NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Acoustic Noise Test Plan

for the

Gamesa G97 CII 60Hz 2MW Wind Turbine

in
Golden Colorado

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

for
Gamesa Wind US
1150 Northbrook Dr.
Trevose PA 19053

J. Roadman and A. Huskey

15 July 2013

Approval By: _____ 15 July 2013
Jason Roadman, NREL Test Engineer — Date

Approval By: _____ 31 July 2013
Ignacio Remón de la Mata, G9X Validation Engineer — Date

1.0 Test Objective

The primary goal of the test is to characterize the acoustic emissions of the Gamesa G97 wind turbine in accordance with the International Electrotechnical Commission's (IEC) standard, *Wind turbines part 11: Acoustic Noise Measurement Techniques*, IEC 61400-11, Edition 2.1, 2006-11 and the Measuring Network of Wind Energy Institutes (MEASNET) standard, *Acoustic Noise Measurement Procedure*, Edition 2. Hereafter these documents are referred to as the Standards. This test plan documents the measurement techniques, test equipment, and analysis procedures for the following quantities at integer wind speeds from 6 to 10 m/s:

- apparent sound power level,
- one-third octave band levels, and
- tonality.

In addition, the National Wind Technology Center (NREL) plans to conduct this test in accordance with its quality system procedures such that the final test report will meet the full requirements of accreditation by A2LA. NREL's quality system procedures require that the test meet all applicable requirements specified by A2LA, Measnet, and ISO/IEC 17025 (or to note any exceptions in the test report).

After approval, this test plan represents a commitment by both NREL and DOE to conduct the test according to the methods described herein.

2.0 Test Turbine

The test turbine will be a G97 CII wind turbine. It is a horizontal axis, three bladed, upwind turbine with full span pitch control. Table 1 provides the key descriptive information of the test turbine.

Table 1. Test Turbine Configuration

Turbine manufacturer and address	Gamesa Wind US, 2050 Cabot Boulevard West Langhorne PA 19047-1811
Make, Model, Serial Number	Gamesa, G97 2MW, sn. 100184308
Production Year of Turbine	2012
Rotor Diameter (m)	97m
Hub Height (m)	90m
Horizontal distance from rotor center to tower axis (m)	4.44m
Stall or pitch-controlled	Pitch-controlled
Tower Type	Trunk – conical tubular
Rated Electrical Power (kW)	2000
Rated Wind Speed (m/s)	10.5 m/s
Rotor speed range (rpm)	9.8 rpm – 17.8 rpm
Rotor control devices	Vortex Generators
Number of Blades	3
Blade Tip Pitch Angle (deg)	Variable
Blade make, type, serial number	LM GlassFiber, 44000004, 4400001, 4400005
Generator make, type, serial number	Indar TAR500L4R sn. 20616000000
Gearbox make, type, serial number	HANSEN EH806AN21-BN sn EH806A-033/LM0001
Control software	COSMOS

3.0 Test Site

The test turbine is located at site 4.5 at the National Wind Technology Center, 8 miles south of Boulder, Colorado, USA. Figure 1 shows the turbine and permanent meteorological tower locations. This figure also shows nearby obstructions and topographical features of the site. Figure 2 shows a wind rose listing the distribution of the winds at the site gathered during the site assessment. Predominant wind is generally accepted to be 292° true.

Figure 3 details potential sound board locations. The blue shaded regions show locations that provide appropriate ±15° measurement sectors and also meet the inclination angle constraints. A 10m met mast is located 323m on a bearing of 115° true from the turbine, approximately upwind for prevailing winds. This configuration will ensure that data can be collected according to the standard without requiring an exception. Any deviation from these locations would only be utilized if mutually agreed upon by NREL and Gamesa. For practical purposes, the same met mast and sound board locations will be used as in previous tests for this site.

