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Tonality assessment at a residence near a wind farm

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Summary

The South Australian Environment Protection Authority has advised that tonal audibility at residences near wind farms should not exceed 0 dB when assessed in accordance with IEC 61400-11. Following the commencement of operation of a Wind Farm, an investigation was undertaken into a complaint regarding the character of wind farm noise which was received from a resident and that related to specific wind speeds and directions. This paper outlines the comprehensive tonality assessment undertaken at the house using the tonal audibility test in IEC 61400-11, but which considered all wind speeds and directions. An audible tone was detected at a frequency of approximately 124 Hz, occurring at night and during upwind conditions, which corresponded to the conditions identified in the complaint. The tone was found to relate to the gear meshing frequency of the turbines. Modifications were subsequently made to the turbines and then further tonality testing undertaken that demonstrated that the tone was rectified and met the 0 dB criterion for all measurement periods.

1 Introduction

Hallett Hill Wind Farm is the second stage of the Hallett Wind Farms located near Hallett, South Australia, and commenced operation in late 2009. Relatively soon after commencement, a complaint was received from a resident living approximately 1.5 kilometres from the nearest turbine at the wind farm.

In response to the complaint, a detailed tonality assessment was undertaken to assess compliance with the tonality criterion imposed by the South Australian

Environment Protection Authority (SA EPA). An audible tone was detected at a frequency of approximately 124 Hz, typically occurring at night and during upwind conditions, which corresponded to the conditions identified in the complaint.

The tone was found to relate to the gear meshing frequency of the turbine gearbox. A number of turbines were shut down at night in the interim period to ensure that compliance was being achieved with the noise criteria, while a permanent solution was developed. Permanent modifications, in the form of tuned mass dampers, were subsequently made to the turbines to enable the tonality criterion to be met at all times.

This paper describes the tonality assessment methodology employed at the residence near Hallett Hill Wind Farm, and outlines the results of the assessment. It also:

- Highlights that the current IEC 61400-11 tonality assessment methodology intended to be employed at wind turbines may need to be expanded if it is to be applied at residences.
- Compares the tonal audibility criteria applied at Hallett Hill Wind Farm to that applied to other industry and to wind farms in other Australian States.

2 Hallett Hill Wind Farm

2.1 Site description

Hallett Hill Wind Farm is located south of Hallett, South Australia, and comprises 34 wind turbines of the same make, each rated at approximately 2 MW. The turbines run north to south along a ridge line, with the turbine hubs elevated approximately 250 to 300 metres higher than the nearest residential properties in the valley below. The wind farm is managed by AGL Energy Limited (AGL).

2.2 Applicable wind farm noise criteria

The Hallett Hill Wind Farm is subject to the requirements of the South Australian *Wind farms environmental noise guidelines* (SA EPA, 2009) referred to in this paper as the Guidelines. The Guidelines require that the L_{eq} noise level from the wind farm (measured in the field as an L_{90} level) does not exceed the greater of:

- 40 dB(A), or
- the background noise level plus 5 dB(A).

2.3 Tonality criterion at residence

Noise that is tonal in character has a relatively high level of acoustic energy over a narrow frequency range that is not masked by noise at surrounding frequencies. Tonal noise is relatively common, with vehicle engines, aeroplanes and bird vocalisations all common examples of tonal noise experienced at residences.

It is well recognised that tonal noise is more annoying than broadband (non-tonal) noise. In recognition of the increased annoyance caused by tonal noise the Guidelines state that the noise level measured from the wind farm should be increased by 5 dB(A) if “the wind farm exhibits tonality as a characteristic”. No specific test procedure or methodology to apply the penalty is identified as the mandatory test procedure within the Guidelines, but IEC 61400-11 (IEC, 2006) is provided as an example of a suitable procedure.

IEC 61400-11 provides a method for calculating a tonal audibility (ΔL_a), with an audibility of 0 dB indicating a tone is just audible to the average listener, but does not suggest a value of tonal audibility that would be considered acceptable. Contact was made with the SA EPA to determine a suitable criterion to use, and it was advised that wind turbine noise should achieve a tonal audibility of no more than 0 dB at nearby residences.

2.4 Nature of complaint

A complaint was received from a resident located approximately 1.5 kilometres east of the turbines at Hallett Hill Wind Farm. The property was the nearest non-financially involved residence to the wind farm. The complaint related to night time periods of relatively low wind speed, and suggested the issue may be greatest when the wind was blowing from the east (turbines upwind with respect to the house).

Previous noise measurements conducted at the residence demonstrated that the wind farm was operating in compliance with the relevant noise criteria, although these measurements did not include a specific assessment of tonality.

A tonality assessment undertaken by others at a different residence, nearby but slightly closer to the turbines, did not identify a tone. Two assessments of tonality had also been undertaken at the turbines with one assessment identifying an audible tone and the second not. However, the previous assessments at both a residence and the turbines had closely followed the IEC 61400-11 Edition 2.1 methodology, and therefore all considered only a small number of measurements under downwind conditions. There was a possibility that the results of the previous assessments were not directly applicable to the complaint as:

- the lowest wind speed previously assessed for tonality (6 m/s at 10 m height) was potentially higher than the wind speeds noted in the complaint
- the complaint suggested that noise under upwind conditions was subjectively more annoying, when the standard uses downwind measurements.

3 Tonality assessment methodology

3.1 IEC 61400-11 Edition 2.1

The IEC 61400-11 tonality assessment methodology applies at the turbine and is not intended to be applied at a residence. This meant that the assessment methodology

needed to be adapted in some areas for it to be relevant at a residence and for it to cover the range of wind speeds and directions to which the complaint referred.

At the time of the assessment, IEC 61400-11 Edition 2.1 was the relevant version of the Standard. This methodology involves calculation of the tone level for possible tones in selected 10-second spectra and calculation of the masking noise level in the critical bandwidth around the tone. Tonal audibility is then calculated as the difference between the tone level and the masking noise level, adjusted by a frequency dependent audibility criterion.

