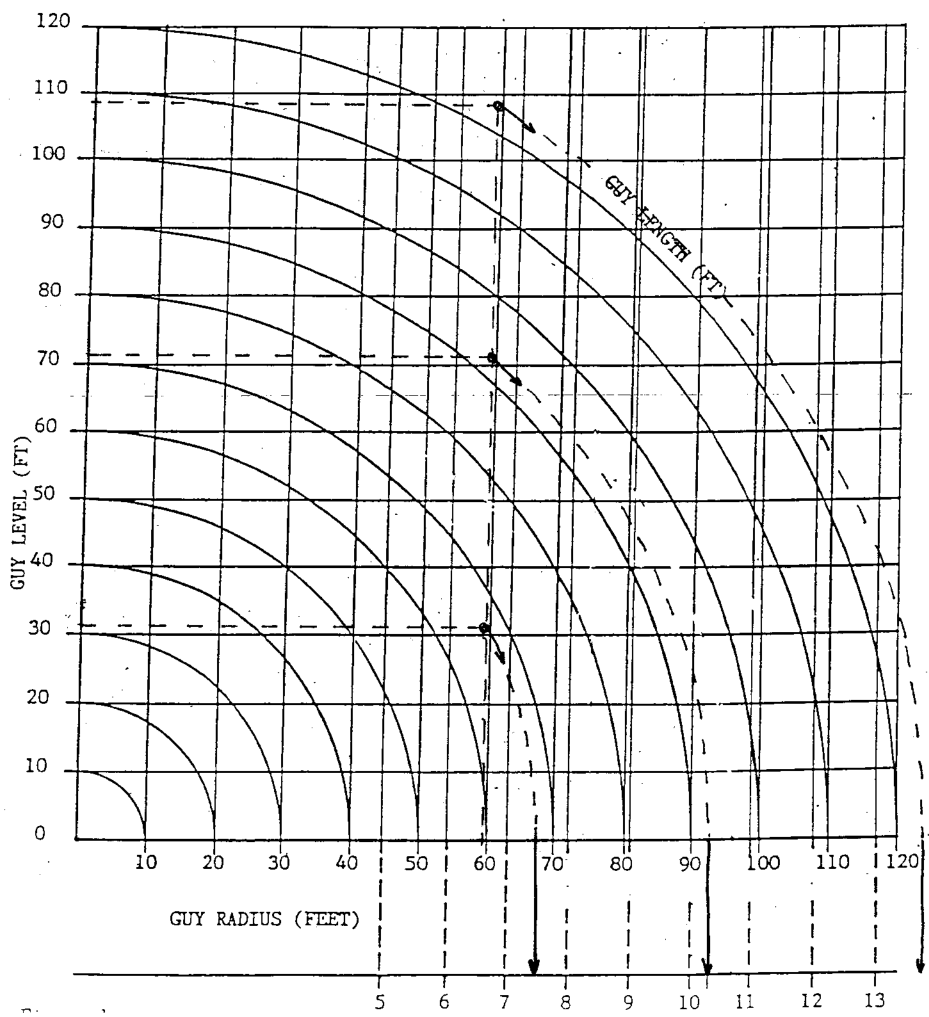

Figure 1. Graph from Bergey Excel installation manual for checking guy wire tension.

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Figure 2. The wire clamps on the top west guy wire.

Figure 3. The southeast anchor point. Note that the bolt of the bottom guy wire does not have a lock nut on it and the nut is not tightened.

Figure 4. Close up of the equalizer plate on the north guy anchor. Note that the bottom guy wire does not have a lock nut.

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Figure 5. Equalizer plate on north guy anchor. Note that the bolt of the bottom guy wire is not secured all the way.

Figure 6. The western middle guy wire connection to the tower.

Figure 7. The up tower terminal strip.

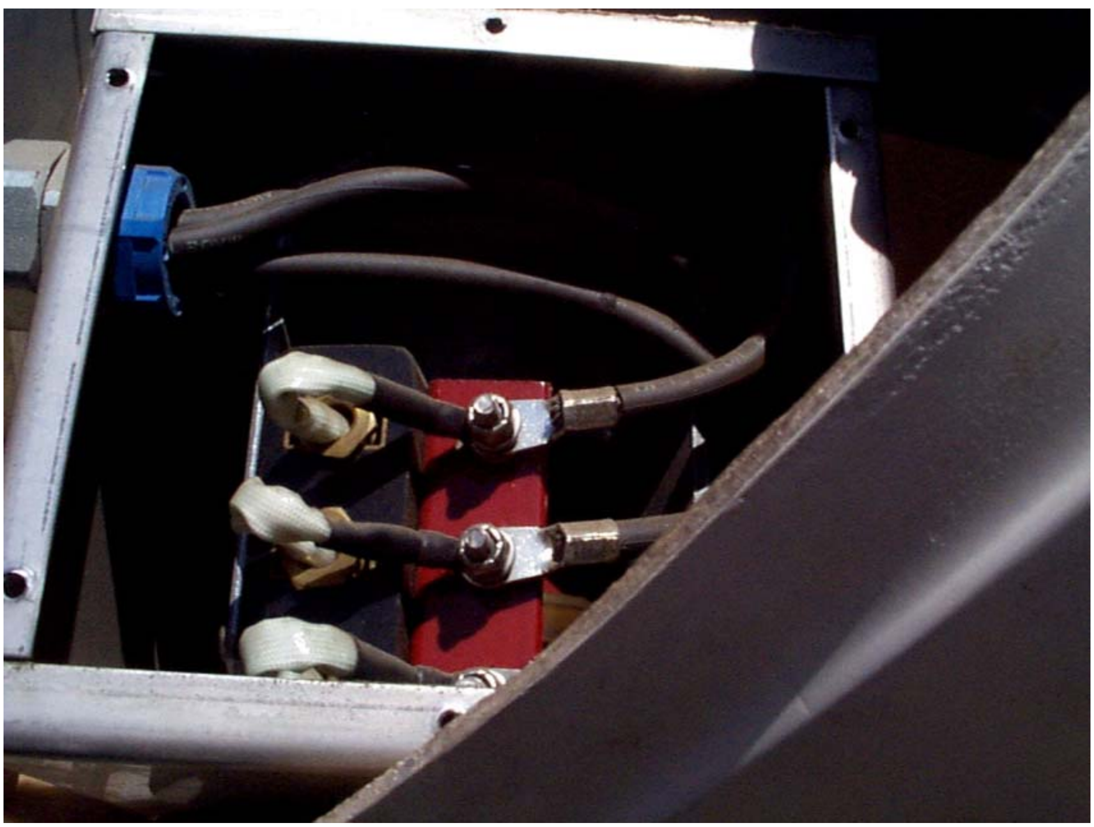


Figure 8. The slip ring assembly.


Figure 9. Nacelle (1).


Figure 10. Nacelle(2).

Figure 11. The tail.

Appendix B: Text from the Draft Revision of IEC 61400-2 Used for the Bergey Excel Duration Test

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."

9.3 ***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 behaviour 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 at least 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.
In the case of a battery connected turbine, the battery voltage shall be varied during the test to simulate normal turbine use.

9.3.1 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

9.3.1.1 **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 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-down 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:

$$O = \frac{T_T - T_N - T_U - T_E}{T_T - T_U - T_E} \times 100\% \qquad (1)$$

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 (T_U 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.

9.3.1.2 **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. If there is trend visible, investigation should take place to the cause of that trend.
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.

