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100 Barr Harbor Dr., West Conshohocken, PA 19428

Standard Test Method for Performance Testing of Wind Energy Conversion Systems[1]

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INTRODUCTION

This test method describes a standard test method of determining and reporting primary performance characteristics of wind energy conversion systems (WECS). It includes field test procedures to determine the power production performance and other operating parameters for a WECS; a field test procedure to determine noise levels associated with the WECS operation; and procedures for deriving the WECS performance parameters and the manner in which these ratings should be presented.

1. Scope

1.1 This test method covers a test method for determining and reporting performance characteristics of Wind Energy Conversion Systems (WECS). It is intended to provide consumers and other users with an equitable basis for comparing the energy production performance and operating characteristics of WECS available in the marketplace.

1.2 This test method is not limited to WECS that produce electricity.

1.3 These procedures and practices were specifically compiled for small WECS (SWECS), but the test method may be generally applicable to WECS of all sizes.

1.4 This test method does not address issues of reliability, durability, or economics.

1.5 For all ratings dependent upon wind speed, the wind is taken to be that which is experienced at the centerline height of the WECS rotor. No standard heights for either the WECS rotor or the anemometer are assumed.

1.6 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ANSI Standard:*

S1.4 Specification for Sound Level Meters[2]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *asynchronous WECS, n*—wind energy conversion system in which the rotor speed is more a function of wind speed than of generator characteristics.

3.1.2 *average noise level, n*—weighted average of the noise levels experimentally obtained for a WECS operating at various wind speeds.

3.1.3 *AWEA (American Wind Energy Association) estimated annual energy output (AEAEO), n*—calculated total energy that would be produced by a WECS during a one-year period, assuming a Rayleigh wind speed distribution, based upon yearly mean wind speed, and 100 % availability.

3.1.4 *bin, n*—wind speed interval used for test data grouping in the Method of Bins data reduction procedure.

3.1.5 *bin sort, n*—bin-by-bin summary of the results of a Method of Bins procedure.

3.1.6 *bin width, n*—size of a wind speed interval used in the Method of Bins data reduction procedure (that is, a bin having a span from 11.5 mph to 12.5 mph has a width of 1 mph).

3.1.7 *centerline height of the rotor, n*—distance between the group and the vertical center of the rotor.

3.1.8 *constant velocity test (CVT), n*—wind energy conversion system test in which a smooth steady airflow is maintained either in a wind tunnel or by moving the WECS, relative to the ground, in calm air.

3.1.9 *cut-in wind speed, n*—lowest wind speed at which a WECS will begin to have power output.

3.1.10 *cut-out wind speed, n*—wind speed above which a WECS will have, due to a control function, no power output.

3.1.11 *downwind, n*—relative orientation of two points where *A* is downwind if the wind first passes *B* then *A*.

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[2] Available from American National Standard Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

3.1.12 *dwell time*, *n*—number of samples in a bin divided by the sampling rate (in samples per second).

3.1.13 *field test*, *n*—performance test that is carried out under naturally occurring atmospheric conditions.

3.1.14 *HAWT*, *n*—horizontal axis wind turbine.

3.1.15 *master bin sort*, *n*—compilation of bin sorts.

3.1.16 *maximum design wind speed*, *n*—maximum wind speed a WECS in automatic, unattended operation, but not necessarily generating, has been designed to sustain without damage to structural components or loss of ability to function normally.

3.1.17 *maximum power*, *n*—maximum power output a WECS, in normal steady state operation, will produce.

3.1.18 *maximum tested wind speed*, *n*—maximum wind speed a WECS in automatic, unattended operation, but not necessarily generating, has sustained without damage to structural components or loss of ability to function normally.

3.1.19 *Method of Bins*, *n*—data reduction procedure by which test data are grouped into wind speed intervals (bins).

3.1.20 *Discussion*—For each bin, the number of samples and the sum of the samples are recorded, allowing the average parameter value to be evaluated.

3.1.21 *overspeed control*, *n*—action of a control system, or part of such system, that prevents excessive rotor speed.

3.1.22 *power curve*, *n*—characteristic of WECS power output versus steady-state wind speed.

3.1.23 *power form*, *n*—physical characteristics that describe the form in which power produced by the WECS is made deliverable to the load.

3.1.24 *power output*, *n*—useful power delivered by a WECS at a stated steady state wind speed.

3.1.25 *rated rotor speed*, *n*—nominal rotational speed of a WECS rotor when it is producing power.

