

# Wind turbine generator systems —

## Part 11: Acoustic noise measurement techniques

The European Standard EN 61400-11:2003, with the incorporation of amendment A1:2006, has the status of a British Standard

ICS 27.180

## National foreword

This British Standard is the official English language version of EN 61400-11:2003, including amendment A1:2006. It is identical with IEC 61400-11:2002, including amendment 1:2006. It supersedes BS EN 61400-11:1999 which is withdrawn.

The start and finish of text introduced or altered by IEC amendment is indicated in the text by tags **A1** **A1**. Tags indicating changes to IEC text carry the number of the IEC amendment. For example, text altered by IEC amendment 1 is indicated by **A1** **A1**.

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English version

**Wind turbine generator systems**  
**Part 11: Acoustic noise measurement techniques**  
(IEC 61400-11:2002)

Aérogénérateurs  
Partie 11: Techniques de mesure  
du bruit acoustique  
(CEI 61400-11:2002)

Windenergieanlagen  
Teil 11: Schallmessverfahren  
(IEC 61400-11:2002)

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European Committee for Electrotechnical Standardization  
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Europäisches Komitee für Elektrotechnische Normung

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## Foreword

The text of document 88/166/FDIS, future edition 2 of IEC 61400-11, prepared by IEC TC 88, Wind turbines, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61400-11 on 2003-03-18.

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with the EN have to be withdrawn (dow) -

Annexes designated "normative" are part of the body of the standard.  
Annexes designated "informative" are given for information only.  
In this standard, annex ZA is normative and annexes A to D are informative.  
Annex ZA has been added by CENELEC.

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## Endorsement notice

The text of the International Standard IEC 61400-11:2002 was approved by CENELEC as a European Standard without any modification.

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## Foreword to amendment 1

The text of document 88/260/FDIS, future amendment 1 to IEC 61400-11:2002, prepared by IEC TC 88, Wind turbines, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as amendment A1 to EN 61400-11:2003 on 2006-06-01.

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## Endorsement notice

The text of amendment 1:2006 to the International Standard IEC 61400-11:2002 was approved by CENELEC as an amendment to the European Standard without any modification.

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## INTRODUCTION

The purpose of this part of IEC 61400 is to provide a uniform methodology that will ensure consistency and accuracy in the measurement and analysis of acoustical emissions by wind turbine generator systems. The standard has been prepared with the anticipation that it would be applied by:

- the wind turbine manufacturer striving to meet well defined acoustic emission performance requirements and/or a possible declaration system;
- the wind turbine purchaser in specifying such performance requirements;
- the wind turbine operator who may be required to verify that stated, or required, acoustic performance specifications are met for new or refurbished units;
- the wind turbine planner or regulator who must be able to accurately and fairly define acoustical emission characteristics of a wind turbine in response to environmental regulations or permit requirements for new or modified installations.

This standard provides guidance in the measurement, analysis and reporting of complex acoustic emissions from wind turbine generator systems. The standard will benefit those parties involved in the manufacture, installation, planning and permitting, operation, utilization, and regulation of wind turbines. The measurement and analysis techniques recommended in this document should be applied by all parties to insure that continuing development and operation of wind turbines is carried out in an atmosphere of consistent and accurate communication relative to environmental concerns. This standard presents measurement and reporting procedures expected to provide accurate results that can be replicated by others.

This amendment to IEC 61400-11:2002 addresses special cases where 95 % of rated power is reached below 10 m/s speed at 10 m height and for sites where wind speeds of 10 m/s at 10 m height are very rare. Furthermore a clarification on regression analysis and frequency weighting is included.

## WIND TURBINE GENERATOR SYSTEMS –

### Part 11: Acoustic noise measurement techniques

#### 1 Scope

This part of IEC 61400 presents measurement procedures that enable noise emissions of a wind turbine to be characterised. This involves using measurement methods appropriate to noise emission assessment at locations close to the machine, in order to avoid errors due to sound propagation, but far enough away to allow for the finite source size. The procedures described are different in some respects from those that would be adopted for noise assessment in community noise studies. They are intended to facilitate characterisation of wind turbine noise with respect to a range of wind speeds and directions. Standardisation of measurement procedures will also facilitate comparisons between different wind turbines.

