

AS 4959—2010

Acoustics—Measurement, prediction and assessment of noise from wind turbine generators



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 - Association of Consulting Engineers Australia
 - Australian Acoustical Society
 - Clean Energy Council
 - Department of the Environment, Water, Heritage and the Arts
 - Environment Protection and Heritage Council
 - University of Newcastle
-

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Australian Standard[®]

**Acoustics—Measurement, prediction
and assessment of noise from wind
turbine generators**

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PREFACE

This Standard was prepared by the Standards Australia Committee EV-016, Acoustics—Wind Turbine Generator Noise.

The objective of this Standard is to provide wind farm developers and relevant regulatory authorities with a suitable framework to develop a method for the measurement, prediction and assessment of noise from wind turbine generators (wind farms).

The term ‘informative’ has been used in this Standard to define the application of the appendix to which it applies. An ‘informative’ appendix is only for information and guidance.

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STANDARDS AUSTRALIA

Australian Standard

**Acoustics—Measurement, prediction and assessment of noise from
wind turbine generators****1 SCOPE**

This Standard provides a methodology for assessing the impact of noise from wind turbine generators (WTGs) at all receivers in the vicinity of a wind farm.

This Standard deals specifically with noise from wind farms in the presence of wind—a situation that can result in large variations in measured noise levels due to the windspeed-dependence of both the background noise and wind turbine generator noise. The measured noise levels will be reasonably accurate and repeatable if the recommended methodology is followed.

This Standard is applicable to both horizontal and vertical axis WTGs generating electricity. Other noise sources may be more appropriately measured and assessed using other Standards (see list of referenced documents).

The scope of this Standard does not include:

- (a) The methodology for sound power level measurements of WTGs (see IEC 61400-11).
- (b) The methodology for measurement of other characteristics that may be present in the noise emission of WTGs such as infrasound, low frequency noise (noise outside the normal auditory range of the human ear), impulsivity, and low frequency modulation of broad band or tonal noise (see IEC 61400-11).
- (c) The methodology for measuring, predicting and assessing the noise from small WTGs used as generators in standalone power systems or used for water pumping, milling or other purposes.

Small WTGs are those with a swept rotor area of less than 200 m² (See IEC 61400.2.)

- (d) The methodology for measuring, predicting and assessing the noise from service equipment used at the wind farm for maintenance and construction. (See AS 1055.2 and AS 2436).
- (e) The methodology for measuring, predicting and assessing the noise from other equipment such as switchyards or substations. (See AS 1055.2).

NOTES:

- 1 Appendix A provides a flow chart of the methodology contained within this Standard.
- 2 Appendix B contains an informative worked example on prediction of sound pressure levels, monitoring background levels, and compliance testing.
- 3 Appendix C gives an informative guide on wind impact effects on microphones and spectrum analysers. It also gives guidance to the visual inspection of physical damage to microphone windshields.

2 REFERENCED DOCUMENTS

The following documents are referred to in this Standard.

AS

- 1055 Acoustics—Description and measurement of environmental noise
- 1055.2 Part 2: Applications to specific situations
- 1259 Acoustics
- 1259.1 Part 1: Sound level meters—Non-integrating
- 1259.2 Part 2: Sound level meters—Integrating-Averaging
- 2436 Guide to noise control on construction, maintenance and demolition sites

AS IEC

- 60942 Electroacoustics—Sound calibrators

IEC

- 61400 Wind turbine
- 61400-2 Part 2: Design requirements for small wind turbines
- 61400-11 Part 11: Acoustic noise measurement techniques

IEC

- 61672 Electroacoustics
- 61672-3 Part 3: Sound level meters—Periodic tests

ISO

- 1996 Acoustics—Description, measurement, and assessment of environmental noise
- 1996-2 Part 2: Determination of environmental noise levels
- 9613 Acoustics—Attenuation of sound during propagation outdoors
- 9613-1 Part 1: Calculation of the absorption of sound by the atmosphere
- 9613-2 Part 2: General method of calculation

ETSU-R-97 The assessment and rating of noise from wind farms

3 DEFINITIONS

For the purpose of this Standard, the definitions below apply.

