

ENVIRONMENTAL NOISE ASSESSMENT OF WIND FARMS

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ABSTRACT

Energy recovered from wind farms is becoming very popular in North America. However, the environmental impact of large wind farms is still under study and regulations are being fine-tuned to alleviate the impacts. Noise is perceived to be a major environmental concern of wind farms. The overall characteristics of wind farms and its noise potential will be discussed in this short review paper through a case study. Appropriate regulatory guidelines will be applied and the noise impact of wind farms are assessed and discussed in this paper.

RÉSUMÉ

L'énergie récupérée des centrales d'éoliennes devient de plus en plus populaire en Amérique du Nord. De plus, l'impact environnemental des grandes centrales d'éoliennes est sous étude et les réglementations vont être raffinées afin d'atténuer les impacts. Le bruit est la principale inquiétude environnementale concernant les centrales d'éoliennes. L'ensemble des caractéristiques des centrales d'éoliennes et leur bruit potentiel seront traités dans ce bref compte-rendu, et ce, par l'entremise d'une étude de cas. Des lignes directrices réglementaires appropriées seront appliquées et l'impact du bruit des centrales d'éoliennes sera évalué et traité dans le présent article.

1. INTRODUCTION

Recently there has been major emphasis, particularly in Ontario and Alberta, on developing facilities to generate electricity from wind energy. Wind power, in spite of its "green" energy source, can have significant impacts on neighbours of wind turbine installations. One of the major concerns is noise.

2. WIND TURBINE CHARACTERISTICS

The size and power generating capabilities of wind turbines vary widely from small units capable of several kilowatts (KW) to large commercial units capable of megawatts (MW). The small units are often mounted on a communications style tower. These wind powered generators can be quite noisy because of the high rotational speed. The propeller blades of smaller units are relatively short, one to several metres in diameter. Thus, to develop any amount of power, they must rotate at high speed. Another undesirable characteristic of small wind turbines is that they respond directly and quickly to both wind direction changes and wind speed changes/wind gusts. Thus, the sound generation can be highly variable, increasing the annoyance potential.

Commercial wind farms use large wind turbines, usually with capability of at least 1.5 MW per unit. The typical commercial wind turbine is supported on a cylindrical mast about 80 m tall and has three blades, each about 40 m long. These units are constant speed devices, with the ability to vary the pitch of the propeller blades to maintain a relatively

constant speed, regardless of wind speed. The angular speed of rotation is relatively slow, at about 14 rpm (as opposed to hundreds or thousands of rpm for small turbines).

The turbine gear head, controls and generator are located in a nacelle, about the size of a bus, at the top of the tower. Wind speed and direction are monitored by a computer control system that points the propeller head to the desired direction relative to the wind, with an active drive system. Mechanical noise generated by the various moving parts is minimal and of no concern at the distances to the receptors of concern (including at the base of the mast).

Usually a minimum wind speed of about 12 km/hr is required for a useful amount of power to be generated. About 75 km/hr is the maximum sustained wind speed, at which large wind turbines would usually be shut down.

Although the rotational speed of large units is slow, because of the length of the blades, the linear speed of the tips of the blades is relatively high, at about 125 m/sec (450 km/hr). Thus, some sound is generated by the movement of the blades through the air. However, the major sound generation appears to occur as a blade passes past the mast. This results in a broadband "swishing" sound. In any event, the large, modern, commercial wind turbines are relatively quiet and usually much quieter than the smaller, high speed devices.

3. CHARACTERIZING WIND TURBINE SOUND EMISSIONS

International Standard IEC 61400 11, Wind Turbine Generator Systems, Part II: Acoustic Noise Measurement Tech-

niques [1], provides a standardized method of measuring the sound emissions from wind turbines, for purposes of providing data for specifications and for noise assessments. This method is relatively sophisticated and complex. It provides the A weighted sound power level of a wind turbine, including variation with wind speed and directivity. The acoustic measurements include octave and third octave as well as narrow band spectra. The sound measurements are made with a microphone flush mounted in a hard reflecting board on the ground, relatively close to the wind turbine, to minimize the influence of terrain effects, wind noise at the microphone and atmospheric conditions. Simultaneous measurements of wind speed and direction must be made at a height of at least 10 m, within four diameters of the rotor and normalized to 10 m, regardless of the wind turbine hub height.

The end result is a set of data providing sound power levels as a function of wind speed. This data is the basis for assessing off site sound levels and the potential noise impact.

4. NOISE ASSESSMENT CRITERIA

Alberta and Ontario both have environmental noise criteria to which wind turbine installations must comply.

