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Assessment of the methods addressing atmospheric stability effects in the latest SA EPA "Wind farms environmental noise guidelines", New Zealand NZS 6808 and Australian AS 4959

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ABSTRACT

Wind farms are an important part of the renewable energy strategy; however with the developments predominantly occurring in rural areas with low background noise levels, they can significantly alter the existing noise environment creating considerable impacts for the affected sensitive receivers. The South Australian EPA "Wind farm environmental noise guidelines" and New Zealand Standard NZS 6808 "Acoustics – Wind farm noise" are the predominant environmental noise assessment methods employed in Australia and New Zealand. Both of these documents have undergone recent revisions along with the introduction of Australian Standard AS 4959 “Acoustics – Measurement, prediction and assessment of noise from wind turbine generators”. This paper investigates and assesses the recent changes in methods with a particular focus on addressing the effect of atmospheric stability on the developed noise criteria.

INTRODUCTION

Wind turbine generated noise levels are unique when compared to standard industrial noise sources as they are highly dependant on the local wind conditions. The emitted noise levels are a function of the wind speed experienced by the wind turbine generator (WTG). The general relationship can be summarised that as the wind speed increases, the sound power of the WTG increases up to a rated power wind speed at which the WTG emits the maximum noise. Figure 1 below shows a typical sound power curve for a WTG.

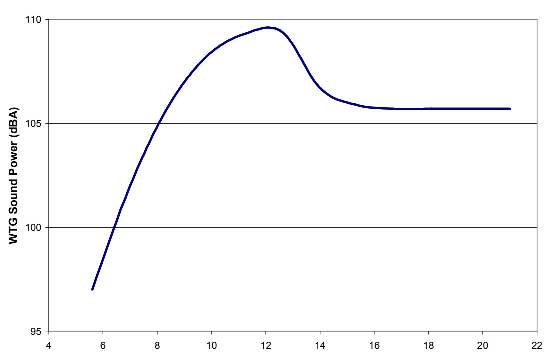

Figure 1. Wind turbine generator sound power curve

As such, this requires a different approach to develop applicable design noise criteria for wind farms, compared to the usual industrial developments because as the wind speed increases it has the potential to create background noise at the sensitive receivers leading to a masking effect of the WTG noise. Standard methods require measurement of noise levels at the sensitive receivers in conjunction with wind speeds at the WTG location. They aim to determine the variance in the background noise environment at the receiver with respect to the changing wind speeds at the WTG site. This is a consistent approach across all of the main assessment methods utilised in Australia and New Zealand as outlined in South Australian EPA "Wind farm environmental noise guidelines", New Zealand Standard NZS 6808 "Acoustics – Wind farm noise" and the newly introduced Australian Standard AS 4959 “Acoustics – Measurement, prediction and assessment of noise from wind turbine generators”.

Previous versions of these guidelines and standards have not taken into account the van den Berg effect (van den Berg, 2003) when developing noise criteria. This relates to the fact that the relationship between hub height wind speeds at the WTG and ground level wind speeds at the sensitive receiver will be different based on the applicable wind profile which is dependant on the atmospheric stability.

This paper investigates the recent changes in the assessment methods outlined in the local guidelines with a particular focus on the benefits of incorporating atmospheric stability into criteria development and thus taking into account the van den Berg effect.

METEOROLOGY

Atmospheric Stability

The degree of stability in the atmosphere is determined by the temperature difference between an 'air parcel' and the air surrounding it. This difference can cause the air parcel to move vertically, and this movement is characterised by four basic conditions that describe the general stability of the atmosphere. In stable conditions, this vertical movement is discouraged, whereas in unstable conditions the air parcel tends to move upward or downward and to continue that movement. When conditions neither encourage nor discourage that movement beyond the rate of adiabatic heating or cooling they are considered neutral. When conditions are extremely stable, cooler air near the surface is trapped by a layer of warmer air above it, with this condition being called an inversion which results in virtually no vertical air motion. These conditions are favourable for noise propagation as the density of the changes increases with altitude which alters the speed of sound creating a refractive effect, which leads the sound waves that would normally radiate out to space to refract back down to surface of the earth leading to an increased experienced noise level at the receiver.

