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Small Wind Turbine Testing Results from the National Renewable Energy Laboratory

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Abstract

In 2008, the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) began testing small wind turbines (SWTs) through the Independent Testing project. Using competitive solicitation, five SWTs were selected for testing at the National Wind Technology Center (NWTC). NREL's NWTC is accredited by the American Association of Laboratory Accreditation (A2LA) to conduct duration, power performance, safety and function, power quality, and noise tests to International Electrotechnical Commission (IEC) standards. Results of the tests conducted on each of the SWTs are or will be available to the public on the NREL website. The results could be used by their manufacturers in the certification of the turbines or state agencies to decide which turbines are eligible for state incentives.

1. INTRODUCTION

The Independent Testing project was established at the National Renewable Energy Laboratory's National Wind Technology Center (NWTC) to help reduce barriers to wind energy expansion. Among these barriers is a lack of independent testing results for small turbines. Independent testing results will meet partial requirements for turbine certification. Certified turbines increase consumer confidence in small turbine technology and certification will help consumers in the selection of turbines.

The turbines selected in the first round of the independent testing project were the Mariah Power Windspire, the Gaia-Wind 11 kW, the Abundant Renewable Energy ARE 442, the Entegrity EW50, and Ventera VT10. Figure 1 shows the selected turbines installed at the NWTC. Power performance, duration, noise, and safety and function tests are performed on all turbines. Power quality testing is performed only on three-phase turbines, as the IEC Standard 61400-21 only applies to turbines with a three-phase grid connection.

2. TURBINES SELECTED

The five turbines are listed and described below in the order of their installation dates.

The Mariah Power Windspire was installed on May 5, 2008**.** It is a vertical-axis turbine mounted on a monopole tower, and has a rotor height of 6.1 m and a rotor area of 1.2 m by 6.1 m. The Windspire uses a 120 VAC, single-phase, grid-connected, permanent-magnet generator wind turbine rated at 1 kW. Testing on the Windspire was terminated on January 14, 2009 after repeated turbine problems.

The Gaia-Wind 11 kW turbine was installed on May 13, 2008. It is a downwind, two-bladed, horizontal-axis turbine. The Gaia-Wind 11 kW has a 133 m^2 swept area and is mounted on an 18.2 m monopole tower. Its three-phase 11-kW induction generator delivers 480 VAC to the grid. At the time of this writing, data collection is complete with the exception of a post duration test inspection.

The Abundant Renewable Energy ARE 442 was installed on June 11, 2008. It is a horizontal-axis, three-bladed turbine with a swept area of 41 m^2. It operates upwind and uses a furling mechanism for power control. The ARE 442 is mounted on a 30.5 m lattice tower. The turbine uses a single-phase, grid-connected, permanent-magnet generator that is rated at 10 kW at 240 VAC. Testing is complete.

The Entegrity EW50 was installed on March 3, 2009. It is a horizontal-axis, downwind machine. It has a swept area is 177 m^2 and is mounted on a 30.5 m monopole tower. The EW50's three-phase induction generator produces 50 kW at 480 VAC. At the time of this writing, data collection for power performance and acoustic noise is complete and undergoing analysis. Data collection continues for duration testing, safety and function, and power quality.

The Ventera VT10 completed installation on March 23, 2010. It is a downwind, horizontal-axis, three-blade turbine. Its swept area is 35 m^2, and it is mounted on a 24.7 m lattice tower. The VT10 uses a single-phase, grid-connected, permanent-magnet generator that is rated at 10 kW at 240 VAC. Pitchable tips govern the rotor speed. At the time of this writing, data collection is in progress for all tests.

Figure 1. From left to right: Windspire, Gaia-Wind 11 kW, ARE 442, EW50, and VT10. PIX numbers left to right: 15705, 15733, 16390, 15704, 16948

3. RESULTS

The available results to date are presented below, though some are preliminary and subject to change.

