Review of the application of NZS6808 to wind farms in Australia

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ABSTRACT

NZS6808 : 1998 "Acoustics – The Assessment and Measurement of Sound from Wind Turbine Generators" has been applied in various forms across Australia for wind farm projects. This paper reviews license conditions issued by authorities when granting approval for wind farms in Australia and provides a detailed analysis of data from one such wind farm in Victoria where NZS6808 has been referenced in conditions of approval. The analysis shows confidence levels associated with the measurement of sound from a wind farm when NZS6808 is applied and concludes that the use of this standard in approval conditions for testing compliance is ill advised. An alternative method to test compliance is proposed.

AUSTRALIAN STATE ASSESSMENTS

NZS6808 : 1998 "Acoustics – The Assessment and Measurement of Sound from Wind Turbine Generators" has been adopted widely throughout Australia since its introduction. Although there is now a guideline prepared by the South Australian Environmental Protection Authority in February 2003 (Environmental Noise Guidelines: Wind Farms), the fundamental basis of determining acceptability for sound emissions from a wind farm project follows the principal of a target sound pressure level or background plus 5dB(A) similar in form and general methodology to NZS6808. The South Australian assessment methodology uses background defined in terms of LA90 with a minimum compliance level of 35dB(A) compared to the NZS6808 requirement where background is defined in terms of LA95 with a 40dB(A) minimum compliance level.

Victoria has a "Policy and planning guidelines for development of wind energy facilities in Victoria". This document requires applicants for development approval to provide

> An assessment of the noise impact of the proposal on existing dwellings prepared in accordance with New Zealand Standard NZ6808:1998, Acoustics— The Assessment and Measurement of Sound from Wind Turbine Generators.

Tasmania also requires compliance with NZS6808 (e.g. Development Proposal and Environmental Management Plan for Wind Energy Projects" DPIWE, July 2004). Queensland has also used NZS6808 in assessing compliance for wind farms although there is no formal procedure defined by the Qld EPA.

NSW defers to the South Australian Environmental Noise Guidelines in their published assessment methodologies.

Western Australia and the Northern Territory do not have formal guidelines although assessments in potentially sensitive areas in Western Australia have been completed using the SA Environmental Noise Guideline (personal communication WA EPA).

A number of smaller wind turbine installations were commissioned before the publication of NZS6808, the largest being at Crookwell in NSW consisting of 8 turbines having a capacity of 4.8MW. The development conditions from the Crookwell Shire Council required a monitoring program to check the predictions made in the statement of environmental effects to demonstrate compliance with manufacturers' equipment specifications and the NSW EPA conditions for low frequency emissions at receptor sites. A condition was also coined where a commitment was required to work collaboratively with the EPA to develop noise guidelines for wind farms.

LOCAL COUNCIL APPROVALS

Local Council approval conditions for wind farms across Australia largely reflect the directions of the appropriate State Authorities. For example, the noise conditions imposed by the Ararat Rural City Council for the Challicum Hills installation in Victoria simply requires compliance with NZS6808 to the satisfaction of the Responsible Authority, and the Port Pirie Regional Council in South Australia requires compliance with the SA EPA Interim Environmental Guidelines: wind farms. However, some local councils insert modifications to the NZS6808 requirements or add additional noise test conditions. For example, the Bald Hill installation in Victoria has the standard compliance limit suggested in NZS6808 but adds a separately assessed night time compliance limit for sleep protection purposes where a breach of NZS6808 for 10% of the night, amounts to a breach of the condition.

Some council approvals specifically require compliance checking after construction. For example, the South Gippsland Shire Council and Moyne Shire Council in Victoria have imposed conditions that required post construction monitoring in accordance with NZS6808 for a minimum of 12 months after completion of the last turbine.

APPLICATION OF NZS6808

The New Zealand Standard

> provides guidance on the limits of acceptability for sound received at residential and noise sensitive locations emitted from both wind farms and single Wind Turbine Generators (WTG's).

The guidance provided is not mandatory and section 4.4.4 allows the "Territorial Local Authority" to specify alternative compliance levels at residences or noise sensitive areas on a site-by-site basis, taking into account individual circumstances and characteristics such as: distance to WTG's; other sound sources; amenity values, etc.

