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Acoustics
Noise
Vibration

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Vermont Public Service Board

Docket 8167 on Sound Standards

Submission to Public Service Department

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table of contents

1 Introduction

The Vermont Public Service Board recently issued an Order in Docket 8167, which is an:

> *Investigation into the potential establishment of standards related to sound levels from the operation of generation, transmission and distribution equipment by entities subject to Public Service Board jurisdictions*

The Order, issued September 3 2014, invites the filing of submissions addressing best practices from other jurisdictions related to the regulation of sound from energy facilities, and including pre-construction sound modelling and post construction sound monitoring. This document provides a review of the methods currently employed in various jurisdictions, and provide relevant assessment of the benefits and drawbacks of those methods.

2 Pre-construction sound modelling

Sound modelling has been employed by acoustic engineers for a few decades to predict outdoor sound level contribution of various sources of noise at points of interest. The main streams of environmental noise modelling are Empirical based and Parabolic equation based noise modelling. The latter is believed to have the potential to provide much more robust analysis and prediction methodology. However, the method has significant computational requirements, and commercial applications of parabolic solvers are still considered to be in development, and have not yet been adopted by the mainstream industry, although some examples are showing promise. Empirical based models have been used in the past few decades and have advanced to account for multiple factors such as:

- Geometrical divergence of sound;
- Atmospheric absorption of sound;
- Simplified ground effects considerations
- Reflection from surfaces;
- Screening by obstacles;
- Atmospheric stability classes
- Topographical variation

The three main empirical modelling methods employed world wide are:

1. ISO 9613-2 [1]
2. Harmonoise; and [2]
3. Nord2000 [3]

2.1 ISO 9613-2

IISO 9613-2 specifies an engineering method for calculating the attenuation of sound during propagation outdoors in order to predict the levels of environmental noise at a distance from a variety of sources. ISO 9613-2 is the most commonly used model for environmental noise internationally. Its use is considered industry standard for environmental noise modelling in general, including for energy projects.

The model is meant to predict a level representative of propagation conditions under meteorological conditions favourable to sound propagation. These conditions are for downwind propagation, under a well-developed moderate ground-based temperature inversion, such as those that commonly occur at night.

The modelling standard states that it is applicable to a wide verity of ground based noise sources including most industrial sources. Limitations on the accuracy of the model are also presented in the standard, and from a practical perspective they are:

1. The ground is flat or of constant slope.

2. The acknowledgement that the predicted level is the average sound level, and that short term fluctuations around the average are a result of changing sound attenuation due to atmospheric conditions

3. An estimate of accuracy is provided in the standard for distances below 1000 meters, and for source/receiver height variation of 30m. This puts wind turbine facilities out of this range, as well as certain oil/gas facilities with stack heights above 30m. The uncertainty of the prediction algorithm for those cases is thus somewhat higher than that shown in standard (±3dB). Nevertheless, it remains the industry standard, and general agreement has been found in the field between measurements and predicted values.

2.2 Nord2000

The Nord2000 model was developed in Denmark, Norway, and Sweden between 1996-2001. The method was revised in 2005-2006 and again in 2014 [4] [5] [6] focusing on road and rail traffic noise. The propagation model is considered applicable to road and rail traffic noise, but also to other types of environmental noise such as industrial, airport and wind turbines. Above and beyond the ISO 9613-2 requirements, the model requires the vertical wind speed profile and temperature profile information in order to provide short term noise levels. Long term levels are determined by calculating the predicted levels for a number of weather cases, and applying the site based frequency of occurrence of those weather cases in order to arrive at a weighted average (such as a yearly average). This model has specifically been validated for predicting noise from elevated sources such as wind turbines.

Some of the features of this modelling approach are that the model accounts for:

- **Different impedance grounds.** Rather than categorize the ground effect into hard/soft, there are a variety of ground impedances that can be assigned to the intermediate ground between a source and receiver

- **Terrain effects.** Terrain is broken down into segments and the effects are accounted for per segment. This adds the capability of accounting for more complex terrain as compared to ISO 9613-2

- **Refraction.** Upward and Downward refraction in different atmospheric classes is accounted for based on a curved ray based approach. This would represent the difference between typical daytime and night time conditions.

