ENVIRONMENTAL NOISE FROM WIND FARMS: A PREDICTION PROPOSAL FOR FLAT AREAS

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Uruguay is a small country in South America. By the moment, it has the highest rate of wind energy as MW/inhab in the world. The fast and great development of wind farms has encouraged research on environmental acoustics' issues, especially those related to wind turbines operation. As it is well-known, the prediction methodology of ISO 9613-2 is usually recommended for every stationary noise source. In the case of wind turbines, it can incur on underestimations of more than 10 dB in certain conditions of atmospheric stability. Other methodologies of prediction have been developed but technical consensus about which to use is not reached yet. This paper attempts to present one proposal that has shown a good fit to field data from wind farms on flat areas. It is developed on three steps: the estimation of the acoustic power emitted by the machine, which should consider atmospheric stability conditions; the estimation of sound pressure levels at a short distance from the source; the propagation of sound pressure levels far away from the source. The research is on course, so results could still be improved and this proposal also could be turned into a better one.

1. Introduction

Uruguay is a small country in South America, with an area less than 180.000 km2 and about 3:400.000 inhabitants. It has about 3,1 GW energy generation installed capacity; half of it refers to hydro-power generation. The energy gross generation was about 10500 GWh on 2013 and the gross consumption was about 8400 GWh on the same year (about 3 MW/inhab/year).

As Uruguay has not petroleum, the country needs to buy it. A process of diversifying energy sources has begun some years ago. Renewable sources have been strongly promoted; there are 560 MW installed capacity of wind energy (feb.2015) and other 1.000 MW are in building. Energy consumption is rising with a high rate: about 10 % on 2011-2013 [1]. So, wind energy growth is expected as well.

According to the national Environmental Impact Assessment Decree, every project of energy generation with an installed capacity of 10 MW or more are asked for obtaining an environmental license previous to the beginning of its construction [2]. An Environmental Impact Study is needed and it should include a Noise Impact Study.

Even if limitations of ISO 9613:Part 2 to predict noise from wind turbines are well-known [3], it will remain in use in Uruguay until another technical proposal clearly reveals better results than it.

The research teams of the national public University (Universidad de la República) have a great challenge on helping to develop a better methodology about noise impact assessment from wind-farms, to cooperate with the country sustainable development process.

2. Noise from wind farms

Although mechanical noises of wind turbines have been eliminated with the development in their design, aerodynamic noise generation during operation is inherent to them in nature: it is caused by the interaction of the wind with the machine.

The main issue is about turbulence and releasing of vortexes from the surface and border of the blades. The interaction between wind, blades and tower has also an important role, especially about the beat that can be heard far away from the machine [4].

The highest acoustic emission occurs in low and very low frequencies. It does not be surprising, then, that noise regulations expressed in dBA can be complied at some hundreds of meters far from the turbine. On the other hand, annoyance usually persists and can also affect people living even at greater distances [5].

The European Environmental Noise Directive 2002/49/CE recommends the application of the ISO Standard 9613:2 to predict noise levels from stationary sources when there is not an official national calculation method [6]. However, this Standard was not developed to be applied to wind turbines; so, under some conditions, its predictions may significantly underestimate the expected environmental noise levels.

It is currently accepted that the end of the application of ISO 9613:2 to wind turbines noise prediction is due to G. Van den Berg. His doctorate research included an intense field study; he has demonstrated the incidence of atmospheric stability conditions on noise propagation and thus, on predicted noise levels [4, 7].

Some of the main limitations of the methodology of ISO 9613:2 are discussed on next section.

3. Some limitations of usual methods for wind farms noise prediction

When a calculation approach is needed to estimate environmental noise levels from stationary sources, there is no doubt about applying the ISO Standard 9613:2: it is not only a standard method of calculation but the recommended one by the European Union [6].

This is a strong argument at some developing countries; the need of refusing it and developing another more reliable method for the case of wind farms is not easy to demonstrate to decision makers.

3.1 The origin of the calculation method

First of all, it is important to remember that the ISO 9613:2 prediction method is based on that developed by the CONCAWE (Conservation of Clean Air and Water in Europe, an organization of European oil enter-prises that promotes environmental research since 1963). It was a semi-empiric approach developed in the early ’80s to assess noise impacts from petroleum and petrochemical complexes to neighbor communities [8].

