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Environmental noise due to large wind turbines: what we have learnt

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Abstract

Uruguay began to change its energy matrix some years ago. In that time, the preferred prediction method in the country in environmental impact studies of stationary noise sources was the ISO Standard 9613-2. The Environmental Engineering Department of the Faculty of Engineering (UdelaR) was asked to deeply study the environmental acoustic impacts from large wind turbines and to select an accurate prediction method to be used in the environmental studies to get the environmental license for new wind farms. Thus, we have begun to walk along a wide and complex way. The National Energy Directorate has supported these first studies. We have still a lot to learn but we feel we have technically grown along this 5-years' experience. We have studied about low frequency noise and its adverse human health consequences, the adverse consequences on birds and bats, the different siting criteria and security distances, the compatibility of wind energy devices with other uses of land, and we have focused on the generation and propagation of aerodynamic noise. We have tried some different approaches and finally we arrived to a satisfactory model to describe the main phenomena involved in noise generation: the incoming wind turbulence, the trailing edge noise related to the boundary layer release, and the blade passage ahead the tower. We have achieved accurate results for noise propagation considering geometric divergence and atmospheric absorption for distances greater than 300 m, the minimum security distance from the tower. We have found that the geometric divergence -or the atmospheric refraction of sound pressure waves - is neither squared nor linear, but it is frequency-related.

Keywords: wind turbines; environmental acoustics; environmental impact assessment

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1 Introduction

According to the 2010 Strategic Energy Development Plan for Uruguay, the diversifying of the energy matrix should be prioritized. Alternative and renewable energy sources rose to be exploited at a major scale. Currently, Uruguay has about 1000 MW of installed power lying on renewable energy sources. In this context, wind power generation has received particular attention, offering an authentic green energy as a reliable alternative to traditional sources.

As Uruguay is a small and very windy country, wind energy is now intended to be a "firm" energy. However, some ecologist groups make their voices heard: their complaints on the biological, landscape and noise changes that are induced by the presence and operation of wind farms. In addition, the National Land Planning Act (2008) and its put-in-practice Decree (2009) turned the management of Land Planning issues to the municipalities' concerns and responsibilities. But most of municipalities are technically weak and some environmental emerging problems –including those about noise- could be difficult for them to proper handle.

Although mechanical noises of wind turbines have been eliminated with the development of their design, aerodynamic noise generation during operation is inherent to them in nature. Their major acoustic emission is caused by the interaction between the wind and the blades. Most of the emission occurs in low frequencies. When the Environmental Engineering Department team began to work on these issues, the methodology of ISO Standard 9613:2 for predicting environmental sound pressure levels was the most accepted one. But when it was asked to deeper analyse it, a new research line was born.

2 Step by step

2.1 The ISO Standard 9613-2 prediction methodology

To predict noise levels in the environment associated with the operation of stationary sources -wind turbines included-, the methodology of ISO 9613-2 'Attenuation of sound during propagation outdoors- Part 2: General method of calculation' [1] is usually recommended. The fact that it is a standardized method is a strong endorsement; as it is the method that is imposed and validated for such calculations in the European Union through Directive 2002/49/CE, this endorsement is still stronger.

ISO 9613-2 is surely inspirited on the calculation method developed by Manning (1981) for CONCAWE, a group of oil companies, aiming towards the research on the conservation of water and air in Europe [2]. This method has been used as a basis for a several number of propagation methods for a variety of noise sources. This method calculates the sound pressure level at a remote point according to:

$$L_p = L_w + D - K \quad (1)$$

Each term considers:

L_p: sound pressure level in the short time for band i. (dB re20 μPa)

L_w: acoustic power level for band i. (dB re10-12 W)

D: Correction due to directivity of the source (dB).

K: Sum of the attenuation terms.

The ISO 9613-2 calculation expression is:

$$L_{pi} = L_{wi} + D - A_i \tag{2}$$

L_{pi}: sound pressure level in band i.

L_{wi}: acoustic power level for band i.

D: Correction due to directivity of the source.

A_i: Attenuation for band i, obtained according to equation 1.

Both calculation methods suppose noise point source (thus, quadratic divergence); this is not what it is measured in operating wind farms.

Also, both methods promote the application by frequency bands (not for sound pressure levels A-weighted values). Nevertheless, if it is not possible to work by bands, ISO 9613-2 will accept calculating in dBA using all formula and coefficients corresponding to the band centred at 500 Hz. This way of calculating will cause a great underestimation of immission sound pressure levels if the source emission has high acoustic energy in low frequencies.