2.3 Harmonoise

Harmonoise was developed as a result of the European Environmental Noise Directive (END) 2002/49/EC with the intension of providing a harmonized noise prediction methodology for the European Union member states. Its development occurred mostly after Nord2000 and many of the same principles as Nord2000, with some slight modifications to simplify the curved ray calculations.

2.4 Best Practices

The majority of acoustic consultants use ISO 9613-2, and its use has served the acoustical community well since its publication in 1996. Based on its widespread use and implementation in software, regulators have also widely adopted ISO 9613-2 as the accepted modelling standard.

With the advent of wind turbine projects, the difference between jurisdictional applications of the ISO 9613-2 model is related to the use of appropriate modelling conditions. The main parameters that vary based on the jurisdiction for wind projects are:

2.4.1 Ground factor (G)

This parameter varies between 0 and 1. G=0 represents hard reflective ground such as water, ice, and concrete, whereas G=1 represents porous ground such as those covered by grass, trees or other vegetation and all other ground surfaces suitable for the growth of vegetation. Mixed ground can be modelled as well with a value between 0 and 1. The lower the number, the more conservative the assumption. For a wind turbine project this typically results in a 2dB influence on predicted levels.

Jurisdictions vary in their application of the ground effect coefficient. Many do not specify a ground absorption coefficient – which would generally allow for the use of G=1 (the least conservative) if the standard was used as the guide. Although it may not be evident in regulatory documents, many jurisdictions accept noise modelling done with G=0.5 or less. Ontario allows for G=0.7 or less [7]. Some jurisdictions require the use of hard ground (G=0) such as South Australia [8]. The Institute of Acoustics [9] in the UK prescribes the use of G=0.5, and an additional correction of +3dB to the overall predicted values calculated across valleys. This is to account for concave ground profile, or where the ground falls away significantly between the turbine and the receiver location.

2.4.2 Barrier effects

Some consultants limit the barrier effect to 2dB from terrain. This is advocated primarily to deal with overestimation of barrier effects in very hilly terrain.

2.4.3 Use of Sound Power level of the turbines

The typical sound power levels of turbines are presented as measured in accordance with the IEC 61400-11 measurement standard. Manufacturers typically provide either a guaranteed sound power level, or a measured level with an uncertainty value. Some authors recommend adding the uncertainty to the measured levels if guaranteed levels are not available – in combination of G=0.5, or using the nominal sound emission in combination with G=0.

2.5 Recommendation

While the use of more recently developed and more advanced models (such as Nord2000) is preferred, any of the modelling methods described above can be relied upon for providing useful predictions of noise from wind turbine facilities.

If ISO 9613-2 modelling methodology is deemed acceptable, then it should be accepted with the limitations elaborated above in order to account for a sufficiently conservative approach, specifically for very hilly terrain.

It should be noted, however, that all the modelling methodologies have a degree of uncertainty. ISO 9613-2 has a stated uncertainty of ±3dB for distances up to 1000m, and a mean source-receiver height of 30m. It is expected that for the case of wind energy projects, that the stated distance would be routinely exceeded. It is not stated in the standard what increase in uncertainty level should be expected at larger distances. The Nord2000 model has specifically been validated for wind turbine noise as a source. The validation report for wind turbine noise by DELTA [10] references measurements and predicted levels within 0.5dB when measured in the downwind case over complex (hilly) terrain. This serves as an improvement over the ISO 9613-2 model.

It is recommended that whichever modelling regime is favoured, that consideration be given to the uncertainty of the model. This uncertainty will play into any post construction noise audit.

3 Post Construction Sound Monitoring

Post construction sound monitoring is becoming more and more common for wind turbine operations. For the purposes of clarity, it is first to clarify two forms of sound impingement:

1	Sound Emission	This is the sound that is emitted by a noise source, such as a wind turbine or transformer substation
2	Sound Immission	This is the sound received at any point, for example at a residential dwelling, school, or any other point of interest.