IEC 61400-11 Edition 2.1 has specific data collection requirements that limit the data to be assessed at the turbine. The two one-minute periods nearest to each integer wind speed from 6 m/s to 10 m/s (at standardised 10 m height) are assessed. Additionally, only downwind (±15°) measurements are considered in the assessment. For every possible tone, the tonal audibility values determined for each of the 12 10-second periods at each integer wind speed are then energy-averaged to determine the overall tonal audibility for the tone at that wind speed.

3.2 Adapted methodology at residence

When planning the assessment of tonality at the residence near Hallett Hill Wind Farm, the results of the previous assessment of tonality at a residence (undertaken by others) and a tonality assessment at a site turbine (undertaken by the authors) were reviewed. The measurements at the turbine had detected an audible low frequency tone during only one low wind speed measurement. High frequency tones had also been detected at several higher wind speeds. This suggested that wind speed was one variable that may alter the emission of audible tones and a wide range of wind speeds would need to be considered in the assessment.

It could be reasonably expected that a reduction in the tonal audibility from the wind turbines would occur between the turbine and the house, due to increased masking noise at the residence. The testing at the turbine was therefore not able to confirm whether any tone was audible at the residence 1.5 kilometres away, which is the location where the 0 dB tonal audibility criterion applied.

On review of the previous tonality assessment undertaken at a different residence it was noted that a number of the periods selected nearest to each integer wind speed were during the daytime. This included the periods selected for the wind speed closest to the speed where an audible tone had been detected at the turbine. The authors suspected that masking noise at the residence during the daytime would be higher than at night due to both lower daytime windshear and greater extraneous noise from vehicles and human activity. On this basis it appeared necessary for the testing to include night time measurements, although the level of daytime audibility was also of interest.

To respond to the complaint, a methodology was developed in consultation with AGL (the wind farm managers) that applied the IEC 61400-11 tonal audibility test to a

significantly larger dataset including no limitation of the wind speeds and directions assessed.

3.3 Measurement methodology at residence

A Class 1 sound level meter was deployed outdoors at the residence for a period of 10 days, with the aim of capturing data over a wide range of wind speeds and directions, at varying times of day. The microphone was located at a height of 1.5 m above ground and fitted with an approximately 90 mm diameter windshield. The sound level meter was configured to log the noise level also continuously record a 16-bit audio signal with sampling rate of 16 kHz for the entire 10 days of measurements.

The captured audio signal at the residence was then analysed using a Hanning window with 2 Hz frequency resolution in general accordance with the IEC 61400-11 tonality assessment procedure using MATLAB R2009a software (MathWorks, 2009). The differences in the adopted assessment procedure relative to the reference IEC 61400-11 method were:

- For each consecutive two-minute period over the whole 10 day period, the tonal audibility of any possible tone was calculated as the energy-average of the 12 10-second tonal audibility values. The departure from the standard being that IEC 16400-11 Ed. 2.1 required a total of only two minutes of data to be assessed at each integer wind speed.
- All wind speeds and directions were considered in the assessment. This is different from IEC 61400-11 Ed. 2.1, which requires that only integer speeds from 6 to 10 m/s are assessed, at measurement locations directly downwind of the turbine.
- Reference was made to hub height wind speed rather than standardised 10 m height wind speed used in IEC 61400-11 Ed. 2.1, to maintain consistency with the Guidelines.

3.4 Removal of extraneous tones

The above methodology provided over 7,000 two-minute periods where the tonal audibility had been calculated at the residence. It was immediately apparent that approximately half of the two-minute measurements at the residence contained audible tones ($\Delta L_a > 0$ dB) at some frequency, mostly due to tones from vehicles and birds. It was recognised it would be impractical to listen to every single measurement with an audible tone to determine whether the source of the tone was the turbines or an extraneous source.

To identify the audible tones that were potentially a result of noise from the wind farm, the approximately 24 hours of audio that had been stored at a turbine during sound power measurements was also analysed in consecutive two-minute periods. The frequency of any identified tone at the residence was then compared to the

frequencies at which tones were identified at the turbine, to determine if the turbine was a possible cause of the tone.

For every two-minute period where the frequency of a tone at the residence matched that of a tone radiated from the turbines, the captured audio file at the residence was listened to in order to determine the source of the tone. Any tone that was a result of an extraneous source was discounted from further assessment.

3.5 Conditions contributing to tones

Once the audible tones ($\Delta L_a > 0$ dB) detected at the residence and identified as due to the wind farm had been identified, further analysis was undertaken to determine trends in tone occurrence with wind speed, direction and time of day, and combinations of all these variables.

4 Assessment results

4.1 Detected tones at residence

Figure 1 provides a comparison of the frequencies of tones detected at the residence near Hallett Hill Wind Farm against the frequencies of tones detected at the turbine, for 0 to 500 Hz. These measurements were undertaken in November 2010. Results are presented as percentage of time that the tone was audible ($\Delta L_a > 0$ dB) rather than the number of detections of an audible tone, to remove the influence of differing measurement duration at the turbine and residence on the results. Note that Figure 1 includes audible tones arising from both the wind farm and extraneous sources.

