



IEC 61400-11

Edition 3.1 2018-06
CONSOLIDATED VERSION

INTERNATIONAL STANDARD



Wind turbines – Part 11: Acoustic noise measurement techniques

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.180

ISBN 978-2-8322-5826-2

Warning! Make sure that you obtained this publication from an authorized distributor.

REDLINE VERSION



Wind turbines – Part 11: Acoustic noise measurement techniques

CONTENTS

FOREWORD.....	5
INTRODUCTION.....	7
INTRODUCTION to the Amendment	7
1 Scope.....	8
2 Normative references	8
3 Terms and definitions	9
4 Symbols and units	12
5 Outline of method	13
6 Instrumentation	14
6.1 Acoustic instruments	14
6.1.1 General	14
6.1.2 Equipment for the determination of the equivalent continuous A-weighted sound pressure level.....	14
6.1.3 Equipment for the determination of A-weighted 1/3-octave band spectra	14
6.1.4 Equipment for the determination of narrow band spectra	14
6.1.5 Microphone with measurement board and windscreen	14
6.1.6 Acoustical calibrator	16
6.1.7 Data recording/playback systems	16
6.2 Non-acoustic Instruments	16
6.2.1 General	16
6.2.2 Anemometers	16
6.2.3 Electric power transducer	17
6.2.4 Other instrumentation	17
6.3 Traceable calibration	17
7 Acoustic measurements and measurement procedures	17
7.1 Acoustic measurement positions	17
7.2 Acoustic measurements	20
7.2.1 General	20
7.2.2 Acoustic measurement requirements	20
7.2.3 A-weighted sound pressure level	21
7.2.4 A-weighted 1/3-octave band measurements.....	21
7.2.5 A-weighted narrow band measurements	21
7.2.6 Optional acoustic measurements at positions 2, 3 and 4.....	21
7.2.7 Other optional measurements	22
7.2.8 Combining measurement series.....	22
8 Non-acoustic measurements	22
8.1 General.....	22
8.2 Wind speed measurements	22
8.2.1 Determination of the wind speed during wind turbine operation.....	23
8.2.2 Wind speed measurements during background noise measurements.....	24
8.3 Downwind direction	24
8.4 Other atmospheric conditions	25
8.5 Rotor speed and pitch angle measurement.....	25
9 Data reduction procedures.....	25

9.1	General methodology for sound power levels and 1/3-octave band levels	25
9.2	Calculation of sound pressure levels	28
9.2.1	General	28
9.2.2	Calculation of average sound spectra and uncertainty per bin	28
9.2.3	Calculation of average wind speed and uncertainty per bin	30
9.2.4	Calculation of noise levels at bin centres including uncertainty	31
9.3	Apparent sound power levels	32
9.4	Apparent sound power levels with reference to wind speed in 10 m height	33
9.5	Tonal audibility	34
9.5.1	General methodology for tonality	34
9.5.2	Identifying possible tones	37
9.5.3	Classification of spectral lines within the critical band	37
9.5.4	Identified tone	40
9.5.5	Determination of the tone level	40
9.5.6	Determination of the masking noise level	40
9.5.7	Determination of tonality	40
9.5.8	Determination of audibility	41
9.5.9	Background noise	41
10	Information to be reported	42
10.1	General	42
10.2	Characterisation of the wind turbine	42
10.3	Physical environment	42
10.4	Instrumentation	43
10.5	Acoustic data	43
10.6	Non-acoustic data	44
10.7	Uncertainty	44
Annex A (informative)	Other possible characteristics of wind turbine noise emission and their quantification	45
Annex B (informative)	Assessment of turbulence intensity	47
Annex C (informative)	Assessment of measurement uncertainty	48
Annex D (informative)	Apparent roughness length	50
Annex E (informative)	Characterization of a secondary wind screen	52
Annex F (normative)	Small wind turbines	56
Annex G (informative)	Air absorption	60
Annex H (normative)	Data treatment for measurement series on different days or with substantially different conditions	61
Bibliography	62
Figure 1	– Mounting of the microphone	15
Figure 2	– Picture of microphone and measurement board	16
Figure 3	– Standard pattern for microphone measurement positions (plan view)	18
Figure 4	– Illustration of the definitions of R_0 and slant distance R_1	20
Figure 5	– Acceptable meteorological mast position (hatched area)	23
Figure 6	– Flowchart showing the data reduction procedure	27
Figure 7	– Flowchart for determining tonal audibility for each wind speed bin	36
Figure 8	– Illustration of L_{70} % level in the critical band	38