3.1 Sound Emission Testing

Sound emission testing is often carried out to verify the noise output turbine(s) in question. The emissions are either compared to the manufacturer specifications, or entered back into the original model in order to evaluate the expected noise level at the points of interest such as residential dwellings, in order to evaluate compliance.

Sound emission testing is fairly standardized. The International Electrotechnical Commission (IEC) has published a widely adopted standard for measuring the noise emission of wind turbines reliably, repeatedly. The IEC 61400-11 standard outlines measurement and reporting methodology for quantifying the apparent sound power of a given turbine. The measurements involve placing a microphone close to the turbine, on a reflective ground plane, directly downwind of the turbine being measured, and measure sound levels with and without the turbine operating, for a range of wind speeds and power ratings.

The measurements are attended measurements during which a data acquisition system obtains signals from the turbine in question, as well as a microphone placed at a distance equal to the height of the turbine (including the blade).

Simultaneous measurements are conducted which include sound, wind speed, wind direction, temperature, turbine parameters (power output, nacelle wind speed, nacelle yaw, blade pitch and rpm). The measurements are repeated with the turbines operating, and parked. The resulting data is used to calculate the sound power level (LwA) of the turbine. The standard also outlines a detailed tonality calculation and assessment, which results in reported tonal audibility by wind speed. The measurements are detailed and precise, and can produce reliable values for turbine acoustic emissions.

3.2 Sound immission testing

Sound immission testing is carried out with the intention of evaluating compliance with sound limits directly. In contrast to the sound emission approach described above, the assessment of compliance does not typically rely on modelling in situ conditions for evaluating compliance. Compared sound emission testing, immission testing methodologies vary substantially in practice. The main obstacles in conducting reliable measurements of sound immission from wind energy facilities are:

1. The noise source emission varies based on conditions at hub height near the turbine – typically as a function of the amount of power generated by the turbine.
2. There are usually multiple turbines in a facility, and conditions are not necessarily the same at all of them
3. Background noise typically plays a large role in the measured levels at the immission point, and background noise contamination can be problematic
4. Background noise is complex and composed of 3 parts:
    a. Environmental noises unrelated to wind speed (traffic noise, flora/fauna,)
    b. Environmental noises related to wind speed (vegetation)
    c. Self noise of the measurement system – typically related to wind speed
5. Arriving at a sound measurement metric comparable to that used in the permitting process

3.2.1 UK-ETSU-R-97: The Assesssment and Rating of Noise from Wind Farms

This document was created by the Energy Technology Support Unit (ETSU) for the UK Department of Trade and Industry (DTI). This document was not created as a UK Government document, but was provided as a guidance document for the UK Government to assess noise from wind farms. Subsequently, the government planning documentation, "Planning Policy Statement 22 (PPS22)", refers to the ETSU-R-97 as the study to use, when dealing with noise from wind farms. Although this document was created in 1996, it appears to be the current document which is still referenced in the UK. There has been a more recent document by the Institute of Acoustics in the UK called the "Good Practice guide to the application of ETSU-R-97 for the assessment and rating of wind turbine noise". Furthermore, it does provide a comprehensive review of several of the issues which must be dealt with regards to the assessment and measurement of wind turbine noise. Also, being one of the first comprehensive studies several of the more recent studies, including the New Zealand and Australia studies have been based on this study.

3.2.1.1 Measurement Parameters

There are both wind and sound level measurement parameters which the ETSU document relies upon. The sound level descriptor which this document predominantly relies upon is an A-weighted L90 level using a 10 minute interval ($L_{A90,\ 10min}$). The sound level limits, the background sound level and the measured noise immission level use the $L_{A90,\ 10min}$. Although, it will be discussed further in later sections, the ETSU document does make use of FFT analysis for tonal penalties; as such recordings are also required. Furthermore, for background correction purposes the document allows for the correction being applied to L_{eq} and L_{90} levels but states that the L_{90} correction is not accurate. The wind speed is also to be measured in 10 minute intervals. The wind speed should be provided at a 10m height. The ETSU document recommends using a 10m high anemometer but also allows for the extrapolation of the 10m wind speed using the hub height wind speed using a standard wind velocity profile.