3.1. Duration Testing

The duration test is conducted according to section 9.4 of the IEC Standard 61400-2: Design Requirements for Small Wind Turbines. Duration testing provides information about the turbine's structural integrity, quality of environmental protection, and dynamic behavior. The test requires a minimum of 6 months of operation, 2,500 hours of power production in winds of any velocity, 250 hours of power production in winds of 1.2 V_{ave} and greater, and 25 hours of power production in winds of 1.8 V_{ave} and greater. Section 6.2 of IEC Standard 61400-2 defines V_{ave}, which depends on the small wind turbine class identified by the manufacturer and based on the wind speeds in which the turbine was designed to operate; "class I" turbines are designed for strong wind environments, and "class IV" turbines are designed for lower wind environments, with a "class S" for other designs specified by the manufacturer. The standard requires that the turbine must not experience any major failures during the test period and it must achieve an operational time fraction of 90% or greater.

The operational time fraction is defined by the following: $O = \frac{T_T - T_N - T_U - T_E}{T_T - T_U - T_E} \times 100\%$

Where T_T is the total test time, T_N is the time attributed to turbine faults and manufacturer-mandated inspections and maintenance, T_U is the time during which the turbine status is unknown due to lost data or data-acquisition failure and maintenance, and T_E is the time that is excluded from analysis due to grid faults and laboratory-mandated inspections or stops.

The dynamic behavior of the turbine is assessed by observing the turbine in a range of operating conditions. The turbine is observed at wind-speed intervals from cut-in wind speed to 20 m/s for at least one hour in total. Tower vibrations, noise, yaw behavior, and tail movement all are documented in the logbook and included in the duration-test report.

Another factor of reliable operation is that the turbine should experience no significant power degradation. Each month the average power is plotted for each wind-speed bin and analyzed for any obvious trends in power production. Examination of power degradation plots indicated no apparent power degradation for the Gaia-Wind 11kW, ARE 442, or EW50.

Part of the reliable-operation requirement for the duration test includes no significant wear, corrosion, or damage to turbine components. The structural integrity and material degradation are investigated through inspections of the turbine before, during, and after the testing period. Blades, welds, and other turbine components were visually inspected and photographed before the test and any apparent abnormalities documented. After the required test data is collected, the turbine is lowered and disassembled for inspection of components. Routine inspections of the ARE 442, Gaia-Wind 11 kW, and EW50 before and during the tests did not reveal any abnormalities. Post-test inspections for the Gaia-Wind 11 kW or EW50 have not occurred. The post-test inspection of the ARE 442 revealed the turbine system to be in generally good condition, except for cracks in each blade.

The IEC standard requires reporting maximum wind speed and Turbulence Intensity (TI). TI is the ratio of the wind-speed standard deviation to the average wind speed. These values characterize the wind resource the test turbine experienced. The NWTC has a relatively high maximum wind speeds and high TI.

3.1.1. Windspire

Duration testing on the Windspire was terminated on October 14, 2008. The turbine had experienced repeated problems. These problems included repeated loose nuts at the base of the turbine, a broken washer at the base of the turbine, broken welds at the top of the turbine, airfoil displacement in the struts, and an inverter failure. The Windspire is a class IV turbine.

The following dynamic observations were made: *"The turbine was exhibiting unsteady behavior periodically. There was a noise that seemed to come from the tower approximately three times per revolution. The washers at the foundation base were loose and the bolts and nuts on the foundation had shifted."*

3.1.2. Gaia-Wind 11kW

Table 1 shows the final duration results for the Gaia-Wind 11 kW. The turbine accumulated 2,705 hours of total run time, with an operational time fraction of 90.8%. The Gaia-Wind 11 kW is a class III turbine.

The low operational time fraction for August and September of 2008 was caused by the failure of two contactors in the controller. Investigations suggest that the 2-pin flat connectors used to wire the contactors were poorly connected when installed by Gaia-Wind's electrical supplier. Additionally, the Gaia-Wind 11 kW turbine controller originally was designed for a 50-Hz grid, and it is possible that the original contactors were underrated for the 60-Hz grid at the NWTC. It now is standard for all contactors in the controller to be installed with tube connectors for a more secure connection and all turbine controllers on a 60-Hz grid are installed with the higher-rated contactors. Since the replacement of the contactor and pin connectors, the turbine has run with a high operational time fraction.