3.1 AGL

Above ground level. Usually expressed in metres.

3.2 Background A weighted sound pressure level ($L_{A90,T}$)

The A-weighted sound pressure level, obtained by using time-weighting 'F' that is equal to or exceeded for 90% of the time interval considered in the absence of the noise under investigation.

NOTES:

- 1 L_{A90} is used for assessment of background noise levels as it excludes short term extraneous noise events such as wind gusts, dogs barking or a plane flying overhead that are not a constant part of the background noise environment of a location.
- 2 For the purposes of this Standard measurement time interval (T) should be 10 minutes, to align with the standard interval used for the collection of meteorological data on a wind farm site.

3.3 Background noise level

The derived background sound pressure level at a given wind speed corresponding to the best fit regression curve of the plotted measured background noise data and the wind speed data (see Clause 6.3.4).

3.4 Cut-in wind speed

The wind speed at which a wind turbine generator begins to generate electricity.

3.5 Hub height

The height above ground level of the central point of the wind turbine generator rotor. Usually expressed in metres.

3.6 Rated wind speed

The wind speed at which a wind turbine generator reaches its maximum electricity generation.

3.7 Receiver

A location requiring prediction of the impact of wind turbine generator noise. Generally taken to be an existing dwelling, a future dwelling with development approval, or the location of potential future noise sensitive development (an occupied dwelling where people might sleep or stay) promoted by the planning system for that jurisdiction.

3.8 Relevant receiver

A receiver at which predicted noise levels may exceed a noise level limit determined by the Relevant Regulatory Authority, which may require background and potential wind farm noise measurement. (See Clause 6.2)

3.9 Time average A-weighted sound pressure level ($L_{Aeq,T}$)

The value of A-weighted sound pressure level of a continuous steady sound obtained by using time weighting 'F' that, within a measurement time interval (T), has the same mean square sound pressure as a sound under consideration whose level varies with time. It is given by—

$$L_{Aeq,T} = 10 \log \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{P_{A(t)}^2}{P_0^2} dt \right] \quad \dots (1)$$

where

$P_{A(t)}$ = Instantaneous A-weighted sound pressure of the sound signal at time t

P_0 = Reference sound pressure equal to 20 μ Pa

t_1, t_2 = Start and finish times of the measurement time interval T .

NOTE: Time average A-weighted sound pressure level during time interval T (10 minutes for the purposes of this Standard) is also called equivalent continuous A-weighted sound pressure level.

3.10 Wind farm

A group of wind turbine generators (WTGs) installed in the same region and operated by the same operator. It is not necessary that all WTGs are located on the same premises.

3.11 Wind speed

A measurement of wind speed at a specified measurement height above ground level over a specified time interval.

3.12 Wind turbine generator (WTG)

A wind turbine generator used to generate electricity.

4 GUIDE TO ACCEPTABLE NOISE LIMITS

4.1 General considerations

In order to determine the acceptability of predicted wind farm noise levels at relevant receivers, it is necessary to consider the unique noise characteristics of both the wind farm

and the noise environment of the area around the actual or proposed wind farm. Wind farms are often proposed for areas with rural characteristics where background noise levels are likely to be low, particularly at wind speeds around the cut-in wind speed of a typical WTG when it begins to generate both electricity and noise.

Therefore, when setting criteria, the Relevant Regulatory Authority should consider the existing ambient noise environment at receivers around the proposed wind farm and the characteristics of wind turbines noise, so as to provide a satisfactory level of protection of amenity. The criteria should be flexible to account for agreements between landowners and wind farm developers or for circumstances where the amenity of the ambient noise environments differs from a rural area.

As a noise source, it is a unique characteristic of a WTG or wind farm that the noise level from each WTG will increase with increasing wind speed and that the background noise within the ambient noise environment at receivers will generally also increase under these conditions (due to wind influenced noise from vegetation, foliage etc.). It is therefore possible that the minimum noise level limit set by a Relevant Regulatory Authority may be exceeded by the background noise itself before it is exceeded by noise from a WTG or wind farm.

In recognition of this characteristic, it is therefore recommended that the Relevant Regulatory Authority allow the minimum noise level limit to be exceeded, provided the wind farm noise level does not exceed the background noise level by a specified amount.