3.2.1.2 Assessment of Background Sound Levels

As this ETSU document relies upon the background sound levels to determine the applicable limits, it is necessary to measure and monitor the background sound levels prior to site construction and operation.

The background sound levels and 10m high wind speeds are to be measured. The background sound levels are to be measured as $L_{A90,10min}$. The data is filtered by time of day as separate curves are required to be developed for day and night time periods. Also, data which includes periods of precipitation, and other events not considered part of the typical ambient environment are removed from the data set.

This data is to be correlated to the wind speed for the 10 minute interval and plotted against each other. A regression line is plotted through the day and night time data sets to develop the background sound level curves which will be used to develop the day and night time sound level limits.

3.2.1.3 Assessment of Blade Swish and Tonality

The ETSU document discusses the blade swish and outlines that it is a factor. However, it does not propose any penalties for blade swish and states that further research is required.

According to the ETSU document, the identification of a risk of tonality is somewhat subjective, in that it seems to indicate that the decision as to whether a particular noise is to be considered tonal is up to the auditor. However, once it has been suspected that there may be tones present, the guide essentially prescribes the Joint Nordic Method for assessing tonality. The Joint Nordic Method, similar to ISO 1996-2 and IEC 61400-11, prescribes a narrowband method of evaluating the acoustic energy in a tone as compared to the surrounding masking bands. The tonality is then calculated as a ratio of the two energies. ISO 1996-2 also provides applicable penalties based on the degree of tonality.

According to the ETSU document, once it is determined that tonality is an issue, it is penalized with a a tonal penalty using a sliding scale between 1.5 to 5dB depending on the audibility of the tone. The maximum of 5dB is prescribed when the audibility of the tone exceeds 6.5dB which is consistent with the Joint Nordic Method.

3.2.1.4 Measurement and Assessment of Noise Immissions

The ETSU document does not require that compliance be demonstrated at all wind speeds, but rather at the critical wind speed. This may either be governed by complaints or may be governed by the typical wind speed in the area. In order to obtain an appropriate sample size, it is recommended that 20 to 30 measurement intervals ($L_{A90,\ 10min}$) be conducted within +/- 2m/s of the critical wind speed. The noise measurement location is to be at a height between 1.2-1.5m and is to be located approximately 10m from any building facades to ensure that reflections are not a concern.

The sound levels are filtered to remove intervals where poor weather conditions existed or where the sound levels are dominated by extraneous noise sources.

This data is then taken and correlated to the 10m high wind speed which is also measured. A regression line is plotted through the data set for the critical wind speeds and if it is determined that this curve is below the sound level limit curve and there are no tones then the wind farm is considered compliant and no further assessment is required.

If however, the curve falls above the limit line or with the inclusion of a tonal penalty the sound level curve is above the limit line, the data set is then to be background corrected to remove the ambient sound levels from the measured sound levels. This curve is then considered in comparison with the limit curve to determine compliance.

3.2.2 NZS 6808:2010: New Zealand Standard: Acoustics – Wind farm noise [12]

This standard, released in 2010, outlines sound level limits as a function of the measured on-site 10 minute LA_{90}+5 or 40dBA, whichever is higher. The noise levels are with reference to wind speed at hub height of the nearest turbine. They note the vulnerability of LA_{eq} measurements to wind gusting for its unacceptability as a metric. The standard assumes that the wind turbine noise LA_{90} at the dwelling is equivalent to the predicted wind turbine noise LA_{eq} at the dwelling, predicted using ISO 9613-2. For the purposes of compliance testing, LA_{90} levels are measured in 10 minute intervals and related to the wind speed at the hub. ON/OFF testing is permitted to establish the contribution from the turbine compared to the background noise. For the wind turbine noise measurements, 1440 data points is the standard's minimum requirement. It should be noted that the British study (UK-ETSU-R-97) forms the basis of most of the requirements and is used to support the requirements.