CONCAWE postulates that noise levels decrease according to a spherical divergence law to whom some empirically adjusted corrections are added. As spherical divergence is assumed, noise source is assumed to be well-described as a point source.

Correction terms include:

- Atmospheric absorption
- Ground effects

- Meteorological effects
- Barrier effects
- Source height effects
- Miscellaneous effects.

The method has some restrictions: the ground effects' corrections are for distances between 100 m and 2000 m; the height of sources is from 10 m to 20 m and the receiver is 1,20 m over the ground surface.

The meteorological corrections are not expressed in terms of Pasquill-Gifford stability classes but in terms of another set of six classes that are defined by the wind speed and the atmospheric gradient of temperature.

Once the general model is developed, CONCAWE analyzes some possible simplifications. As the meteorological corrections seemed to have a small influence on the results for the distances and heights for which the model was developed, it was one of the recommended simplifications to the original model.

3.2 The ISO 9613:2 approach

In the same way of CONCAWE method, the ISO approach also considers noise point source – that is, spherical divergence- and a set of correction terms. In this case, no meteorological correction is mentioned [9].

The main limitations of this approach could be the following ones [10, 11]:

- The hypothesis of point source or spherical divergence.
- Atmospheric conditions (neutral, instability or under an inversion layer).
- Wind speed from 1 m/s to 5 m/s measured at a height from 3 m to 11 m over the ground level.
- Source and receiver over a plane surface (a surface with a continuous slope; not valid for complex terrain).
- 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).
- Distances from source to receiver between 100 m to 1000 m.

3.3 The root causes of the method limitations

When the ISO prediction method is applied to wind turbines noise, all of the abovementioned elements have a limiting role on the estimated noise levels.

But the most important restrictions come from two earlier assumptions which are at the very beginning of the concept frame of environmental acoustics [12]:

- 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 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 involved phenomena on a right way.

4. Another prediction approach: a proposal for flat areas

Once the main hypotheses have been refused, modifying the basic equation of the ISO prediction model is now allowed. This proposal has been developed for prediction studies, that is, for noise impact assessments before the construction of a wind farm [10].

The main calculation process for estimating the sound pressure level at a distance d from a wind turbine is presented on Fig.1.

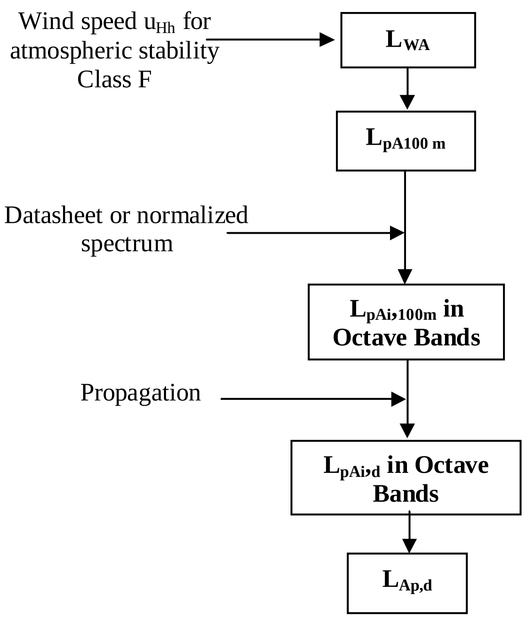

Figure 1. General calculation scheme

There are three main issues to consider:

- Take into account the atmospheric stability to estimate the wind turbine's acoustic power level.
- Reduce the set of correction terms.
- Modify the propagation or divergence law.

4.1 Estimation of the wind turbine's acoustic power level

One of the more important issues on underestimation of environmental noise levels is the underestimation of the acoustic power level.

To avoid underestimation, the wind speed at the hub height should be obtained assuming Class F of atmospheric stability to convert the wind speed at a given height "h" to the wind speed at H_h.

Then, the wind speed at a height of 10 m should be obtained downloading u_{Hh} to u_{10m} as if the atmosphere was neutral (Class D).

L_{WA} is then read from the manufacturer datasheet as a function of u_{10m}.

The calculation sequence is schematized in Fig.2.