9.3.2 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 behaviour by observation or instrumentation.

Appendix C: Calibration Sheets of Instrumentation Changes

Center #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Transducer DOE #: 02792C

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

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

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

Tested By: Reda
Date : 11/15/2001

C1

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Transducer DOE #: 02793C

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

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

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

Tested By: Reda
Date : 11/15/2001

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Pressure Transmitter DOE #: 02794C

Model # : PTB101B S/N : S2830007

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

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

Note:
Uncertainty of the nominal value is ± 1 mb

Tested By : Reda
Date : 11/16/2001

RTD Calibration Certificate

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

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

Calibrated for:
NWTC - Certification Team

Procedure:
CI02 Calibrate RTD 011129
Deviations: NONE

Item Calibrated:

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

Cal Date: November 19, 2001

Results:

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

*over temperature range of -20 to +45 C

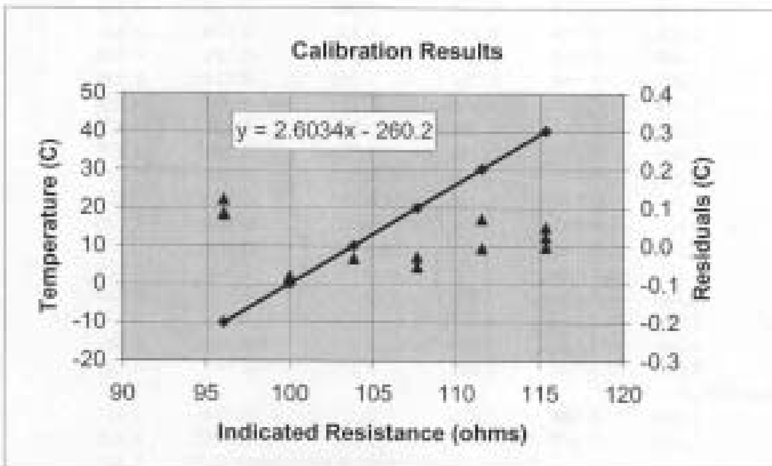
Certificate Number / File Name:
RTD Cal 0464507, 011119.xls

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

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

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

Mark Meadors — 19 Nov '01
Mark Meadors   Date



RTD Cal 0464507, 011119.xls   Page 1 of 2

C4

Phoenix Contact Universial Frequency Converter Calibration

Date Calibrated:	3/1/01
Report No:	F-to-V 0103011
Calibration Laboratory:	National Renewable Energy Laboratory 1617 Cole Blvd Golden, CO 80401
Cal Location:	National Wind Technology Center 18200 State Hwy 128 Boulder, CO 80303
Technician:	Mak Meadors x
Frequency Source: S/N: Calibrated by: Date: Cal Due:	Fluke Documenting Process Calibrator, Model 743B 6965608 Instrument Repair Labs 11/14/00 11/14/01
Voltage Measurement: S/N: Calibrated by: Date: Cal Due:	Campbell Scientific Model 23X Datalogger 1214 Campbell Scientific 1/13/01 1/13/02
Device(s) calibrated: Model: S/N: Calibration Method:	Ultra Slim Pack Frequency Input, Field Configurable Isolator G478-0001 B2MCD GI27 010227, Calibrate frequency to voltage devices
Device Condition:	Good

Calibration Uncertainty:

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

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

Calibration Factors:

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

F-to-V Cal, Ultraslimpack 010302.xls

Page 1 of 2

Appendix D: Tear-Down Inspection Report

Bergey Excel Tear-Down Report

Jeroen van Dam, Jim Adams, Trudy Forsyth
September 10, 2002

After completion of all FVP tests, the powerhead of the Bergey Excel turbine was torn down and thoroughly inspected. This report describes the findings of that tear-down, which took place between August 19 and September 4, 2002. The turbine had been on site for three years, operating for most of that time period.

Blades

The blades, which were inspected, were the new blades with SH3052 airfoil, which had been installed on the turbine on March 18, 2002. All blades had cracks near the transition from the hub to the airfoil. The crack on the low-pressure side of blades 1 and 2 can be seen in Figure D.1 and Figure D.2. It is not clear whether these are surface cracks or structural cracks. The paint had eroded from the leading edge tape of blade 1. The leading edge tape is still intact, so this is only cosmetic (Figure D.3).

Nacelle Frame and Cover

All welds on the nacelle frame look fine. There are some unexplained indentations on the top of the yaw shaft (Figure D.4). These were most likely caused during production and were there before the turbine was installed. On the nacelle cover, cracks were found near some of the bolt holes for the bolts connecting the cover to the nacelle frame (Figure D.5).

Tail

The tail boom does not show any abnormalities. Cracks were found on the tail surface near the lower upwind bolt and around the two most downwind bolts. The cracks near the downwind bolts are through cracks, and these cracks seem serious enough to require replacement of the tail (Figure D.6 and D.7). The tail hinge does not show any abnormal signs of wear.

Generator

The magnet can has corrosion on the contact surfaces of the blades (Figure D.10). There are some surface scratches on both the windings and the magnet can, which are most likely caused by assembly and disassembly (Figure D.8). The windings do not show any sign of overheating (Figure D.9).

Bearings

Locktite™ had been used to install the yaw bearings. Green traces of it can be found on the yaw bearing, as shown in Figure D.11. Corrosion was found on the main shaft under the front rotor bearing (Figure D.10). Grease was found near the seal of the lower yaw bearing—it is not clear if this grease had come out of the bearing. All four bearings (two yaw bearing and two rotor bearings) have been sent to Barber Nichols. Their report is included in this appendix. The bearings were found to be in good condition.

Slip Rings

The slip rings do not show any sign of wear. The top slip ring track and brush have grease on them (Figure D.11 and Figure D.12). This grease is either grease used to install the lower yaw bearing or grease that leaked from the lower yaw bearing. The grease dripped onto the top slip ring channel.

Furl Damper

The furl damper shows some sign of leakage, which is considered normal according to the owner's manual (Figure D.13). Some damage was found on the plastic cover around the furl cable. This damage was reported earlier during field inspections of the turbine. Because there are no moving parts near the cable, it is assumed that the damage occurred before turbine installation.

Figure D.1. Hub-blade transition of blade 1, low-pressure side.

Figure D.2. Hub-blade transition blade 2, low-pressure side.

Figure D.3. Paint erosion on leading edge of blade 1.

Figure D.4. Indentations on the top of the yaw shaft.

Figure D.5. Cracks near a bolt hole on the nacelle cover.