3.1.26 *Rayleigh wind speed distribution*, *n*—mathematical idealization giving a ratio of time the wind blows within a given wind speed band, probability interval of V to $V + dV$, to the total time under consideration. This is a Weibull wind speed distribution with a constant of two and depends only on mean wind speed, defined as follows:

$$F^{\bar{V}}(V)dV = \frac{V}{2}\frac{\pi}{\bar{V}^2} EXP\left[-\frac{\pi}{4}\left(\frac{V}{\bar{V}}\right)^2\right] dV \tag{1}$$

where:

$F^{\bar{V}}(V)$ = Rayleigh frequency distribution as a function of V,
$\bar{V}$ = mean wind speed,
V = instantaneous wind speed, and
dV = wind speed probability interval.

3.1.27 *rotor*, *n*—system of rotating aerodynamic elements attached to a single shaft that converts the kinetic energy in the wind into mechanical shaft energy.

3.1.28 *rotor diameter*, *n*—twice the distance from the rotor axis to the outermost point on the blade.

3.1.29 *rotor speed*, *n*—angular velocity of a WECS rotor about its rotational axis.

3.1.30 *steady-state wind speed*, *n*—condition where a constant wind speed continues until dynamic transients in WECS behavior have subsided.

3.1.31 *synchronous WECS*, *n*—wind energy conversion system in which the rotor speed is more a function of generator characteristics than of wind speed.

3.1.32 *tower*, *n*—subsystem of a WECS that supports the rotor, or other collection device, above the ground.

3.1.33 *upwind*, *adj*—relative orientation of two points where *A* is upwind of *B* if the wind first passes *A* then *B*.

3.1.34 *utility interconnection*, *n*—electrical connection between a WECS and a utility grid in which energy can be transferred from the WECS to that utility grid.

3.1.35 *VAWT*, *n*—vertical axis wind turbine.

3.1.36 *WECS*, *n*—wind energy conversion system.

3.1.37 *wind shear*, *n*—variation of wind velocity with respect to spatial variation in a plane normal to the wind direction, usually in the vertical direction.

4. Significance and Use

4.1 This test method is intended to provide consumers and other users with an equitable basis for comparing the energy production performance and operating characteristics of WECS available in the marketplace.

5. Apparatus

5.1 *Test Machine*:

5.1.1 The manufacturer, or other testing entity, may not modify or adjust any component of the WECS in order to enhance its performance beyond that of a regular production machine operating in a typical user installation.

5.1.2 If a manufacturer institutes a model change or a modification that can be expected to produce a detrimental change amounting to more than 10 % of an established rating, then a retest for the affected parameter(s) and an amended test report are required. In the case of power output performance, a 10 % degradation at any wind speed in the range from 12 to 35 mph (5.4 to 15.6 m/s) will necessitate retesting.

5.1.3 On WECS that can be either electronically adjusted or mechanically outfitted to match operational capabilities or characteristics to a specific site, the test machine should be set up assuming a 12 mph (5.4 m/s) or 16 mph (7.2 m/s) average wind speed and a Rayleigh distribution of wind speed probability density. The manufacturer has the option of setting-up for 10 mph (4.5 m/s) or 14 mph (6.3 m/s) or 18 mph (8.0 m/s), or combination thereof, average wind speeds, performing separate tests to arrive at separate power curves, and using the results to calculate the AWEA estimated annual energy output at these averages. In this case, however, the manufacturer must specify, in all literature containing these ratings, that this option was exercised.

5.2 *Instrumentation*:

5.2.1 *Anemometry*—The accuracy of the test anemometer should not be less than ±1 mph (0.4 m/s) over a range of 7 to 45 mph (3.1 to 20.1 m/s). The test anemometer should be calibrated within a period of 6 months prior to the test. This calibration is to be U.S. National Institute of Standards and Technology (NIST) traceable. The manufacturer, or other testing entity, should determine the best type of anemometer to be used for the test.

NOTE 1—Use of a secondary calibration source (anemometer manufacturer, laboratory, etc.) is acceptable so long as NIST traceability is maintained.

NOTE 2—Anemometers that display significant hysteresis effects should be avoided, since they can distort the outcome of a Method of Bins procedure.

NOTE 3—It is preferable to use an anemometer that can respond rapidly to changes in wind speed and direction.

5.2.2 *Power Monitoring*—The power monitoring instrumentation used for the test shall have a cumulative accuracy within 3 % over a range of 5 to 125 % of the WECS maximum power. Each component of this instrumentation should be calibrated within a period of 6 months prior to the test. This calibration is to be NIST traceable. For WECS that have a power form of alternating current (AC) electricity the instrumentation shall provide a true root-mean-square (RMS) reading of real power.

NOTE 4—Use of a wattmeter is strongly recommended.

5.2.3 *Temperature Monitoring*—The thermometer or other temperature indicator shall be accurate to within ±1°F (±0.6°C) over the range of temperatures experienced during the test. The thermometer or other temperature indicator shall have a least count of 1°F (0.6°C) or less.

5.2.4 *Atmospheric Pressure Monitoring*—The barometer used to measure atmospheric pressure shall have an accuracy of ±3 % over the range of pressures experienced during the test. The barometer shall have a least count of 2.5 mm Hg or less.