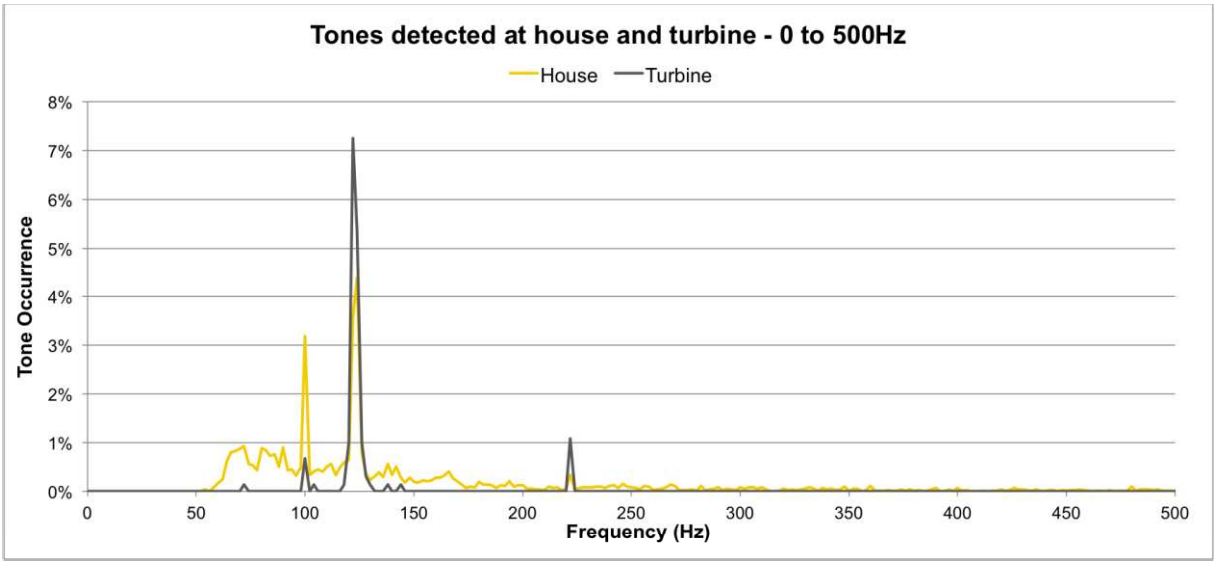

Figure 1 – Occurrence of audible tones at the residence and turbine

Audible tones were detected at the residence at many of the frequencies at which tones were detected at the turbine. However, the source of the tone at the residence did not always match that at the turbine. Taking the 100 Hz tone as an example, this tone was detected more regularly at the residence than at the turbine. At the turbine this tone appeared to be associated with turbine yaw, but at the house the source

was a motor near the logger or occasionally vehicle noise, but was never due to noise from the turbines.

Of the tones detected at the residence only some 124 Hz, 222 Hz, and 1130 Hz tones (not shown on Figure 1) were attributed to the turbines. The clear majority of the tones attributed to the turbines were the 124 Hz tone, with detection of the other tones rare at the residence. Note that the frequency of the tone referred to as the 124 Hz tone was primarily concentrated at 122 Hz and 124 Hz, with occasional occurrences at 120 Hz, 126 Hz or 128 Hz.

The other tones that were detected at the residence that did not match the frequency of those detected at the turbine were the result of vehicle movements (both local and distant), aeroplanes overhead, a water pump and farm machinery. Bird vocalisations also resulted in a large number of higher frequency tones at the residence.

In total, audible 124 Hz tones attributed to Hallett Hill Wind Farm were detected at the residence for 456 two-minute periods out of a total of 7,065 measurements, or 6.5% of the measurement period. This number of audible tones detected at the residence provided the ability to investigate the conditions under which the tone was audible. The analysis of the 124 Hz tone considered wind speed, wind direction and time of day. While trends against both wind speed and against time of day were visible, neither variable alone was the clear cause of tonal audibility. It was only when an analysis including both variables was conducted that a clearer relationship to the complaint became apparent.

The occurrence of tonal audibility against both wind speed and time of day is shown in Figure 2, where occurrence is the percentage of time that a tone is audible (ΔL_a > 0 dB) out of the total number of measurements for that particular wind speed and time of day combination. From Figure 2, it is clear that the 124 Hz tone was normally audible at wind speeds of approximately 5 to 6 m/s during the night. The tone was however rarely audible during the day, or at other speeds during the night. The audibility of the other two tones (222 Hz and approximately 1130 Hz) showed similarly small patterns of distribution; detected predominantly at night and at a small range of wind speeds.

The wind directions under which the tone occurred were also analysed. There was a hint in the results that the tone occurred most under easterly winds, although tones were detected under most wind directions.

Figure 3 presents the level of tonal audibility of the 124 Hz tone at the residence. They are presented as the number of two-minute detections in each 0.5 dB wide audibility bin centred at each half decibel. Note that the 0 dB bin is only 0.25 dB wide, considering tones with audibility from 0 dB to 0.25 dB. The audibility of tones at matching frequency but attributed to an extraneous source are also shown. These primarily resulted from vehicle movements, both local and distant, and occasional aeroplanes.

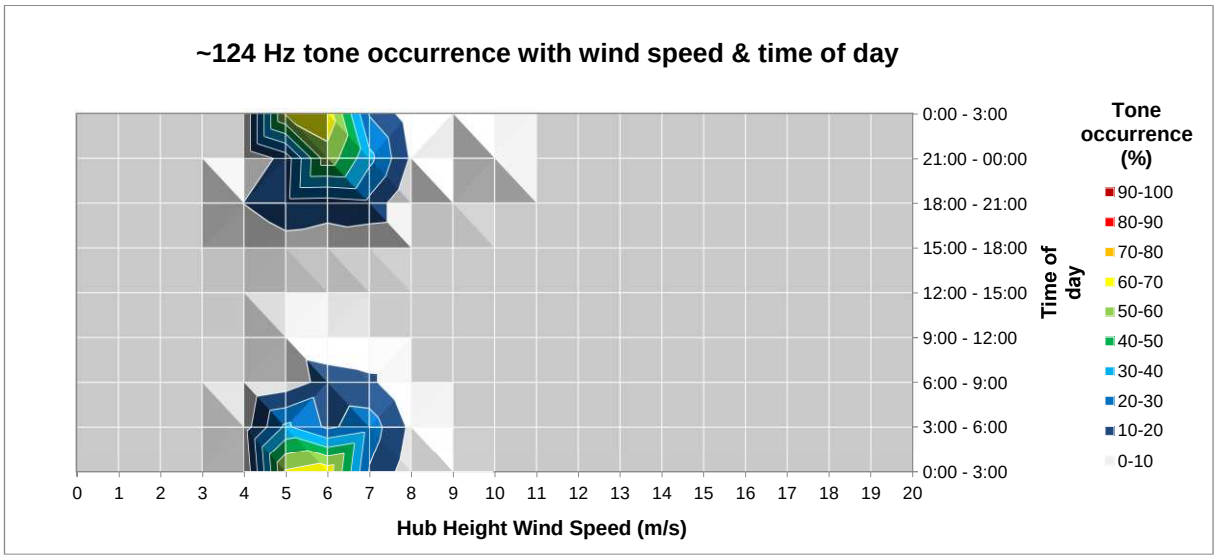

Figure 2 – Occurrence of 124 Hz tone at the residence with wind speed and time of day