4.1 ALBERTA

All new, permanent, energy related facilities under the jurisdiction of the Alberta Energy Utilities Board (AEUB), such as compressor stations, electric power plants, pumping stations, etc., including wind turbine electricity generation facilities (wind farms), must take environmental noise impact into account in their design and prepare a Noise Impact Assessment (NIA). The same applies to modifications to an existing permanent installation where there is a reasonable expectation of continuous or intermittent sound emission.

The objective is to keep increases in environmental sound exposures to acceptable minimums and not adversely affect the quality of life at neighbouring properties, especially in rural areas. Indoor sound levels and sleep interference are identified concerns.

The requirements are contained in Noise Control Directive ID 99 08 [2]. The directive is receptor based and includes taking into account the ambient sound environment of the receptors. However, specific quantitative noise criteria are not provided in the Directive. Site specific consideration on a case by case basis is permissible, to determine what is considered to be a reasonable Permissible Sound Level (PSL) that should apply to the facility at the nearest or most impacted receptor (residence).

The Noise Control Directive is supported by a much longer guide document [3], that provides technical background, such as calculation of Leq, sound level at a distance, addressing tonal components, etc., a method of determining PSL, requirements for the NIA, as well as procedures for dealing with noise complaints.

The PSL is computed from the Basic Sound Level (BSL) plus adjustments for day versus night, seasonal operation,

tonal/impulse characteristics and ambient sound environment. The BSL at a receptor starts at 35 dBA and is adjusted upwards to account for location relative to roadways, presence of industry and density of development. The BSL nighttime values typically range from 40 to 56 dBA.

4.2 ONTARIO

Ontario Ministry of Environment (MOE) has established guidelines, specifying noise limits, applicable to industrial and commercial sound sources [4, 5]. A stationary source is the site of a facility as a whole, including all relevant sound (noise) sources, even if they can move around the site. A wind turbine or wind farm qualifies as a stationary source. In Ontario, under the Environmental Protection Act (EPA), most permanent processes, facilities, equipment, or things that can emit what are identified as contaminants into the natural environment, first require a Certificate of Approval (C of A). To obtain a C of A, it must be shown that the operation will comply with defined emission levels. Noise (and vibration) are defined as environmental contaminants. Unlike defined chemical substances for which there are regulations under the EPA, there are no regulations for noise (and vibration). In the case of noise, there must be compliance with the noise guideline criteria limits of References 4 and 5. Like in Alberta, the criteria limits apply at sensitive receptors and not at the property line of the facility.

Recently, MOE issued an adaptation of the noise guidelines, specifically for wind turbines. In the Ontario noise guidelines, three types of receptor environments are defined:

Class 1: Urban, where the ambient sound environment is determined by the activities of man, usually by road traffic and where Aurban hum@ is ever present.

Class 2: Where the daytime sound environment resembles that in Class 1 areas but where night, and possibly evening, are much quieter and are more like Class 3 (see below).

Class 3: Rural, where the ambient sound environment is dominated by the sounds of nature because there is little or no road traffic and no significant population or industry nearby.

The noise criteria specific to wind turbines in each type of area are shown in Figure 1. The requirement is that in any hour of operation, the sound levels at any sensitive receptors (in terms of one hour Leq in dBA) must not exceed the indicated limits or the one hour Leq ambient, primarily due to road traffic, whichever is greater. The numerical limits in Figures 1 are referred to as exclusion limits (sources do not need to be lower than the exclusion limits regardless of the ambient).

The noise guideline limits increase as a function of wind speed, recognizing that even in very quiet undeveloped (rural) areas, the ambient, background sound levels will be higher in the presence of wind, increasing with wind speed. The criteria are increasingly more stringent from Class 1 to

Class 3 areas; Class 3 being 5 dBA lower at night. Except for individual wind turbines in urban areas for demonstration purposes, commercial wind farms will use a significant number of turbines, and inherently would be located primarily in Class 3 areas. Even if in a largely undeveloped area, some receptors may be in a Class 2 area (and possibly a Class 1 area), if located near a major roadway such as a provincial highway or freeway, where the ambient due to road traffic is elevated for much of the time due to road traffic. The exclusion limits range from 40 dBA to 53 dBA, subject to the ambient environment applicable to each receptor.