At each nominal wind speed, the noise limit should be the higher of—

- (a) minimum noise level limit; or
- (b) background noise levels plus the specified amount.

The noise limits should be specified at nominal wind speed intervals of 1 m/s between the wind speed at which the WTG starts to generate electricity ('cut-in' wind speed) and the wind speed at which the WTG reaches its maximum generation ('rated' wind speed).

4.2 Cumulative development

In considering the protection of existing amenity, the Relevant Regulatory Authority should be cognisant of the potential for cumulative effects from the staged development of existing wind farms, or the construction of additional wind farms, to influence measured background noise levels at relevant receivers, i.e. the noise generated by existing WTGs should not be considered as part of the background noise in determining criteria for subsequent development.

To provide a satisfactory level of protection of amenity against the potential adverse effects of wind farm noise, the cumulative impact of all wind farm development in an area should meet the noise limits derived from measurements of the background noise environment at relevant receivers prior to any wind farm development taking place. Where it is not possible to satisfactorily demonstrate that existing developments are not influencing measured background noise levels, predicted noise levels from the wind farm should not be permitted to exceed the minimum noise level limit.

4.3 Compliance checking

When establishing criteria, the Relevant Regulatory Authority should take account of the procedure to be followed for compliance testing. In particular, the criteria should refer to the L_{Aeq} contribution from the wind farm but should account for the combination of operational wind farm noise and other ambient noise which is most conveniently measured as an L_{A90} that is used as the basis of compliance testing.

NOTE: Work done in the United Kingdom by the working group on noise from wind turbines, documented in ETSU-R-97 indicates that the measured L_{Aeq} of wind turbine noise is generally 1.5-2.5 dB higher than the L_{A90} measured over the same period.

4.4 Special audible characteristics

When setting limits of acceptability, the limits should take into account the fundamental characteristics of wind farm noise, including aerodynamic noise from the rotating blades, occasional aerodynamic modulation, the mechanical noise of the gearbox and other components and also other infrequent and short term noises that may occur, such as braking. Should a special audible characteristic (not usual to a correctly functioning wind turbine) such as tonality be present it is recommended that the predicted noise levels from the WTG or wind farm be adjusted by adding a penalty to the predicted level, to take into account the adverse subjective response likely to be generated by the characteristic. See Clause 7.3 for compliance assessment of noise from WTGs or wind farms containing tonality.

NOTE: WTG manufacturers typically provide a guarantee that there will be no audible tones within the noise emissions of a WTG.

5 PREDICTION OF WIND FARM NOISE

5.1 General

The prediction of noise levels in the vicinity of a proposed WTG, wind farm or wind farms shall give an expected level of noise with all WTGs operating at wind speed intervals of 1 m/s between cut-in and the maximum wind speed for which sound power level data is available from the manufacturer.

The resultant noise level at any relevant receiver shall be calculated by logarithmic summing of the contribution of each individual WTG at all sites at a given wind speed.

NOTE: An example of logarithmic summing is given in Appendix B.

A number of approaches are possible depending on distance and topography to check whether noise impacts are likely.

5.2 Indicative predictions

Indicative noise levels from the proposed WTG or wind farm may be calculated in accordance with Equation 2. This approach is generally accepted as being slightly conservative (i.e. over-prediction of noise levels).

$$L_R = L_w - 10 \log (2 \pi R^2) - \Delta L_a \quad \dots (2)$$

where

L_R = sound pressure level from a single WTG at 1.2 m to 1.5 m above local ground level in dB(A) at distance R in metres

L_w = sound power level of the WTG in dB(A) referenced to the proposed hub height. This should be obtained from the WTG manufacturer and be measured in accordance with IEC 61400-11 or other relevant Standard. These values relate to the WTG operational noise at a range of wind speeds usually between cut-in and a wind speed equating to 95% of the rated power of the WTG (for technical reasons data is often not available for the rated wind speed of the WTG). If data is not available for lower wind speeds down to cut in, the minimum sound power level available should be used for wind speeds where no sound power level is provided. Consideration should be given to using values that the manufacturer is prepared to contractually guarantee.