3.2.3 AS 4959-2010: Standards Australia: Acoustics – Measurement, prediction and assessment of noise from wind turbine generators [13]

This standard was also released in 2010 shortly after the New Zealand standard. There are more similarities than differences, in terms of the compliance testing. Specialty wind screens are recommended for ambient noise measurements at wind speeds above 5m/s. There are two choices for measurements: attended and unattended. In the unattended case, 2000 data points are required covering a range for wind speeds (referenced to hub height). The LA_{eq} contribution is calculated as the LA_{90} +X dBA (where X = 1.5 dBA or more, based on consultant's justification). Based on the data, a regression curve is derived fitted to linear or up to third order polynomial equations describing the LA_{eq} with respect to wind speed. Attended measurements can also be conducted during which ON/OFF measurements are taken at a single location. Here, both the LA_{eq} and LA_{90} are measured in 10 minute intervals. If the $LA_{eq} > (LA_{90} + 3dB)$, the data point is discarded. Attended measurements must consist of 10 data points above the critical wind speed by up to 3m/s and 10 data points below the critical wind speed by up to 3m/s. For attended measurements, $LA_{eq,turbines} = LA_{eq,ON} - LA_{eq,OFF}$ (using logarithmic subtraction).

3.2.4 Massachusetts Department of Environmental protection (MassDEP) and Massachusetts Clean Energy Centre (MassCEC) [14] [15]

The Massachusetts noise limit is defined as limiting the increase in ambient noise by no more than 10dB. MassDEP's current protocol for determining compliance involves conducting short term measurements which include sound levels measured with the turbines operating and shut down.

The measurements are conducted in 10 minute intervals with the wind conditions and turbine operations noted. The protocol requires the comparison of the L_{90} noise level for the ambient (the 10th percentile quietest time) to the L_{max} of the measurements with the turbines operating. L_{max} represents the maximum instantaneous level measured at anytime during the 10 minute interval.

Although the benefit of this approach is conceptually straightforward, the main criticism is the uncertainty introduced by the variability of levels during any given measurement period, and the high degree of sensitivity of the L_{max} parameter to transient events, or wind gusts on the measurement system. Additionally, while jurisdictions such as in New Zealand and Australia also employ limits based on ambient, they always compare the same parameter with/without the operation of the turbines. The MassDEP methodology, however, compares L_{90} to L_{max}, with a limit of 10dB allowed.

3.2.5 Maine [16]

The Maine Department of Environmental Protection Rule Chapter 375 “No Adverse Environmental effect standard of the site location law” includes Section I(8) describing measurement procedures for wind energy facilities.

Based on the requirements stipulated, measurements are carried out at 4-5ft above ground, during the operation of the facility, with measurements of both statistical and energy average in 10-minute intervals. Nearby meteorological measurements are also required at 10 meter height above ground.

Measurements are to be obtained during times when the turbine noise is expected to be most noticeable – namely when the hub height wind speeds are sufficient to cause maximum noise output from the closest turbine, and the ground level (10m) wind speeds are below 6 miles per hour (3 m/s). Measurement points affected by extraneous noise sources that affect the ability to demonstrate compliance shall be excluded from all compliance report data.

No background correction is made on the measured data. Minimum required number of samples is also not stated.

Tonality is evaluated by analysing each 10 minute interval 1/3rd Octave Band level, and evaluating the difference between the measured level in a specific band and its surrounding contiguous bands.

3.2.6 Ontario Ministry of Environment and Climate Change wind turbine noise compliance protocol [17]

The Ontario Ministry of Environment and Climate Change (MOE) publication “Compliance Protocol for wind turbine noise” outlines a 4 step process that covers a complaint response protocol, as well as detailed post construction noise immission measurement protocols.