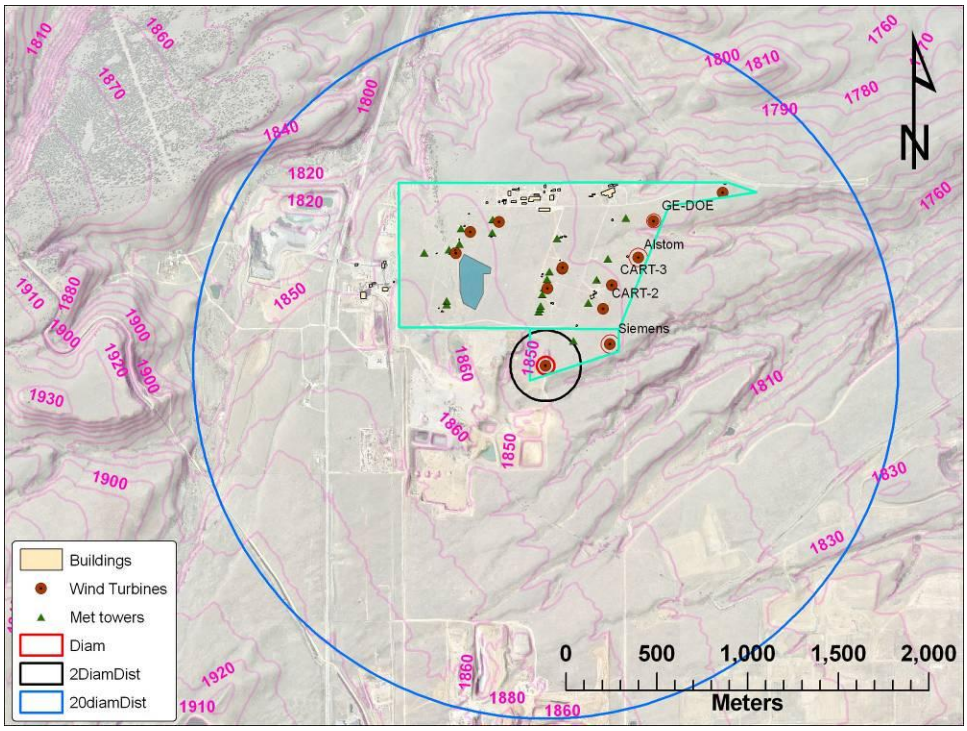

Figure 1. Test Turbine Location

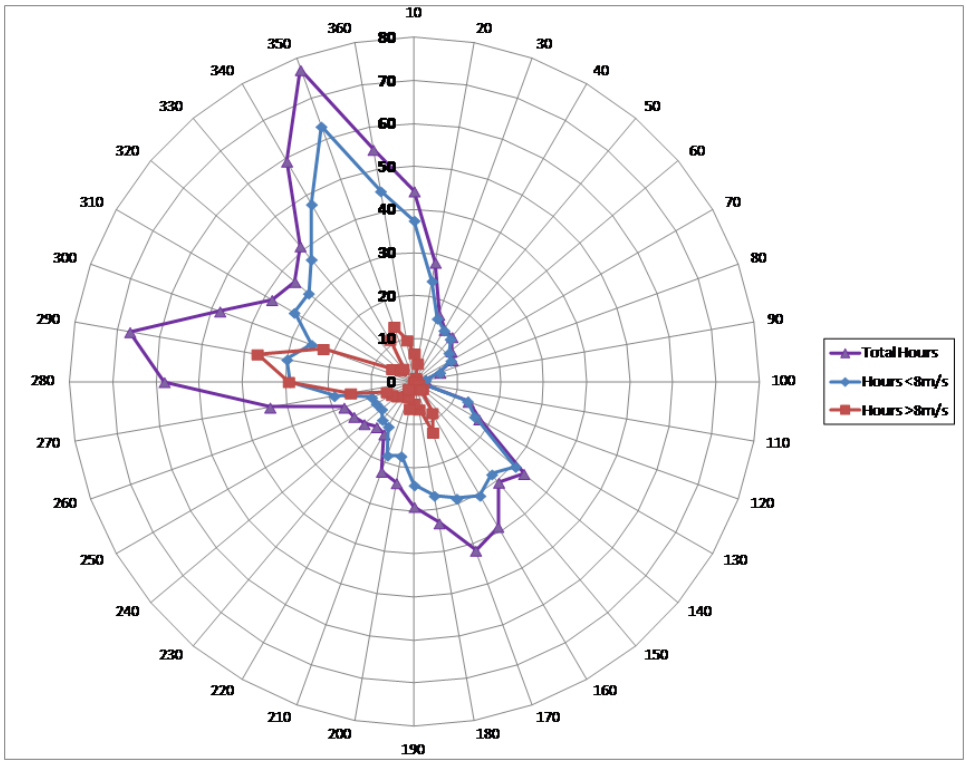

Figure 2. Wind distribution from site calibration.