The New Zealand Standard was prepared in such a way to fit most easily with the standard NZS 6802 Acoustics – Assessment of Environmental Sound. This standard has a compliance limit guide of 'background plus 10dB(A)', i.e. the L10 or Leq sound level from a sound source under investigation must not exceed the L90 sound level in dB(A), measured in the absence of the sound under investigation, by more than 10dB(A) as directed by the Responsible Authority in any particular case. Earlier versions of NZS6802 used a background defined to be an L95 statistical parameter and NZS6808 uses this term in preference to L90.

NZS6808 sets a compliance limit guideline in terms of the L95 (background) compared to either the predicted or measured Leq sound from the WTG's at the pre-construction / design phase. After construction, during operation, compliance is assessed in terms of the trended statistical L95 results, after adjustment for background sound levels, against the same compliance trend curve used for the design assessment phase. 10-minute sound level integration periods are suggested for each data point that must be synchronised with the meteorological averaging periods.

A correction for background L95 must be made to determine the WTG's L95 contribution to the measured L95 values. The method of correction is not specified in NZS6808 but a method is described in IEC 61400 Wind Turbine Generator Systems – Part 11: Acoustic Noise Measurement Techniques. This correction method requires a logarithmic subtraction of background noise from the 'wind turbine operational noise+background' if the differences are 6dB(A) or greater. For differences of less than 6dB(A) but more than 3dB(A) the correction is 1.3dB(A). For differences of less than 3dB(A) it should be reported that the wind turbine noise was less than the background noise.

The SA Environmental Noise Guidelines for Wind Farms generally follows the same assessment and prediction methodology as NZS6808 except for the use of the L90 background parameter in lieu of L95 and a lower target base noise level of 35dB(A) instead of 40dB(A). 10-minute integration times are also specified for sound level and meteorological measurements.

COMPLIANCE CHECK CONFIDENCE LEVELS

It is important to determine what level of confidence one can assign to measurement results when testing compliance with development approval conditions.

The SA wind farm noise guideline states that Environmental Protection Orders may be issued if compliance with the guidelines cannot be demonstrated that could lead to restricted operations.

NZS6808 describes post installation compliance testing as a

> precise method for the post installation compliance testing of sound from WTGs in the far field, i.e. at distances where the cyclic variations in sound due to blade rotation are no longer discernible.

This precise (prescriptive) method has inherent uncertainty.

NZS6808 states in section 3, 'Definitions and symbols' that wind speed is to be measured in m/s with a tolerance of 0.5m/s but does not delve into measurement uncertainties associated with other values or the effects that such uncertainties can have on the derivation of the criterion curve and the method of testing compliance. IEC 61400-11 has an annex that provides information on measurement uncertainties associated with determining wind turbine sound power levels and much of the content of this Annex D is applicable to NZS6808 and similar methodologies. The following uses information in the format of IEC 61400-11.

There are two types of uncertainty; A and B. Type A uncertainties are components evaluated using statistical methods and type B uncertainty components are those evaluated by judgement.

Type A uncertainty is the standard error (U_A) of the estimation of the fitted curve at each integer wind speed.

$$U_A = \sqrt{\frac{\sum (y - y_{est})^2}{N-2}}$$

N is the number of measurements used in the regression analysis and ($y-y_{est}$) is the residual from the measured sound pressure level and the estimate of the sound pressure level using regression.

An example of the Type A uncertainty standard error associated with the determination of background sound pressure level, L95 at selected integer wind speeds for a typical measurement location is shown in Table 1. The data set used for this calculation was obtained in Victoria from 9170 10-minute L95 background samples using a third order polynomial curve fit, as described in NZS6808 and a second order curve fit as required in IEC 61400-11.