R = distance between the source and the receiver, in metres

ΔL_a = $\alpha_a R$

α_a = attenuation of noise due to air absorption, in dB/m. It may be reasonable to use a value of $\alpha_a = 0.003$ dB(A)/m applied to the total sound power level for each WTG for distances of $R < 500$ m. However, for distances where $R > 500$ m a full octave band analysis of air absorption of noise from each WTG that incorporates the variation in α_a for different octave bands shall be carried out. Appropriate values for α_a are provided below based on values provided in ISO 9613-1, corresponding to a temperature of 15°C and a relative humidity of 70%.

Octave Band Centre Frequency	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
Atmospheric Absorption Coefficient α_a dB/m	0.0001	0.0004	0.0011	0.0023	0.0041	0.0087	0.0264	0.0937

Sound power levels for WTGs are sometimes provided referenced to standardized 10 m AGL wind speeds usually derived from wind speeds measured at hub height or from electrical power data and the WTG power curve. All analysis should be referenced to hub height wind speed data. If sound power level data referenced to hub height is not available, wind shear information related to the sound power levels (usually provided by the manufacturer together with the sound power levels) shall be used to adjust the wind speeds of the sound power level data to the hub height of the WTGs at the proposed site. A worked example of the adjustment of sound power levels to hub height and the prediction of wind farm noise using Equation 2 is provided in Appendix B.

NOTE: Past approaches to background noise measurement have also referenced them to 10 m AGL wind speeds, typically based on actual 10 m AGL measurements. However, the use of 10 m AGL wind speed as the reference for WTG sound power levels and baseline background noise measurements can result in a mismatch between the reference wind speeds used for baseline noise measurements and wind turbine sound power levels, unless site specific wind shear is taken into account. The relationship between wind speed at different heights above the ground (wind shear) and in particular the actual hub height wind speed (which generally determines the WTG sound power level) and the actual wind speed that would be measured at 10 m AGL varies from site to site and in different atmospheric conditions. This can result in significant errors when comparisons are made between background noise levels and wind turbine noise immission levels at relevant receptors, particularly in stable atmospheric conditions.

5.3 More complex prediction models

ISO 9613-2 provides a more detailed approach to carrying out air absorption calculations. There are also other models with a significantly higher level of complexity than Equation 2, which may be used for the prediction of noise levels from a wind farm.

These models take into account additional factors which may influence the noise levels at a receiver, such as screening, acoustic absorption, and reflection effects due to vegetation, ground cover, and topography and the propagation effects of wind.

In particular, such models may reduce the conservatism of predictions made using Equation 2 noted in Clause 5.2 in situations where a relevant receiver has WTGs at similar distances but different directions from it.

The accuracy of such models is heavily dependant on the assumptions used within them and such assumptions should be reported and justified together with an estimation of predictive accuracy.

6 MEASUREMENT OF BACKGROUND NOISE LEVELS

6.1 Instrumentation

Noise measuring instrumentation should be in accordance with IEC 61672-3 or AS 1259.1 and AS 1259.2, and AS IEC 60942 for sound calibrators.

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

- (a) Reference level checking device (acoustic calibrator) (12 months).
- (b) Microphone (24 months).
- (c) Statistical noise logging system (24 months).
- (d) Data recording/playback system (24 months).
- (e) Anemometer (24 months).

An instrument shall always be re-calibrated prior to continued use if it has been repaired or is suspected of fault or damage.

6.2 Determination of relevant receivers

Knowledge of predicted wind farm noise levels at all receivers (including those of landowners of the wind farm itself) is of prime importance in the determination of which receivers are relevant (as defined in Clause 3.8).

The determination of whether a receiver is relevant or not shall be undertaken in conjunction with the Relevant Regulatory Authority, who will take into consideration the potential for future noise sensitive development promoted by the planning system for that jurisdiction.

NOTE: The assessment of background noise levels at the locations of such future development is likely to be of little practical benefit, as the noise environment is likely to change significantly should the development take place, particularly if the development includes changes to the landscape such as the planting of shrubs and trees.