The Pasquill-Gifford (P-G) (Pasquill, 1961) stability category scheme is normally used to describe atmospheric stability. Stability class under the P-G scheme is designated a letter from A-F (and sometimes G), ranging from highly unstable to extremely stable, with class D symbolising neutral conditions which are the most prominent day time conditions.

van den Berg Effect

While assessing complaints of noise from wind turbines, van den Berg originally demonstrated the well known fact in meteorology (and in particular atmospheric boundary layer physics that effects many disciplines) that wind profiles change significantly with atmospheric stability. This is shown below in Figure 2, with the exponent of a logarithmic or power law expression for the velocity modified under differing stability conditions (see for example Irwin, 1979). Prior to this work the wind profile had been assumed to be constant for varying meteorological conditions when considered in environmental noise assessments.

It is apparent from Figure 3 when the velocity profile is referenced to hub height that low ground level wind speeds and therefore low background noise levels can correlate with high upper level wind speeds under stable conditions, and therefore potential exceedance of noise criteria derived from background noise levels correlated to ground level wind speeds (as shown in Kochanowski et al, 2008).

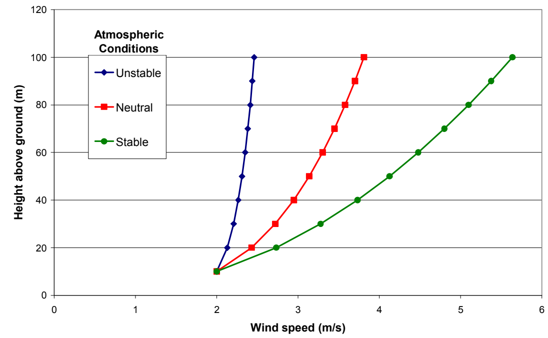

Figure 2. Wind speed profile variation with stability

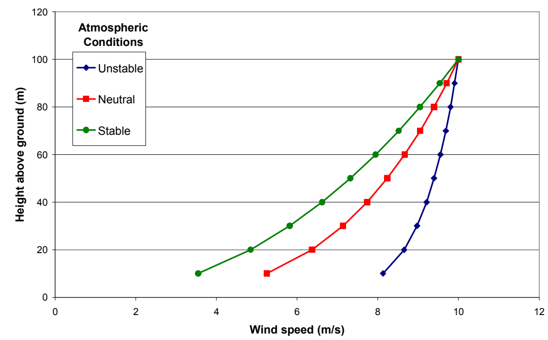

Figure 3. Velocity profile referenced to hub height

The van den Berg effect has been recognised recently by Land and Environment Courts in New South Wales, Victoria, and New Zealand. This paper reviews the updated guidelines and standards to assess in what steps have been taken to take into account this effect.

ASSESSMENT GUIDELINES AND STANDARDS

SA EPA Guidelines

The SA EPA Wind farms – environmental noise guidelines are the only state developed guidelines currently available and enforce in Australia relating to noise assessments of wind energy projects. The guidelines have been also adopted as the preferred assessment method by other states such as New South Wales and Western Australia. The 2009 revisions of the guidelines supersede the original 2003 version.

The noise criteria are set out for two types of receivers which are outlined in the Table 1 below.

Table 1. Receiver types

Receiver type	Relationship with wind farm project
Relevant	The landowner is unconnected with the wind farm project
Non-relevant	The landowner has entered into an agreement with the wind farm developer and is a beneficiary of the project

For the relevant receivers the following predicted noise levels from a wind farm development should not exceed:

- $L_{Aeq,10}$ 35 dBA in localities which are primarily intended for rural living, or
- $L_{Aeq,10}$ 40 dBA, in other zones, or
- The background noise level ($L_{A90,10}$) by more than 5 dBA.

Rural living zones are considered to be "rural-residential lifestyle" areas which are not used for primary production other than for the occupiers' own use.

Criteria for non-relevant receivers are in accordance with the World Health Organization (WHO) Guidelines for Community Noise and which recommend noise levels of 30 dBA for internal areas and 45 dBA for outdoor areas.

The 2003 version of the SA Guidelines provided a base criteria of $L_{Aeq,\,10}$ 35 dBA for all relevant receivers. Through the distinction of the different rural zones in the 2009 update of the Guidelines, a higher allowable noise level has been set for areas which contain some rural industry noise.

Background noise measurements should be carried out within 30 m of a house and in the direction of the wind farm ensuring that the position is not sheltered from the wind farm by any elements. In cases where microphone wind levels have exceeded 5 m/s manufacturer windshield specifications have to be provided to display the validity of the data otherwise measurements at wind speeds in excess of 5 m/s need to be discarded. As per standard noise survey methodology, rain affected samples are also to be removed from analysis. A total of 2,000 valid measurement intervals, where at least 500 points are collected for the worse case wind direction, are required for the regression analysis to develop background noise levels at integer wind speeds. Worse case wind direction is defined as a spread of 45° either side of the direct line between the nearest wind turbine and the relevant receiver.

