Detection of Wind Turbine Noise in Immission Measurements

Benoît Fauville, Francis Moiny
General Physics Unit, Faculty of Engineering, University of Mons, Mons, Belgium.

Summary
For many years wind farms are accused to be sources of annoyance due to the noise emitted when wind turbines rotate. After its propagation over several hundred meters, the noise is more or less stationary but can feature an amplitude modulation that can be especially annoying for the human hearing. To control noise levels at immission according to the local noise regulation or to realize scientific studies, wind turbine noise has to be measured. A lot of care in the choice of the measurement place is necessary to obtain relevant recordings. Besides a data processing is needed to avoid the periods with a dominant background noise (i.e. all noises without those coming from wind turbines): during strong wind, moments with important transportation noises or even animal and neighborhood sounds. Attempts to detect the wind turbine noise by means of criteria are presented. They are based on the evolution of the total sound pressure, on 1/3-octave band spectra and on audio samples by the use of periodograms.

PACS no. 43.50.Rq, 43.60.Cg

1. Introduction

Unwanted sounds i.e. noises have an impact on the people's life quality and health. A recent report from the European Environment Agency [1] highlights this wide problem and puts numbers on the health consequences. The consequences are diversified and depend on many factors like the sound pressure level at the receiver, its own perception and its sound sensitivity. A specific consequence is the annoyance due to the noise source. Measurement of this annoyance and its dependences are largely studied (see the review [2] for a global vision on the subject).
Wind Turbines (WTs) are sources of noises. Major sources are the trailing edge noise and the inflow turbulence noise [3]. The WT noise, at several hundred meters of the wind farm, features a broadband spectrum with a possible amplitude modulation that can be heard by people living on the neighborhood. Impacts on their quality of life are real and touch their health by sleep disturbances, annoyances, etc. [4, 5].
Our University is located in Wallonia, southern Belgium, where WTs are source of considerable discussions and has become a societal problem since, among other things, a weak regional legislation has been adopted (see introduction of the Walloon decree of 13 February 2014 [6]).
These reasons explain why we are studying the WT noise at immission and its measurement. Analyses were previously performed following a first campaign of measurement conducted in the small village of Tourpes [7]. This paper is in the direct continuity of that work.

2. Immission measurements

Measurements were carried out in the garden of a citizen living in Tourpes at 1 km from the nearest WT of a wind farm which contains 11 WTs of 2 MW with a hub height of 98 m. The map in Figure 1 shows the measurement place (red star 0) and the WTs (circles 1 to 11). The nearest WT is the no. 3.
During three weeks spreading from February to March 2014, a sound level meter class 1 Nor140 from Norsonic and a weather station MetPak Pro from Gill Instruments recorded respectively equivalent sound pressure levels, statistical levels, 1/3-octave band spectra, audio signals and wind speeds, temperature, humidity, air pressure.
The sound level meter was placed at 1.5 m high with its outdoor kit and a 90 mm windscreen. It was supplied by a battery changed each week in the same time as its memory card. The calibration was checked before and after the recordings. The deviation was smaller than 0.5 dB. The weather station was placed at 2 m high and supplied by the

same battery. Both devices were located far enough from the house and from trees or other plants with leaves to avoid a too high vegetation noise induced by wind.

Figure 1. Map of measurement location and WTs

There is no hill or valley between the measurement place and the wind farm (direct view). The village has a low car flow but a highway is present 4 km in the south-west and can be sometimes heard. A railroad lies between the WTs and the village (see the straight line Figure 1 just below the number 0) causing regular passages of trains.

3. Data analysis

The integration times for equipment were 2 s for the weather station and 0.5 s for the sound level meter. Besides audio recordings were taken with a 12 kHz sample frequency and coded on 8 bits. So the quantity of data collected during these 3 weeks is important. However many periods of time were characterized by high levels of background noises or moments with no clear WT noise due to low winds. Data analysis enables to put a great part of the non-relevant measures to one side but has to be made with care.

Note that analyses are performed with a time period $T = 10$ minutes on acoustic parameters with an A-weighting. This last choice is not linked to the way annoyance can be felt by people but simply to make analyses easier.