Wind farm developers commonly enter into contractual agreements with the owners of land suitable for a wind farm site prior to progressing any significant development activities such as noise studies. Such agreements provide the wind farm developer with 'wind rights' to progress the development of the site (subject to regulatory approvals) and in return provide the landowner with a level of commercial compensation. Such agreements may contain specific clauses related to agreed noise levels from the wind farm on the landowner's property.

The Relevant Regulatory Authority may wish to take such agreements into consideration when determining the relevance of a receiver.

One approach to determining relevant receiver locations is to compare predicted noise levels at receivers against the minimum noise level limit. Where the limit is met at high wind speeds such as >13 m/s (at hub height), background noise measurements may not be required. However, if a location is particularly sheltered and wind related background noise may be low even when wind speeds on the wind farm site itself are high, measurements should still be taken.

NOTE: The sound power level of some models of wind turbines may be lower at a hub height wind speed of 13 m/s than at some wind speeds below this. Should this be the case, the maximum sound power level below 13 m/s should be used for prediction purposes.

When considering a group of receivers it is acceptable to select as relevant the receiver that is likely to be representative of the worst case situation, e.g. a house that has very few likely sources of wind induced background noise that is located amongst a group of nearby houses. The worst case situation may not always be the closest receiver to the wind farm site. The selection of the 'worst case' receiver within a group should be justified and discussed with the Relevant Regulatory Authority.

6.3 Measurement procedure and considerations

6.3.1 General

Sequential 10 minute $L_{A90, 10 \text{ min}}$ background noise measurements shall be taken at each relevant receiver concurrently with 10 minute average wind speed and direction measurements on the wind farm site. Care shall be taken to ensure that the clocks on all equipment used are synchronized. This should be checked both at the commencement and the completion of a measurement campaign. Any differences due to time zones, daylight saving or time stamping should be understood and taken into account.

NOTE: Some instrumentation particularly meteorological loggers time stamps data at the beginning of the measurement interval, whilst some noise loggers time stamps data at the end of the measurement interval.

Data obtained during the monitoring period shall cover the range of wind speeds and wind directions generally to be expected at the wind farm site and in particular the range of wind speeds (at hub height) between the 'cut-in' and 'rated' wind speeds of a WTG of the general type proposed for the site. The wind direction or wind directions that will result in the maximum noise impact from the WTG or wind farm at relevant receivers, seasonal variation in the occurrence of these wind directions and the likelihood of obtaining data with the wind from these directions should also be considered prior to the commencement of monitoring. It is recommended that the range of wind speeds and directions that must be covered during monitoring is discussed with the Relevant Regulatory Authority prior to measurement taking place.

Data points should not be included in analysis that may be adversely influenced by microphone wind effects (see Appendix C) or rain periods. Influences on background noise levels from rainfall may not always be related to rainfall in the actual location of the microphone and may not occur until some time after the rain has ceased, e.g. increased flow in streams and creeks may increase background noise levels. The possibility of insects, fauna or other extraneous noise sources affecting data should also be considered.

A measurement program of the duration to provide a representative range of at least 2000 valid data points covering the required range of wind speeds and directions shall be conducted.

Consideration shall be given to possible seasonal variations in background noise levels at relevant receivers and this shall be discussed with the Relevant Regulatory Authority before background noise measurements take place, to ensure that the data collected will be accepted by the Relevant Regulatory Authority as representative.

Where regression curve analysis does not conform to the expected trends, i.e. there is not a clear relationship between increasing wind speed and increasing background noise levels or there appears to be more than one distribution, then further investigations are necessary to determine possible causes.

6.3.2 Noise measurements

The locations selected for background noise measurements shall be within 20 m of a relevant receiver and generally on the side of the receiver that is towards the wind farm.

However, consideration may be given to monitoring at locations further away from the receiver if they are used extensively for leisure and recreation purposes by the occupants. The intention to measure at such a location should be discussed with the Relevant Regulatory Authority prior before measurements commence.

Measurement positions shall be more than 5 m from any significant vertical reflecting surface to avoid reflections which may influence the background noise measurement and where possible, should also be at least 5 m away from other structures or objects (such as trees and power lines, etc). Noise measurements shall be taken at a height of between 1.2 m AGL and 1.5 m AGL.