NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Wind Turbine Generator System

Acoustic Noise Test Plan

for the

Gamesa G97 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
2050 Cabot Boulevard West,
Langhorne, PA 19047

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Approval By: Arlinda Huskey 23 March 2012
Arlinda Huskey, NREL Test Engineer Date

Approval By: 20.03.2012
Jesús González Moreno, G9X Chief Validation & Certification 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 standards 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,
- third octave band levels, and
- tonality.

In addition, the National Wind Technology Center (NREL) plans to conduct this test in accordance with our quality system procedures such that the final test report will meet the full requirements of our accreditation by A2LA. NREL's quality system requires that we 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 wind turbine. Table 1 provides the key descriptive information of the test turbine.

Table 1. Test Turbine Configuration

Turbine manufacturer and address	Gamesa
Model	G97
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	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

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 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 being located upwind of the turbine, as shown in Figure 3. This configuration will ensure that data can be collected according to the standard without requiring an exception. Correlation between the temporary anemometer and the primary anemometer will be investigated. Any deviation from these locations would only be utilized if mutually agreed upon by NREL and Gamesa.

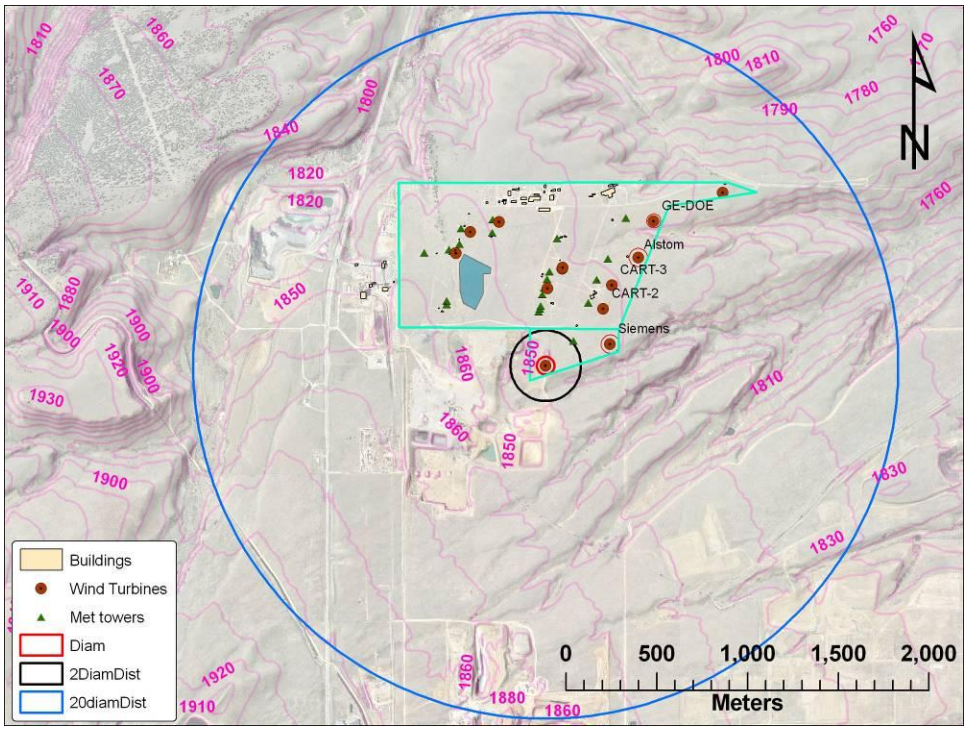