Table 1 Type A uncertainty

Wind Speed m/s	2nd Order Standard Error, U_A dB(A)	3rd Order Standard Error, U_A dB(A)
4	4.4	4.2
5	4.9	4.6
6	5.1	4.9
7	4.8	4.8
8	4.7	4.7
9	4.9	4.8
10	4.5	4.3

The choice of wind measurement site can have a significant bearing on the results (Site Effects). Wind speeds measured at the hubs of each wind turbine generator in a large wind farm are often different. Wind farms cover large areas and the ground topography can vary near each WTG. The wind monitoring point is generally chosen to represent the wind speed 10m above ground level at a location in an open area relatively central to the wind farm, as per the requirements of NZS6808.

The overall U_A vales for the full wind speed range measured to 20m/s was 4.4dB(A) for the 2nd order trend curve and 4.2dB(A) for the 3rd order polynomial curve fit.

Type B uncertainty components are observed in such things as:

- calibration of acoustic instruments, U_{B1}
- tolerances on the chain of acoustic measurement instruments, U_{B2}
- uncertainty on the measured wind speed, including anemometer calibration and site effects, U_{B7}
- background correction, U_{B9}

For type B uncertainties the standard deviation U of such a distribution for measurement ranges described as +/-a is:

$$U = \frac{a}{\sqrt{3}}$$

Table 2 shows typical values expected for the uncertainty components using Type 1 instruments and the measurement arrangement described in IEC 61400-11 using a ground board with microphone pointing towards the WTG.

The conversion of wind speed uncertainty to dB in table 2 assumes a conversion into dB based on the slope of the curve of wind speed vs. sound pressure level from the data used to prepare Table 1, which is approximately 2.8dB per m/s.

The combined standard uncertainty U_C is the root sum of the squares of the individual components:

$U_C = \sqrt{(U_A^2 + U_{B1}^2 + U_{B2}^2 + U_{B7}^2 + U_{B9}^2)}$

U_A is the standard uncertainty in determining the compliance curve only in the range where the background plus 5dB is greater than the 'base noise level' (40dBA L_{95} for NZS6808 or 35dBA L_{90} for the SA methodology).

Table 2 Type B uncertainty components

Component	Possible Typical Range	Possible Typical standard uncertainty	Possible worst case standard uncertainty
Calibration, U_{B1}	+/-0.3 dB	0.2 dB	0.3 dB
Instrument, U_{B2}	+/- 0.3 dB	0.2 dB	0.4 dB
Wind speed measurement, U_{B7}	+/- 1.5 dB	1.8 dB	6.6 dB
Background, U_{B9}	Equals the applied correction	Example, 1.3 dB	0.8 dB

The combined uncertainty in determining the background derived compliance curve is approximately 4.6dB(A) outside the base sound level. Likewise, the combined uncertainty in determining a curve for any of the operating conditions will also be at least 4.6dB(A). The example used would be typical of the combined uncertainty to be expected from any measured data set when applying NZS6808 using Type 1 equipment. Type 2 equipment is allowed in NZS6808 and it is common practice to use integrating sound level meters that point the microphone upwards. The accuracy required in AS1259.1 – 1990 "Acoustics – Sound Level Meters Part 1: Non-integrating" and "Part 2: Integrating – averaging" for Type 2 sound level meters pointing at right angles to the sound source is +/-0.7dB for the instrument and 3dB from directivity effects below 1000Hz.

The uncertainty caused by correcting a WTG sound measurement for background noise is suggested in IEC 61400-11 to be equal to the correction applied (Table 2). However, the correct method to use when subtracting x +/-Ux from y +/-Uy is to combine the errors as the root sum so that the combined error from subtraction, Usub is

$Usub = \sqrt{(Ux^2 + Uy^2)}$

Additional uncertainties are caused by site effects, trend options and the possible lack of data used to form the trend curve.

SITE EFFECTS

Site effects are Type B uncertainty components. The assessment methodology of NZS6808 is simply to determine the sound level caused by WTG's compared to an absolute and background derived baseline. Care should be used when choosing a representative location. The location should experience background noise representative of the residence at which a compliance check is made. NZS6808 sets the compliance condition based upon the most sensitive part of a day for noise intrusion. The assessment is based on providing acoustic amenity in a bedroom to prevent sleep disturbance.