The procedures present methodologies that will enable the noise emissions of a single wind turbine to be characterised in a consistent and accurate manner. These procedures include the following:

- location of acoustic measurement positions;
- requirements for the acquisition of acoustic, meteorological, and associated wind turbine operational data;
- analysis of the data obtained and the content for the data report; and
- definition of specific acoustic emission parameters, and associated descriptors which are used for making environmental assessments.

The standard is not restricted to wind turbines of a particular size or type. The procedures described in this standard allow for the thorough description of the noise emission from a wind turbine. If, in some cases, less comprehensive measurements are needed, such measurements are made according to the relevant parts of this standard.

#### 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60386:1972, *Method of measurement of speed fluctuations in sound recording and reproducing equipment*

IEC 60651:1979, *Sound level meters*

IEC 60688:1992, *Electrical measuring transducers for converting a.c. electrical quantities to analogue or digital signals*

IEC 60804:2000, *Integrating-averaging sound level meters*

IEC 60942:1997, *Electroacoustics – Sound calibrators*

IEC 61260:1995, *Electroacoustics – Octave-band and fractional-octave-band filters*

IEC 61400-12:1998, *Wind turbine generator systems – Part 12: Wind turbine power performance testing*

### 3 Definitions

For the purposes of this standard, the following definitions apply:

#### 3.1

##### **apparent sound power level**

$L_{WA}$  (in dB re. 1 pW)

the A-weighted sound power level re. 1 pW of a point source at the rotor centre with the same emission in the downwind direction as the wind turbine being measured,  $L_{WA}$  is determined at each wind speed integer from 6 to 10 m/s

#### 3.2

##### **audibility criterion**

$L_a$  (in dB re. 20  $\mu$ Pa)

a frequency dependent criterion curve determined from listening tests, and reflecting the subjective response of a 'typical' listener to tones of different frequencies

#### 3.3

##### **A-weighted or C-weighted sound pressure levels**

$L_A$  or  $L_C$ , respectively (in dB re. 20  $\mu$ Pa)

sound pressure levels measured with the A or C frequency weighting networks specified in IEC 60651

#### 3.4

##### **directivity**

$\Delta_i$  (in dB)

the difference between the A-weighted sound pressure levels measured at measurement positions 2, 3, and 4 and those measured at the reference position 1 from the turbine corrected to the same distance from the wind turbine rotor centre

#### 3.5

##### **inclination angle**

$\phi$  (in  $^\circ$ )

the angle between the plane of the microphone board and a line from the microphone to the rotor centre

#### 3.6

##### **reference distance**

$R_0$  (in m)

the nominal horizontal distance from the centre of the base of the wind turbine to each of the prescribed microphone positions

#### 3.7

##### **reference height**

$z_{ref}$  (in m)

a height of 10 m used for converting wind speed to reference conditions

#### 3.8

##### **reference roughness length**

$z_{0ref}$  (in m)

a roughness length of 0,05 m used for converting wind speed to reference conditions

#### 3.9

##### **sound pressure level**

$L_p$  (in dB re. 20  $\mu$ Pa)

10 times the  $\log_{10}$  of the ratio of the mean-square sound pressure to the square of the reference sound pressure of 20  $\mu$ Pa

**3.10****standardized wind speed** **$V_s$  (in  $\text{ms}^{-1}$ )**

wind speed converted to reference conditions (height 10 m and roughness length 0,05 m) using a logarithmic profile

**3.11****tonal audibility  $\Delta L_{a,k}$  (in dB)**

The difference between the tonality and the audibility criterion at integer wind speeds  $k = 6, 7, 8, 9, 10$