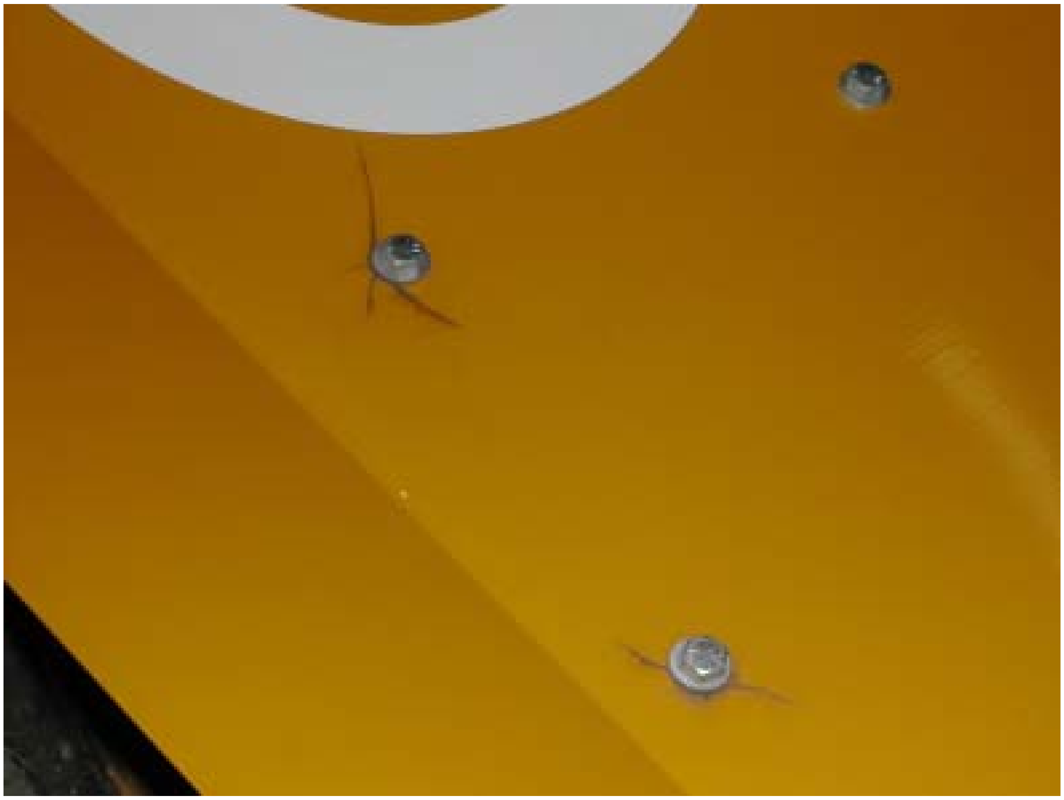


Figure D.6. Cracks near the downwind bolts on the tail vane.

Figure D.7. Same cracks as in Figure 6, seen from other side.

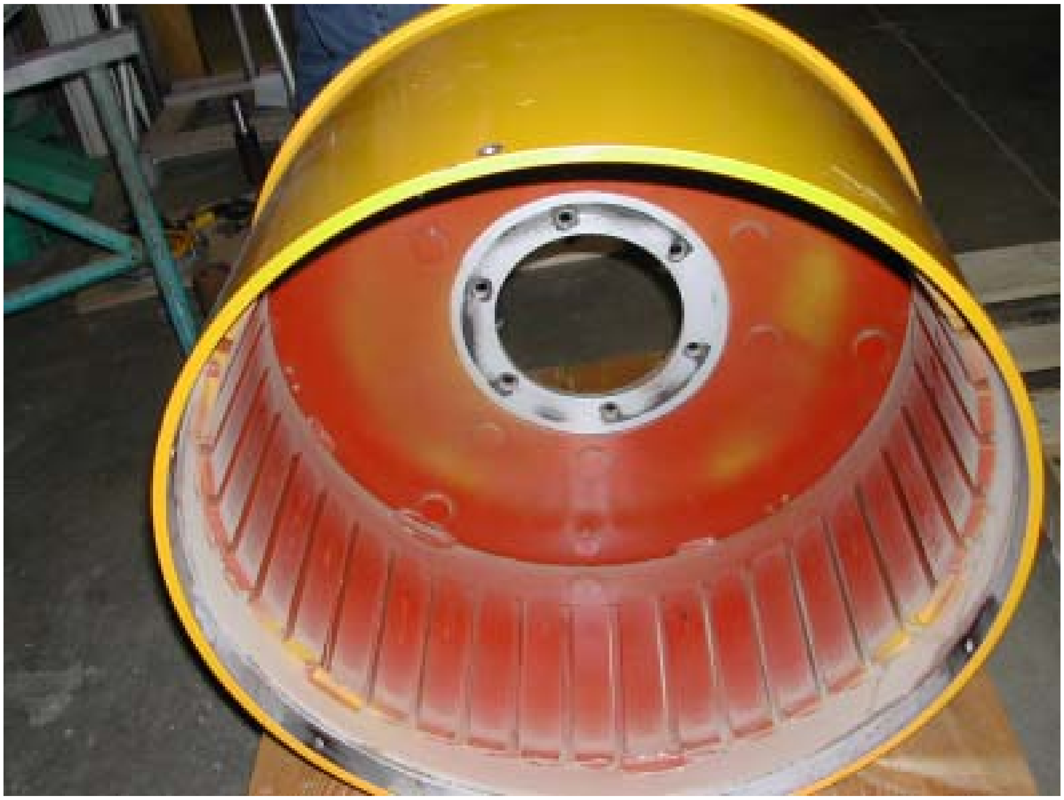


Figure D.8. The magnet can.

Figure D.9. The windings (view from windward side).

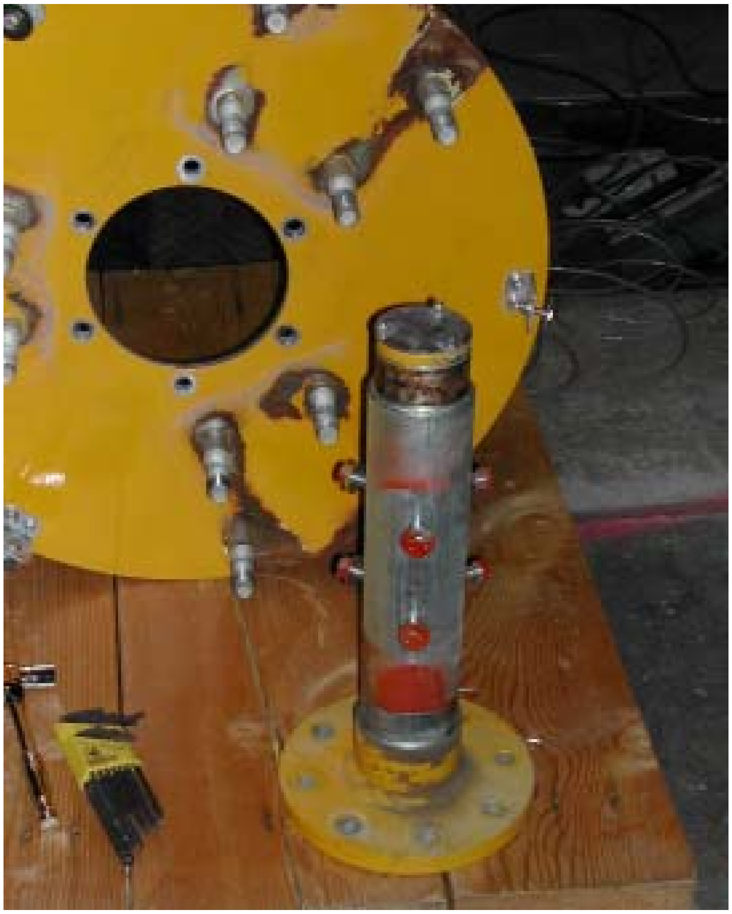


Figure D.10. Main shaft and windward side of magnet can.