The majority of the remaining time, classified as T_N during the test, is attributed to braking-time faults, vibration errors, and maintenance. The braking-time faults occurred when the turbine took longer to brake than was specific in its design; this usually occurred during high winds. The vibration errors are expected to have occurred from birds nesting in the nacelle. With guidance from Gaia-Wind, NREL installed a screen over the opening in the nacelle to prevent birds from entering. Since the installation of the screen, the turbine has run without vibration errors.

Table 1. Final Duration Results for the Gaia-Wind 11 kW

Month	Hours of Power Production Above: 0 m/s	9 m/s	13.5 m/s	Max	TI @ 15 m/s (%)	T_T (hours)	T_U (hours)	T_E (hours)	T_N (hours)	O (%)
Overall	2704.9	710.6	215.0	41.9	19.0	7094	172.5	152.0	624.6	90.8
Jun 2008	238.2	36.2	3.8	28.6	18.5	518	11.3	7.8	3.3	99.3
Jul	256.0	8.5	0.3	23.9	-	744	78.2	2.2	38.8	94.1
Aug	115.8	4.5	0.0	19.2	-	744	6.3	20.0	323.0	55.0
Sep	120.5	11.7	1.8	22.4	-	720	36.2	30.3	174.7	73.3
Oct	236.0	45.0	12.2	32.8	17.3	744	0.7	1.3	0.0	100.0
Nov	348.0	98.7	22.5	37.0	20.9	721	22.1	0.0	0.0	100.0
Dec	339.7	160.5	54.8	41.4	17.4	744	7.9	27.2	32.8	95.4
Jan 2009	385.0	155.5	56.0	38.8	19.9	744	4.9	32.0	36.5	94.8
Feb	333.2	107.3	36.8	41.9	20.0	672	3.2	27.0	0.0	100.0
Mar	332.5	82.7	26.8	36.7	18.0	743	1.7	4.2	15.5	97.9

Note on Total time T_T: times are recorded in local time, and daylight/standard time changes in November & March. This results in an extra hour in November and a missing hour in March. This is seen in Tables 1, 2, and 3.

The following dynamic behavior observations were made: *"The turbine tracks winds well in all observed wind speeds. No excessive vibration was observed. There is an occasional, slight audible thumping noise as blades pass behind the tower."*

3.1.3. ARE 442

Table 2 shows the final results for the ARE 442. The ARE 442 accumulated 3,241 hours of total run time with an operational time fraction of 91.2%. The ARE 442 is a class II turbine.

The low operational time fraction that occurred in November 2008 was caused by failure of the turbine's insulated-gate bipolar transistors (IGBTs) during a simulated grid fault for safety and function testing. The majority of the remaining time, classified as T_N during the test, is attributed to over-temperature and overvoltage faults that the turbine experiences in high winds. The diversion loads for the turbine were originally located inside the data shed and did not dissipate heat properly, which resulted in temperature faults during high power production. The diversion loads were moved outside of the data shed in February 2009, which eliminated the over-temperature faults. However, the turbine then experienced overvoltage faults.