**3.12****tonality  $\Delta L_k$  (in dB)**

the difference between the tone level and the level of the masking noise in the critical band around the tone at integer wind speeds  $k = 6, 7, 8, 9, 10$

**4 Symbols and units**

|                  |                                                                                                                                                                                       |      |
|------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| $D$              | rotor diameter (horizontal axis turbine) or equatorial diameter (vertical axis turbine)                                                                                               | (m)  |
| $H$              | height of rotor centre (horizontal axis turbine) or height of rotor equatorial plane (vertical axis turbine) above local ground near the wind turbine                                 | (m)  |
| $L_A$ or $L_C$   | A or C-weighted sound pressure level                                                                                                                                                  | (dB) |
| $L_{Aeq,k}$      | equivalent continuous A-weighted sound pressure level at each integer wind speed, where $k = 6, 7, 8, 9, 10$                                                                          | (dB) |
| $L_{Aeq,c,k}$    | equivalent continuous A-weighted sound pressure level corrected for background noise at each integer wind speed and corrected to reference conditions, where $k = 6, 7, 8, 9, 10$     | (dB) |
| $L_{Aeq,i}$      | equivalent continuous A-weighted sound pressure level in position 'i' corrected for background noise where $i = 1, 2, 3$ , or 4                                                       | (dB) |
| $L_n$            | equivalent continuous sound pressure level of the background noise                                                                                                                    | (dB) |
| $L_{pn,j,k}$     | sound pressure level of masking noise within a critical band in the ' $j^{\text{th}}$ ' spectra at the ' $k^{\text{th}}$ ' wind speed, where $j = 1$ to 12 and $k = 6, 7, 8, 9, 10$   | (dB) |
| $L_{pn,avg,j,k}$ | average of analysis bandwidth sound pressure levels of masking in the ' $j^{\text{th}}$ ' spectra at the ' $k^{\text{th}}$ ' wind speed, where $j = 1$ to 12 and $k = 6, 7, 8, 9, 10$ | (dB) |
| $L_{pt,j,k}$     | sound pressure level of the tone or tones in the ' $j^{\text{th}}$ ' spectra at the ' $k^{\text{th}}$ ' wind speed, where $j = 1$ to 12 and $k = 6, 7, 8, 9, 10$                      | (dB) |
| $L_s$            | equivalent continuous sound pressure level of only wind turbine noise                                                                                                                 | (dB) |
| $L_{s+n}$        | equivalent continuous sound pressure level of combined wind turbine and background noise                                                                                              | (dB) |
| $L_{WA,k}$       | apparent sound power level, where $k = 6, 7, 8, 9, 10$                                                                                                                                | (dB) |
| $P_m$            | measured electric power                                                                                                                                                               | (W)  |
| $P_n$            | normalised electric power                                                                                                                                                             | (W)  |