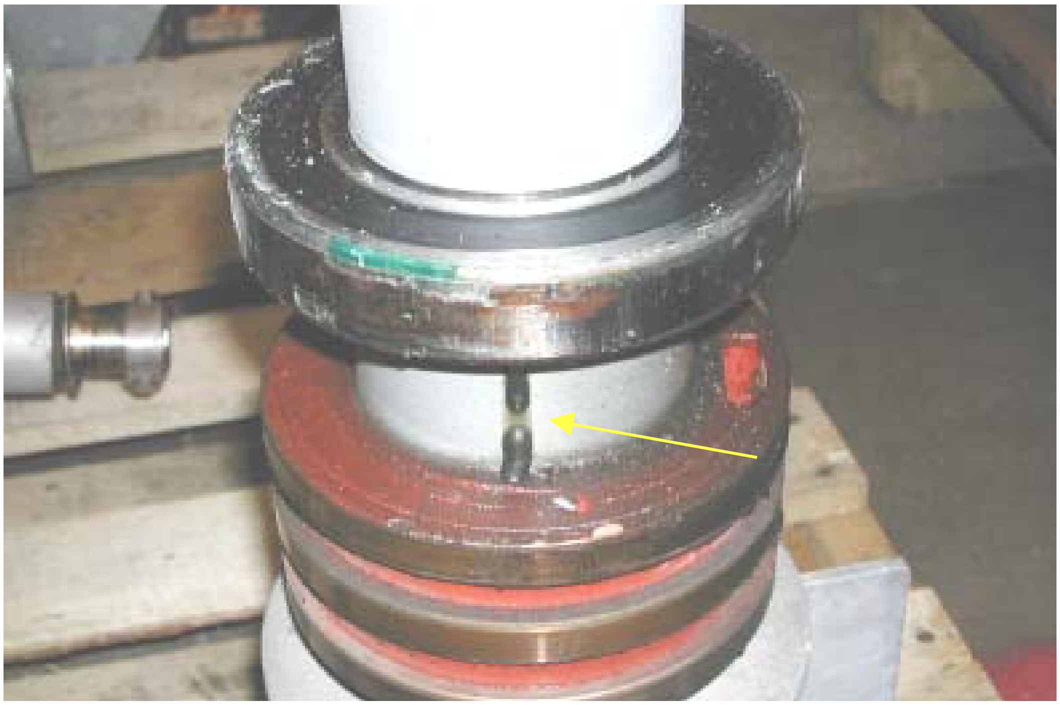


Figure D.11. Lower yaw bearing and slip rings. Note grease track from yaw bearing to top slip ring track.

D8

Figure D.12. The slip ring brushes. Note the grease on the top brush.

Figure D.13. The furl damper with some signs of leakage on the right side.

Barber Nichols bearing analysis report

Barber Nichols

Barber- Nichols Inc. 6325W 55th Avenue ARVADA, CO 80002 (303) 421-8111 FAX (303) 420-4679

To: Jerry Bianchi, NREL
From: Dave Lowe
Date: December 20, 2002
Subject: Evaluation of large wind turbine bearings

The following contains an evaluation of wind turbine ball bearings. These bearings were removed from a wind turbine by NREL after testing by NREL. Two sets of bearings were evaluated. One set is used on the generator shaft and the other set for the gimbal.

All bearings are in very good condition. No evidence of wear or pitting was observed on the ball tracks during a visual inspection. All bearings were smooth when rotated by hand. Following is a description of the bearings and comments on the grease present in the bearings.

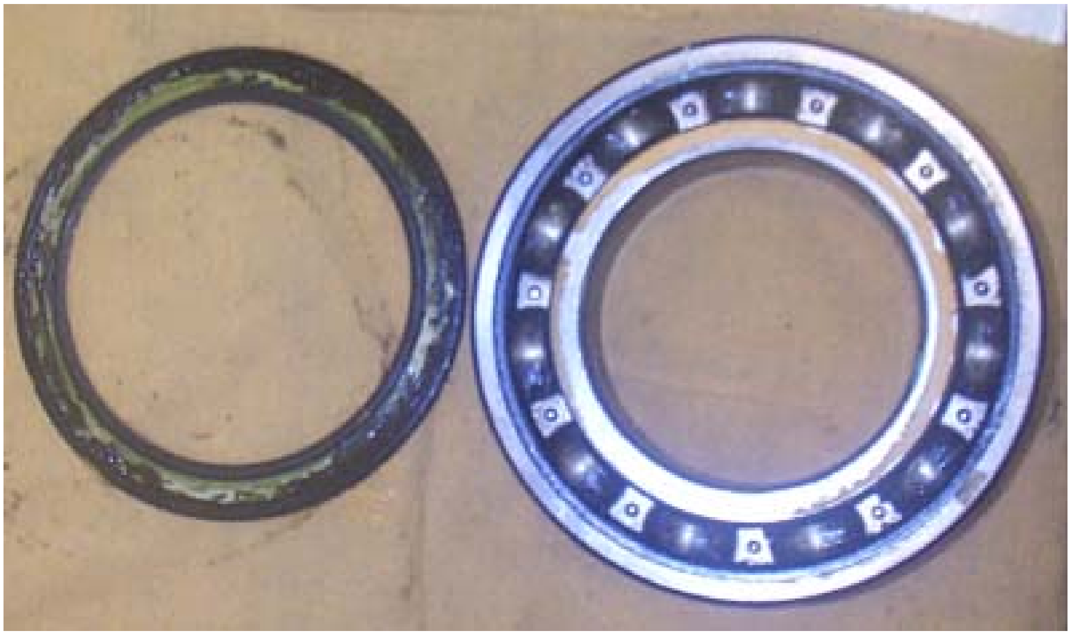
Rear Generator Bearing
NTN 6215

The grease is in very good condition with light color and good consistency. A band of brown discolored grease is present on the outside part of the non-painted shield. The rest of the shield is covered with new-looking green grease. The discoloration is probably due to moisture. There is no evidence of corrosion. (The grease looks like Chevron SRI-2, but this was not confirmed). This bearing contains less grease than the other bearings. It is probable that this is the standard grease pack for this bearing.

D11

Front Generator Bearing
Nachi 6313NSE

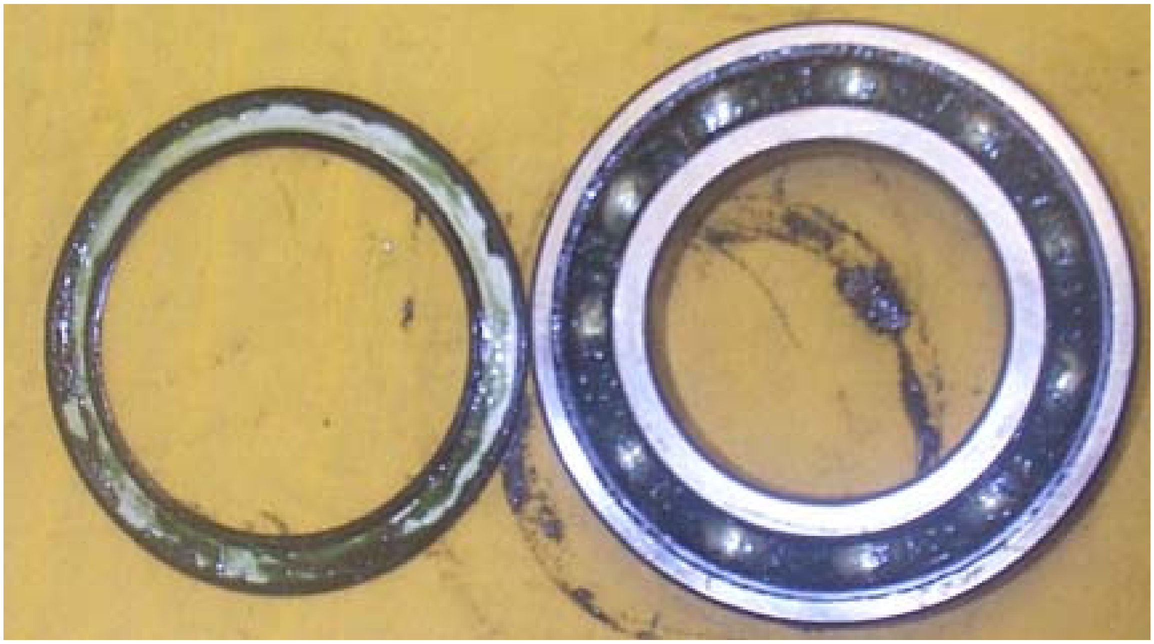
The grease is in good condition. It is somewhat thicker and darker than new grease. Most of the grease present in the bearing is on the unpainted (red paint) side of the bearing.