Table 2. Final Duration Results for the ARE 442

Month	Hours of Power Production Above: 0 m/s	10.2 m/s	15.3 m/s	Max Gust	TI @ 15 m/s (%)	T_T (hours)	T_U (hours)	T_E (hours)	T_N (hours)	O (%)
Overall	3240.6	552.6	156.7	42.9	18.9	7249	99.7	214.8	612.0	91.2
Jul 2008	295.8	7.5	0.0	27.8	15.8	735	3.1	152.2	0.0	100.0
Aug	286.8	9.5	0.0	26.5	16.9	744	31.0	4.0	0.0	100.0
Sep	217.5	8.8	0.7	23.2	13.8	687	49.6	5.3	0.3	99.9
Oct	279.7	35.7	6.7	34.0	16.9	744	0.9	5.0	9.5	98.7
Nov	156.0	8.2	0.0	34.3	19.5	721	0.0	0.1	332.8	53.8
Dec	379.2	131.8	41.8	42.9	18.2	744	1.0	10.2	124.2	83.1
Jan 2009	466.5	146.3	44.3	42.9	20.0	744	0.7	1.8	79.8	89.2
Feb	389.3	104.5	46.3	39.5	19.7	672	4.0	31.7	42.3	93.3
Mar	416.8	68.3	13.2	34.9	18.4	743	3.9	1.5	20.3	97.2
Apr	353.0	32.0	3.7	28.4	18.0	720	43.5	3.0	2.8	99.6

The following dynamic observations were made: *"During high winds, the rotor operates at yaw errors of between approximately 30 degrees and 60 degrees and the furl movements excite the tower slightly. Overall, it appears that no excessive vibrations are occurring. In winds of between 8 m/s and 12 m/s the turbine tracks the wind well."*

3.1.4. EW50

Table 3 shows the preliminary results for the EW50. At the time of this writing, the turbine has accumulated 1,383 hours of total run time with an operational time fraction of 98.3%. The EW50 is a class II turbine.

A low operational time fraction occurred in August 2009 as a result of the failure of the controller's UPS after a grid outage. Entegrity service personnel bypassed the UPS and returned the EW50 to operation. A low operational time fraction in January 2010 was caused by a grid fault which blew a fuse in the control panel.

Table 3. Preliminary Duration Results for the EW50

Month	*Hours of Power Production Above:* 0 m/s	10.2 m/s	15.3 m/s	*Max Gust*	*TI @ 15 m/s (%)*	T_T (hours)	T_U (hours)	T_E (hours)	T_N (hours)	*O (%)*
Overall	1383.0	266.1	40.3	36.1	19.5	8706	1000.5	116.5	140.0	98.2
Apr 2009	164.2	29.3	5.5	31.0	18.2	684	0.1	5.7	0.0	100.0
May	148.2	9.8	0.0	21.5		744	0.5	6.0	0.0	100.0
Jun	105.7	11.2	1.2	30.0	17.6	720	0.0	0.2	0.0	100.0
Jul	81.5	7.7	0.7	28.1	24.0	744	14.3	0.0	0.0	100.0
Aug	32.5	0.5	0.0	18.0		744	370.9	14.3	70.7	80.3
Sep	70.8	13.3	1.3	27.4	16.4	720	144.6	31.5	0.0	100.0
Oct	163.7	44.2	1.7	30.5	18.1	744	11.7	49.2	0.5	99.9
Nov	121.2	8.0	0.0	22.3		721	0.1	6.3	0.0	100.0
Dec	207.5	62.7	12.2	36.1	19.0	744	0.7	0.0	0.0	100.0
Jan 2010	111.7	46.2	14.2	33.2	21.6	744	29.2	2.7	68.8	90.3
Feb	38.3	12.2	3.2	28.9	19.7	672	393.8	0.3	0.0	100.0
Mar	137.7	21.0	0.3	25.1	18.1	743	63.6	0.3	0.0	100.0

The following dynamic behavior observations were made: *"In light winds the EW50 was observed yawing to face upwind, and remain stable in the upwind position. In the upwind position the EW50 consumed power, depending on the wind speed. After 10 minutes of consuming power, the EW50 controller shut down and act of stopping the EW50 returned it to the downwind position. After 10 minutes, the EW50 sensed sufficient wind, and the EW50 released the brakes and started again."*

3.1.5. VT10

As of this writing the VT10 has less than one month of operation. It is a class III turbine.

The following dynamic behavior observations were made: *"The turbine tracks the wind well. Its blade tips govern rotor speed by pitching to stall, as designed. The turbine rotor emits more noise while governing than during normal operation, but no excessive vibrations observed during governing or normal operation."*

3.2. Power Performance Testing

Power performance testing is conducted per IEC standard 61400-12-1, Power Performance Measurements of Electricity Producing Wind Turbines, referencing Annex H for small wind turbines. Products of the test include a measured power curve and an estimation of annual energy production (AEP).