The report "Noise immission from wind turbines" (ETSU W/13/00503/REP 1999), prepared by the National Engineering Laboratory, concluded that wind speeds should be determined from the power curve of the turbine under investigation. Differences of 3dB were reported due to inaccuracies in converting wind speeds from remote measurement points to the hub height. Part of the conclusions state that

> Measuring wind speed10m above the ground can lead to unacceptable uncertainty in noise emission of tall wind turbines, and declaration of wind turbine noise should be based on wind speed calculated by means of the power curve.

NZS6808 states that WTG hub height wind speed measurements are preferable, but not essential.

TREND OPTIONS

The methods chosen to trend the measurement data can affect results quite significantly, as shown in Figure 1. The uncertainties associated with different trend techniques can be in excess of 5dB(A) at high wind speeds and can be in the order of 2dB(A) in the 8m/s to 12m/s wind speed range in this example. These uncertainties are sample and trend option dependent.

It is reasonable to presume that sound from a WTG increases with increasing wind speed and that there are no sound emissions below cut-in. If this is true then a curve having only one inflexion would be expected. This type of curve is provided by a second order polynomial. Third order polynomials force a curve to have two inflexions, and so on.

A similar single inflexion curve would be expected for background sound level measurements at different wind speeds due to the noise floor of the instrumentation that would prevent a zero pressure level reading in calm conditions.

The regression analysis specified in IEC 61400-11 is a second order polynomial. No other options are allowed.