Figure 9 – Illustration of lines below the $L_{70} \% + 6$ dB criterion	39
Figure 10 – Illustration of $L_{pn,avg}$ level and lines classified as masking.....	39
Figure 11 – Illustration of classifying all spectral lines.....	40
Figure E.1 – Example 1 of a secondary wind screen	53
Figure E.2 – Example 2 of secondary wind screen	54
Figure E.3 – Example on insertion loss from Table E.1	55
Figure F.1 – Allowable region for meteorological mast position as a function of β – Plan view	57
Figure F.2 – Example immission noise map	59
Figure G.1 – Example of 1/3-octave spectrum.....	60
Table C.1 – Examples of possible values of type B uncertainty components relevant for apparent sound power spectra.....	49
Table C.2 – Examples of possible values of type B uncertainty components for wind speed determination relevant for apparent sound power spectra	49
Table D.1 – Roughness length.....	50
Table E.1 – Example on reporting of insertion loss.....	54

INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND TURBINES –

Part 11: Acoustic noise measurement techniques

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

This consolidated version of the official IEC Standard and its amendment has been prepared for user convenience.

IEC 61400-11 edition 3.1 contains the third edition (2012-11) [documents 88/436/FDIS and 88/440/RVD], its amendment 1 (2018-06) [documents 88/615/CDV and 88/644A/RVC] and its corrigendum (2019-10).

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendment 1. Additions are in green text, deletions are in strikethrough red text. A separate Final version with all changes accepted is available in this publication.

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

This third edition constitutes a technical revision, introducing new principles for data reduction procedures.

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

A list of all parts of the IEC 61400 series, under the general title *Wind turbines*, can be found on the IEC website.

The committee has decided that the contents of the base publication and its amendment will remain unchanged until the stability 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.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

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. This International Standard has been prepared with the anticipation that it would be applied by:

- wind turbine manufacturers striving to meet well defined acoustic emission performance requirements and/or a possible declaration system (e.g. IEC/TS 61400-14);
- wind turbine purchasers for specifying performance requirements;
- wind turbine operators who may be required to verify that stated, or required, acoustic performance specifications are met for new or refurbished units;
- wind turbine planners or regulators 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 ensure 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.

INTRODUCTION to the Amendment

This amendment to IEC 61400-11:2012 addresses the situation where a measurement consists of measurements series on different days or with substantially different conditions. Furthermore, clarifications have been introduced on tonality analysis and reporting. Editorial changes have been made.

WIND TURBINES –

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 away enough 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.

This International 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. A method for small wind turbines is described in Annex F.

2 Normative references

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

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

IEC 60942:2003, *Electroacoustics – Sound calibrators*

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

IEC 61400-12-1:2005, *Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines*

IEC 61400-12-2, *Wind turbines – Part 12-2: Power performance verification of electricity producing wind turbines*¹

¹ To be published.

IEC 61672 (all parts), *Electroacoustics – Sound level meters*

ISO/IEC Guide 98-3, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

FINAL VERSION



Wind turbines – Part 11: Acoustic noise measurement techniques

CONTENTS

FOREWORD.....	5
INTRODUCTION.....	7
INTRODUCTION to the Amendment	7
1 Scope.....	8
2 Normative references	8
3 Terms and definitions	9
4 Symbols and units	12
5 Outline of method	13
6 Instrumentation	14
6.1 Acoustic instruments	14
6.1.1 General	14
6.1.2 Equipment for the determination of the equivalent continuous A-weighted sound pressure level.....	14
6.1.3 Equipment for the determination of A-weighted 1/3-octave band spectra	14
6.1.4 Equipment for the determination of narrow band spectra	14
6.1.5 Microphone with measurement board and windscreen	14
6.1.6 Acoustical calibrator	16
6.1.7 Data recording/playback systems	16
6.2 Non-acoustic Instruments	16
6.2.1 General	16
6.2.2 Anemometers	16
6.2.3 Electric power transducer	17
6.2.4 Other instrumentation	17
6.3 Traceable calibration	17
7 Acoustic measurements and measurement procedures	17
7.1 Acoustic measurement positions	17
7.2 Acoustic measurements	20
7.2.1 General	20
7.2.2 Acoustic measurement requirements	20
7.2.3 A-weighted sound pressure level	21
7.2.4 A-weighted 1/3-octave band measurements.....	21
7.2.5 A-weighted narrow band measurements	21
7.2.6 Optional acoustic measurements at positions 2, 3 and 4.....	21
7.2.7 Other optional measurements	22
7.2.8 Combining measurement series.....	22
8 Non-acoustic measurements	22
8.1 General.....	22
8.2 Wind speed measurements	22
8.2.1 Determination of the wind speed during wind turbine operation.....	23
8.2.2 Wind speed measurements during background noise measurements.....	24
8.3 Downwind direction	24
8.4 Other atmospheric conditions	25
8.5 Rotor speed and pitch angle measurement.....	25
9 Data reduction procedures.....	25