The noise limits in Ontario increase with wind speed from 40dBA at 6m/s to 51dBA at 11m/s wind speed measured at 10m height. The measurement protocol requires the measurement of sound is conducted at the residential dwelling bedroom window height (1.5/4.5m) in 1/3 Octave values and in 1 minute intervals. LAeq is measured for each interval. Meteorological measurements are also made simultaneously at 10m height, at the same location. The unattended measurements are filtered to include only night time levels between 10pm and 5am. Additionally, the data set is filtered to exclude precipitation and gusty periods.

Ambient noise levels are quantified by conducting measurements with the turbines in the vicinity parked, during the same measurement campaign. The protocol requires a minimum number of data points of 120 points with the turbines operating, and 60 with the turbines parked for each integer wind speed. The turbine contribution is calculated by logarithmically subtracting the mean LAeq from the ON/OFF measurements for each wind speed bin.

Tonality is assessed based on wind speed, and the average tonal audibility per ISO 1996-2 annex C.

3.2.7 International Energy Agency (IEA) Recommended Practices for Wind Turbine Testing – 10. Measurement of Noise Immission from Wind Turbines at Noise receptor locations [18]

This document was developed through a series of meetings with participants of the International Energy Agency ("IEA") Research and Development agreement. The members of the working group included experts from Denmark, USA, The Netherlands, Italy, Germany, UK, and Sweden. It was first published in 1997. The document is a guide that recommends measurement techniques and methods for characterisation of the noise immission from wind turbines. Although no jurisdictions explicitly mandate the use of these guidelines for measuring noise immissions, it is a well accepted document in this field and contains some of the most in-depth methodologies for measuring noise immissions. It includes 3 methods for measuring equivalent continuous A-weighted sound pressure levels (LA_{eq}) and one method for measuring A-weighted percentiles (LA_{xx}). Tonality is assessed based on FFT measurements, and a comparison between the tone level and the noise level in the surrounding masking band. Requirements are also provided for instrumentation requirements, calibration, preferred weather conditions, measurement locations, etc for the measurements.

The two main obstacles identified from the outset of the document are wind induced noise over the microphone, and ambient noise levels contaminating the measured levels. To address those issues, the document suggests using secondary wind screens or vertical reflecting boards ('small' ones for mounting on the dwelling wall, or 'large' ones for placing away from reflecting surfaces). Additionally, to address the noise contamination by ambient noise, the methods involve applying a correction to the overall levels based on measurements done to quantify the ambient noise level.

3.2.7.1 Equivalent continuous A-weighted sound levels (LA_{eq})

For the methods measuring equivalent continuous A-weighted sound levels (LA_{eq}) 3 methods include:

1. Measurement of noise level from turbine(s) alone
2. Measurement of combined noise level (turbine + background) at a target wind speed
3. Measurement of noise level from turbines(s) alone at a target wind speed

All the methods above are attended measurements. Method 1 and 3 measure the combined noise and background noise separately, and subtract the background levels from the combined levels to arrive at the noise levels from the turbines only. The background levels are determined by measurements taken when the turbines are parked. A third order regression curve is fitted to the background noise data, and the levels from the curve are used in the 'background-correction' of the levels measured with the turbines operational. If the background noise level is within 3dB of the combined noise level, the data point should be flagged and stated, and combined level is reduced by only 3dB, and reported as the upper limit of the turbine noise. In method 1, this is done for a variety of wind speeds. In Methods 3, it is done at a predetermined 'target wind speed'. The document suggests a target wind speed of 8m/s if regulations do not specify otherwise. In this case, the measurements are limited to wind speeds of ±2m/s of the target wind speed.

Method 2 measures the noise level with the turbines operational only. There is no correction due to background noise. The document notes that these measurements can be used to demonstrate that noise from turbine(s) is below a specified limit. It cannot, however, be used to demonstrate that the noise from the turbines is above a specified limit. This is because the contribution due to background noise is not quantified.