For small turbines, statistical data is collected in 1-minute sets and sorted into 0.5-m/s-wide wind speed bins. Data collection is complete when the wind speed bins (between 1 m/s below cut-in and 14 m/s) contain 10 minutes of data each. The total database consists of at least 60 hours of data. Wind speed bins are plotted against the corresponding bin power to produce a power curve. Power curves are normalized to sea-level air density; the NWTC is approximately 1,850 m above sea level. Therefore, the site-specific air density at the NWTC is relatively low, averaging slightly less 1.0 kg/m^3.

Figure 2 shows the power curve for all five small turbines tested. The EW50 is scaled on the right axis, the rest are scaled on the left axis. The Gaia-Wind 11 kW and ARE 442 are the final curves. The EW50, VT10 curves are preliminary. The original inverter on the Windspire was optimized for power performance and failed after several months of operation. After the failure, a production model inverter was installed and operated until testing on the Windspire was suspended. The required amount of data was not collected on either inverter due to failures. Figure 2 shows the incomplete power curve for the second, production model inverter.

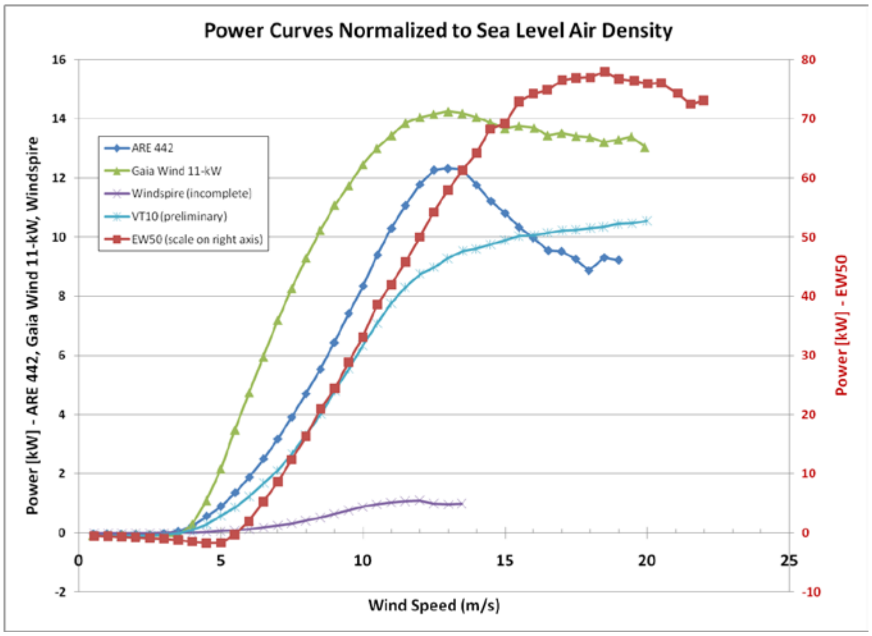

Figure 2. Power Curves of the Five Turbines Tested

Annual energy production (AEP) is estimated by applying the power curve generated from power performance testing to a Rayleigh distributed wind resource. The AEP is calculated for annual average wind speeds at hub height for 4 m/s to 11 m/s. In Table 3 below, the measurements reported assume no energy production beyond the highest filled bin in the power performance test. The AEP for the EW50 has not been published, and the AEP for the VT10 is preliminary. The AEP is not reported for the Windspire because the required amount of data was not collected.