3.1. First selections

The wind speed can be a first criterion. If the wind is too strong, the “wind-equipment noise” (noises generated by the interaction of wind turbulences and microphone) becomes dominant despite the presence of a windscreen. If the wind speed is not too high a global correction can be applied, depending on the windscreen [8]. When it is too high ($\gtrsim$ 5 m/s measured at the weather station), the period is forgotten.

1 km away from the source, the WT noise is more or less stationary with a great part of its acoustic energy in the low and medium frequencies (atmospheric absorption acting preferentially on high frequencies) for an equivalent sound pressure level $L_{Aeq,T}$ that will never be higher than 55 dB(A). Thus three simple and automatic criteria have been defined:

- the difference between the equivalent level and the 90th percentile $L_{Aeq,T} - L_{A90,T} < 3$ dB(A);
- the levels in the 1/3-octave bands must have small contributions (< 30 dB(A)), which could be a sign of birds or rain for example;
- the global $L_{Aeq,0.5s}$ cannot exceed 55 dB(A).

The first criteria remove the whole period if it is not validated. Two others only remove the parts concerned except if the period time decreases below 8 minutes.

After these first selections, periods with a dominant WT noise were selected but not only. Two methods were tried to generate a more relevant and reliable selection.

3.2. 1/3-octave band criteria

The first way to isolate periods with dominant WT noise is based on 1/3-octave band criteria. Indeed, after a review and a listening of all first-selected periods, a pattern in the 1/3-octave band criteria was noticed during audible WT noise. Figure 2 shows a typical A-weighted spectrum with a clear WT noise. A first wide maximum is spread on the bands centered on 315, 400 and 500 Hz. A second maximum is centered typically on 100 or 120 Hz.

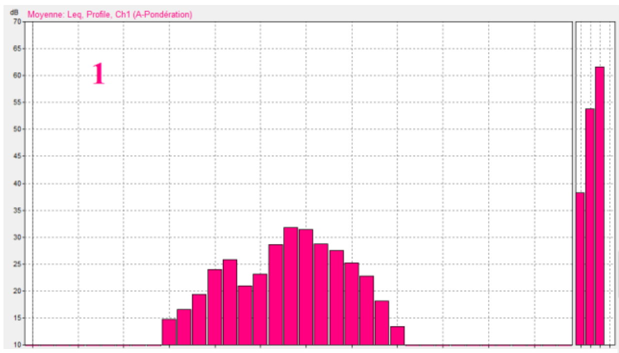

Figure 2. Typical WT noise 1/3-octave band spectrum

Another kind of 1/3-octave spectrum was recording and is shown in Figure 3. The first maximum is shifted towards 630 and 800 Hz whereas the second stays in the same position and becomes dominant.

The difference is probably due to a change in wind direction. Indeed the wind principally comes from the south leading preferentially the sound from the wind farm towards the measurement place (see the map Figure 1). More unusual during the campaign, a wind blowing on the left side of the wind farm and the village happened. The difference between wind directions can be observed in Figure 4 where both cases are plotted: the first set corresponding to the spectrum Figure 2 and the second to Figure 3. The difference between the wind directions was validated by a Student's t-test highly significant.

