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Long term measurements: a way to minimize uncertainties on acoustic impact control of wind farms

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Abstract

In this presentation we will first quickly present the state of the art in acoustic impact control of wind farms in France. The current guidelines or normative (e.g. AFNOR PRs 31-114 in project) are based on the principle of scattered diagram of noise level versus wind velocity, as in IEC 61400-11 (Wind turbine generator systems – Part 11: Acoustic noise measurement). The noise indicator used for impact control in France is the result of a statistic analysis of the measured samples (usually the median value).

Regarding this methodology, the main input parameters data are: wind velocity data, noise level data, power production of the machines, meteorological conditions (e.g. wind directions, temperature gradient), ground impedance and other environmental data which may have an impact on noise.

The goal of this paper is to present a sensitivity analysis of this “French method”: we will study the variations (uncertainty) in the output of this method when a variation (uncertainty) is applied on the input parameters.

In our case the sensitivity analysis we will be done for one of the most influent input parameters: the wind velocity at hub height. In fact this parameter is one of the most difficult to measure (it’s almost impossible when turbine is running), and is by nature very fluctuant (not stable). IEC 61400-11 also focuses on this parameter which may induce the most important uncertainties on the apparent sound power level (cf. Annex D - Table D.1 of the norm).

This sensitivity analysis will be presented on a specific example of impact control measurements. For a given uncertainty on wind velocity data (including metrological uncertainties) and also on noise data (only metrological uncertainties) we will present the calculation of the resulting uncertainty on the “French noise indicator”.

Finally, we will show how those uncertainties can be reduced by increasing the number of samples (i.e. the number of measurement days) using long term measurements (noise monitoring).

Introduction

To obtain a building permit for a wind farm in France, according to the neighbourhood noise regulations stated in the « Décret 2006-1099 du 31 août 2006 », an acoustic study is needed. Such regulations require measurements compliant with actual French standard NFS 30-010 (the AFNOR project Prs 31-114 is going to set new standards for future noise measurements).

The current regulations set noise limits related to the background noise level, to be fulfilled in term of “emergence”, defined as the difference between ambient noise and background noise. These limits are shown in picture 1 here below.

FRENCH NEIGHBORHOOD NOISE REGULATION 2006	Max increase level / background noise	
	Night 10pm-7am	Day 7am-10pm
OUTSIDE Ambient level > 30dB(A)	+3 dB(A)	+5 dB(A)
INSIDE (windows open or close) Ambient level > 25dB(A)	+7 dBlin 125Hz-250Hz	
	+5 dBlin 500Hz-4KHz	

***Picture 1**: current neighbourhood noise limits in France*

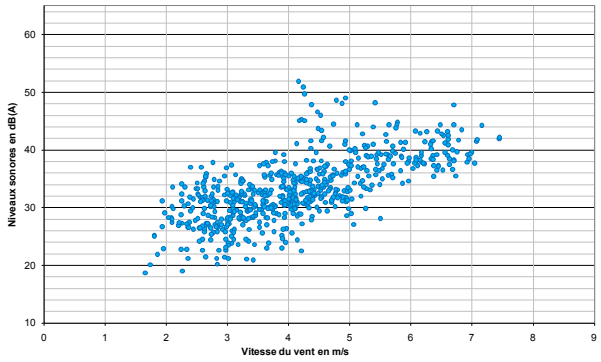
The criteria has to be fulfilled for the dB(A) value of the “emergence”, as well as for the octave band values, the latter measured inside habitations.

The state of the art for the analysis to state on the “emergence” values is given in the next chapter.

State of the art

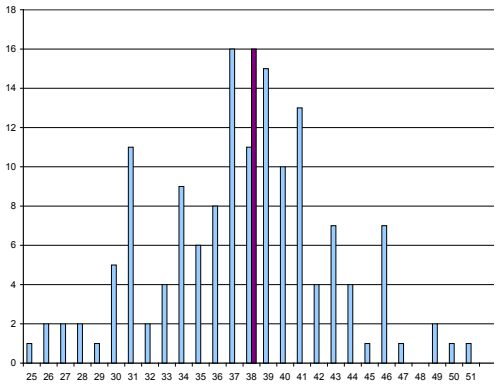
The main difficulty to face in order to perform such analysis is the variability of the input values, due to the meteorological effects, to long distance noise propagation effects and to the variations on the wind turbines noise power levels.

The general methodology currently used for the “emergence” analysis” is based on the correlation between the wind speed and the noise values, by means of a statistical approach through scatter diagrams. This analysis is done for the major wind directions on site.



***Picture 2**: Example of a typical scatter diagram for background noise.*

The noise indicator finally used for impact control is the result of the statistic analysis of the measured samples (usually the median value), as shown in the following picture.