5.2.5 *Tachometer*—The tachometer or other device used to measure rotor speed shall have an accuracy within 2 % over the WECS operating range. The tachometer shall have a least count not greater than 2 % of the WECS maximum operating speed.

5.2.6 *Sound Level Meter*—The sound level meter shall be in accordance with ANSI *S*1.4 for Type 2 instruments. The sound level meter shall be set to the A-weighting network and, where possible, "slow meter response." A wind screen should be placed on the microphone used in the test.

6. Sampling Rates

6.1 *Wind Speed/Power Output*:

6.1.1 The minimum sampling rate shall be one data point every 30 s.

NOTE 5—There is no maximum sampling rate.

6.2 *Air Temperature and Atmospheric Pressure*:

6.2.1 Readings should be taken at the beginning and end of a test period and once per hour in between.

6.2.2 The average of these readings for each test period, rounded to the nearest whole unit, will be used to calculate the test air density.

7. Preparation of Apparatus

7.1 *Site*:

7.1.1 The criteria used in choosing a test site should be those normally used for installation purposes.

7.1.2 The vicinity of the test site should be free of topographical features capable of producing abrupt changes in wind shear.

7.1.3 The vicinity of the test site shall be free from any noise sources, other than natural wind background noise, that might produce sound levels in excess of those produced by the test WECS.

7.2 *Installation of Apparatus*:

7.2.1 It is recommended that the centerline height of the rotor be at least 25 ft (7.6 m) above the ground.

7.2.2 The tower, load, and wiring, or its equivalent, should be representative of typical customer installations.

7.2.3 The load should be large enough to ensure that the WECS output quantities that determine energy transfer capability (voltage, pressure, torque, etc.) will be maintained within generally recognized operating limits during the course of the test.

NOTE 6—If lead-acid batteries constitute the load, then the battery storage system should be large enough to maintain the individual cells below 2.35 V.

NOTE 7—Wind energy conversion systems intended for utility-interconnected operation should be connected to motor-generators for this test method only if the motor-generator has sufficient capacity to maintain the WECS output within accepted utility industry standards for voltage and frequency.

7.2.4 The test anemometer is to be located at a height within ±3 ft (0.9 m) or 1/10 of the rotor diameter, whichever is greater, of the rotor centerline height. Shear corrections, such as the "1/7 power law," are not allowed under this test method.

7.2.5 The test anemometer should not be closer than 1.5 rotor diameters from the horizontal center of the rotor on a horizontal-axis wind turbine (HAWT) and 2 rotor diameters on a vertical-axis wind turbine (VAWT).

7.2.6 The test anemometer should be within six rotor diameters of the center of the rotor.

7.2.7 During the course of the test, the test anemometer must never be in the wake of any portion of the WECS rotor or structure.

NOTE 8—If the distance requirements set forth in 7.2.5 of this section are met, the upwind wake is assumed negligible.

7.2.8 Power monitoring instrumentation shall be placed in the WECS power circuit, or its equivalent, in a manner that ensures that only power delivered to the load is measured.

NOTE 9—All internal WECS losses due to excitation, friction, or controls must be supplied from the WECS side of the power monitoring instrumentation or deducted from the gross power measurements.

7.2.9 Air temperature shall be monitored at the base of the WECS tower, or equivalent structure.

NOTE 10—A height of 5 ft (1.5 m) is recommended.

7.2.10 The thermometer bulb or other temperature transducer shall be shielded from direct sunlight, and any other radiation source, during the test(s).

7.2.11 The thermometer should be well exposed to the air for ventilation.

7.2.12 Atmospheric pressure shall be monitored at the base of the tower, or equivalent structure.

7.2.13 The manufacturer, or other testing entity, shall determine the best location for the tachometer sensor.

7.2.14 As shown in Fig. 1, there are three sampling positions for the sound level meter located at various angles relative to the wind direction and the base of the WECS tower. Each sampling position is 100 ft (30.5 m), or 1.5 rotor

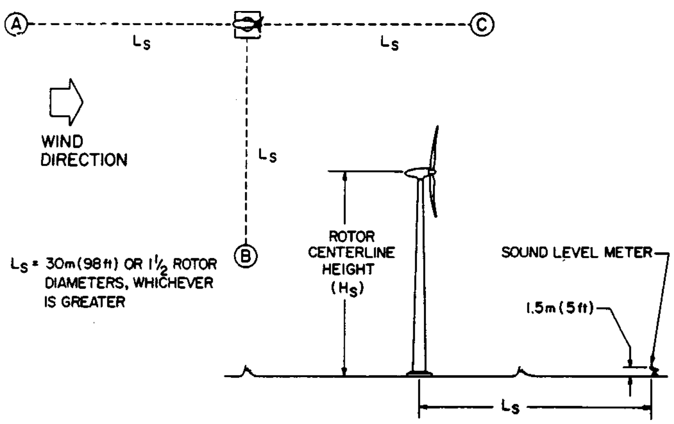

FIG. 1 Sound Level Meter Positions

diameters, whichever is greater, from the base of the tower, or equivalent structure, and 5 ft (1.5 m) above the ground:

7.2.14.1 *Point A*—Upwind of the tower.