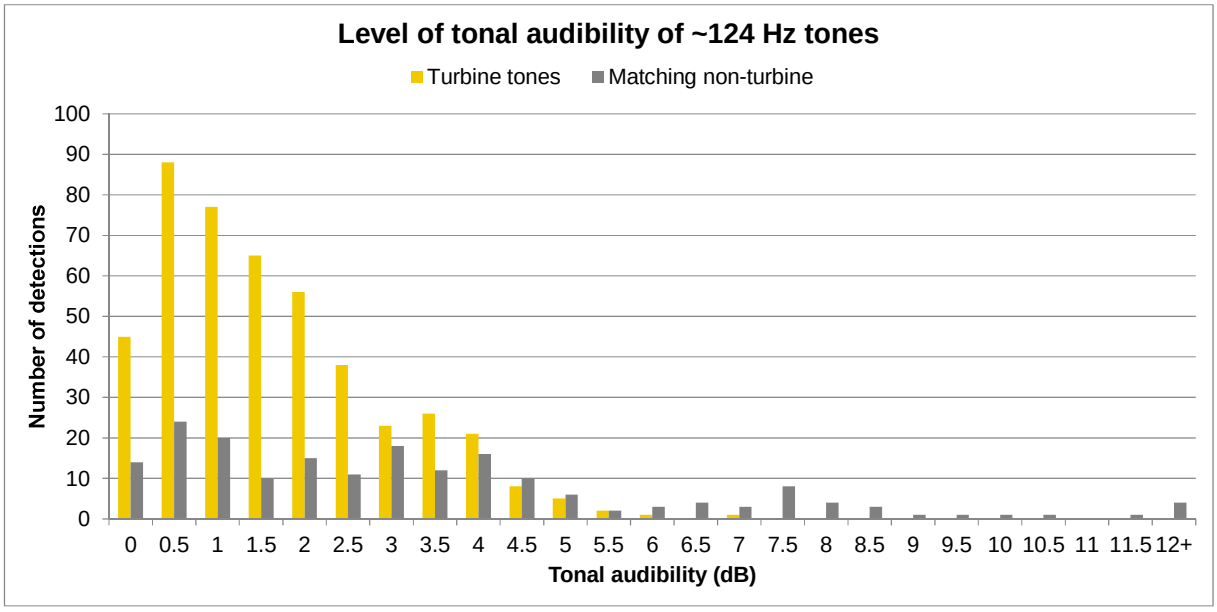

Figure 3 – Level of tonal audibility of 124 Hz tone at residence

Figure 3 shows that the maximum audibility of the 124 Hz tone at the residence was about 7 dB. However, the vast majority of the audible tones had an audibility of 4 dB or lower.

4.2 Application of tonality penalty

At the time the tone was detected, the SA EPA had not specified how the 5 dB(A) tonal penalty should be applied to the measured overall noise levels at a residence. A number of approaches were possible:

- Apply it only to those 10-minute data points where it occurred, given the relatively low occurrence, and reassess compliance with the criteria based on a modified regression curve. Compliance would need to be reassessed considering upwind and crosswind conditions rather than just downwind as is strictly required by the Guidelines.
- Apply a fixed 5 dB(A) penalty to the overall average measured level (under downwind conditions) at each wind speed at which the tone was detected.

The first approach would have resulted in the wind farm remaining compliant with the criteria even with the audible tone, due to the relatively low occurrence of the tone and the fact that it occurred mainly under upwind through to crosswind conditions when overall noise levels were already lower than under downwind. However, it was recognised that this would not have resolved the original complaint.

The second approach would result in the wind farm being borderline non-compliant with the noise criteria at the residence at the speed at which the audible tone was detected.

AGL decided that, as the complaint appeared to relate to tonality, modifications should be made to the turbines in order that the 0 dB audibility criterion was achieved at the residence. This was undertaken as it was considered a more appropriate response to the complaint and provided a conservative approach to the manner in which a tonality penalty might be applied.

5 Solution

The turbine supplier identified that the tone related to the gear meshing frequency of the turbine gearbox. Development of the modifications to the turbines went through a number of stages that are broadly discussed here. A permanent solution was installed in late 2011 with testing confirming then that the 124 Hz tone was not detected with audibility greater than 0 dB at the residence.

5.1 First stage – installation of foam

The turbine supplier suggested that previous testing at turbines of this model had indicated that installation of 50 mm thick foam lining inside the nacelles of the turbines would mitigate tonal noise emissions. Linings were therefore immediately installed in the nacelles of the turbines after the detection of the audible tones at the residence and the assessment of tonal audibility repeated to determine whether the mitigation had been successful. The follow up test indicated that installation of the foam linings had removed the occurrences of audible 222 Hz and 1130 Hz tones at the residence, but the audibility of the 124 Hz tone was not significantly altered.

5.2 Second stage – temporary turbine shutdowns

When the follow up testing indicated the 124 Hz tone was still audible the nearest turbines to the residence were immediately shut down at night for wind speeds of around 6 m/s, while a more permanent engineering solution was developed.

While the initial analysis of tonal audibility of the residence was not particularly suggestive of a trend in results with wind direction, a stronger trend towards higher audibility of the 124 Hz tone during easterly winds was apparent during the testing following installation of the foam linings. A higher level of tonal audibility under easterly winds matched the observations of the resident regarding times of annoyance.

Ten days of testing was subsequently undertaken at a turbine in general accordance with the IEC 61400-11 Edition 2.1 methodology. This included installation of the microphone on an acoustically reflective ground board. The significant deviation from the standard was that like at the residence, all 10 days of audio was analysed for tonality, rather than just the two one-minute blocks nearest to each integer wind speed.

Figure 4 presents the average tonal audibility of the 124 Hz tone at the turbine with wind speed and direction. Note that 0º corresponds to upwind conditions with respect to the measurement location, 180 degrees downwind, and +/- 90 degrees to either side of the nacelle. Average tonal audibility has been calculated as the logarithmic average of all occurrences within each bin where a 124 Hz tone was detected, including occurrences with audibility lower than 0 dB.