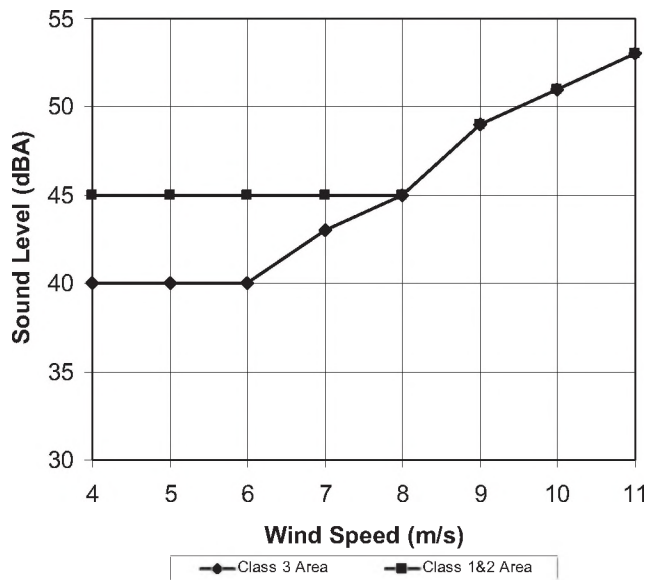


Figure 1. Ontario Wind Turbine Noise Criteria

5. ENVIRONMENTAL NOISE ASSESSMENT

A major commercial wind farm could consist of from about 80 to 120 wind turbines up to several hundred units. A small operation could be as few as a dozen turbines. The placement of turbines within a wind farm depends on a number of factors including exposure to wind, topography, distance from obstructions that could create wind shadows, presence of environmentally sensitive areas and habitat, suitability for construction of the foundations for each turbine, access and presence of neighbouring receptors of concern. To minimize interference of “stealing each others wind,” large wind turbines are typically spaced about 500 m from each other. Also, proper wind farms are planned so that the minimum distance from any receptor of concern to the closest wind turbine would be at least 400-500 m. As a result, a wind farm of 100+ turbines will require a very large area, possibly 40,000 to 50,000 acres. This can result in a situation of several hundred receptors that can, potentially, be within the noise influence area of a different group of wind turbines, even in a sparsely populated rural area. Each receptor must be analysed individually taking into account the distance, terrain, topographical elevations, atmospheric absorption and

screening.

Thus, assessing potential noise impact from a large wind farm is only practicable with the use of some sort of computerized acoustical modelling procedure. In the case of Ontario, the analysis must also be done over the range of wind speeds indicated in Figure 1. Also, in Ontario, the wind turbine noise guideline procedures specifically indicate that only wind turbines within 1000 m of any receptor need be included in the calculations. This can sometimes be an important factor in the analysis since an extra fraction of a decibel can result in the sound level for some receptors being marginally in excess of the limit and therefore, in the category of non compliance. Typically there is a great emphasis by the proponents/clients to be able to submit a “clean” proposal, where the noise levels from all turbines satisfy the noise criteria limit even if some potential excesses would be marginal and acoustically insignificant. For example, wind turbines at distances of 5-15 km would generate noise levels at a receptor that would be inaudible and hence, of no impact and of no concern. However, if enough sources each producing inconsequential sound levels are automatically included in the calculation, the resulting total can artificially exceed the regulatory limit. Table 1 shows an example from an actual wind farm noise assessment where 32 turbines are included; 22 of which are beyond 1000 m from the receptor. The result is non compliance, by one decibel, in the analysis for this receptor. When only noise sources within 1000 m are included (T101 – T110), compliance with the 40 dBA criterion is indicated, as seen in the subtotal in Table 2.

Wind turbines, responsible for legitimate excess over the sound level limit at any receptor, must be identified and either relocated or eliminated. This is the only practicable mitigation measure. Where excesses occur, it is usually not the case that a particular turbine, individually, exceeds the limit. The excess is usually due to the cumulative effect (energy summation) of a number of sources. Thus, the decisions as to how to resolve excesses are not necessarily simple or as straight forward as eliminating one offending source.

The algorithms with which the analysis of the propagation of sound from each source to receptor is done are normally based on International Standard ISO 9613 Part II. The computer model usually includes some form of digital terrain modelling to account for topography. If topographical mapping is available electronically, with the contours encoded in three dimensions (3 D), this aspect of the analysis is simplified, since the terrain model will automatically read in the topography. Otherwise, if this information must be handled and entered manually, the process can be very time consuming and tedious.

Figure 2 shows a sample result from the graphical output of a computerized, 3 D, acoustical model of a wind farm with over 120 wind turbines. The sources (wind turbines) are indicated with plus signs. The indicated sound levels are one hour Leq values, in dBA, giving the cumulative effect of all sources within 1000 m of each receptor, in this case. Also shown are sound level contours in one decibel increments. Topographical contours are also shown in the background.