Table 3. Measured AEP for the Gaia-Wind 11 kW, ARE 442, EW50, and VT10

Hub height annual average wind speed	***Gaia-Wind 11kW*** *AEP-measured*	***ARE 442*** *AEP-measured*	***EW50*** *AEP-measured*	***VT10*** *AEP-measured*
m/s	*kWh*	*kWh*	*kWh*	*kWh*
4	17,716	7,884	11,006	5,213
5	32,122	15,327	41,796	11,318
6	46,292	23,516	83,543	18,688
7	58,690	30,967	130,785	26,267
8	68,525	36,718	178,132	33,129
9	75,474	40,459	220,869	38,639
10	79,617	42,350	255,754	42,531
11	81,326	42,770	281,396	44,854

3.3. Safety and Function Testing

Safety and function testing is conducted according to section 9.6 of the IEC Standard 61400-2: Design Requirements for Small Wind Turbines. Its intent is to test the essential functions of the turbine system. For each turbine, NREL collects data to characterize the turbine's power control, rotor-speed control, behavior upon loss of load, normal start-up, normal shutdown, and emergency shutdown. Additionally, NREL performs turbine-specific tests to verify the turbine controller's function and predicted behavior. Although safety and function testing examines the essential functions of the turbine, it does not certify whether a turbine is safe to operate. The following tables in this section are summaries of the Safety & Function test.

Table 4 shows the final safety and function data summary for the Gaia-Wind 11 kW. The turbine performed as designed with one exception. When the turbine was shut down manually using the disconnect switch and then was restarted, an overspeed error was present on the controller. The error had to be reset before the turbine could be started again.

Table 4. Final Safety and Function Test Summary for the Gaia-Wind 11 kW

Test Method	Comment	Complies with Design
Power control	Turbine controls power output per design	Yes
Rotor speed control	Turbine controls rpm to 61, per design	Yes
Normal start-up	Turbine starts after several motor pulses in design wind speed and above, and below cut-out; over-speed error on start-up after manual shutdown	Partially
Normal shutdown	Turbine shuts down normally in winds less than cut-in and greater than cut-out	Yes
Emergency stop	Turbine stops within 2 to 3 seconds of pressing emergency stop button	Yes
Loss of grid	Turbine brakes immediately and stops within 2 to 3 seconds of load loss	Yes
Undervoltage / overvoltage	In an overvoltage simulation the turbine brakes immediately	Yes
High wind speed shutdown	Turbine stops in winds greater than 25 m/s and waits for start-up per the design	Yes
Rotor overspeed	Turbine brakes immediately in simulated 10% overspeed and deploys tip brakes at 15% simulated overspeed	Yes
Generator overcharge	Turbine brakes immediately in simulated generator overcharge	Yes
Excessive vibration	Vibration error registers on turbine controller after activating vibration sensor	Yes
Cable twist	Cable-twist error registers on turbine controller after lifting cable-twist arm	Yes

Table 5 shows the final safety and function data summary for the ARE 442. The turbine's two diversion loads were originally installed inside the data shed according to the manufacturer's design. They later were moved to an enclosure outside of the data shed after it was determined that their placement was causing repeated over-temperature faults. When the diversion loads were installed in the data shed, the over-temperature faults would occur in high-wind conditions as heat built up inside the data shed. Temperatures measured near the turbine's sensors indicated that the turbine shut down near or below its set point.

Table 5. Final Safety and Function Test Summary for the ARE 442

Test Method	Comment	Complies with Design
Power control	Power is limited by the capacity of the inverters, these max out at 12 kW; after that, power is diverted to the diversion loads	Yes
Rotor speed control	During start up in high winds, measurements indicate a much higher rotor speed then what was indicated by the manufacturer	Appears non-compliant
Yaw control	The turbine tracks the wind under all conditions; due to the furl mechanism, the rotor almost always has a yaw error	Yes
Normal start-up	Turbine starts in any winds ranging from cut-in to 25 m/s	Yes
Emergency stop	Turbine stops when stop button is pushed on the voltage clamp; this has been tested for a wide range of wind speeds	Yes
Loss of grid	Disconnecting the grid causes an immediate shutdown; in two events where a grid outage occurred in high-wind conditions, the IGBT's in the voltage clamp failed, although the turbine still shut down	Partially
Overvoltage fault	In high winds the turbine currently experiences the overvoltage fault, demonstrating that this feature works	Yes
Over-temperature fault	Temperatures measured near the turbines sensors indicate that the turbine shuts down near or below its set points	Yes

Table 6 shows the preliminary safety and function data summary for the EW50. One notable exception was found in the controller input. When the turbine's control panel manual three-way switch is set to "Off" and the grid experiences an outage, the EW50 will be in a "Run" state once power is restored, thereby overriding the control panel's manual switch.