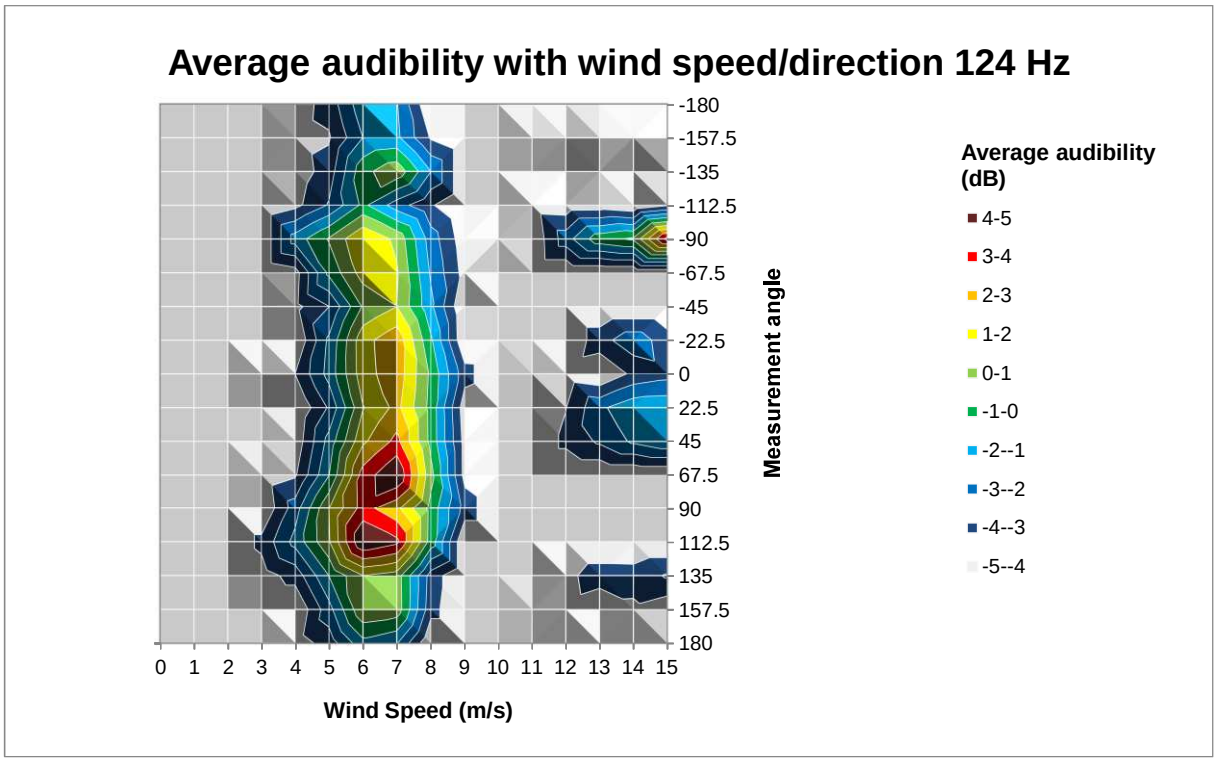

Figure 4 – Average tonal audibility of 124 Hz tone at turbine with wind speed and direction

Analysis of the results at the turbine against wind speed and direction confirmed that tone audibility was greatest at speeds of 6 to 7 m/s (hub height). It was rarely audible ($\Delta L_a > 0$ dB) at lower speeds, or at speeds between approximately 8 m/s and 12 m/s, but was sometimes audible at higher speeds. Of note, the tone was never found to

be audible at high wind speeds at the residence, most likely due to the increased ambient masking noise at those high wind speeds.

We note that IEC 61400-11 Ed. 2.1 requires the assessment of tonal audibility at wind speeds of 6 to 10 m/s at 10m height, which equates to 8.3 to 13.9 m/s at hub height. The wind speed that the tone was most audible (6 to 7 m/s at hub height), was therefore below the range of wind speeds that tonality was required to be assessed under the IEC 61400-11 Ed. 2.1 standard. The limited range of wind speeds required to be assessed for tonality was a shortcoming of IEC 61400-11 Ed. 2.1.

The measurements at the turbine confirmed radiation of the tone was strongest to one side and upwind of the turbine, and weakest to the other side and downwind. The difference in average tonal audibility between the best and worst case directions was in the order of 7 dB. This information was used to further fine tune the turbine shut downs at the site, to shut down more turbines when the residence was to the worst-case direction from those turbines, but keep other nearer turbines on when those turbines could provide more broadband noise to mask the presence of the tone from more distant turbines.

5.3 Final stage – permanent solution (tuned mass dampers)

The 10-day measurements conducted at the turbine also provided information regarding the likely propagation path of the tone, and a baseline against which future improvement could be judged. The turbine supplier undertook a series of vibration measurements on the turbine and with that additional information trialled a number of solutions to control tonal noise emission from the turbine. The installation of two tuned mass dampers to the torque arms of the gearbox was the final solution selected for installation on all of the turbines on site.

Following installation of the tuned mass dampers to all turbines we repeated the tonality testing at the residence, where it was found that the 124 Hz tone was not audible during any 2 minute period during 40 days of tonality assessment. From our discussions with the resident we understand that an improvement in character of the turbine noise was noted following installation of the tuned mass dampers.

6 Further comments and analysis

6.1 Comparison to other tonality assessment criteria

The tonal noise criterion applied to wind farms in South Australia, such as Hallett Hill Wind Farm, is strict by Australian standards. The tonality assessment criteria applied both to wind farms in other States and to other industries are less stringent than the 0 dB audibility criterion applied at Hallett Hill Wind Farm.

In Victoria, NZS 6808:2010 (Standards New Zealand, 2010) is now applied to new wind farms, which references the detailed tonality assessment methodology from

Annex C of ISO 1996-2:2007 (ISO, 2007). This methodology is broadly similar to that specified in IEC 61400-11 Ed 2.1 although differs slightly in practice.