The SA Guidelines have been updated to carry out the regression analysis relative to hub height wind speeds at the turbine location instead of previously relaying on wind speeds at 10 m above ground. Should the wind data be only available at lower levels the Guidelines state that:

> Atmospheric stability conditions should be taken into account to assure accurate conversion of the data from the different height.

The SA Guidelines also recommend the use of ISO 9613-2 or CONCAWE noise propagation model with the following conservative inputs:

- Atmospheric conditions at 10°C and 80% humidity
- Weather category 6 (if CONCAWE method utilised)
- Hard ground (zero ground factor)

However, the updated SA Guidelines do not give consideration to the effect of atmospheric stability on the noise propagation nor is there any potential allowance for the generation of time specific or wind direction specific criteria especially if distinct groups of data are present in the scatter plots. The introduction of relating wind speeds to hub height rather than to data at 10 m above ground will only reduce the error previously associated with estimating the wind shear model for the site.

New Zealand Standard NZS 6808

The current version of the NZS 6808:2010 supersedes the original issue of the Standard which was published in 1998.

The assessment initially requires a prediction of the noise emissions from the wind farm to identify the location of the $L_{90,10\,min}$ 35 dBA noise contour. This can be carried out using the full ISO 9613-2 noise propagation algorithm in noise modelling software or utilising simpler scaled down version of the ISO 9613 which can be calculated by hand. If sensitive receivers are identified within the 35 dBA contour, noise monitoring should then be carried out.

The Standard sets acceptable noise limits (at sensitive locations and at any wind speed) at a level which should not exceed the background noise by more than 5 dB or level of $L_{90,10\,min}$ 40 dBA, whichever is greater. For the 2010 version of the standard a "High Amenity Area" criteria was introduced lowering the criteria to background noise + 5 dB or $L_{90,10\,min}$ 35 dBA, whichever is lower. This was introduced to allow for special circumstances where a more stringent level may be justified especially when predicted wind farm noise levels are on average more than 8 dB above the existing background noise during evening and night times.

The noise monitoring in the Standard requires the correlation of background noise data with wind speeds at the wind turbine location for a minimum of 10 days which is equivalent to 1440 data points. A regression analysis is to be carried out to determine whether any relationship between the two is present. The 2010 version of the Standard requires wind speeds to be referenced to hub height. This reduces the error of assuming a constant wind profile for various atmospheric stabilities when the wind speeds were referenced to 10 m above ground and then extrapolated to hub height.

The Standard highlights that:

> If there are markedly different groups within the scatter plot then separate scatter plots may be required for different conditions, including wind direction and times-of-day.

This allows for the potential to develop criteria that could be restricted to various time periods or to develop atmospheric stability specific criteria. If it is impractical to accommodate the multiple criteria into the operation strategy of a wind farm, the more stringent and most conservative criteria should be applied for the whole project.

However there is no guidance to specific meteorological criteria or reference to atmospheric stability conditions and when these separate regression analyses should be developed. It is essentially left up to the discretion of the acoustic engineer carrying out the assessment whether such criteria are applicable for a given site.

Australian Standard AS 4959–2010

The Australian Standard AS 4959–2010 has been developed in an effort to standardise the measurement, prediction and assessment methods used to assess the noise emissions from wind farms across Australia. Input is required from the Relevant Local Regulatory Authority to determine what is considered a minimum noise level limit based on the existing ambient noise environment at the affected receivers. The Relevant Local Regulatory Authority should allow the minimum noise level limit to be exceeded provided the background noise level is not exceeded by a certain amount.

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

- Minimum noise level limit
- Background noise levels plus the specified amount

This allows for individual council or state bodies to determine what are deemed as appropriate noise criteria for their specific areas while applying standardised measurement, prediction and assessment methodology for Australia-wide wind energy developments.

Similar to the NZS 6808, an indicative noise prediction equation is specified (which is the same as per NZS 6808:1998). It is explicitly stated that all analysis should be referenced to hub height wind speeds, with an explanation (as provided above) that the…

> …actual wind speed that would be measured at 10m AGL varies from site to site and in different atmospheric conditions.

The noise monitoring requirements are consistent with the SA Guidelines (2009), requiring at least 2000 valid data points which cover the required range of wind speeds and directions. Exclusions are required of rain affected samples and wind speeds at the microphone in excess of 5 m/s without specially built microphone windshields for higher wind speeds. A regression analysis as per the other guidelines is to be carried out relating to hub height wind speeds.