D12

Lower Yaw Bearing
NTN 215L8

The grease present is dark in color but in very good condition.

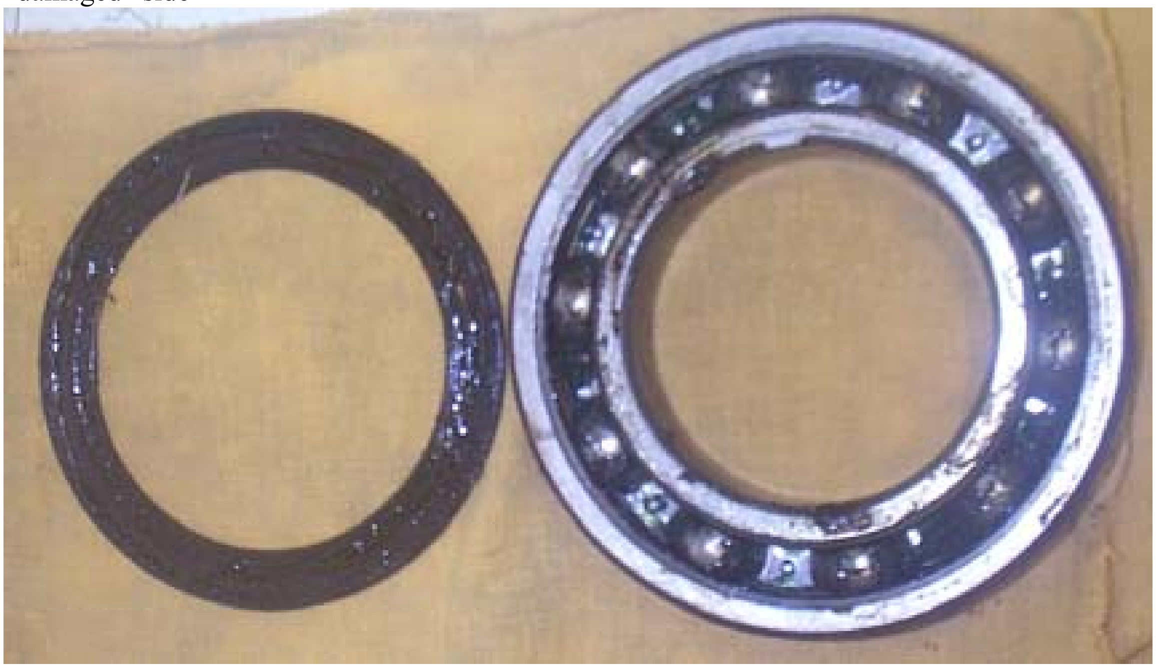


D13

Upper Yaw Bearing
Nachi 6215NSL

The grease on the "damaged" shield is a little darker than the other side. (The shield was slightly damaged during bearing removal.)

"damaged" side



D14

Appendix E: Up Tower Turbine Inspection Checklist

Turbine Inspection Checklist for the Bergey Excel

At the conclusion of the duration test, a final inspection was performed on the turbine on the tower before it was removed for the Component Wear and Durability Assessment. The same inspection was performed halfway through the duration test (September 2001). The results of this inspection will be compared to the results of that inspection. Any deviations should be further inspected once the turbine is removed from the tower.

Conducted by: Jerry Bianchi, Jeroen van Dam Date: August 6, 2002

The winds were below cut-in wind speed and coming from the north-northeast.

Task	Comments/Findings
Wind Turbine Generator:	
1. Inspect each of the anchor points. Ensure that all hardware is secure and the guy wires are properly tensioned. Check to ensure that no strands are broken.	No broken strands found. The abnormalities found in the earlier inspection have been solved; extra nuts have been installed where required. The tension of the guy wires was checked through the eigenfrequency of the wires as recommended in the installation manual. The observed values are given in Table 1. Figure 1 gives the recommended values. A deviation of 1 second is allowed. All guys, except for the top guys, seem to have too much tension on them.
2. Check the turbine's grounding.	The guy wires are each connected to a ground rod. The grounding of the top guy wire on the west side was broken (Figure 2). The tower is grounded to the frame of the electrical boxes located on the side of the foundation. The frame on its turn has a wire going to ground.
3. Furl the turbine and check that the damper restricts the tail's unfurling to a period of at least 3 seconds when the winch cable is rapidly released.	It takes about 5 seconds for the tail to return to normal position. There are some loose strands in the furl cable on the winch. The cable also does not follow a clean path on the winch drum.
4. While climbing the tower, check the following: tower fasteners, any cracks, guy wire attachments, furl cable, and the furl cable swivel.	All tower fasteners are secure; no cracks visible. No loose strands in the furl cable were noticed. On the center guy wire on the western side of the tower, the wires still cross in the second clamp; also, the dead end is not straight between the two clamps. At the bottom of the tower, some crossbars are bent. Some corrosion is present at the lowest tower section junction.

Task	Comments/Findings
5. With the turbine braked, the rotor should turn with strong resistance. With the brake released, the rotor should spin easily and smoothly.	The turbine was not shorted. The rotor rotated easily and smoothly.
6. Visually inspect the rotor blades for: -Cracks (especially near the hub and just past the stiffener) -Condition of the leading edge tape (especially outboard of the pitch weight) -Tip damage.	Only the downwind side of the blades could be inspected from the tower. The blades have been replaced by new blades since the last inspection. Cracks were found at each hub-blade transition. We could not determine if these cracks are in the paint only. No damage was observed on the leading edge or tip.
7. Remove the nose cone and check blade nuts (recommended torque is 150 ft-lbs). Check the main bearing for play. Check the seal for integrity and loss of grease.	The nose cone was not removed. Play is hard to detect with the weight of the rotor pre-loading the bearing.
8. Manually yaw the turbine (should be smooth without shocks).	Starting the turbine's yaw is difficult, but once there is some momentum, the yawing continues easily and smoothly.
9. Check the yaw bearing for play.	Due to the weight of the turbine, this was difficult to check. No play was observed (most likely caused by the turbine weight that pre-loads the bearing).
10. Check the furl bearing for play.	The same is valid as for the yaw bearing.
11. Check fasteners for presence and torque, if possible. All should be present and should have a reasonable torque. Recommended torque for alternator, mainframe connection is 80 ft-lbs.	All fasteners and split pens were present. There were no signs of bolts loosening.
12. Check rear alternator bearing for seal integrity and grease loss.	The seal is intact with no signs of grease loss.
13. Check windings and magnet of generator, as far as they are visible.	Some windings are visible through the louvers in the alternator, but the view is not good enough to make a statement of their condition.
14. Open the nacelle junction box to check electrical wiring.	No signs of damage or wear on the terminal strip.