One key difference is that ISO 1996-2 specifies acceptable tonal audibility values, applying a sliding penalty to tones with audibility greater than 4 dB, with a maximum penalty of 6 dB applicable for tones with audibility greater than 10 dB.

Figure 5 provides a comparison of the frequencies of audible tones detected at the residence near Hallett Hill Wind Farm using both the ISO 1996-2 and IEC 61400-11 Ed. 2.1 methodologies. The results are presented as the percentage of two-minute periods for which an audible tone ($\Delta L_a > 0$ dB) was detected at the frequency. It can be seen that the results are relatively similar, although the ISO 1996-2 methodology results in a 2% higher occurrence of tones at 122 and 124 Hz.

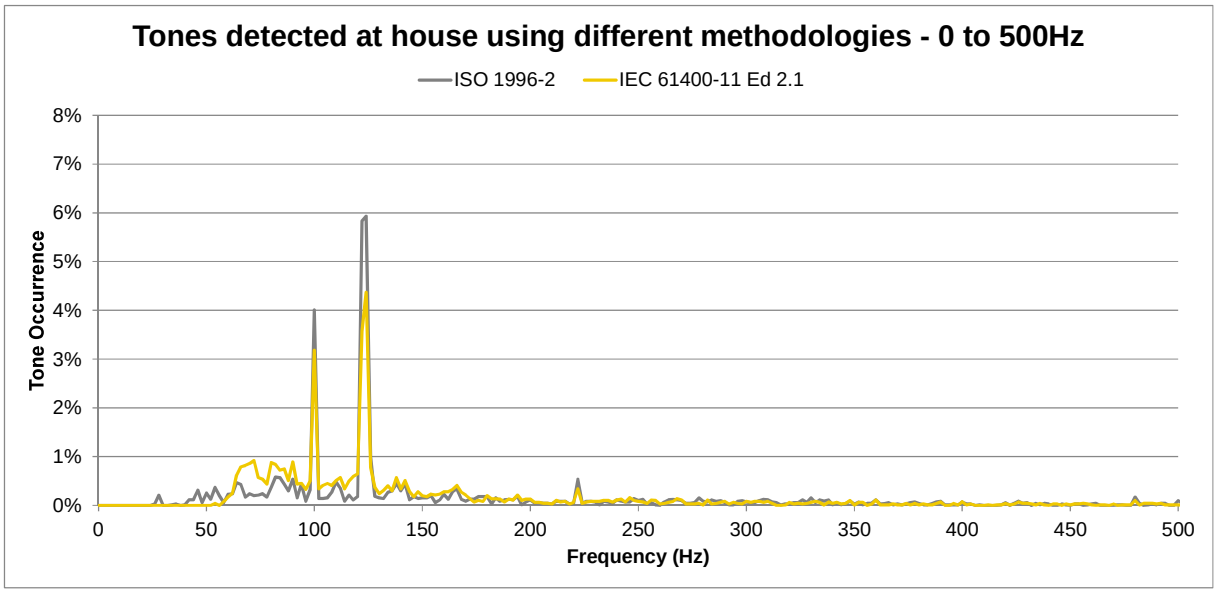

Figure 5 – Tones detected at residence using two different methodologies, 0 to 500 Hz

Figure 6 presents the level of tonal audibility of the 124 Hz tone at the residence using both the ISO 1996-2 and IEC 61400-11 Ed. 2.1 methodologies on the same data set. Review of the number of dections at each level of audibility suggests that for this tone, the ISO 1996-2 methodology typically increases the level of audiblity by approximatly 1 dB, when compared to the level calculated using IEC 61400-11 Ed. 2.1. However, we note the difference in audiblity between the IEC 61400-11 Ed. 2.1 and ISO 1996 methods does vary, with experience assessing other tones suggesting that for some tones the IEC method might report an average level up to 2 dB higher than the ISO method.

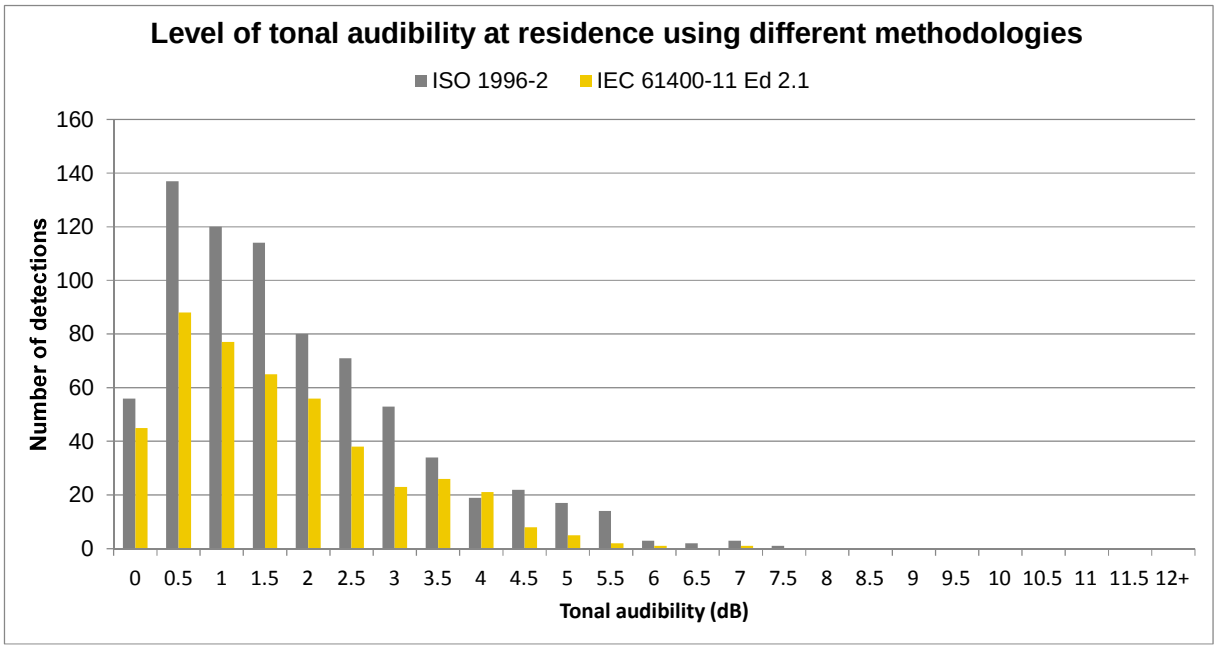

Figure 6 – Tonal audibility level of 124 Hz tone at residence using two different methodologies

Given that the maximum penalty that would be applied under ISO 1996-2 is 3.5 dB, and that no penalty would be applicable to the detections at 4 dB or lower, the tonality criteria applied at Hallett Hill Wind Farm is considerably more stringent than would be applied to wind farms assessed in Victoria under ISO 1996-2.