CONCAWE's model use the meteorological categories proposed by Parkin and Scholes (not the currently preferred Pasquill-Gifford's ones); the possibility of neglecting differences between these categories is studied in one of the annexes of the Report. ISO 9613-2 does not consider calculating differences due to different meteorological conditions when the main calculation hypotheses are satisfied: wind speed between 1 m/s and 5 m/s at a height of 3 m and 11 m above the floor and averaged over a short period of time, moderate temperature inversion with the base at ground level. It must be said that these conditions are not always met when the source is a wind turbine (for typical heights, wind speeds of operation of wind turbines are usually from 4 m/s to 25 m/s at hub height).

2.2 Understanding the ISO Standard 9613-2 limitations

There are some limitations for the use of ISO 9613-2 to predict environmental sound pressure levels due to big wind turbines [3]. Some of them are the following:

- Hypotheses about wind speed and atmospheric stability are not always fulfilled.
- Atmospheric conditions (neutral, instability or under an inversion layer) have high incidence both on generation and on propagation of noise [4].
- At the distances of interest, a wind turbine cannot be supposed as a point source [5].

- The Standard supposes the distance from source to receiver to be between 100 m to 1000 m.
- Average height of source and receiver between 0 to 30 m (this is, maximum height of source is 60 m for a receiver of 0 m height).
- Source and receiver should be placed over a plane surface (a surface with a continuous slope; so, the method is not valid for complex terrain).
- If calculations are done in dBA, a great underestimation should be done in low frequencies phenomena.

Some experimental findings also refer to better results when not considering ground attenuation effects during propagation [6].

In the case of wind turbines, there are also from two earlier assumptions which are at the very beginning of the concept frame of environmental acoustics that not only are not fulfilled by they oppose to the physics'/fluid mechanics' phenomena involved in aerodynamic sound generation [7]:

- The hypothesis of perfect fluid, which is opposite to the main phenomena that are related to release of vortexes from a boundary layer; these phenomena only can occur if the air is considered as a viscous or real fluid.
- The hypothesis that acoustic processes are adiabatic, because they are very fast and they involve only very small amounts of energy. Most of vibration phenomena can be well-described as adiabatic ones, but it is not the case of wind turbine noise. Noise generation is related to turbulent phenomena that exchange energy with the propagation medium; they are not conservative phenomena, but diffusive ones.

These are thought to be the root causes that make both CONCAWE and ISO methods not appropriate to the prediction of environmental noise levels caused by wind turbines, as they cannot describe the main involved phenomena on a right way.

In recent years it has been verified that the differences between sound levels predicted by ISO 9613 Part 2 and those that do occur in the environment due to the operation of wind turbines are very significant: some authors have been recorded differences in the order of 15 dB above the calculated value (e.g. upon the occurrence of certain combination of environmental conditions, the method of calculation of the Standard may underestimate the expected environmental sound pressure levels) [4, 8, 9].

2.3 Considering atmospheric stability

The first big advance to improve noise prediction levels from big wind turbines appeared about 2003 [10]. It was related to the need of explicitly taking into account the atmospheric stability condition. Two different problems occur when there is a stable or thermal inversion atmospheric condition:

- The underestimation of the wind speed at the hub height, which would result in the underestimation of the emitted acoustic power level.

- The overestimation of the sound pressure level depletion, due to the low atmospheric turbulence and hence, low energy dissipation.

The relation between wind speed at 10 m and at hub height may consider the atmospheric stability [11]. If it is not known, the conversion form measured wind speed data (that are usually taken at 10 m over the ground level) to hub height ones, should be done by supposing a stable atmospheric profile (a logarithmic profile or a potential profile with exponent value 0,65, as proposed by [10]).

2.4 Obtaining the emitted acoustic power

The simplest way to obtain the emitted acoustic power is to use the manufacturer datasheet, where L_{WA} should be read as a function of the wind speed at 10 m. It is strongly recommended to take into account the abovementioned procedure in order to consider the worst case (thermal atmospheric inversion). Then, to convert the A-weighted L_W value to its band components, a reference spectrum should be used (e.g., see [12])

A less simple way to obtain the acoustic spectrum of the emission is to use a theoretical approach and a model that has been built considering the different noise generation processes: the incoming edge noise, the trailing edge noise and the blade passage noise.

For a typical three-blade wind turbine, the noise immission level in any down-wind site can be intended as the result of the contributions of these three phenomena all along each blade. According to this, a theoretical model has been built by our team; it is the so-called “MDT module” [13].

The incoming edge noise is caused by the fluctuation of pressure along the blade produced by the incoming turbulence. It can be described by combining the turbulence spectrum modelled by the approach of Von Karman and the aerodynamics theory. The trailing edge noise can be obtained by applying the turbulence spectrum from Von Karman to the boundary layer thickness, thus determining the pressure drop in the main vortexes.