|                           |                                                                                                                             |                   |
|---------------------------|-----------------------------------------------------------------------------------------------------------------------------|-------------------|
| $R_i$                     | slant distance, from rotor centre to actual measurement position 'i', where $i = 1, 2, 3$ , or 4                            | (m)               |
| $R_0$                     | reference distance                                                                                                          | (m)               |
| $S_0$                     | reference area, $S_0 = 1 \text{ m}^2$                                                                                       | (m <sup>2</sup> ) |
| $T_C$                     | air temperature                                                                                                             | (C)               |
| $T_K$                     | air temperature                                                                                                             | (K)               |
| $U_A, U_B$                | uncertainty components                                                                                                      | (dB)              |
| $V_H$                     | wind speed at hub height, $H$                                                                                               | (m/s)             |
| $V_D$                     | derived wind speed from power curve                                                                                         | (m/s)             |
| $V_n$                     | wind speed measured by the nacelle anemometer                                                                               | (m/s)             |
| $V_z$                     | wind speed at height, $z$                                                                                                   | (m/s)             |
| $V_s$                     | standardized wind speed                                                                                                     | (m/s)             |
| $f$                       | frequency of the tone                                                                                                       | (Hz)              |
| $f_c$                     | centre frequency of critical band                                                                                           | (Hz)              |
| $p$                       | atmospheric pressure                                                                                                        | (kPa)             |
| $z_0$                     | roughness length                                                                                                            | (m)               |
| $z_{0\text{ref}}$         | reference roughness length, 0,05 m                                                                                          | (m)               |
| $z$                       | anemometer height                                                                                                           | (m)               |
| $z_{\text{ref}}$          | reference height for wind speed, 10 m                                                                                       | (m)               |
| $\beta$                   | angle used to define allowable area for anemometer mast location                                                            | (°)               |
| $\kappa$                  | the ratio of standardised wind speed and measured wind speed                                                                |                   |
| $\Delta_i$                | directivity at ' $j^{\text{th}}$ ' position, where $i = 2, 3$ , or 4                                                        | (dB)              |
| $\Delta_{\text{Ltn},j,k}$ | tonality of the ' $j^{\text{th}}$ ' spectra at ' $k^{\text{th}}$ ' wind speed, where $j = 1$ to 12 and $k = 6, 7, 8, 9, 10$ | (dB)              |
| $\phi$                    | inclination angle                                                                                                           | (°)               |

## 5 Outline of method

This Part of IEC 61400 defines the procedures to be used in the measurement, analysis and reporting of acoustic emissions of a wind turbine. Instrumentation and calibration requirements are specified to ensure accuracy and consistency of acoustic and non-acoustic measurements. Non-acoustic measurements required defining the atmospheric conditions relevant to determining the acoustic emissions are also specified. All parameters to be measured and reported are identified, as are the data reduction methods required for obtaining these parameters.

Application of the method described in this International Standard provides the apparent A-weighted sound power levels, spectra, and tonality at integer wind speeds from 6 to 10 m/s of an individual wind turbine. Optionally, directivity may also be determined.

The measurements are made at locations close to the turbine in order to minimise the influence of terrain effects, atmospheric conditions or wind-induced noise. To account for the size of the wind turbine under test, a reference distance  $R_0$  based on the wind turbine dimensions is used.

Measurements are taken with a microphone positioned on a board placed on the ground to reduce the wind noise generated at the microphone and to minimise the influence of different ground types.

Measurements of sound pressure levels and wind speeds are made simultaneously over short periods of time and over a wide range of wind speeds. The measured wind speeds are converted to corresponding wind speeds at a reference height of 10 m and a reference roughness length of 0,05 m. The sound levels at standardized wind speeds of 6, 7, 8, 9, and 10 m/s are determined and used for calculating the apparent A-weighted sound power levels.

**A1** If this part of IEC 61400 is used for verification that actual noise emission is in accordance with a reference/declared noise level, the verification measurement shall be made in accordance with the present standard for a wind speed range given by:

- Annual average wind speed at 10 m height onsite  $\pm 1$  m/s as a minimum. As a minimum, three integer wind speed values and 8 m/s shall be reported (i.e. site average = 4,8 m/s, use 4, 5, 6, and 8 m/s).
- If the declaration measurements indicate that audible tones are present at other wind speeds, these wind speeds shall be included as well.

Where local codes or contracts between parties involved (i.e. manufacturers, developers, owners) require measurements at a different wind speed or wind speed range, this part of IEC 61400 may be applied at those wind speeds. **A1**

The directivity is determined by comparing the A-weighted sound pressure levels at three additional positions around the turbine with those measured at the reference position.

Informative annexes are included that cover

- other possible characteristics of wind turbine noise emission and their quantification (Annex A);
- criteria for recording/playback equipment (Annex B);
- assessment of turbulence intensity (Annex C);
- assessment of measurement uncertainty (Annex D).

## 6 Instrumentation

### 6.1 Acoustic instruments

The following equipment is necessary to perform the acoustic measurements as set forth in this standard.