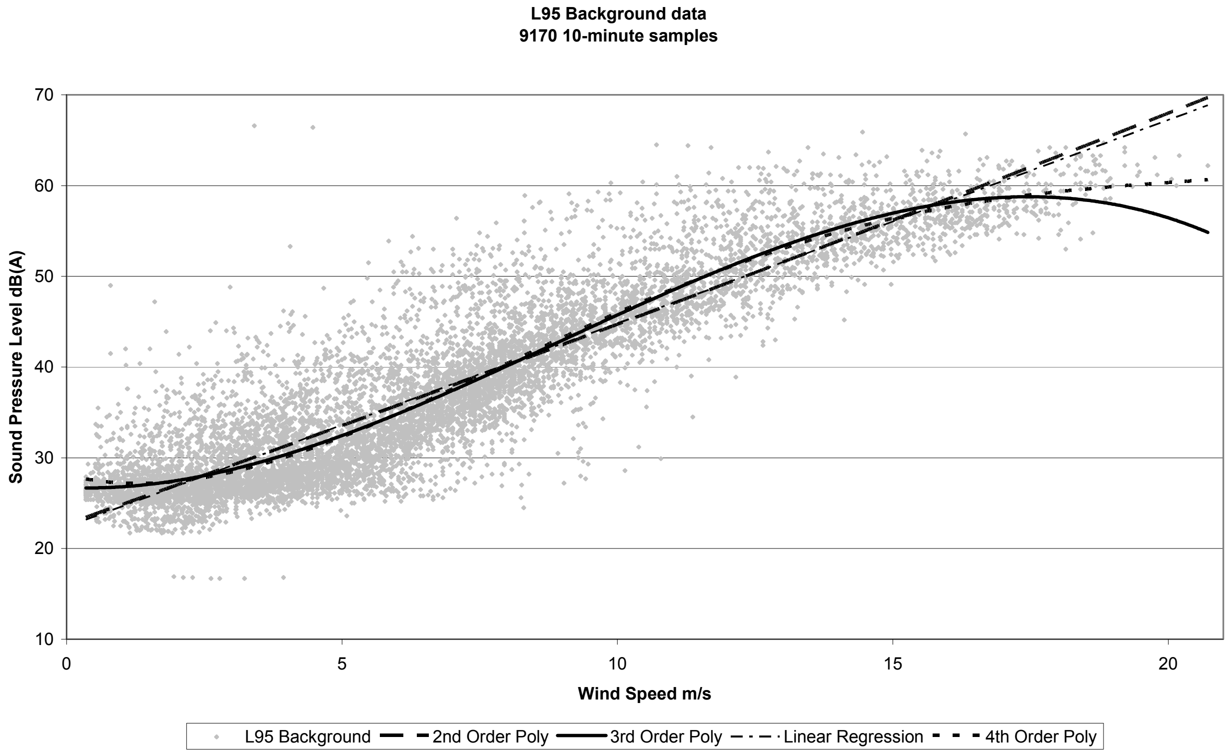

Figure 1 Example background L95 trend options

Figure 2 shows an example chart of a compliance curve derived from background data compared against a WTG sound pressure level curve using NZS6808. The WTG curve has 5dB y-axis error bars applied representing typical uncertainty in the measurement data. Wind speed uncertainty of 0.5m/s has been applied to the y-axis, as described earlier.

Without adding confidence levels to the compliance curve it is clear that non-compliance cannot be demonstrated unless the apparent exceedance of one curve above the other is greater than 5dB. If confidence levels were also applied to the compliance curve, non-compliance may only be demonstrated if the mean of the WTG sound exceeds the mean of the compliance curve by more than 10dB.

SAMPLE UNCERTAINTY

The example chart in Figure 1 shows few data points at higher wind speeds. Determining sample size is a very important measurement issue because samples that are too small may lead to inaccurate results. The minimum sample size

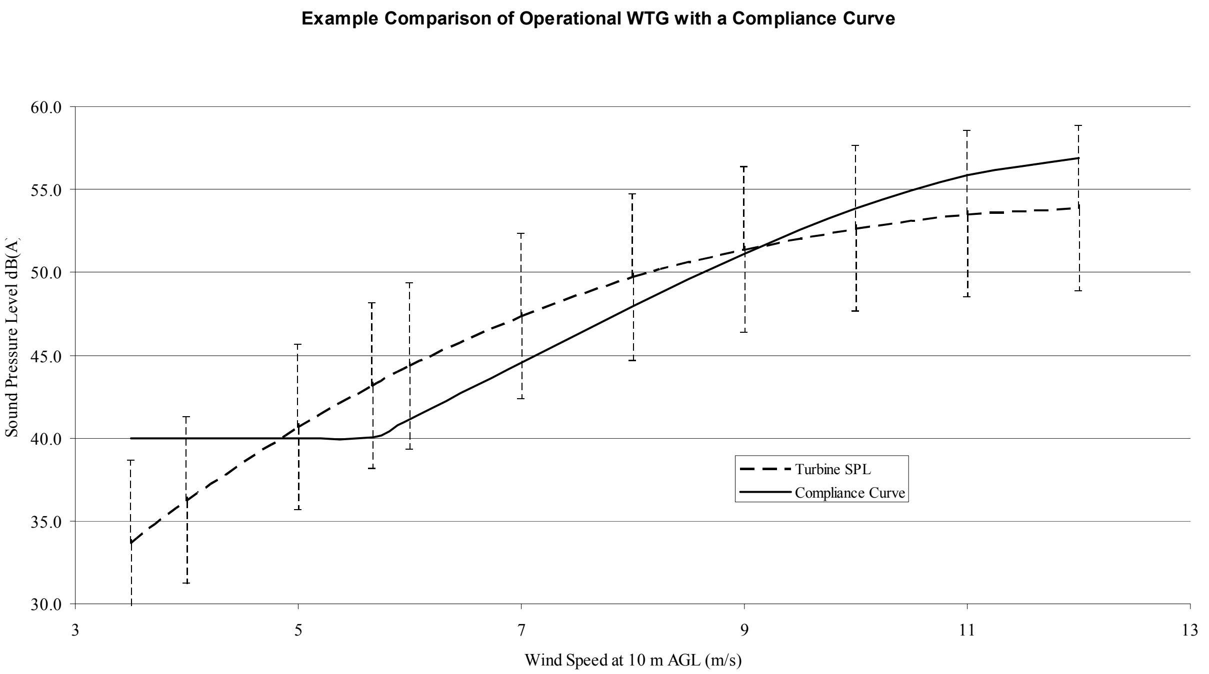

Figure 2 Example Comparison of Operational WTG with a Compliance Curve

needed to estimate a process parameter, such as the population mean can easily be determined in many cases.