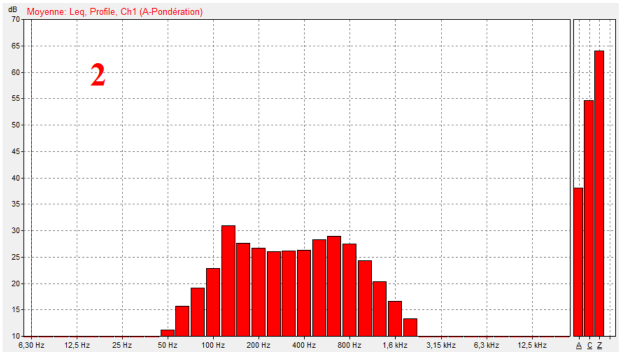

Figure 3. Second kind of WT noise spectrum

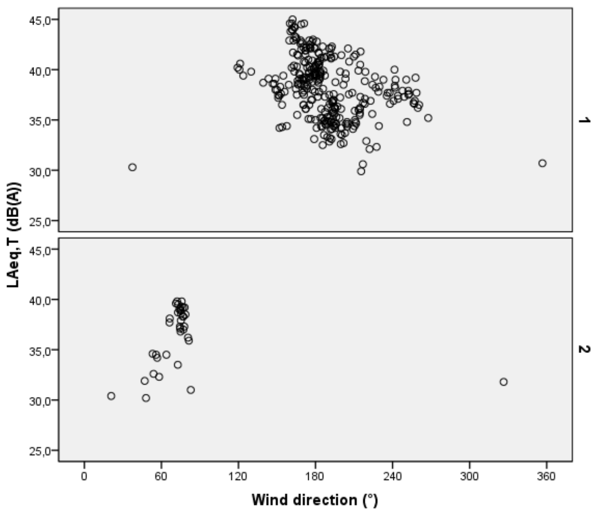

Figure 4. A-weighted levels according to the wind direction for the typical case (1) and a more unusual case (2)

The difference between these two cases makes difficult to develop an automatic process identifying the periods with a dominant WT noise. Attempts using a Matlab code did not give good results. Despite many tests to compare 1/3-octave band levels between them, periods with dominant backgrounds are sometimes forgotten whereas periods with no WT noise are selected.

In order to avoid the lack of precision appearing for 1/3-octave band criteria, a second way that uses the audio recordings was tried.

3.3. Audio recording criteria

The audio signal was recorded in the same time as the acoustic levels and during the whole campaign without interruption. It explains the change of memory cards every week. The audio quality is low (12 kHz sample frequency coded on 8 bits) but sufficient to listening to specific events again, especially the WT noise at immission. But analyses can be constructed based on these recordings?

Different methods were tested to select the one giving the more relevant result. The method which was taken on is the periodogram. A periodogram is an estimate of the spectral density of a signal [9]. In practice, it is calculated from the modulus-squared of the Fast Fourier Transform of a digital signal. The variance of this raw method can be high and do not decrease with the number of samples N. The Welch method improves the results by averaging the periodograms calculated on L sets of M samples ($N = LM$) and by using a window function (Hamming) to avoid cutting the sequence abruptly. The method is directly given by Matlab thanks to the function `pwelch`. The function plots the estimate of the power spectral density in dB/Hz (the estimate is divided by the sample frequency) according to the frequency (linear axis) till the Nyquist/Shannon frequency.

For instance, the periodogram of the spectrum Figure 2 is presented in Figure 5. The interesting part is situated under 1 kHz, others frequencies being weakly influenced by the WT noise. Note that the signal is A-weighted before the calculation of the periodogram and only the differences between levels are relevant due to a non-calibration of the absolute level of the recording.

Both maxima previously found are visible: a large around 400 Hz and a second thinner as a tonality. A zoom of the part circled in red is shown in Figure 6. Many peaks are present but not always at the same regularity and as high as the peak at 120 Hz. So a first criterion based on this peak and an

additional about the large maximum could be tested.
Unfortunately the peak at 120 Hz is not fixed and can move towards a higher frequency or towards 100 Hz… And some other kinds of noise (not too high in dB(A), without a great emergence and positioned in low frequencies) also present an important acoustic energy at 100 Hz as a local maximum. Therefore a fixed and precise criterion around 120 Hz is used and some periods are missed, or a more flexible criterion is applied and non-relevant periods are selected.
Note firstly that, if the stricter analysis is used, the periods highlighted are very often dominated by the WT noise. In this sense, it is reliable but incomplete. Secondly, the calculation time is clearly far longer than for the 1/3-octave band criteria. The reason is the calculation of the periodogram is more complex and applied to data including many hours for which 1 second is characterized by 12 000 numbers. So a lot of care had to be brought in the data formatting.