9.1	General methodology for sound power levels and 1/3-octave band levels	25
9.2	Calculation of sound pressure levels	28
9.2.1	General	28
9.2.2	Calculation of average sound spectra and uncertainty per bin	28
9.2.3	Calculation of average wind speed and uncertainty per bin	30
9.2.4	Calculation of noise levels at bin centres including uncertainty	31
9.3	Apparent sound power levels	32
9.4	Apparent sound power levels with reference to wind speed in 10 m height	33
9.5	Tonal audibility	34
9.5.1	General methodology for tonality	34
9.5.2	Identifying possible tones	36
9.5.3	Classification of spectral lines within the critical band	36
9.5.4	Identified tone	39
9.5.5	Determination of the tone level	39
9.5.6	Determination of the masking noise level	39
9.5.7	Determination of tonality	39
9.5.8	Determination of audibility	40
9.5.9	Background noise	40
10	Information to be reported	41
10.1	General	41
10.2	Characterisation of the wind turbine	41
10.3	Physical environment	41
10.4	Instrumentation	42
10.5	Acoustic data	42
10.6	Non-acoustic data	43
10.7	Uncertainty	43
Annex A (informative)	Other possible characteristics of wind turbine noise emission and their quantification	44
Annex B (informative)	Assessment of turbulence intensity	46
Annex C (informative)	Assessment of measurement uncertainty	47
Annex D (informative)	Apparent roughness length	49
Annex E (informative)	Characterization of a secondary wind screen	51
Annex F (normative)	Small wind turbines	55
Annex G (informative)	Air absorption	59
Annex H (normative)	Data treatment for measurement series on different days or with substantially different conditions	60
Bibliography	61
Figure 1	– Mounting of the microphone	15
Figure 2	– Picture of microphone and measurement board	16
Figure 3	– Standard pattern for microphone measurement positions (plan view)	18
Figure 4	– Illustration of the definitions of R_0 and slant distance R_1	20
Figure 5	– Acceptable meteorological mast position (hatched area)	23
Figure 6	– Flowchart showing the data reduction procedure	27
Figure 7	– Flowchart for determining tonal audibility for each wind speed bin	35
Figure 8	– Illustration of L_{70} % level in the critical band	37

Figure 9 – Illustration of lines below the $L_{70} \% + 6$ dB criterion	38
Figure 10 – Illustration of $L_{pn,avg}$ level and lines classified as masking.....	38
Figure 11 – Illustration of classifying all spectral lines.....	39
Figure E.1 – Example 1 of a secondary wind screen	52
Figure E.2 – Example 2 of secondary wind screen	53
Figure E.3 – Example on insertion loss from Table E.1	54
Figure F.1 – Allowable region for meteorological mast position as a function of β – Plan view	56
Figure F.2 – Example immission noise map	58
Figure G.1 – Example of 1/3-octave spectrum.....	59
Table C.1 – Examples of possible values of type B uncertainty components relevant for apparent sound power spectra.....	48
Table C.2 – Examples of possible values of type B uncertainty components for wind speed determination relevant for apparent sound power spectra	48
Table D.1 – Roughness length.....	49
Table E.1 – Example on reporting of insertion loss.....	53

INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND TURBINES –

Part 11: Acoustic noise measurement techniques

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

This consolidated version of the official IEC Standard and its amendment has been prepared for user convenience.

IEC 61400-11 edition 3.1 contains the third edition (2012-11) [documents 88/436/FDIS and 88/440/RVD], its amendment 1 (2018-06) [documents 88/615/CDV and 88/644A/RVC] and its corrigendum (2019-10).

This Final version does not show where the technical content is modified by amendment 1. A separate Redline version with all changes highlighted is available in this publication.

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

This third edition constitutes a technical revision, introducing new principles for data reduction procedures.

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

A list of all parts of the IEC 61400 series, under the general title *Wind turbines*, can be found on the IEC website.

The committee has decided that the contents of the base publication and its amendment will remain unchanged until the stability 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.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

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. This International Standard has been prepared with the anticipation that it would be applied by:

- wind turbine manufacturers striving to meet well defined acoustic emission performance requirements and/or a possible declaration system (e.g. IEC/TS 61400-14);
- wind turbine purchasers for specifying performance requirements;
- wind turbine operators who may be required to verify that stated, or required, acoustic performance specifications are met for new or refurbished units;
- wind turbine planners or regulators 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 ensure 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.

INTRODUCTION to the Amendment

This amendment to IEC 61400-11:2012 addresses the situation where a measurement consists of measurements series on different days or with substantially different conditions. Furthermore, clarifications have been introduced on tonality analysis and reporting. Editorial changes have been made.

WIND TURBINES –

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 away enough 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.

This International 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. A method for small wind turbines is described in Annex F.

2 Normative references

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

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

IEC 60942:2003, *Electroacoustics – Sound calibrators*

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

IEC 61400-12-1:2005, *Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines*

IEC 61400-12-2, *Wind turbines – Part 12-2: Power performance verification of electricity producing wind turbines*¹

¹ To be published.

IEC 61672 (all parts), *Electroacoustics – Sound level meters*

ISO/IEC Guide 98-3, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*