Turbine	T101	T102	T103	T104	T105	T106	T107	T108	T109	T110
Sound Level, dBA	34.1	33.9	32.7	31.5	30.9	27.8	24.5	25.5	21.6	21.4
Sum, dBA	40 (Sum of T01 to T110)									
Turbine	T111	T112	T113	T114	T115	T116	T117	T118	T119	T120
Sound Level, dBA	19	18.9	18	16.7	16.6	15.4	15.2	14.8	14.7	13.9
Turbine	T121	T122	T123	T124	T125	T126	T127	T128	T129	T130
Sound Level, dBA	13.4	12.8	12.6	11.7	11.1	11	9.6	9.4	9.2	8.6
Turbine	T131	T132								
Sound Level, dBA	8.3	2.8								
TOTAL, dBA	41 (Sum of all 32 turbine noise level)									

Table 1. Examples of individual source contributions.

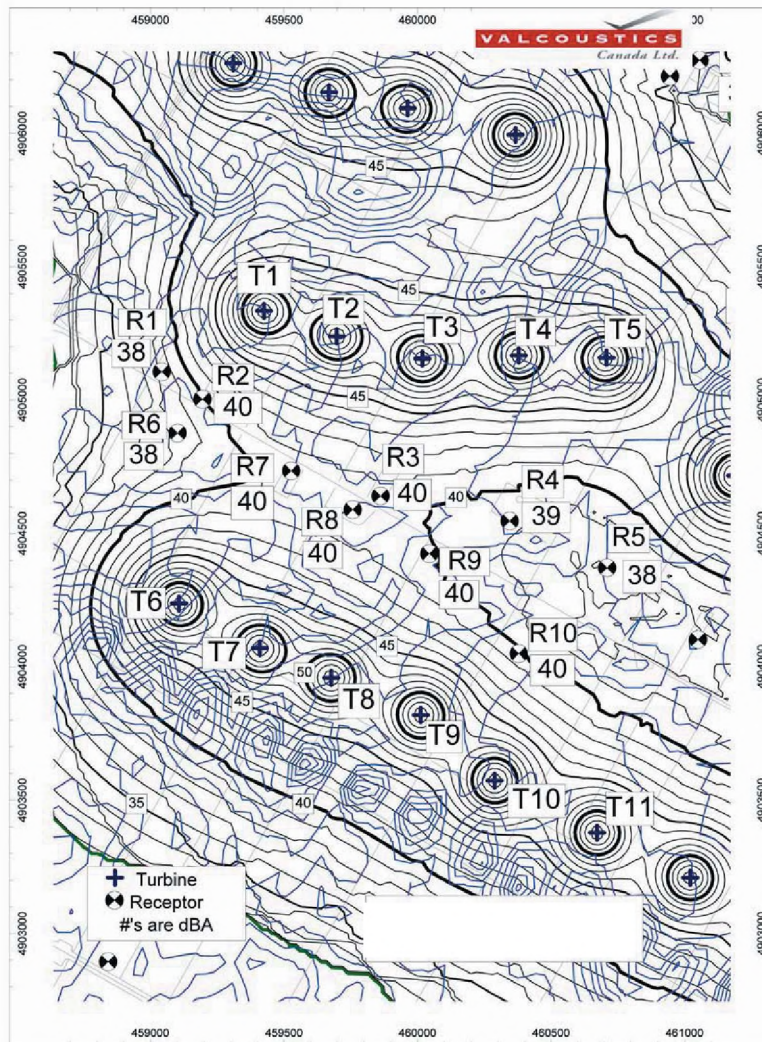


Figure 2. Results of Outdoor Noise Propagation Model.

Separate calculations should be done for daytime and nighttime, even if source and environmental conditions remain the same because the receptor heights for daytime are normally at first floor height or standing height above grade; receptor heights for nighttime are at upper storey bedroom windows - second or higher storey height. Also, individual analyses over the range of wind speeds is typically required.

6. CONCLUSIONS

Major wind farms for electricity generation use large wind turbines, usually located in quiet rural areas, with low ambient sound levels. Jurisdictions, such as Alberta and Ontario, have stringent noise restrictions, as low as 40 dBA at adjacent receptors. Modern, large, wind turbines are usually quiet. Thus, it is practicable to meet the applicable noise criteria, due to the large distances (at least 400-500 m) between wind turbines and between the receptors and the closest turbines. Turbines beyond 1000 m normally result in sound levels of no significance. Even very large wind farms can be designed for insignificant noise impact on neighbouring receptors, since only a small group of the total number of turbines will affect any individual receptor. Because of the complexity due to the large number of sources and receptors, complicated to-

pography, and various factors such as different wind speeds, the noise analyses are facilitated by modern, computerized, 3D, acoustical modelling techniques that address propagation of sound outdoors.

