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Wind turbine generator systems –
Part 11: Acoustic noise measurement techniques

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CONTENTS

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WIND TURBINE GENERATOR SYSTEMS –

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FOREWORD

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International Standard IEC 61400-11 has been prepared by IEC technical committee 88: Wind turbines.

This consolidated version of IEC 61400-11 consists of the second edition (2002) [documents 88/166/FDIS and 88/171/RVD] and its amendment 1 (2006) [documents 88/260/FDIS and 88/264/RVD].

The technical content is therefore identical to the base edition and its amendment and has been prepared for user convenience.

It bears the edition number 2.1.

A vertical line in the margin shows where the base publication has been modified by amendment 1.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of the base publication and its amendments will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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.

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

3.4
directivity
Δ_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
ϕ (in °)
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 µPa)
10 times the $\log_{10}$ of the ratio of the mean-square sound pressure to the square of the reference sound pressure of 20 µPa

3.10
standardized wind speed
V_s (in 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 ΔL_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^{th}' spectra at the 'k^{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^{th}' spectra at the 'k^{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^{th}' spectra at the 'k^{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 m^2	(m^2)
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_{0ref}	reference roughness length, 0,05 m	(m)
z	anemometer height	(m)
z_{ref}	reference height for wind speed, 10 m	(m)
β	angle used to define allowable area for anemometer mast location	(°)
κ	the ratio of standardised wind speed and measured wind speed	
Δ_i	directivity at 'i^{th}' position, where i = 2, 3, or 4	(dB)
$\Delta_{Ltn,j,k}$	tonality of the 'j^{th}' spectra at 'k^{th}' wind speed, where j = 1 to 12 and k = 6, 7, 8, 9, 10	(dB)
ϕ	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.

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 ±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.

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.