In all methods, averaging time is recommended between 1-10 minutes, with a minimum of 10 data points, and a minimum total measurement time of 30 minutes. In the cases with target wind speeds, a minimum of 10 data points are required on either side of the target wind speed

In method 3, once the data has been corrected, and the level at a specific wind speed is of interest to compare to the regulatory limit, a straight line is drawn through the measured levels (best fit) and the level at the target wind speed is compared against the regulatory noise limit in order to determine compliance.

In addition to these requirements, suggestions for techniques to employ for cases of low signal-to-noise ratio are presented, some with cautions about decreased precision and increased uncertainty. These suggestions include:

1 Change of time of day of measurements
2 Repositioning of microphone
3 Use of secondary windscreen
4 Measurement at reduced wind speeds*
5 Measurement at reduced distance*
*For these methods, corrections are later applied to the measurements to account for the higher signal measured

3.2.7.2 A-weighted percentiles (LA_{xx})

The main difference between this measurement procedure as compared to the continuous A-weighted sound level measurements is that unattended recording equipment may be implemented. The techniques described for the previous measurements still apply. The parameters are slightly different. LA_{10}, LA_{90} and LA_{95} are described as the most commonly measured percentiles. The method is recommended to be used in situations where the limit is expressed in percentiles and, in particular, when the limits are related to ambient sound measured previously (pre-construction) at the residential dwelling location.

Wind measurements can be measured either at hub height, or at 10m height. A minimum of 20 measurements of 10 minutes each is required during times when the wind speed is within ±2m/s of the target wind speed. There is also a requirement that there be at least 10 measurements on either side of the target wind speed.

If the measured percentiles are below the limits, then background noise measurements are not required. If they are above those limits, the same measurement parameters must be completed with the turbines parked.

3.2.7.3 Tonality

Narrowband spectrum measurements are described for both fixed-speed turbines and variable speed turbines. For fixed speed turbines, at least 5 measurements of 1-2 minute duration are required within ±1m/s of the target wind speed. The resolution depends on the frequency of the tone:

Table 1: Frequency resolution for FFT measurements of tone from turbine

Tone frequency [Hz]	FFT Resolution [Hz]
< 2000	2.0 – 5.0
> 2000	2.0 – 12.5

A more intensive analysis is suggested for non-stationary tones. In most cases, the above measurement method is deemed to be sufficient. Calculation methods for tone level and masking band level are provided and the tonality is described as the difference between the two.

3.2.7.4 Ambient survey

A good guide to assessing the ambient sound at a site pre-construction is included in Appendix 3 which includes recommendations on selection of which sites to measure, how to reduce the data, and how to arrive at a regression curve describing the background noise level.

3.3 Recommendations

From the many jurisdictions outlined above it is evident that there are many ways to measure sound immission from wind energy projects. Below is a breakdown of the advantages and disadvantages of various aspects:

Table 2: Comparison of measurement parameters

Parameter	Advantage	Disadvantage
Attended Measurements	Practitioner present to verify field conditions	Limits the total number of conditions that measurements can capture
Unattended measurements	Able to capture long term variations in noise levels, and isolate specific conditions of interest	Unable to claim perceptual confirmation (i.e. whether the measured tonal noise was from the turbine, or from the equipment at the nearby farm house)
1-minute measurements	Short Interval that can isolate a stable condition (e.g. for the entire measurement, the wind was blowing downwind, at a stable wind speed of 5m/s, and the turbine was generating >75% power)	There will need to be a large enough sampling of individual measurements before making conclusions confidently. This may make for large amounts of data
10-minute measurements	Measurements still relatively short (compared to 1 hour measurements), but long enough that short term variation in conditions don't greatly effect measured levels	Large variations can happen in 10 minutes, with a high chance of data contamination
Leq (Energy equivalent sound level)	Captures the acoustic energy within the measurement time frame. This value is the same as that predicted by the model	Leq is susceptible to contamination by transient events, wind gusts, etc.
L90 (10th percentile sound level)	Provides a stable parameter that is	Not directly comparable with the