***Picture 3**: Example of statistic analysis and median calculation of the noise samples*

This analysis is done for each wind speed class, and for some homogeneous conditions based on specific periods (day or night), wind direction (headwind, crosswind, downwind) and, if necessary, on specific environmental noises.

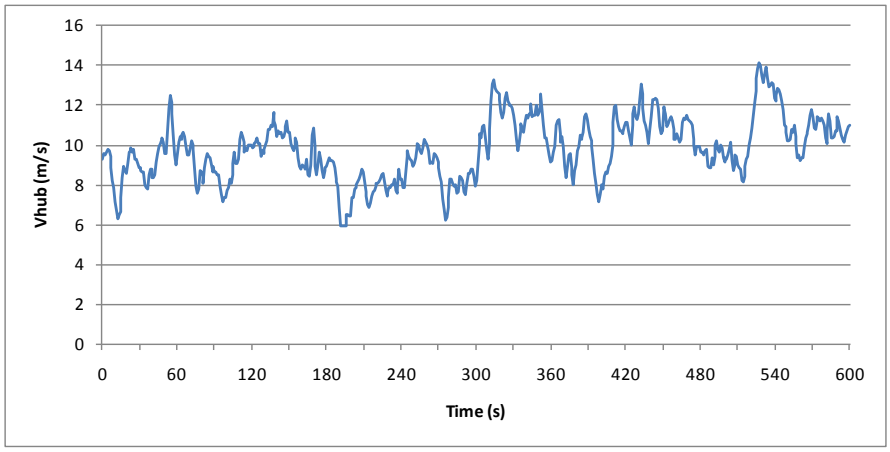
In the end, the output is a risk indicator, based on a large number of data (usually 5-7 days of continuous measurements), and is more representative than a simple analysis based on spot measurements.

Anyway, this indicator has revealed to be sensitive to several parameters, which are listed in the following chapter.

Main influent parameters

The most influent input parameter influencing the risk indicator is the wind velocity at hub height, which is the most difficult to be measured effectively.

Furthermore this parameter is very unstable, due also to the effect of the turbine blades movement.



***Picture 4**: illustration of the variation of a measured 1s wind speed at hub height, during 10 mn recording*

Even the IEC 61400-11 norm focuses on this parameter, which may induce the most important uncertainties on the apparent wind turbine sound power level (cf. Annex D - Table D.1 of the norm).

The wind uncertainty affects thus the noise measurements uncertainty and the "emergence" uncertainty as well, which can be sometimes too high if related to the limit value of 3 dB(A).

In order to better clarify this issue, a sensitivity analysis has been carried out to find out a way to ensure a lower uncertainty on the results of the acoustic impact study.

Methodology

The Monte Carlo method

Monte Carlo methods are a class of computational algorithms that rely on repeated random sampling to compute their results. They are often used in simulating physical and mathematical systems.

Because of their reliance on repeated computation of random or pseudo-random numbers, these methods are most suited to calculation by a computer and tend to be used when it is unfeasible or impossible to compute an exact result with a deterministic algorithm.

Given a series of input parameters X_i, they can be represented by a density probability function $p_x(x_i)$ (x_i are the possible values for X_i). The best assessment for the X_i value is noted as $E(X_i)$ and the associated uncertainty is $u(x_i) = \sigma(X_i)$.

The purpose of the application is to estimate the uncertainty associated to the output variables $u(Y)$ simulating M times the input parameters X).

The random variables x_{ik} are simulated based on the density probability function $p_x(x_i)$, in order to generate "real samples" of Y variables for each shooting k, by means fo the following equation:

$y_k = f(x_{1k}, x_{2k} \ldots x_{nk})$, for $n = 1 \ldots M$

Here is the pattern to follow for the application of this approach:

- Define, inside the system to be studied, the input variables X_i influencing the uncertainty of the variables Y.
- Define the density probability function g_{Xi}, related to the above X_i variables.
- Define the number of shootings for the application of the method.
- Simulate M series of random numbers $(x_{i1}, x_{i2}, x_{i3} \ldots x_{ik} \ldots x_{iM})$ for each one of the selected input variables, where $I = 1, \ldots N$.
- Calculate the M samples for Y using the equation $yk = f(x_{1k}, x_{2k} \ldots x_{Nk})$, where $k = 1 \ldots M$.

The uncertainty $u(Y)$ equates the standard deviation of the sample.