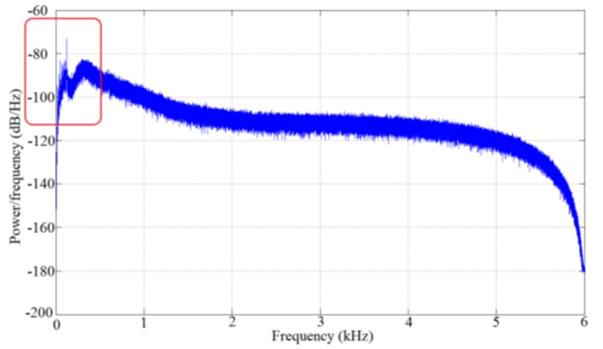

Figure 5. Welch power spectral density of WT noise

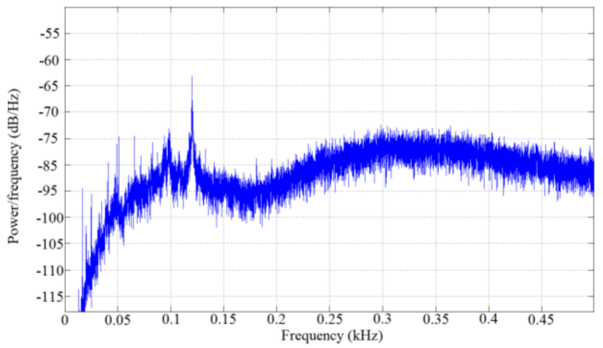

Figure 6. Detail of the Welch power density Figure 5

4. Conclusions

Actually the WT noise is often pointed as a problem by people living nearby. It is important to understand why they complain about it and that passes by the measurement at immission. At 1 km of a wind farm, the sound pressure level will never be higher than 55 dB(A) and the presence of many other acoustic events make difficult to isolate the WT noise. First criteria based on the dynamic and the level of the $L_{Aeq,T}$ and its high frequency components in its 1/3-octave band spectrum enable a rough selection among the periods that can be dominate by the WT noise.
Other criteria are necessary to obtain a precise method of selection. 1/3-octave band spectra depend on the wind direction but, despite this report, no enough relevant criteria were determined. Another approach based on the use of the periodogram was tested. The selection gives moments with a dominant WT noise, but this selection is incomplete. Other ways will be explored soon.
This work is carried out in the framework of a PhD thesis at the University of Mons.

References

[1] European Environment Agency: Noise in Europe 2014, EAA Report, No 10/2014.

[2] C. Marquis-Favre, E. Premat: Noise and its effects - A review on Qualitative Aspects of Sound. Part II: Noise and Annoyance. Acta Acustica united with Acustica 9 (2005), 626-642.

[3] D. Bowdler, G. Leventhall (editors): Wind Turbine Noise. Multi-Science Publication, 2011.

[4] R. H. Bakker, E. Pedersen, G. P. van den Berg, R. E. Stewart, W. Lok, J. Bouma: Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress. Science of the Total Environment 425 (2012), 42-51.

[5] D. McBride, D. Shepherd, R. Thorne: Investigating the impacts of wind turbine noise on quality of life in the Australian context: A case study approach. Proc. Internoise 2014, No 683.

[6] 13 février 2014 - Arrêté du Gouvernement wallon portant conditions sectorielles relatives aux parcs d'éoliennes d'une puissance totale supérieure ou égale à 0,5 MW, modifiant l'arrêté du Gouvernement wallon du 4 juillet 2002 relatif à la procédure et à diverses mesures d'exécution du décret du 11 mars 1999 relatif au permis d'environnement et modifiant l'arrêté du Gouvernement wallon du 4 juillet 2002 arrêtant la liste des projets soumis à étude d'incidences et des installations et activités classées (M.B. 07.03.2014 - entrée en vigueur 10 jours après publication).

[7] B. Fauville, F. Moiny: Wind turbine noise: practical noise immission measurements. Proc. Internoise 2014, No 465.

[8] J. Cooper, D. Leclercq, M. Stead: Wind induced aerodynamic noise on microphones from atmospheric measurements. Proc. 20th International Congress on Acoustics, ICA 2010.

[9] T. Dutoit: Traitement du signal. Lecture notes, Faculty of Engineering of Mons, 2007.