Table 6. Preliminary Safety and Function Test Summary for the EW50

Test Method	Comment	Complies with Design
Power control	Turbine controls power output per design	Yes
Rotor speed control	Turbine controls rpm per design	Yes
Normal start-up	The turbine starts normally. If the anemometer mounted on the turbine indicates enough wind, and the rotor is not up to speed, the generator will motor start the rotor.	Yes
Normal shutdown	The turbine shuts down normally as winds drop below cut-out, The tip breaks deploy and when the rotor slows to approximately 18rpm the parking brake on the high speed shaft engages	Yes
Emergency stop	In moderate winds the turbine stops in approximatly15 seconds of opening the disconnect switch	Yes
Loss of grid	In moderate winds the turbine stops in approximately 15 seconds of load loss	Yes
Rotor overspeed	The controller has halted the turbine in very strong winds due to a “generator overspeed” fault	Yes
Overvoltage/undervoltage	Test pending	—

Table 7 shows the preliminary safety and function data summary for the VT10. The design of the VT10 allows for the rotor to spin when disconnected from the grid. The rotor is governed mechanically as the tips pitch to stall. The designed governing speed is 260 to 280 rpm, but the turbine at the NREL site governs at 220 to 240. Governing happens at 13m/s when the turbine is connected to the grid and the inverter is extracting power, and it governs at approximately 7 m/s when it is not connected to the grid. When the rotor speed drops below the governing speed, springs return the rotor to its normal operating state. The VT10 is designed to spin at all times, even when there is a grid outage. If the rotor must be stopped, a parking brake is available and may be engaged when the rotor is below governing speeds.

Table 7. Preliminary Safety and Function Test Summary for the VT10

Test Method	Comment	Complies with Design
Power control	Turbine controls power output per design	Yes
Rotor speed control	Turbine controls rpm, but approximately 40 rpm lower than designed	Yes
Normal start-up	The turbine starts normally	Yes
Emergency stop	The inverter stops, when commanded. However the rotor does not stop. As designed, when the generator is disconnected from the grid, the rotor governs itself in winds above 7m/s	Yes
Loss of grid	As designed the rotor governs itself when disconnected from the grid.	Yes
Rotor overspeed	Test pending	—
Overvoltage/undervoltage	Test pending	—

Table 8 shows the partial final safety and function data summary for the Windspire. Safety and function testing was not completed for the Windspire before the test program was terminated due to turbine problems. The Windspire normally experiences two resonances, before it reaches its rated speed of 180 rpm.

Table 8. Final Safety and Function Test Summary for the Windspire, publication pending.

Test Method	Comment	Complies with Design
Power control	Turbine controls power output per design	Yes
Rotor speed control	Turbine controls rpm per design; maximize at 390 rpm	Yes
Normal start-up	The turbine starts normally; it experiences two resonance modes	Yes
Normal shutdown	The turbine shuts down normally as winds drop below cut-out, however it maintain a low rpm (3–10) when braked; the turbine was not designed to shut down in high winds	Yes

Emergency stop	Turbine stops within 2 to 3 seconds of opening the disconnect switch	Yes
Loss of grid	Turbine stops within 2 to 3 seconds of load loss	Yes
Rotor overspeed	Data was not collected for this test	Unknown
Overvoltage/undervoltage	Data was not collected for this test	Unknown