Task	Comments/Findings
15. Remove the slip ring cover plate and: -Check brushes for ease of movement in the brush holder -Check slip-rings for signs of arcing damage -Check that no grease has leaked from the yaw bearings onto the slip rings -Take pictures.	The wire connection to the slip rings had no damage. The slip ring races had no signs of uneven wear. The races had some lubricant on them. Insulation intact.
16. Check the yaw damper. Some leakage around the front seal is OK. Take picture of current state.	The visible parts of the yaw damper looked OK. There were no signs of leakage.
17. Check the furl cable.	The furl cable in the nacelle had no broken strands, and the connection to the tail had no visible cracks or deformation. It must be noted that the furl cable has been replaced since the last inspection.
18. Check tail boom and fin for cracks or loose hardware.	As seen from the tower, all fasteners were present and no damage was observed on the tail boom and tail vane.
19. Check the turbine for any oil, grease, cracks, corrosion, or wear.	No corrosion visible. The shield of the furl cable had some wear. Because there are no parts near the location of the wear, this must have happened before or during installation. No signs of grease were found. Traces of bird feces were found in the nacelle.

Table 1: Observed Time in Seconds for Guy Wires to Complete 20 Oscillations.

Guy Wire:	West		Southeast		North		Recommended
Observation:	1	2	1	2	1	2	+/- 1 sec
Bottom	5.4	5.5	5.7	5.9	5.3	5.7	7.5
Middle	7.7	7.8	7.7	7.9	6.4	7.1	10.2
Top	14.2	13.7	12.8	12.4	13.0	13.7	13.8

The measured distance from the tower to the guy wires was 59 ft.

Guy levels are assumed to be 31.4, 71.4, and 108.6 ft.

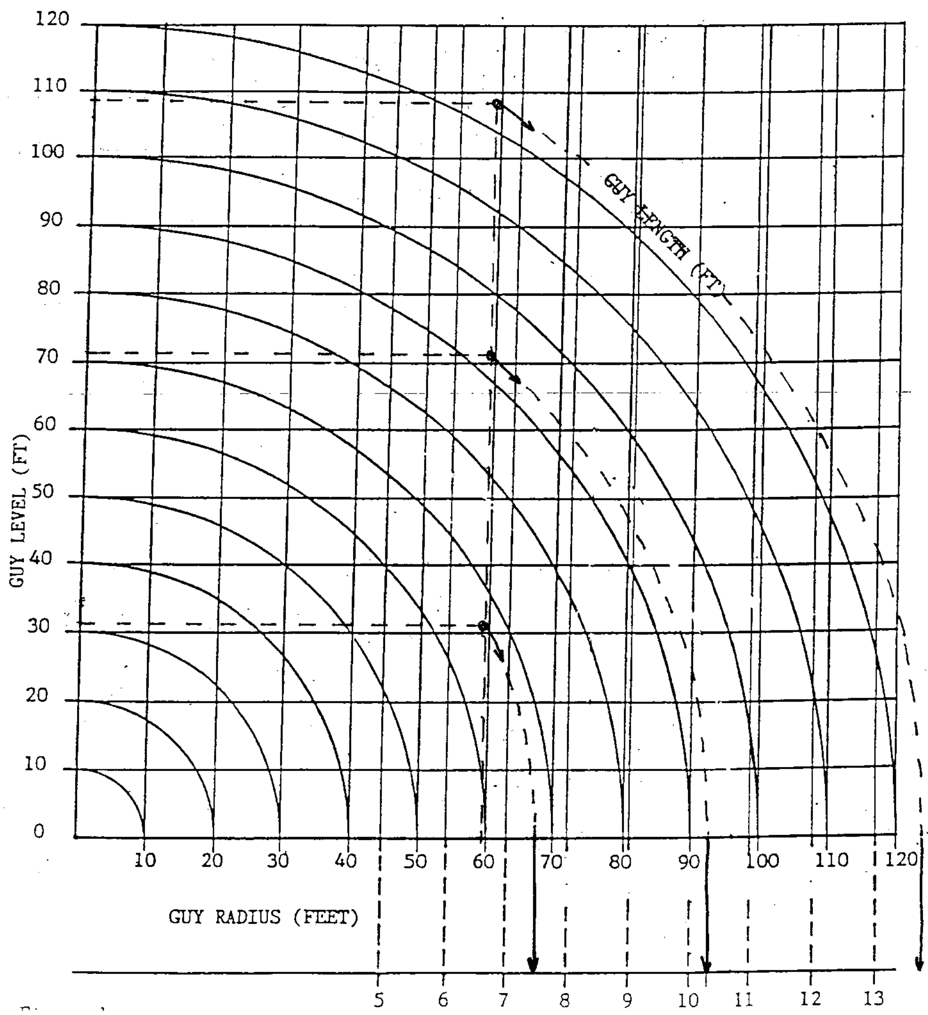


Figure 1. Graph from Bergey Excel installation manual for checking guy wire tension.

Figure 2. Broken ground wire at the top west guy wire.

Appendix F: Infrared Inspection of the Gridtek Inverter

F1

Short Report on the Electrical Inspection of the Bergey Excel-S/60

Jeroen van Dam, Mark Rumsey

On March 27, 2002, an electrical inspection of the Bergey Excel–S/60 was performed by Mark Rumsey of Sandia National Laboratories. This inspection took place as part of the duration test carried out under the FVP.

The Excel-S/60 turbine system consists of a Bergey Excel turbine and a Gridtek 10 inverter, which is connected to the grid. Figure 1 gives an overview of the layout of the system inside the data shed. The Gridtek 10 inverter was the only turbine system component of interest that could easily be inspected. Some pictures of the wind turbine were also taken, but the effect of the sun dominates any possible interesting effects. At the time of the inspection, the hub-height wind speed was between 15 and 20 m/s.

The pictures below were taken with an infrared camera. Normal pictures are also shown to give the reader an idea of what can be seen in the thermal image.

Disclaimer: The thermal images shown below cannot be seen as absolute temperature graphs but should be seen as more indicative pictures. The color showing up on the pictures is dependent on the temperature of the component and the emissivity (black body vs. reflecting surfaces) of the component. Further, the picture can be influenced by reflections of sunlight or other heat-radiating sources. (The pictures were taken with an emissivity of 95%.)

Figure 1. Overview of the turbine system inside the data shed. The Gridtek 10 inverter is in the center with disconnect switches to the turbine and the grid on either side. The boxes on the bottom are for NREL instrumentation.

Figure 2 gives an overview of the inside of the inverter. A number of hot components were found inside the inverter:

- Resistors in the top of the inverter. Figure 3 shows two pairs of resistors that are clearly warmer then the ambient temperature. The camera indicated temperatures in the range of 160°F for the resistors in the front of the inverter and 200°F in the back of the inverter.
- The inductor on the bottom left (Figure 6). Temperatures around 190°F were indicated.
- The inductor on the right side
- Some chips on the inverter board

Figure 2. Overview of the inside of the inverter.