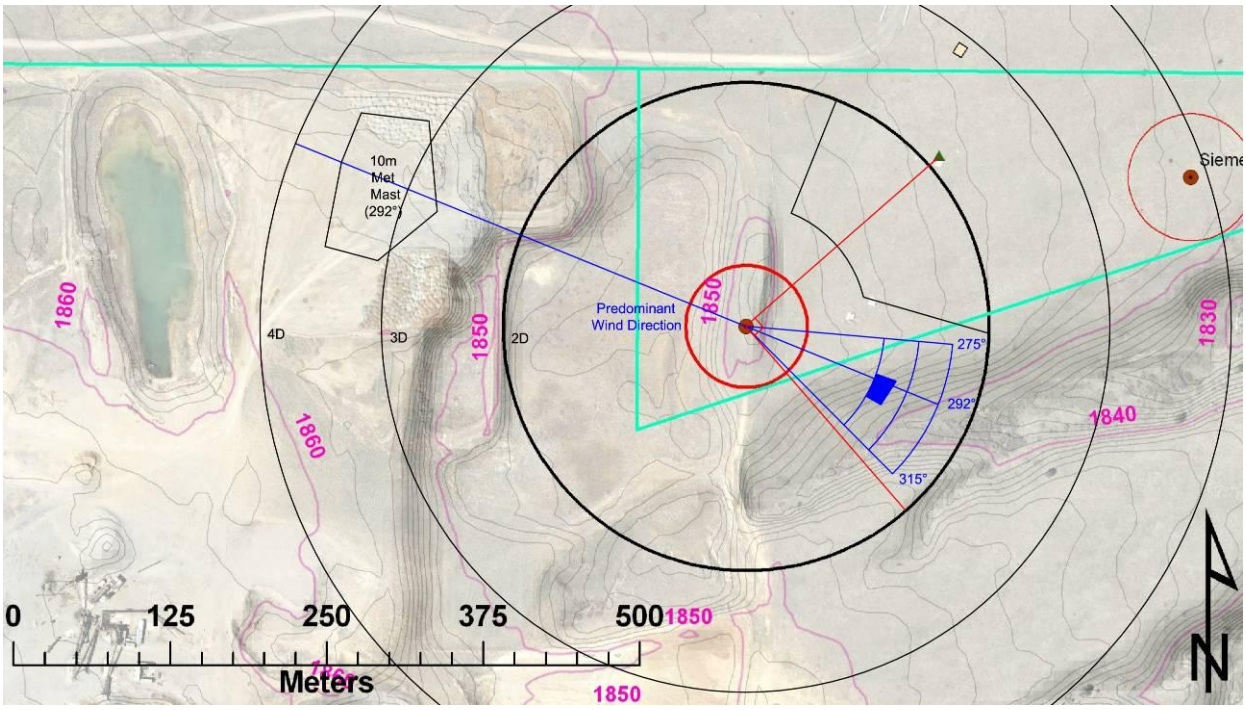

Figure 3. Possible sound board and temporary anemometer locations (1m contour intervals)

Nearby sources of noise that might interfere with noise testing of the test turbine are given in Table 2.

Table 2. Nearby noise sources

Source	Location	Shutdown for noise test
GE 1.5	4.0	As needed
Alstom ECO110 3.0MW	4.1	As needed
CART-3	4.3	Yes
CART-2	4.3	Yes
Siemens 2.3MW	4.4	Yes
Southwest Windpower Skystream (2 turbines)	3.2	No

4.0 Test Instrumentation

Table 3 shows the list of instrumentation that will be used for the test. For acoustic measurements when the turbine is operating below 95% rated power, the power will be measured and wind speed will be derived from the power curve. For points above 95% rated power, the wind speed will be derived from the correlation between nacelle anemometer and the wind speed derived from power per the standard. For background noise measurements, the wind speed will be measured using the 10 m anemometer and correlated to the wind speed derived from turbine power. A microphone with wind screen will be placed in the downwind reference position to measure the total and background noise.

Table 3. Equipment list

Instrument	Manufacturer	Model Number
Signal Analyzer	Delta Acoustics	Noiselab Professional 3.0
Microphone	Bruel & Kjaer	4189-A-021
Preamplifier	Bruel & Kjaer	4012
Calibrator	Bruel & Kjaer	4230
Digital Recorder	Delta Acoustics	Noiselab Professional 3.0
Anemometer (10m tower)	Thies	First Class
Nacelle anemometer	Gamesa controller	NA
Wind Vane	Met One	SD-201
Pressure Sensor	Vaisala	PTB101B
Temperature Sensor	Met One	T200
Power	Camille Bauer	Sineax M 563
Meteorological Data Acquisition System	National Instruments	EtherCAT
Pitch angle	Gamesa controller	NA
Rotor speed	Gamesa controller	NA
Power	Gamesa controller	NA

5.0 Test Procedures

Testing will begin once three conditions are fulfilled:

1. This test plan is complete and signed by both the client and NREL
2. NREL has complete installation and checkout of meteorological and turbine instrumentation required for the test
3. The client has signed a test readiness document that indicates that the turbine is ready for testing.