3.4. Power Quality

IEC standard 61400-21, Measurement and Assessment of Power Quality Characteristics of Grid Connected Wind Turbines, applies to three-phase turbines. Power quality tests are performed for the Gaia-Wind 11 kW and the Entegrity EW50 because they are three-phase systems. Measurements include reactive power, flicker, voltage fluctuations, and harmonics. At the time of this writing, only partial results for the EW50 exist and final results for the Gaia-Wind 11 kW are awaiting publication; published test report will be posted on NREL's Independent Testing website: http://www.nrel.gov/wind/smallwind/independent_testing.html

3.5. Noise Testing

IEC standard 61400-11, Acoustic Noise Measurement Techniques, does not contain information specific to small wind turbines, however noise will be addressed specifically in the next revision of this standard. One result of the noise test is to characterize emissions from a turbine in terms of sound power level. For small wind turbines, the IEC standard is followed with some modifications. Ten-second averages are used instead of 1-minute averages to better characterize the more-dynamic nature of small wind turbines. Also, to determine the sound power levels at the integer wind speeds, binning data is used instead of regression analysis. Figure 7 shows the sound power levels for the Gaia-Wind 11 kW, ARE 442, and EW50. Testing on the Windspire was not completed, and testing on the VT10 has not begun.

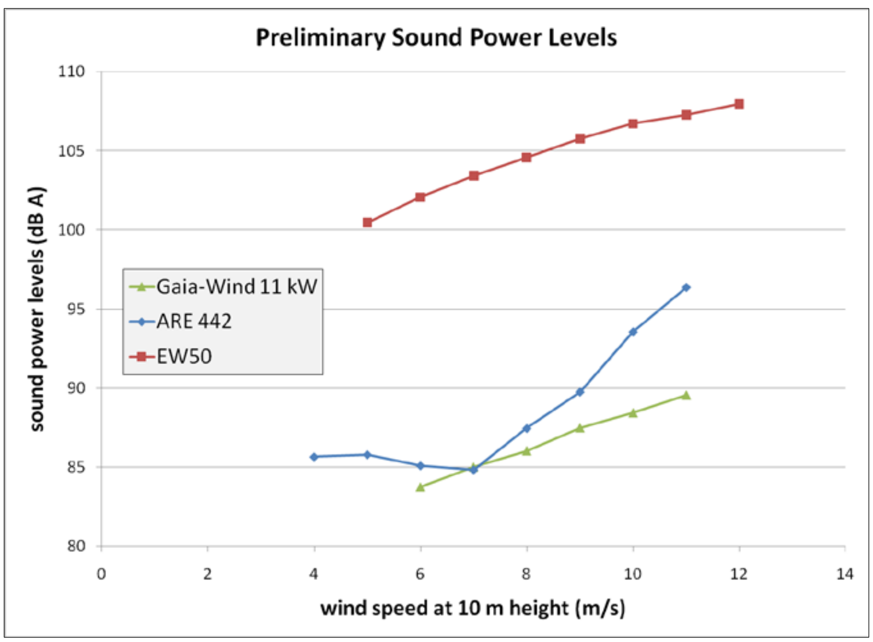

Figure 7. Preliminary Sound Power level for Gaia-Wind 11 kW, ARE 442, and EW50

4. Conclusion

This paper presents the partial results of International Electrotechnical Commission tests on five small wind turbines at the National Renewable Energy Laboratory (NREL). The final results and complete test reports will be provided to the public through the NREL website: http://www.nrel.gov/wind/smallwind/independent_testing.html. These results may be used by the public, certifying bodies, and state agencies to incentivize small wind turbines.

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14. ABSTRACT *(Maximum 200 Words)*
In 2008, the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) began testing small wind turbines (SWTs) through the Independent Testing project. Using competitive solicitation, five SWTs were selected for testing at the National Wind Technology Center (NWTC). NREL's NWTC is accredited by the American Association of Laboratory Accreditation (A2LA) to conduct duration, power performance, safety and function, power quality, and noise tests to International Electrotechnical Commission (IEC) standards. Results of the tests conducted on each of the SWTs are or will be available to the public on the NREL website. The results could be used by their manufacturers in the certification of the turbines or state agencies to decide which turbines are eligible for state incentives.

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