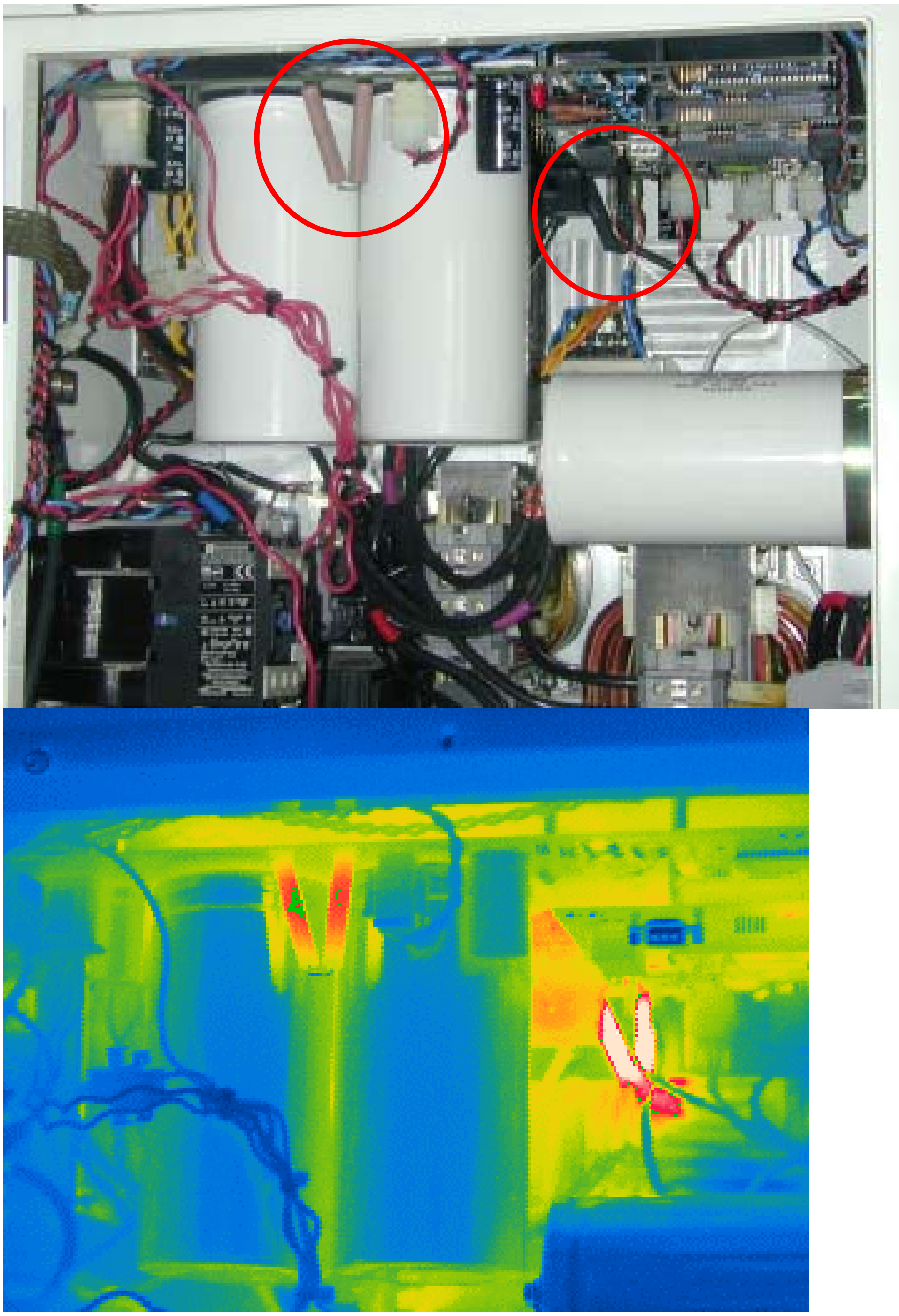


Figure 3. Two sets of resistors are clearly warmer than anything around them.

F4

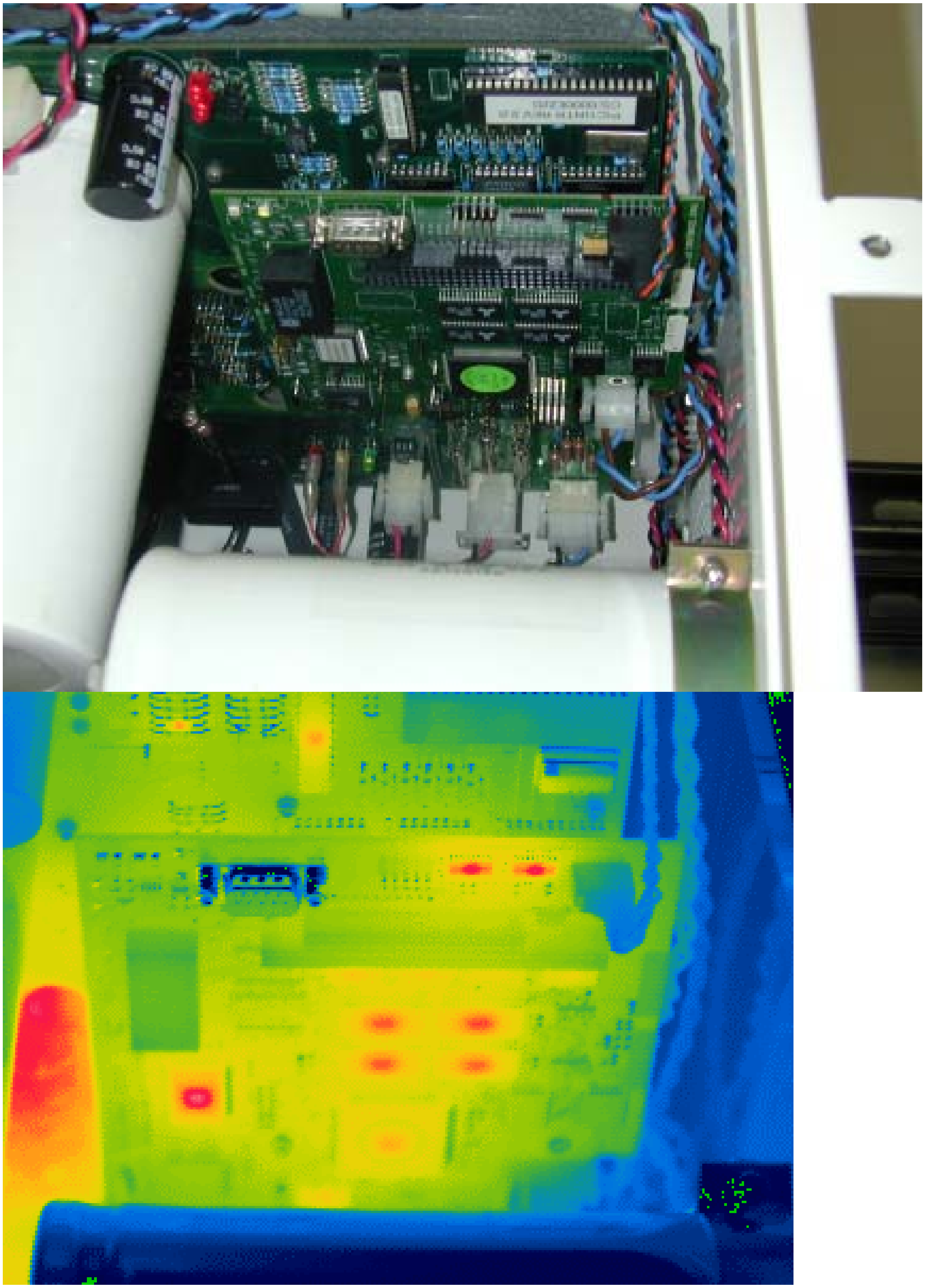


Figure 4. A close-up of the main inverter board (red color indicates about 160°F).