When sample data is collected and the sample mean is calculated, that sample mean is typically different from the population mean. The difference between the sample and population means can be thought of as an error. The margin of error is the maximum difference between the observed sample mean and the true value of the population mean.

The uncertainty caused by a particular number of samples in a particular wind speed range 1m/s wide can be determined if one assumes that the standard deviation of the background data is representative if the background plus WTG sound contribution in the same frequency range.

Table 3 shows the uncertainty, E for an example background measurement data set, separated into 1m/s wind speed bins for each integer of wind speed in m/s with different confidence levels. It is evident that the ambient (background, L95) data has a higher uncertainty at higher wind speeds because the number of samples are reducing, despite the fact that the standard deviation of the measurement set is also reducing. For confidence levels of 99% and 99.9% the mean value errors increase.

Table 3 E in dB(A) for different confidence levels and standard deviation in dB(A) for each integer wind speed

Wind Speed	Standard Deviation	No. of Data Points	95% confidence error, +/-E	99% confidence error, +/-E	99.9% confidence error, +/-E
3m/s	3.22	822	0.22	0.29	0.37
4m/s	4.01	778	0.28	0.37	0.47
5m/s	4.43	739	0.32	0.42	0.54
6m/s	4.63	788	0.32	0.43	0.54
7m/s	4.57	844	0.31	0.41	0.52
8m/s	4.47	814	0.31	0.4	0.52
9m/s	4.48	500	0.39	0.52	0.66
10m/s	4.08	402	0.4	0.52	0.67
11m/s	4.12	386	0.41	0.54	0.69
12m/s	4.04	295	0.46	0.61	0.77
13m/s	3.85	237	0.49	0.64	0.82

Sampling errors are minimised in IEC 61400-11 by specifying a minimum of 30 data pairs in each integer wind speed reference point. For 30 data pairs using a standard deviation of, say, 4dB(A) this will produce a sampling error of +/-1.4dB(A) at the 95% confidence level. More data points would reduce this type of error further.

Table 4 shows the uncertainty, E for different confidence levels (95%, 99% and 99.9%) during wind farm operation with a limited number of data points at higher wind speeds.

Table 4 E in dB(A) for different confidence levels and standard deviation in dB(A) for each integer wind speed

Wind speed (m/s)	Number of Data Points	95% confidence error, +/-E	99% confidence error, +/-E	99.9% confidence error, +/-E
4	**145**	**0.65**	**0.86**	**1.10**
5	**134**	**0.75**	**0.99**	**1.26**
6	**113**	**0.85**	**1.12**	**1.43**
7	**78**	**1.01**	**1.33**	**1.70**
8	**47**	**1.28**	**1.68**	**2.15**
9	**24**	**1.79**	**2.35**	**3.01**
10	**18**	**1.88**	**2.47**	**3.16**
11	**20**	**1.81**	**2.37**	**3.03**
12	**9**	**2.64**	**3.47**	**4.43**

The recommended number of samples in NZS6808 is based on a 10 day to 14 day monitoring period to determine the background level, and thence derive the compliance curve. If a small number of samples is obtained in particular wind speed ranges it would be advisable to repeat the survey. Often it is required to determine different compliance curves for seasonal effects, particular wind directions or times of day. Care should be taken to ensure that any such subset of data has enough data points throughout the wind speed range to minimise sampling errors.

NOISE DOSE RELATIONSHIP

NZS6808 is based on the premise that noise nuisance from wind farms can be minimised if the compliance curve derived from the methodology described is met.

Typical background data at high wind speeds can vary by some 20dB(A) at 10m/s, as shown in Figure 1. At times when the background is at the low end of this range it would be easy to hear a wind turbine that met a mean background plus 5dB(A) acceptability criterion. Conversely, when the background is at the upper end of the range significant masking of WTG noise can occur.

Meeting the criteria outlined in NZS6808 does not mean that a wind farm cannot be heard clearly at times.