As outlined in NZS 6808, the Australian standard similarly states that:

> 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.

Further on in the Standard it is emphasised that:

> Consideration should be given to carrying out separate correlation of background sound levels with wind speed for different directions and/or times of day, particularly where atmospheric stability issues are apparent or are suspected.

By separating the collected data into different times of day and/or wind directions, specific criteria can be generated which apply to the particular conditions.

Unfortunately no guidance is provided on the minimum sample sizes of the separate regression analyses as well as when should they be undertaken, i.e. what is considered a sufficient occurrence of atmospherically stable conditions and/or down wind conditions such that separate analysis is required.

DISCUSSION

It is unfortunate that the updated versions of the guidelines and standards only provide minimal guidance if any, in relation to the effect of atmospheric stability on wind farm noise emissions.

Based on the above assessment techniques, only the AS 4959 explicitly mentions the possibility of carrying out separate correlations of background noise for different wind directions and/or times of day particularly where atmospheric stability issues are apparent or suspected.

One other particular observation is the lack of guidance in the guidelines and standards as to when such an assessment is deemed appropriate, along with what is considered a sufficient and practically obtainable sample data size to carry out the correlation studies of noise levels versus hub height wind speeds at the WTG site.

The NSW Industrial Noise Policy notes that atmospheric stability represents a significant noise impact and calls for additional assessment when instability occurs for 30% or more of the total night-time during winter (June, July and August), a similar threshold level should be adopted for wind farm noise assessments. The occurrence of various atmospheric stability classes can be easily calculated from long term collected proponent wind mast data based on the standard deviation of the change in wind direction as outlined by the Sigma Theta descriptor.

Splitting up the correlation analysis into individual Pasquill Stability Criteria can lead to very small sample sizes especially if stable conditions were not prevalent during the carried out noise survey. Should a minimum sample size be introduced, this then has the potential to significantly increase noise assessment costs, as well as delay project deadlines. This would likely be due to the fact that the noise survey would have to be carried out during a site-specific time of year when the stable conditions would be most prevalent (usually the night time during winter months).

There is also the issue of the practical application of these criteria, i.e. when should one set of criteria begin to apply compared to another during shoulder periods when there is a change in the atmospheric conditions. This would have significant implications on the WTG programming should different operating modes be required for different stability noise criteria. As outlined in the NZS 6808, the most conservative criteria should be applied for the whole project however this has the potential to unfairly limit full capacity operation of the wind farm especially without explicitly outlining when such measures should be applied.

Developing regression curves between day and night times can provide significantly increased sample sizes from the noise survey, thus the determination of specific criteria for each time of day. This will potentially take into account the occurrence of most of the stable conditions at each site as they predominantly occur during the sunset hours. Based on seasonal analysis on the likelihood of stable conditions occurring, specific criteria could be applied to certain times of year when there is an increased likelihood of stable conditions occurring at regular intervals.

Another benefit of time specific criteria is that they are easier to understand for the general public (especially the affected receivers) as it would clearly state at what time of day and/or year specific criteria would be applicable. Implementing stability specific criteria leaves the public confused as to when certain criteria apply, since it is generally very difficult to determine in what current stability state the atmosphere is in without meteorological monitoring equipment. This leaves affected receivers with no option but to trust the wind farm operator that they are correctly monitoring atmospheric conditions and applying control measures to reduce noise emissions as outlined per the applicable development conditions. This is not a desirable situation for sensitive receivers which do not have a good relationship with the wind farm operators, based on the fact there is regular opposition to wind farm developments.

CONCLUSION

This review of the updated Australian and New Zealand guidelines and standards for the assessment of noise from wind turbine farm developments has identified the need to take into account some of the effects relating to atmospheric stable conditions as part of the assessment process.

A strength of the updated versions of these documents, is that they have reduced the potential error associated with wind shear approximation by referencing all wind measurements to wind turbine hub heights rather than 10 m above ground level. However these assessment methods do not take into account the potential atmospherically stable effects during the criteria generation process.

The AS 4959 and NZS 6808 provide clauses for the potential to develop condition or time of day specific noise criteria, yet it's shortfall is that there is no explicit method outlined.

It is the opinion of the author that future updates of the reviewed documents should include explicit and detailed methodology on when and how atmospheric effects should be taken into account as part of the assessment, as well as the generation of atmospherically stability specific criteria - whether they are relative to individual stability classes or relating to times of day and year when stable conditions have been determined to be most prevalent for the specific development site Such an approach would result in the development of more accurate and realistic criteria and allow for the improved operation of WTGs .

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