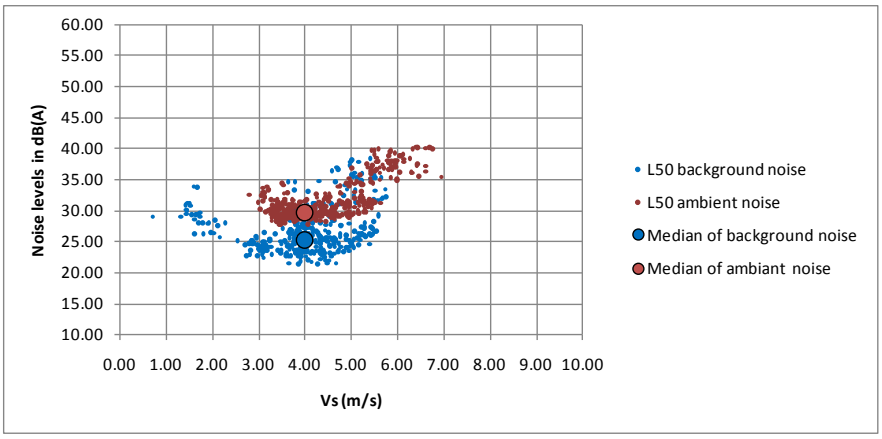
$$u(Y) = \sqrt{\frac{\sum_{k=1}^{M} y_k^2 - \frac{1}{M}(\sum_{k=1}^{M} y_k)^2}{M-1}}$$

Application on a given measurement sample

For the purposes of this study, the Monte Carlo method has been applied to a given sample of long term measurement data.

The input variables X_i are selected in a sample of long term ambient and background noise measurements for a given wind speed and for headwind - crosswind conditions.

The graph here below shows the scatter diagram of the collected data (background noise over wind speed) at about 700 meters of a wind farm with 5 machines. This diagram points out an “emergence” of 4.3 dB(A) at 4 m/s.



***Picture 5**: Scatter diagram of noise measurements over 30 days period, for a 23pm-5am period, and crosswind-headwind conditions.*

The background and ambient noise values are the statistical indicators L_{50} calculated over 5 minutes recording periods.

The wind speed (v_{hub}) has been measured at the hub height (H_{hub}) with a 5 minutes sampling and converted to the standard wind speed (v_s at 10 m height), parameter to be used for the noise impact control.

$$v_s = \frac{\ln\left(10/0{,}05\right)}{\ln\left(H_{hub}/0{,}05\right)} * v_{hub}$$

In the sensitivity analysis we first set the wind speed standard deviation and the noise level standard deviation to fixed values. In this paper we will make the simplistic assumption that the standard deviations are:

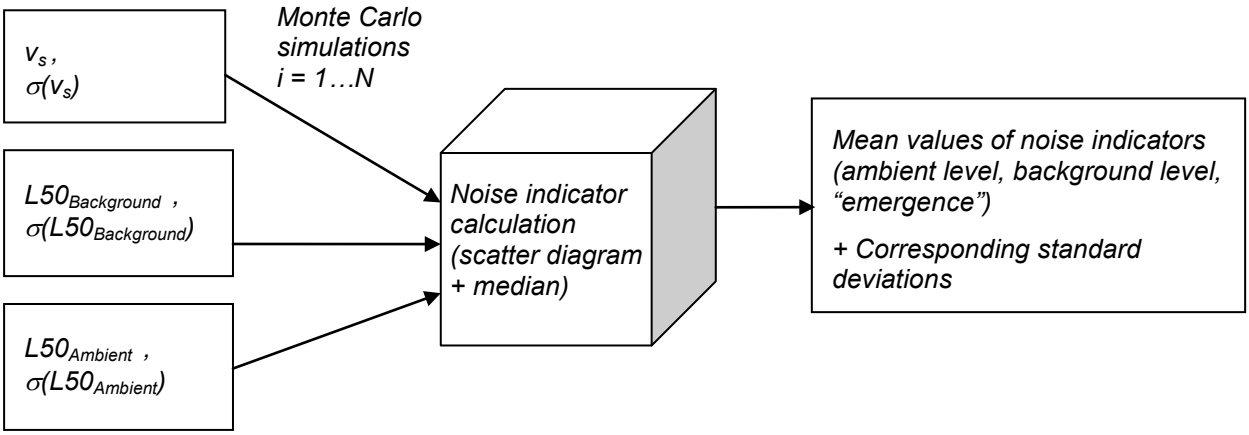
- $\sigma(v_s) = 0.5$ *m/s*
- $\sigma(L50_{Background}) = 1$ *dB(A)*
- $\sigma(L50_{Ambiant}) = 1$ *dB(A)*

Then, we will calculate the resultant standard deviation on the “French noise indicator”, using the Monte Carlo method.

For each sample length from 10 up to 200, the Monte Carlo method has been applied to the standard deviations of the wind speed, the background noise level and the ambient noise level, in order to calculate the standard deviation on the output indicators.