The test will continue until, at a minimum, all requirements listed in Table 4 are fulfilled. Testing will continue until Gamesa and NREL agree that sufficient data has been collected.

Table 4. Minimum Data Requirements for Acoustics test

Measurement Type	Requirements
Overall measurements	At least 30 one-minute averages.
For A-weighted sound pressure level: (for turbine and background measurements)	At least 3 minutes of data with wind speeds ±0.5 m/s of the integer values of 6, 7, 8, 9, and 10 m/s
For octave or third octave band measurements: (for turbine and background measurements)	At least 3 minutes of data with wind speeds ±0.5 m/s of the integer values of 6, 7, 8, 9, and 10 m/s
Narrow band measurements: (for turbine and background measurements)	At least 2 minutes of data with wind speeds ±0.5 m/s of the integer values of 6, 7, 8, 9, and 10 m/s

6.0 Reporting

Within 12 hours of the conclusion of a measurement session, an email will be sent that includes a table detailing the collected turbine and background measurements binned against measured wind speed.

More detailed preliminary reports will be issued within 48 hours after a measurement session concludes, ideally sooner if personnel availability allows. These reports will include:

1. A table detailing total acquired data sets to date and sound pressure levels per wind speed bin (1-min averages)
2. A graph of sound pressure level versus hub height wind speed (1-min averages)
3. A graph of sound pressure level versus output power (1-min averages)
4. A graph of sound pressure level versus pitch angle (1-min averages)

The final report will include:

1. Description of the test turbine
2. Description of the test site
3. Description of the test instrumentation
4. Description of the measurement procedure
5. Results with uncertainty including:
    a. A-weighted sound power level (as function of standardized wind speed, rotor speed and power)
    b. Plots of all data and regression lines
    c. One-Third Octave Spectra (graphical and tabular)
    d. Tonal analysis
    e. Low frequency analysis
6. Exceptions to the requirements of the IEC and MEASNET standards, test plan, or NREL quality system

7. Raw and processed data will be made available to Gamesa, preferably in MS Excel format. Note, as some of what is listed below was not part of the original scope of work, this data will be made available as close to the original agreed upon timing, but may not immediately accompany the report.
    a. 1-second and 1-minute averaged data
    b. Description of variable names
    c. Tables showing total number of wind speed bins
    d. Sound power level vs. wind speed at 10 m per wind speed bin
8. A final test result summary will be included separately that follows the Gamesa supplied format listed on below.

Wind speed at 10m height [m/s]	3	4	5	6	7	8	9	10
Electrical power output calculated from the power curve [kW]								
Measured pitch angle [degrees]								
Measured rotor speed [1/min]								
Sound power level [dB]								
Combined uncertainty in the sound power level, U_C [dB]								
Tonality, $\mathbf{\Delta L_k}$ [dB]								
Tonal audibility, $\mathbf{\Delta L_{a,k}}$ [dB]								
Frequency of the most prevalent tone [Hz]								

7.0 Roles and Responsibilities

Table 5 lists the planned test team, and identifies roles and responsibilities for each team member.

Table 5. Roles of Test Participants

Title	Name	Role(s)
Test Engineer	Jason Roadman NREL	Overall test management and responsibility. NREL approval of test plan. Test set-up, checkout, conduct. Collection of test data. Analysis of test data. Resolution of problems during testing. Review and report test results. Final report
Test Engineer	Arlinda Huskey NREL	Collection of test data. Resolution of problems during testing. Review of test data, results, and report.
Test Technician	Jerry Hur NREL	Selection of instruments Installation, maintenance and checkout of test equipment Implementation of corrective actions for problems Responsible for ensuring safety of personnel and equipment at test site.
Turbine Technician	Aaron Rodgers	Operation and maintenance of test turbine (under supervision of site manager)
Client, Test Engineers	Paula Negro Muniain, Gamesa	Supervise operation and maintenance of test turbine. Primary turbine manufacturer contact for NREL Provided information needed for test plan Reports any change in turbine configuration to NREL Resolution of any problems with test turbine Provides test evaluation to NREL
Client	Ignacio Remón de la Mata, Gamesa	Approve test plan

8.0 Schedule

All test equipment is on site. NREL is ready to start measurements and will begin data collection as soon as appropriate winds are available, the turbine is in good working order, and the data acquisition system has been checked out after the turbine is repaired. Specific measurement dates will be agreed upon between NREL and Gamesa based on the meteorological forecast for WTG site. Typically these decisions will require response with less than 48 hours of notice. Data collection will continue until Gamesa and NREL agree that sufficient data has been collected.