It is common for industrial noise policies in use in Australia to prescribe adjustment to the measured noise level where tonality is a characteristic. However, industrial noise criteria in Australia prescribe the application of a penalty on the basis of an A-weighted one-third octave band difference assessment rather than the more detailed narrow band audibility tests required for wind farms. These one-third octave band assessments would typically impose a penalty for tonality if the A-weighted level of any one-third octave band exceeds the level in both adjacent bands by 5 dB or more. In NSW, a difference of 15 dB or more is required for any low frequency tones in one-third octave bands below 160 Hz (NSW EPA, 1999).

The measured two-minute one-third octave band spectra at the residence near Hallett Hill Wind Farm were calculated to compare the A-weighted level in the 125 Hz band to that in the adjoining 100 Hz and 160 Hz bands. It was found that the maximum difference due to the 124 Hz tone from the turbines was 5 dB but that this occurred in only one period. For the remainder of the periods, the difference was 4 dB or lower. This demonstrates that the tonality assessment criteria applied to wind farms are significantly more stringent than that applied to other industry within Australia.

6.2 Modulation of tone

During the tonality assessment at the residence it was noted that the 124 Hz tone was not steady in nature. Listening to audio collected at the turbine it was clear that the tone was the modulated at blade pass frequency, but still exhibited some randomness in level, possibly due to variation in loading on the gearbox due to wind gusts. The blade pass modulation of the tone and directivity of the tone at the turbine suggested that the tone was radiated off the blade, and the turbine supplier later confirmed this through measurements.

The modulation of the tone at the residence was at a similar level to that at the turbine but was more random in nature, and could not be described as blade pass modulated. The modulation at the residence is believed to be due to a combination of the following factors:

- A number of out-of-phase turbines contributing to the audible tone at the residence meant that modulation from the individual turbines resulted in more random total level at the residence.
- Relatively small differences in frequency in the tonal contributions from each turbine resulting in a more rapid beating effect in the tone level at the residence. For example, a tone at 122 Hz from one turbine and at 124 Hz from another turbine could potentially result in a 2 Hz modulation at the residence.

Figure 7 presents a power spectral density of the 124 Hz tone, when measured at the turbine. A Hanning window with frequency resolution of 0.05 Hz and averaging time of 2-minutes was used for the analysis. A number of side bands all spaced at blade pass frequency from the main tone and each other are evident, which indicates that the tone is blade pass modulated. Note that as mentioned earlier, the tone referred to as the 124 Hz tone was typically radiated at frequencies of between 120 Hz and 128Hz, which varied with wind speed. In the example given in Figure 7, the tone is being radiated at 122.5 Hz.

In a study into subjective reactions to steady and beating low frequency tones, Moorhouse et al (2005) suggested that subjects were “more tolerant of the steady tones than of the corresponding beating tone by 3-5 dB.”

The modulating nature of the tone at Hallett Hill Wind Farm may have resulted in increased annoyance relative to a steady tone. This was noted when the authors were listening to collected audio files that contained wind turbine tones. A sliding penalty beginning from 4 dB audibility, as specified by ISO 1996-2 may not be an appropriate adjustment to reflect potential increased annoyance due to an amplitude modulated tone. On the basis that the difference in annoyance due to an amplitude modulated tone is about 4 dB, the application of a sliding penalty from 0 dB may better reflect the increased annoyance. A sliding penalty from 0 dB would also better reflect the increased annoyance with increasing tonal audibility than the fixed 5 dB(A) penalty currently imposed in South Australia.