The application of the Monte Carlo method is then basically:

- The selection of the values to be considered as input, based on the chosen sample length, for the purpose of this study, the selection is made for a given wind speed (4 m/s) and for headwind-crosswind conditions.
- The application of the probability function on these samples, with M iterations.
- The calculation of noise indicators (ambient level, background level, “emergence”) for each iteration.
- The calculation of the mean values and of the standard deviation of these indicators.



***Picture 6**: Principle of the Monte Carlo simulations*

Limits of the application

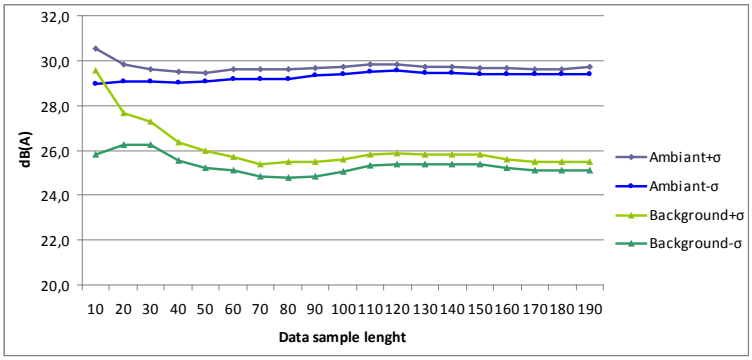
The limits of this application reside basically in the fact that the results cannot be exactly applied on other measurement samples: in fact, the uncertainties are valid only for the sample data considered in this study. Any extrapolation to another period or campaign is not possible: in this case, the only solution would be to apply again the whole Monte Carlo method.

Anyway, the purpose of the study is not to define the uncertainty for the “emergence”, but to identify a trend for this parameter, trend which can be considered valid for any measurement sample.

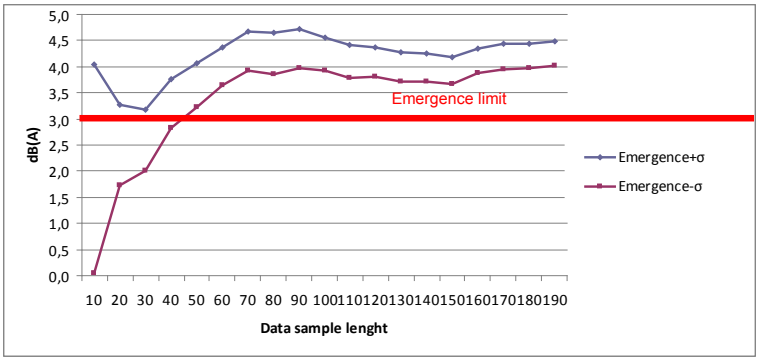
Results

The following graphs show the results obtained with the application of the Monte Carlo method on the given sample. The first graph shows the upper and lower values

calculated for the background and ambient noise, while the second one shows the upper and lower values calculated for the “emergence”.



***Picture 7**: Influence of the number of samples on the standard deviation of the ambient and background noise indicator (at 4 m/s, night period).*



***Picture 8**: Influence of the number of samples on the standard deviation of the “emergence” indicator (at 4 m/s, night period).*

The analysis of the given graphs allows the identification of a general trend for the standard deviation. By growing the available measurement samples, we can obtain lower values of the standard deviation, meaning more precise values of the “emergence”.

Furthermore, we can observe that for shorter samples the standard deviation for the “emergence” can be close (or even higher) to the limit value of 3 dB(A), situation which could jeopardize the whole impact study.

In this example, we can see that a good estimation of the “emergence” is obtained with more than 70 or 80 samples, which means a total duration of about 6-7 hours of background noise and about 6-7 hours of ambient noise (always at 4 m/s on night period).

It also means that a minimum of 10 days measurements is necessary, if we are searching for such a good estimation of the “emergence” for 5 wind conditions (ex: from 3 m/s to 7 m/s). If we also take in consideration that the wind usually doesn’t blow every night in the same directions, it may be necessary to get **a minimum of 20 days measurements**, which would be a better approximation of a “good” duration.

Conclusions: « Long measurements = Low risk »

The quality of an acoustic impact control depends on the quality of the measurements and also on the duration those measurements. The sensitivity analysis developed in this paper shows that longer measurements may improve the quality of the “emergence” estimation, with a lower sensitivity to uncertainties.

This study shows that, in some cases, the typical duration of 5-7 days measurements is not long enough, and a quite better estimation can be achieve with longer measurements: like 10 to 20 days.

Improving the duration is thus a way to reduce the risk of imprecise results.

References

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