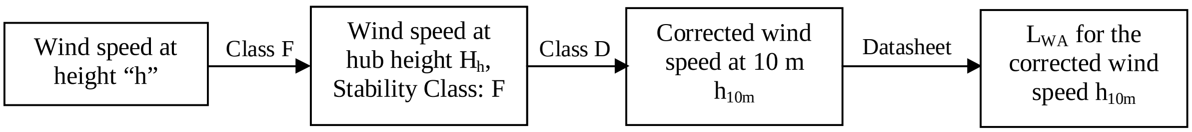

Figure 2. Calculation of L_{WA}

4.2 Correction terms

The set of correction terms from the ISO 9613:2 is reduced in this proposal. Taking into account some comparisons between measured and calculated values [10, 11, 13], only the atmospheric absorption correction is considered in this proposal.

Coefficients of atmospheric absorption as a function of temperature and humidity should be taken from reliable data, as those in ISO 9613:1.

4.3 Propagation or divergence law

4.3.1 From L_{WA} of the source to L_{pA} 100 m far from it

The propagation of noise is calculated in two steps. The first of them is the weakest point of this proposal; it refers to the conversion of the L_{WA} to a sound pressure level, $L_{pA100\ m}$, at a point 100 m far from the wind turbine tower and 1,20 m to 1,50 m over the ground level.

To find the value of $L_{pA100\ m}$, a simple linear adjustment is done, with basis on measured data:

(1) $$L_{pA} = 0,75\ L_{wA} - 25,6$$

Even though it is only a numerical adjustment, its results are very close of that from the experimental adjustment of Van den Berg (2003). He has found a difference of 58 dBA between L_{WA} and L_{pA} 400 m away from the wind turbine tower. If a linear decay is assumed, the expected differences will be 55 dBA at 200 m and 52 dBA at a 100 m distance, which is very close to that obtained with our proposal.

4.3.2 L_{pA} beyond 100 m

When $L_{pA,100\ m}$ 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.

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

The divergence term is calculated from the sound pressure level at 100 m. It can be obtained as:

(2) $$Div = 10 * \log (d/100)^{ni}$$

n_i depends on the central frequency of each octave band. The proposed values for n_i are presented on Table 1.

It should be said that using $n_i = n_i(f_i)$ is possible because it has been demonstrated that the first hypotheses of environmental acoustics are not complied by wind turbine noise. Then, the meaning of n_i is not strictly linked to a propagation surface or a geometric decreasing law.

Also, values of n_i are lower at the extreme frequencies, as it was expected to occur on low and very low frequencies. Values of 1,0 or more occur between 250 Hz and 4000 Hz; the highest n_i found value was 1,7.

Table 1. Proposed values for the exponents n_i

Frequency (Hz)	16	31,5	63	125	250	500	1000	2000	4000	8000
n	0,2	0,4	0,5	0,7	1,5	1,7	1,7	1,3	1,0	0,2

This second part of the calculation sequence is schematized in Fig.3.

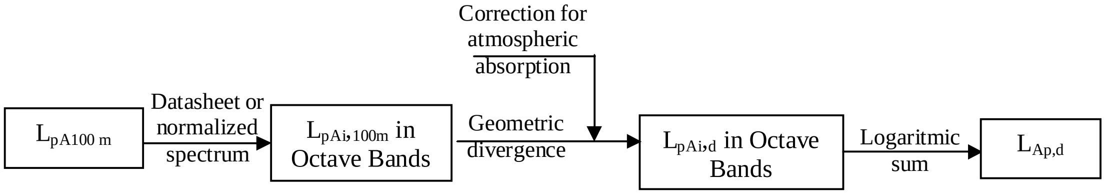

Figure 3. Calculation of $L_{Ap,d}$

5. Conclusions

This proposal has shown to be a good approach for prediction of environmental sound pressure levels associated with the operation of a flat topography wind farm.

Its weakest point is the conversion from L_{WA} of the source to $L_{pA,100m}$ from it.

Even if the three issues cooperate to improve the predictions given by the ISO 9613:2, the most important one is the change in the estimation of L_{WA}.

A better comprehension of the turbulence generation and vortexes propagation will help to improve the selection of the exponents n_i

The research team is going on improving this proposal, emphasizing on the propagation steps. Then, it will attempt in the close future to study the adaption of this methodology for wind farms at complex topography.

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