#### 6.1.1 Equipment for the determination of the equivalent continuous A-weighted sound pressure level

The equipment shall meet the requirements of a type 1 sound level meter according to IEC 60804. The diameter of the microphone shall be no greater than 13 mm.

### **6.1.2 Equipment for the determination of one-third octave band spectra**

In addition to the requirements given for type 1 sound level meters, the equipment shall have a constant frequency response over at least the 45 Hz to 11 200 Hz frequency range. The filters shall meet the requirements of IEC 61260 for Class 1 filters.

The equivalent continuous sound pressure levels in one-third octave bands shall be determined simultaneously with centre frequencies from 50 Hz to 10 kHz. It may be relevant to measure the low-frequency noise emission of a wind turbine. In such cases, a wider frequency range is necessary as discussed in Annex A.

### **6.1.3 Equipment for the determination of narrow band spectra**

The equipment shall fulfil the relevant requirements for IEC 60651 type 1 instrumentation in the 20 Hz to 11 200 Hz frequency range.

### **6.1.4 Microphone with measurement board and windscreen**

The microphone shall be mounted at the centre on a flat hard board with the diaphragm of the microphone in a plane normal to the board and with the axis of the microphone pointing towards the wind turbine, as in Figures 1 and 2. The board shall be circular with a diameter of at least 1,0 m and made from material that is acoustically hard, such as plywood or hard chip-board with a thickness of at least 12,0 mm or metal with a thickness of at least 2,5 mm. A larger board is recommended especially for soft ground. In the exceptional case that the board is split (i.e. not in one piece) there are considerations; the pieces shall be level within the same plane, the gap less than 1 mm, and the split must be off the centre line and parallel with the microphone axis as shown in Figure 1a).

The windscreen to be used with the ground-mounted microphone shall consist of a primary and, where necessary, a secondary windscreen. The primary windscreen shall consist of one half of an open cell foam sphere with a diameter of approximately 90 mm, which is centred around the diaphragm of the microphone, as in Figure 2.

The secondary windscreen may be used when it is necessary to obtain an adequate signal-to-noise ratio at low frequencies in high winds.

For example, it could consist of a wire frame of approximate hemispherical shape, at least 450 mm in diameter, which is covered with a 13 mm to 25 mm layer of open cell foam with a porosity of 4 to 8 pores per 10 mm. This secondary hemispherical windscreen shall be placed symmetrically over the smaller primary windscreen.

If the secondary windscreen is used, the influence of the secondary windscreen on the frequency response must be documented and corrected for.

### **6.1.5 Acoustical calibrator**

The complete sound measurement system, including any recording, data logging or computing systems, shall be calibrated immediately before and after the measurement session at one or more frequencies using an acoustical calibrator on the microphone. The calibrator shall fulfil the requirements of IEC 60942 class 1, and shall be used within its specified environmental conditions.

### **6.1.6 Data recording/playback systems**

A data recording/playback system is a required part of the measurement instrumentation, and the entire chain of measurement instruments shall fulfil the relevant requirements of IEC 60651, for type 1 instrumentation. Examples are given in Annex B.

## 6.2 Non-acoustic Instruments

The following equipment is necessary to perform the non-acoustic measurements set forth in this standard.

### 6.2.1 Anemometers

The anemometer and its signal processing equipment shall have a maximum deviation from the calibration value of  $\pm 0,2$  m/s in the wind speed range from 4 m/s to 12 m/s. It shall be capable of measuring the average wind speed over time intervals synchronized with the acoustic measurements.

**[A1]** Because the nacelle anemometer is *in situ* calibrated during measurement, the demand for calibration does not apply to the nacelle anemometer. The measurements from the nacelle anemometer may be supplied from the wind turbine control system. The nacelle anemometer shall not be used for background noise measurements. **[A1]**

### 6.2.2 Electric power transducer

The electric power transducer, including current and voltage transformers, shall meet the accuracy requirements of IEC 60688 Class 1.