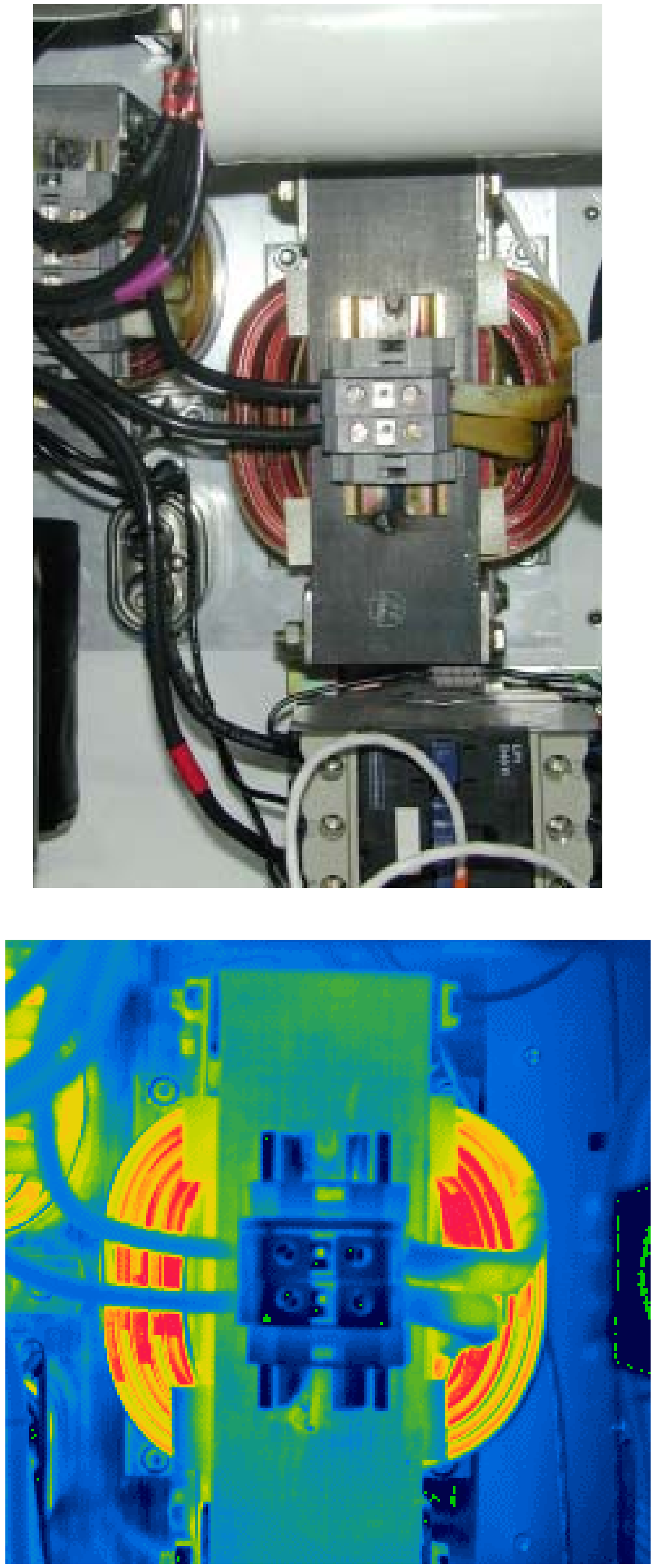


Figure 5. Close-up of the inductor on the right side (red color is about 160°F).

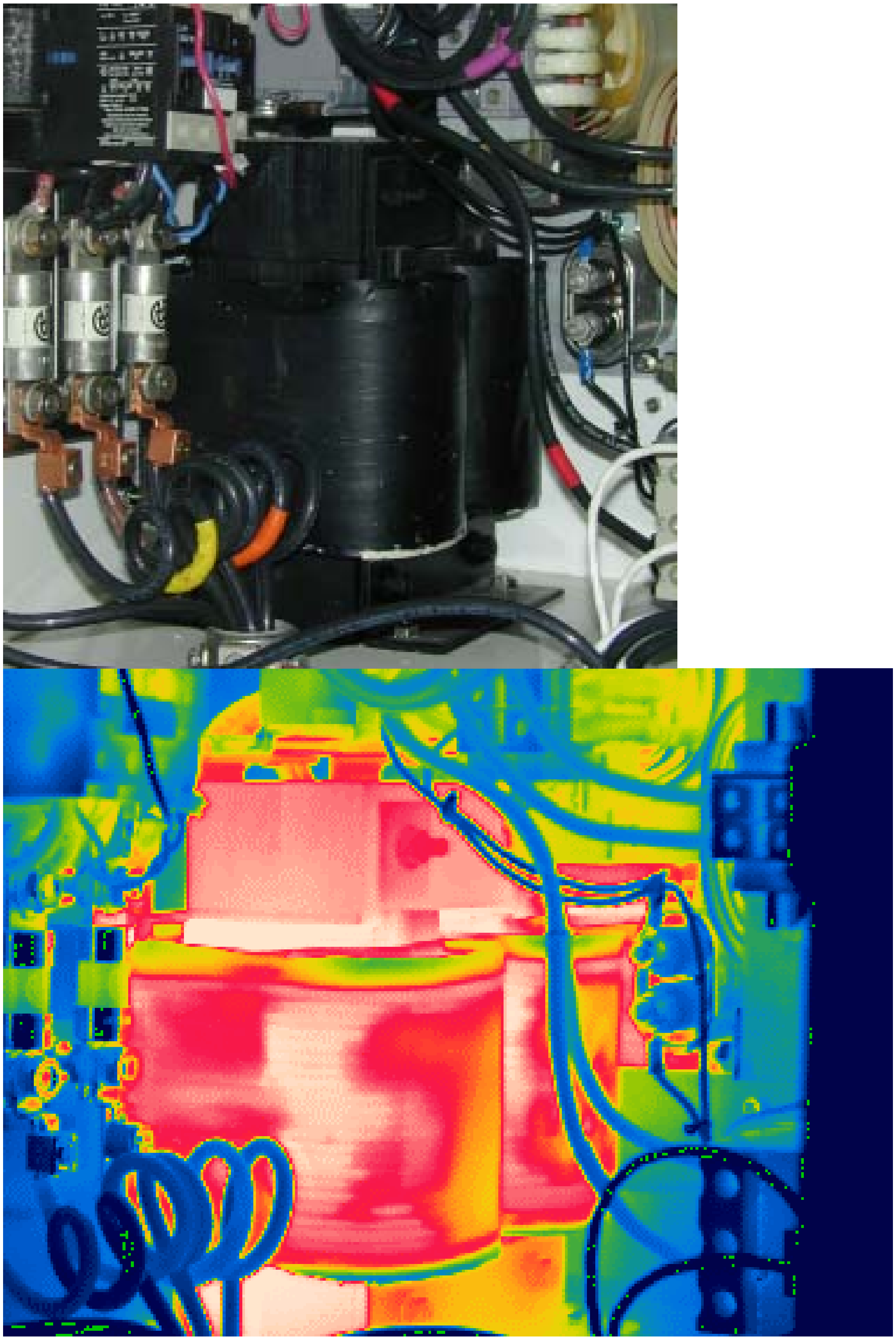


Figure 6. A close-up of the inductor on the bottom left of the cabinet.