MDT has shown an accurately reproduction of the measured spectrum at low and very low frequencies. Even if it slightly overestimates sound pressure levels in medium frequencies, it seems to be a good tool for simulating the generation and the propagation at a short distance from the wind turbine [13]. This is intended to be the best way to begin the medium and long distance propagation, in order to obtain the predicted sound pressure levels at distances of 500 m or more from the wind turbine.

2.5 Sound pressure levels at short- and long distances

According to Uruguayan Act, buildings are not allowed at 300 m or less from a wind turbine. Then, the prediction of environmental sound pressure levels would be needed for distances above 300 m. Distances up to 300 m should be considered as short ones; from 300 m and upper, they should be considered as long distances.

The abovementioned theoretical model shows good results at short distances. For long distances, a propagation module should be added to MDT.

The long-distance sound pressure levels prediction can then be done by direct application of the MDT module, or using the emitted acoustic power level from the manufacturer datasheet. This second way of calculation allows obtaining the sound pressure levels at a 100 m distance by third-octave bands; from this point, they should be propagated by only using the terms due to atmospheric absorption and divergence [8, 11].

To obtain the sound pressure level, L_{pA100m}, at a point 100 m far from the wind turbine tower and 1,20 m to 1,50 m over the ground level, the emitted acoustic power level is read as a function of the wind speed at the hub height (it could also be calculated by third-octave bands using the MDT module). Then, it is converted to a sound pressure level L_{pA100m} by the following linear adjustment (a previous adjustment proposal from our team [11] has been improved with more field data):

$$L_{pA} = 0,8462\ L_{wA} - 37,715 \qquad (3)$$

This expression allows getting a good approach not only for field data but also for other published data, as those from [10].

When $L_{pA,100m}$ is retrieved, the A-weighted sound pressure level will be turned to its composition in octave bands by applying the manufacturer datasheet, a given or a normalized spectrum [11, 12].

Each octave or third-octave band sound pressure level will then be propagated to a distance d and it will be also corrected by the atmospheric absorption term.

Coefficients of atmospheric absorption as a function of temperature and humidity should be obtained by applying the calculation method of ISO Standard 9613 – Part 1.

The divergence term can be calculated from the sound pressure level at 100 m. As it has been demonstrated that the main hypotheses of environmental acoustics are not complied by aerodynamic wind turbine noise, it is possible to suppose different values of "n" for different frequencies [11, 14]. In fact, as turbulent energy dissipation is different at different frequencies, it can explain the use a set of values of n = n (f):

$$Div = 10 * \log (d/100)^{n(fi)} \qquad (4)$$

n(fi) depends on the central frequency of each octave band. Table 1 presents the set of general values of n(f). These are also improved values referred to those from [11].

Table 1: General values for n(f)

Frequency [Hz]	**16**	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
n (f)	0.53	.69	0.97	1.48	2.08	2.10	2.19	1.77	1.28	0.40

Also, different sets of values can be obtained if classifying data by atmospheric stability, by wind speed, by temperature or by % humidity. The most accurate results are retrieved when the set of n-values is selected by atmospheric stability or by wind speed [15].

2.6 Background noise

It must be said that the calculated values are those due to the operation of the wind turbine, but it does not include the background noise. This point is especially important when distances are of 1000 m or more.

The minimum background noise is that of the wind [16]. The spectra for different wind speeds can be obtained either from processing field data or from wind-tunnel tests [17]. Only as an example, two sets of data for different wind speeds are presented in table 2. They were obtained for statistic processing of more than 2400 hours of measurements in rural flat terrain [18]. Extreme frequencies levels show great variability, so it was decided not to include them here.

Table 2: Spectra of wind noise (dBZ)

Frequency [Hz]	63	125	250	500	1000	2000	4000
u (m/s) ≈ 3 m/s	34	27	24	22	19	18	17
u (m/s) ≈ 5 m/s	50	43	36	32	25	23	19

3 Next research steps

The research project supported by the Uruguayan National Innovation and Research Agency by its energy research program ANII_FSE_10942 is close to finish. This prediction model is one of its main results and we think it is an important advance for our country.

Another research project is still in course, supported by the Scientific Research Committee of the University. So, our team will go on working to improve not only this methodology but also for improving the proposed values for n(f) and to get a greater wind speed spectra database. We are also preparing some studies at the IMFIA's wind-tunnel, for experimentally determining some value that were supposed on the MDT module, to have better estimations of them.

We expect then to arrive to a general prediction model for environmental sound pressure levels due to the operation of wind turbines either in flat and complex topography.

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