### 6.2.3 Wind direction transducer

The wind direction transducer shall be accurate to within  $\pm 6^\circ$ .

### 6.2.4 Other instrumentation

A camera and instruments to measure distance are required. The temperature shall be measured with an accuracy of  $\pm 1^\circ\text{C}$ . The atmospheric pressure shall be measured with an accuracy of  $\pm 1$  kPa.

## 6.3 Traceable calibration

The following equipment shall be checked regularly and be calibrated with traceability to a national or primary standards laboratory. The maximum time from the last calibration shall be as stated for each item of equipment:

- acoustic calibrator (12 months);
- microphone (24 months);
- integrating sound level meter (24 months);
- spectrum analyzer (36 months);
- data recording/playback system (24 months);
- anemometer (24 months);
- electric power transducer (24 months).

If the acoustic calibrator is calibrated as a part of the integrating sound level meter, the maximum calibration interval may be extended to 24 months.

An instrument shall always be recalibrated if it has been repaired or is suspected of fault or damage.

## 7 Measurements and measurement procedures

### 7.1 Measurement positions

To fully characterize the noise emission of a wind turbine, the following measurement positions are required.

### 7.1.1 Acoustic measurement positions

One, and optionally another three, microphone positions are to be used. The four positions shall be laid out in a pattern around the vertical centreline of the wind turbine tower as indicated in the plan view shown in Figure 3. The required downwind measurement position is identified as the reference position, as shown in Figure 3. The direction of the positions shall be accurate within  $\pm 15^\circ$  relative to the wind direction at the time of measurement. The horizontal distance  $R_0$  from the wind turbine tower vertical centreline to each microphone position shall be as shown in Figure 3, with a tolerance of 20 % and shall be measured with an accuracy of  $\pm 2$  %.

As shown in Figure 4a), the reference distance  $R_0$  for horizontal axis turbines is given by:

$$R_0 = H + \frac{D}{2} \quad (1)$$

where

$H$  is the vertical distance from the ground to the rotor centre; and

$D$  is the diameter of the rotor.

As shown in Figure 4b), the reference distance  $R_0$  for vertical axis wind turbines is given by:

$$R_0 = H + D \quad (2)$$

where

$H$  is the vertical distance from the ground to the rotor equatorial plane; and

$D$  is the equatorial diameter.

To minimize influence due to the edges of the reflecting board on the measurement results, it shall be ensured that the board is positioned flat on the ground. Any edges or gaps under the board should be levelled out by means of soil. The inclination angle  $\phi$ , as shown in Figure 4, shall be between  $25^\circ$  and  $40^\circ$ . This may require adjustment of the measurement position within the tolerances stated above.

The measurement position shall be chosen so that the calculated influence from any reflecting structures, such as buildings or walls, shall be less than 0,2 dB.

### 7.1.2 Wind speed and direction measurement positions

The test anemometer and wind direction transducer shall be mounted in the upwind direction of the wind turbine at a height between 10 m and rotor centre. The transducers shall be placed at a distance between  $2D$  and  $4D$  from the rotor centre. If method 2 (see 7.3.1.2) is used to determine the wind speed, the allowable region in which the anemometer and wind direction transducer shall be located is given in Figure 5.

The angle  $\beta$  is given by:

$$\beta = \frac{z - z_{\text{ref}}}{H - z_{\text{ref}}} (\beta_{\text{max}} - \beta_{\text{min}}) + \beta_{\text{min}} \quad (3)$$

where

$z$  is the anemometer height, see Figure 6;

$z_{\text{ref}}$  is the reference height of 10 m;

$H$  is the height of the rotor centre or equatorial plane of the wind turbine, see Figure 4;

$\beta_{\text{max}}$  is the maximum angle for  $\beta$ ,  $\beta_{\text{max}} = 90^\circ$ ;

$\beta_{\text{min}}$  is the minimum angle for  $\beta$ ,  $\beta_{\text{min}} = 30^\circ$ .