7. REFERENCES

1. "Wind Turbine Generator Systems, Part II: Acoustic Noise Measurement Techniques," IEC 61400 11, IEC International Standard.
2. "Noise Control Directive," Alberta Energy and Utilities Board, Interim Directive ID 99 08, November 1, 1999.
3. "Noise Control Directive User Guide," Alberta Energy and Utilities Board, Guide 38, November 1, 1999.
4. "Sound Level Limits for Stationary Sources in Class 1 and 2 Areas (URBAN)," Ontario Ministry of Environment, Publication NPC-205, October 1995.
5. "Sound Level Limits for Stationary Sources in Class 3 Areas (Rural)," Ontario Ministry of Environment, Publication NPC 232, October 1995.

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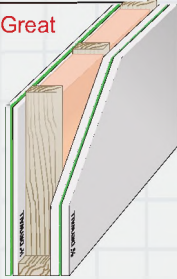
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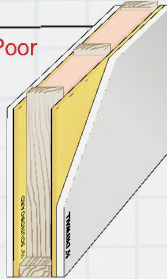
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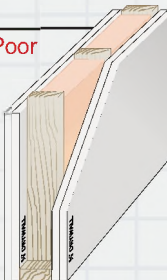
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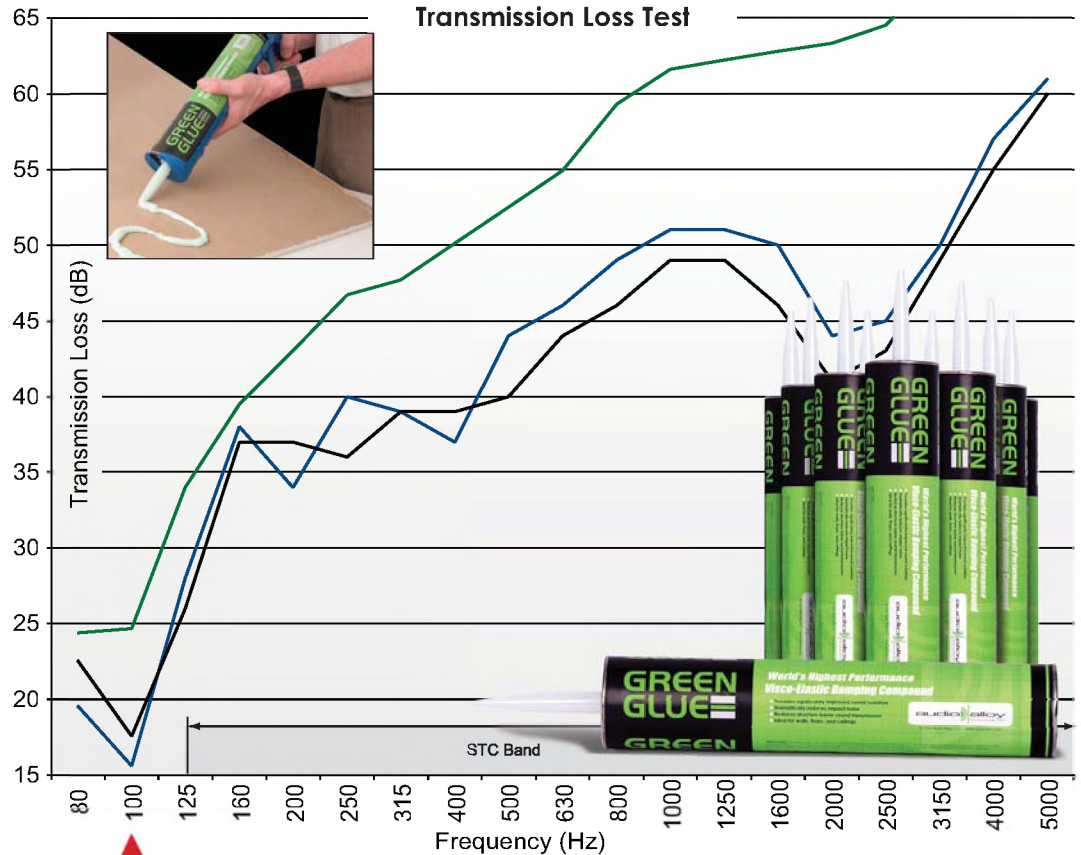
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