It has been reported (Pedersen and Persson Waye 2004) that the characteristic of wind farm noise that is most often described is the swishing or lapping sound caused by the blade passing frequency of WTGs and that noise nuisance is also influenced by visual aspects of a wind farm. Nuisance was related to outdoor activities and a noise - dose - response relationship is provided and compared to transport noise nuisance curves. NZS6808 presents a compliance checking methodology for the far field "where the cyclic variations in sound due to blade rotation are no longer discernible."

It is debatable whether noise nuisance is minimised with the application of an averaged 'background plus' criterion, as described in NZS6808. The target noise level for a dwelling should be reviewed in light of recent research into the cause of nuisance from wind turbine noise. However, if such an approach is to be used then an improved method to determine compliance is required for conditions of approval.

ALTERNATIVE COMPLIANCE ASSESSMENT METHODOLOGIES

The environmental impact assessment process for a wind farm development includes noise modelling of the proposal to determine what sound pressure levels are likely to be observed at key receptor locations. The noise model generally includes sound power data obtained using the method outlined in IEC 61400-11. The sound power determined for a particular type of WTG has an uncertainty of between 0.9dB (typical) and 2.5dB (worst) where site effects can be controlled.

A noise model can provide numerous operating scenarios based upon differing meteorological conditions and can predict sound pressure levels from a single or multiple WTGs.

The method used in NZS6808 to predict sound pressure levels at locations around a WTG or wind farm is a reasonable first check of likely problems but it does not include effects such as ground absorption, for example, which will adversely affect the confidence of predicted results.

A number of variables such as: turbulence, wind shear, inflow angle and air density may differ at an installed site compared to the idealised sound power measurement results obtained using IEC 61400-11. These effects can alter the sound power level of a WTG and should be considered in the noise model. The uncertainty of such predictions reduces with the number of turbines and is not simply applied to the total predicted sound pressure level at a point.

If development approvals were to specify a test methodology resembling or, preferably, identical to IEC 61400-11 for the determination of installed sound power emission levels for each WTG then this could be used to check predictions made through modelling in the development approvals process. IEC 61400-11 has lower inherent uncertainties in its application than those obtained using NZS6808 because, for example; sound level measurements are taken closer to the WTG, a ground board is used for the microphone to minimise extraneous wind noise, Type 1 equipment is used and the microphone points at the sound source. Furthermore, an objective assessment of tonality is provided in IEC 61400-11, rather than the subjective approach outlined in NZS6808. Such measurements would also benefit the developer with regard to warranty issues.

The greatest practical problem with determining compliance in terms of a measurement regime that seeks to determine sound pressure levels at noise sensitive receptors over the full operating range of a WTG or wind farm is that such measurements may take months.

A compliance result can be obtained more quickly if the approach used in Denmark is employed. The Danish method simply relies on a measurement at only 8m/s (10m above ground level) close to the WTG, to minimise wind noise measurement errors and to maximise observed sound emission, which is then used in a noise model to predict the sound pressure level at more remote locations. The compliance limit in Denmark is a fixed value at 8m/s.

The shape of a curve of sound power against wind speed for a particular WTG will be similar in shape to other similar units. If the sound pressure level at a particular wind speed close to a WTG (measured as per IEC 61400-11) is used as a check on the overall measured sound power / wind speed curve, then this curve can be used in a suitably detailed noise model, to check compliance. This method can be implemented with much smaller uncertainty than the method of NZS6808 and in a much shorter time scale.

The application of NZS6808 produces significant uncertainty in results and these translate to a poor compliance check methodology. Measurement uncertainty can be reduced if Australia were to adopt a fixed sound pressure level criterion at a nominated wind speed and this would be suitable as an objective compliance check in development approvals that could quickly be determined.

CONCLUSIONS

The methodology for assessing compliance in NZS6808 has inherent uncertainties that prevent demonstration of non-compliance unless there are gross exceedances of the derived target noise curve for a wind turbine or wind farm. The alternative assessment methodology in the SA Environmental Guideline: wind farms also suffer from similar uncertainties and the use of either method for license conditions is ill advised.

An alternative method to test compliance is recommended, similar to that used in Denmark, where sound pressure levels are taken at one particular wind speed and acoustic modelling is used to determine noise contribution at a remote sensitive receptor.

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