Figure 1. Test Turbine Location

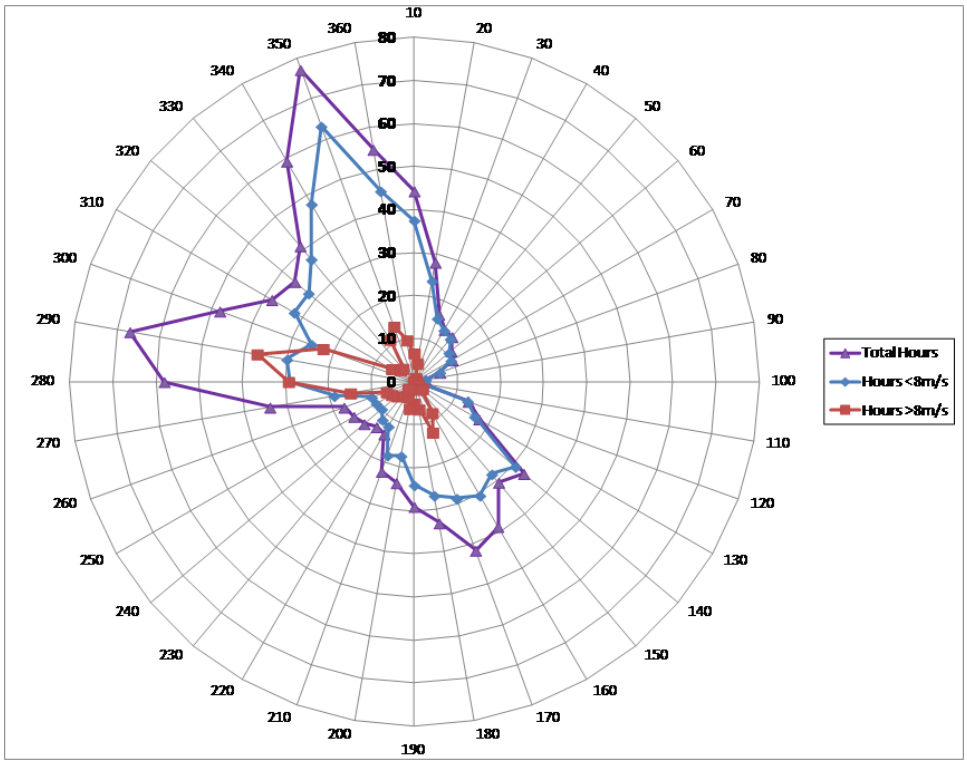

Figure 2. Wind distribution from site calibration.

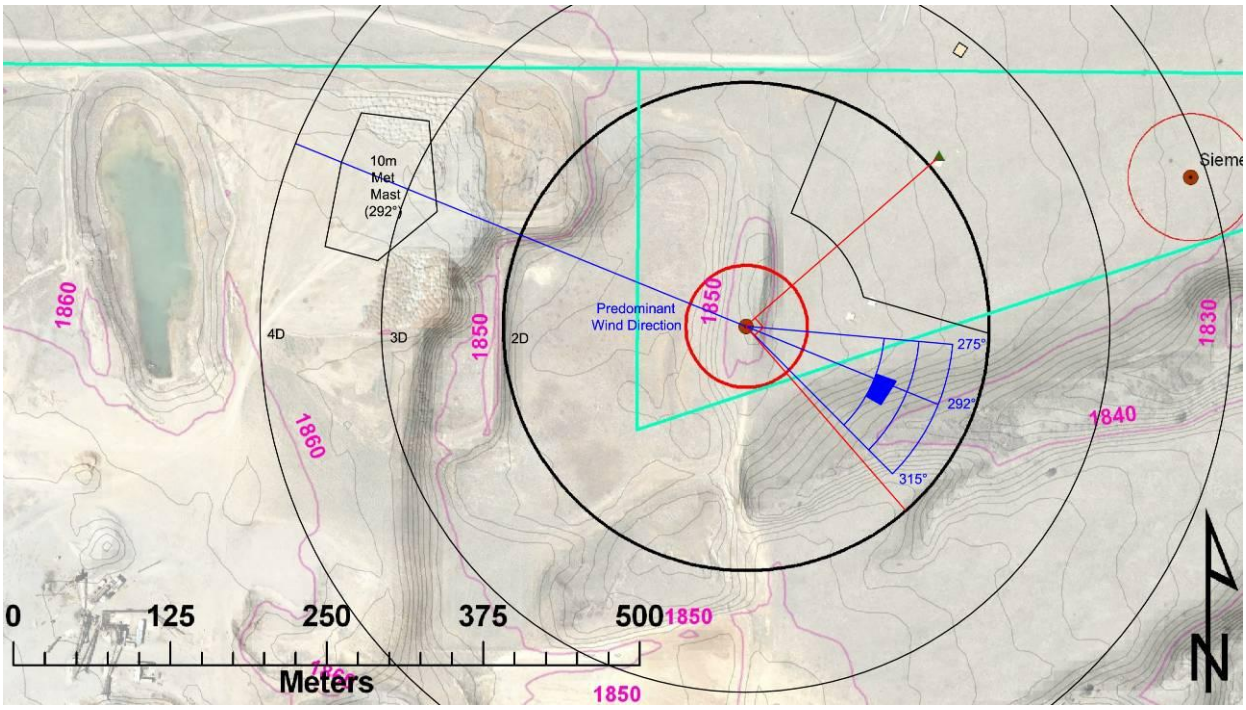

Figure 3. Potential sound board and temporary anemometer locations (1m contour intervals)

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 ECO100 3.0MW	4.1	As needed
CART-3	4.3	Yes
CART-2	4.3	Yes
Siemens 2.3MW	4.4	Yes
Swift 1kW	3.1	No
Southwest Windpower Skystream (2 turbines)	3.2	No
Viryd CS8	3.3	As needed

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 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

Preliminary reports will be issued as soon as possible after a measurement session concludes. If testing concludes before 3:00 pm local time, this report will be delivered by 5:00 pm local time. Otherwise, the report will be delivered before 11:00 am the following day. 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 .xls 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	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	Overall test management and responsibility. NREL approval of test plan. Supervision of test set-up, checkout. Review of test data. Resolution of problems during testing Review and report test results. Final 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	Iván Martínez Llona and Scott Synnestvedt, 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	Jesús González Moreno, Gamesa	Approve test plan

8.0 Schedule

All test equipment is on site. NREL is ready to start measurements. The planned start date for the test is week 11 of 2012. 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 72 hours of notice.

Data collection will continue until Gamesa and NREL agree that sufficient data has been collected.