	less affected by short term transient events, producing more repeatable measurements	pre-construction noise model, may be insensitive to constantly varying source (for example in cases of high amplitude modulation)
Lmax (Maximum instantaneous level occurring during an interval)	Provides the upper limit of measured sound	Because it is the upper limit occurring for any short instance, it is highly susceptible to falsification from transient events such as car passbys, wind gusts, etc
Tonality Octave Band	Simple implementation	Potential for false negatives
Tonality Narrowband	Gives a more accurate assessment on whether a tone is prominent and if a penalty is warranted	Complex implementation

It is this author's opinion that the most reliable combination of parameters are ones that isolate:

1. Wind speeds measured at point of immission
2. Sound levels measured simultaneously
3. Power output of the turbines logged for the same period
4. Measurements carried out at night only
5. Quantify background noise -- this is recommended to be carried out in the same measurement campaign that includes measurements with the turbines operating.
6. Data processed to remove data points measured during precipitation, and data points where the average power output of the turbines in the vicinity is below 75%
7. Evaluate the difference between turbine on/off to infer the contribution from the wind energy facility
8. If there is a suspected tone, assess tonality using objective methods that use narrowband analysis (as opposed to 1/3rd Octave band analysis)

4 References

1 ISO 9613-2:2007 "Acoustics – Description, measurement and assessment of environmental noise – Part 2: Determination of environmental noise levels", 2007

2 IMAGINE Final Report Summary – IMAGINE "Improved Methods for the Assessment of the Generic Impact of Noise in the Environment" Project reference 503549, Netherlands

3 "Nordic Environmental Noise Prediction Methods, Nord2000 Summary Report" DELTA Report AV 1719/01, May 2002

4 “Nord2000. Comprehensive Outdoor Sound Propagation Model. Part 1: Propagation in an Atmosphere without Significant Refraction.” DELTA Report AV 1849/00, March 2006

5 “Nord2000. Comprehensive Outdoor Sound Propagation Model. Part 2: Propagation in an Atmosphere with Refraction.” DELTA Report AV 1851/00, March 2006

6 “Proposal for Nordtest Method: Nord2000 – Prediction of Outdoor Sound Propagation” DELTA Report AV 1106/07, revised January 2014

7 “Noise Guidelines for Wind Farms. Interpretation for Applying MOE NPC Publications to Wind Power Generation Facilities” Ontario Ministry of Environment, October 2008

8 “Wind farms environmental noise guidelines” South Australia Environmental Protection Authority, July 2009

9 “A Good Practice Guide to the application of ETSU-R-97 for the assessment and rating of wind turbine noise”, Institute of Acoustics, UK May 2013

10 “Noise and energy optimization of wind farms. Validation of the Nord2000 propagation model for use on wind turbine noise”, DELTA Report AV 1236/09, October 2009

11 “IEC 61400-11 ed3.0 “Wind turbines - Part 11: Acoustic noise measurement techniques” International Electrotechnical Commission, December 2012

12 Acoustics- Wind farm noise, NZS 6808:2010, 2010.

13 Acoustics- Measurement, prediction and assessment of noise from wind turbine generators, AS 4959-2010, March 5, 2010.

14 “U Noise” Massachusetts Department of Environmental Protection 3.10 CMR 7.00 Air pollution control, Section 7.10

15 “Noise Pollution Policy Interpretation” http://www.mass.gov/eea/agencies/massdep/air/programs/noise-pollution-policy-interpretation.html

16 “Chapter 375: No Adverse environmental effect standard of the site location law” Maine Department of Environmental Protection

17 “Compliance protocol for wind turbine noise. Guideline for Acoustic Assessment and Measurement” Ontario Ministry of Environment, February 2014

18 S. Ljunggren, “Recommended Practices for Wind Turbine Testing – 10. Measurement of Noise Immission from Wind Turbines at Noise receptor locations,” Royal Institute of Technology, Stockholm, 1997