7.2.14.2 *Point B*—Perpendicular to the wind direction (on either side of the tower).

7.2.14.3 *Point C*—Downwind of the tower.

8. Procedure

8.1 In this test a large number of samples, consisting of a wind speed and associated WECS power output, are taken over a wide range of wind speeds. Occasional readings of air temperature, atmospheric pressure, and, in some cases, rotor speed are also collected. In a field test, the wind speed/power output data usually has a large amount of scatter, so a simple correlation procedure, the Method of Bins, is used. In this procedure the range of wind speeds that might be expected to occur during the course of the test is divided into wind speed "bins" of equal width. If, for example, the bin width was 1 mph, then the 13 mph bin would range from 12.5 to 13.5 mph, the 14 mph bin would range from 13.5 mph to 14.5 mph, and so on. Each bin has two cumulative registers. One is a simple counter that is incremented each time a sampled wind speed falls within the range of the bin's width. The second register contains the cumulative sum of the WECS power output readings whose associated wind speeds have fallen within the range of the bin. When a sample is taken the proper bin is located, its counter is incremented by one, and the power reading is added to the sum of all the previous power readings in the bin. Density corrections for each test period, involving temperature and atmospheric pressure, are made after the data has been accumulated in the bins. This allows data from separate test periods to be combined, a necessity if the performance is to be tested over a wide range of wind speeds. When the sum in the second register of a bin is divided by the value in the counter the result is the WECS average power output at that wind speed. If enough data points have been accumulated in each bin, a plot of these average outputs versus wind speed will show only limited scatter. The smooth curve drawn through these plotted points is then the WECS power curve.

8.2 *General Requirements*:

8.2.1 *Duration*—If for any reason a test period lasts less than 15 min, consider that test invalid and discard its associated data.

8.2.2 *Adjustment Limitations*:

8.2.2.1 Do not make manual changes in blade pitch setting or rotor operating speed during or between test periods.

8.2.2.2 Do not disable or override any overspeed/high wind speed protection normally provided with the WECS during the course of the tests.

8.2.2.3 Do not make adjustments to either the load or generator field, or their equivalent, in any sort of synchronization with the taking of data.

8.2.3 *Termination*—Terminate test if the experimentally determined air density varies by 0.0075 lb/ft^3(0.12 kg/m^3).

NOTE 11—This requirement is necessary in order to preserve the validity of the corrections. A new test period may be started immediately.

8.3 *Data Gathering*—Performance Measurements.

8.3.1 *Manual*:

8.3.1.1 Take wind speed/power output data directly from meters provided that there are two observers. Allow the readings to be taken nearly simultaneously.

NOTE 12—Use of digital displays is recommended.

8.3.1.2 Collect data from a real time recording, such as a strip chart, provided that readings are taken at equal intervals not to exceed 30 s.

8.3.2 *Automatic*:

8.3.2.1 The use of automatic sampling and compiling systems is preferred under this test method.

8.3.2.2 Take into account the accuracy of any analog-to-digital converters, amplifiers, or other signal conditioners in satisfying 5.2.1 and 5.2.2.

8.3.2.3 The resolution of any data acquisition system utilizing analog-to-digital converters should not be less than 1 mph (0.4 m/s) for wind speed or 2 % of the maximum power for power output.

8.4 *Data Gathering*—Noise Measurements.

8.4.1 Take separate sound level readings with the WECS operating in low, medium, and high wind speeds (see 8.4.3 for allowable variation) as follows:

8.4.1.1 SL,Low—average sound level at 10 mph (4.5 m/s).

8.4.1.2 SL,Medium—average sound level at 20 mph (8.9 m/s).

8.4.1.3 SL,High—average sound level at 30 mph (13.4 m/s).

8.4.2 Take the readings at the three points described in 7.2.4. Use the highest average obtained for each wind speed in the procedure to determine the average noise level rating (see 9.10).

8.4.3 The sound level for each wind speed and position will be the average of not less than five independent readings taken within ± 2 mph (0.9 m/s) of the prescribed wind speed.

NOTE 13—A second observer, who monitors wind speed and signals when it is within the acceptable bounds, is recommended.

8.4.4 Readings taken under conditions of a steady-state wind speed are preferred.

8.4.5 Take a reading by observing the sound level reading through at least one complete revolution of the rotor and recording the highest level observed.