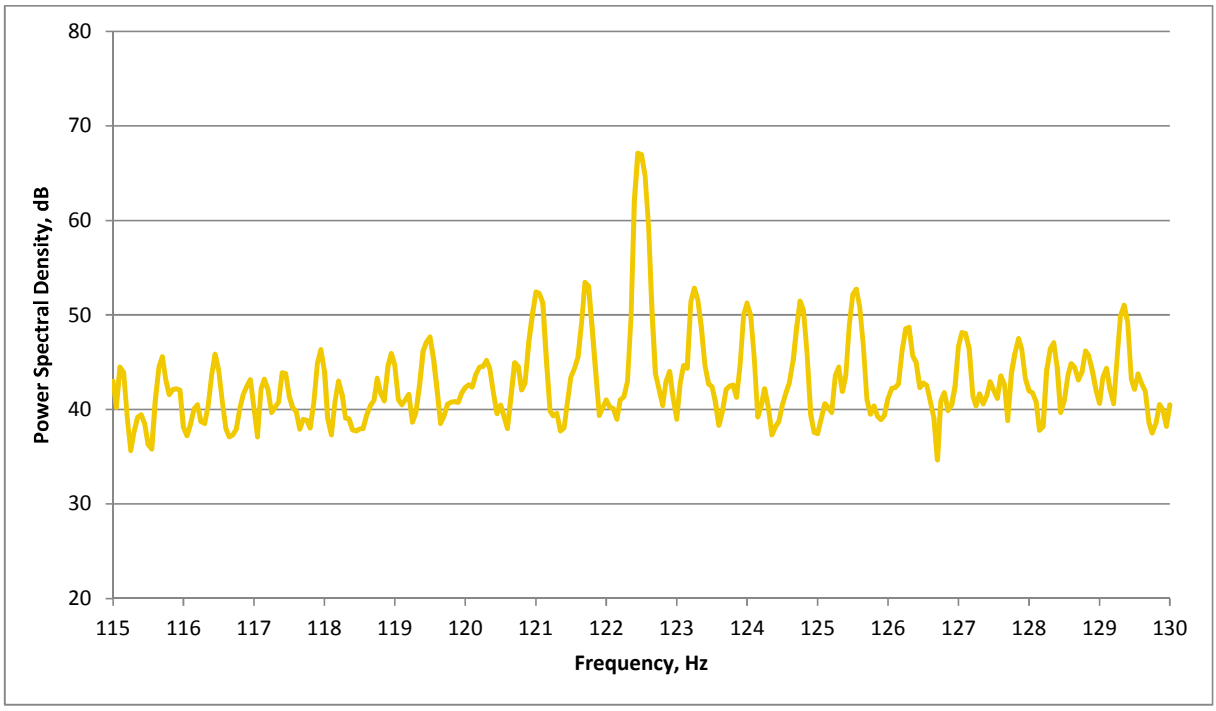

Figure 7 – Power spectral density of 124 Hz tone at turbine showing multiple side bands spaced at blade pass, which indicate amplitude modulation of the tone at blade pass frequency.

7 Recommendations

7.1 IEC 61400-11 Edition 3

Almost a year after the successful mitigation of tonal noise from the turbines at Hallett Hill Wind Farm, the updated version of the IEC Standard was released, IEC 61400-11 Ed. 3 (IEC, 2012). The key difference in tonality assessment procedures between Edition 2.1 and Edition 3 is that Edition 2.1 only considered the two minutes of downwind data gathered nearest to integer wind speeds of 6 to 10 m/s, while Edition 3 considers all downwind data gathered over a similar wind speed range (0.8 to 1.3 times the wind speed at 85% rated power). The use of all data within this wind speed range, rather than only a small sample of data to determine the tonal audibility, is a significant improvement in the new version of the standard. The average level of tonal audibility over a large number of measurements provides a far more consistent and repeatable measure of the tonal noise emissions.

While ideally the new standard might have required the assessment of a wider range of wind speeds and directions, the new standard does state that the range of measurement conditions may be expanded if necessary.

Like Edition 2.1, we believe several deviations are needed from IEC 61400-11 Ed. 3, when the regulatory authority requires application of the standard at a residence rather than a turbine. While an excellent approach for characterising emissions at the source (the aim of IEC 61400-11 Ed. 3), the averaging of all 10 second periods at a

given wind speed may hide a tone at a residence which is audible only under certain wind directions or at certain times of the day.

Compliance assessments in Australia utilise 10-minute averaging during measurements of overall L_{A90} noise levels. For this reason, we suggest that tonality assessments undertaken at residences using IEC 61400-11 Ed. 3 also use a 10-minute averaging period. Any penalty applicable to an audible tone from a wind farm can then be applied to the corresponding 10-minute L_{A90} data point as necessary.

We note that the 10 minute averaging of measurements presents some difficulties when compared to the 2 minute measurements used by IEC 61400-11 Ed. 2.1. Firstly, it is more difficult to find a short period of extraneous noise in a 10 minute audio sample than 2 minute sample. Secondly, a short period of extraneous noise can easily alter a 10 minute audibility result enough for it to be no longer representative of the actual level of turbine tone audibility. This may result in exclusion of excessive periods of measurements from analysis, or a tonal audibility value that is not reflective of that actually caused by the wind farm. Both of these issues can be overcome through exclusion of extraneous noise on a 10 second basis before averaging to get 10 minute levels. This can however be a time consuming process when several weeks of 10 second periods have been gathered at a residence.

We have recently applied this adapted IEC 61400-11 Ed. 3 method as part of a tonality assessment at a residence near a wind farm. Comparison of the two-minute tonal audibility value using Edition 2.1 and the 10-minute averaged results using Edition 3 indicate a similar outcome in terms of maximum and average level of audibility at the residence from application of the two standards.

7.2 Application of a tonality criteria for wind farms

Another finding from the Hallett Hill Wind Farm tonality assessment is that regulatory authorities may need to provide more detail as to how the nominated tonality penalty is to be applied to any detected tones from wind farms.

AGL decided to take a conservative approach to the application of a tonality penalty at Hallett Hill Wind Farm and require the 0 dB criteria to be achieved at the residence at all times. However, when tones of 1 or 2 dB audibility are detected for less than 1% of the time, application of a 5 dB penalty to all measurements under downwind conditions does not appear a reasonable adjustment to reflect the potential increase in annoyance.

Additionally, the application of the same 5 dB penalty to a tonal audibility of 1 dB and to a tonal audibility of 6 dB does not appear to adequately represent the difference in subjective response that may occur between these two scenarios. An alternative approach which is adopted in ISO 1996-2 is the application of a sliding penalty that increases as the tonal audibility increases. This sliding penalty is likely to better account for increased annoyance than a fixed 5 dB penalty.

Finally, application of a consistent penalty to all industrial facilities would appear equitable and should be considered. Application of a consistent approach would be more reasonable than the current situation in Australia where wind farms are subject to significantly more stringent tonality criteria than other industrial facilities.

8 Conclusion

This paper provides a summary of a method for the assessment tonal audibility at residences around a wind farm. The methodology was developed to investigate a compliant received from a resident living adjacent to a wind farm, which was in relation to the character of noise emissions from the site.

The assessment was based on the tonal audibility test provided in IEC 61400-11 Ed. 2.1. However, all 10 days of data gathered at the residence was assessed for tonality, rather than only the 2 minutes of data nearest to each integer wind speed which would normally be assessed using the standard.

The assessment indicated that a tone at 124 Hz which originated from the turbines was audible at the house, and that this tone was most audible upwind and to one side of the turbines, rather than downwind where tonality would normally be assessed. Audible tones were restricted to typically the night time, and to a small number of wind speeds. The wind speed at which the tone was most audible and causing annoyance at the residence was below the wind speed range normally assessed using IEC 61400-11 Ed. 2.1 (6 to 10 m/s at 10 m AGL).

Tuned mass dampers were subsequently installed on the turbines and further tonality testing was undertaken. That testing demonstrated that the tone met the 0 dB tonal audibility criterion for all measurement periods at the residence.

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