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On the detectability of a wind turbines noise under different meteorological conditions

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Long-term measurements for monitoring the noise immission of wind turbines (WT) are difficult because the local noise level is determined by a variety of influences [1]. On the one hand, there is the highly variable emission level, depending on the inflow conditions and on the rotational speed of the turbine. On the other hand, an assignment of the noise to the source is not always clear, because the immission level is often on the same level as the external noise. To improve the understanding of the sound transmission under different meteorological conditions such an assignment of the source noises is essential. The aim of this paper is to show which immission measurement data can be used to evaluate sufficiently high-resolution (temporal and spectral) long-term measurement data to obtain information on sound emission, rotational speed, background noise, amplitude modulation and the local noise exposure coming from a wind turbine. The long-term measurements compare different meteorological conditions and show the influence of the weather on the detectability of the WT noise. These investigations allow statements about the necessary analysis periods, the consideration of meteorological information and new metrics in noise monitoring.

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INTRODUCTION

Long-term measurements for monitoring the noise immission of wind turbines (WT) are difficult because the local noise level is determined by a variety of influences [1]. On the one hand, there is the highly variable emission level, depending on the inflow conditions and on the rotational speed of the turbine. On the other hand, an assignment of the noise to the source is not always clear, because the immission level is often on the same level as the external noise. To improve the understanding of the sound transmission under different meteorological conditions such an assignment of the source noises is essential. The aim of this paper is to show which immission measurement data can be used to evaluate sufficiently high-resolution (temporal and spectral) long-term measurement data to obtain information on sound emission, rotational speed, background noise, amplitude modulation and the local noise exposure coming from a wind turbine. The long-term measurements compare different meteorological conditions and show the influence of the weather on the detectability of the WT noise. These investigations allow statements about the necessary analysis periods, the consideration of meteorological information and new metrics in noise monitoring.

COLLECTION OF MEASUREMENT DATA

In the context of the increasing interest of the population and the regulatory authorities in an environmentally friendly use of wind energy, sound propagation and thus the systematic noise immission measurements around the wind turbines are also of great importance. In order to investigate the flow regimes and wind conditions in the atmospheric boundary layer over complex terrain, a large measurement campaign with European and US-American participation was carried out in Perdigão (Portugal) associated to the European New European Wind Atlas (NEWA) Project 2017 [2]. The terrain at Perdigão is characterized by two parallel ridges, 4500 m long, approximately the same height and 1400 m apart. The main wind direction is typically perpendicular to the ridges from the southwest or northeast. On the southwestern ridge there is a wind turbine, of which the sound immission was recorded at several locations. Influenced by the terrain, various interesting wind field phenomena occur, which may have a decisive influence on the sound transmission. In previous studies it has been shown how the propagation, wind speed deficit and turbulence of the WT wake is strongly dependend on atmospheric conditions [3,4].

The acoustic measurements carried out in Perdigão are intended to answer the questions of whether the noise from the wind turbine can be measured and how much it depends on atmospheric stratification and wind conditions. The measurement setup with the description of the topography and the positions of our microphones is described in [5].

The basis for the analysis of the results presented here are data from three sound monitoring stations (of type SV979), which were set up at different distances from the WT in the complex terrain. The data were stored in blocks of hours with a sampling rate of 10 Hz over a period of 40 days. The approx. 3000 data sets contain high-resolution time series of 44 one-third octave bands from 0.8 to 16 kHz. Of these, 12 one-third octave bands with a center frequency of 40 to 500 Hz were analyzed. Thus, a total of about 34,000 time series were analyzed.

METHODOLOGY

The large amount of data can only be analyzed systematically with suitable procedures. The simplest method is the temporal averaging in suitable time periods, where then each averaging period can contain different situations from sound generation to immission. Thus, important information such as extraneous noise or special conditions for sound generation and propagation are blurred. The same happens in broadband averaging with weighted or unweighted sound pressure levels such as LAeq or LZeq or via percentile averaging, which can be performed in time periods or frequency ranges.

The method we use determines the spectrum of the signal from individual time series of the one-third octave bands by means of a Fast Fourier Transformation (FFT). Only short time windows from 2048 data points are analyzed, corresponding to about 3.4 minutes. The time windows are applied with overlap to provide a one-minute sampling interval and thus provide 58 spectra per hour. In the best case, a sharp peak at the frequency corresponding to three times the rotational frequency of the WT is obtained. This would then indicate that the recorded signal can be assigned to the WT. The size of the time window must be chosen large enough to obtain a sufficiently high spectral resolution of the FFT. On the other hand, the time window must remain small so that the result remains representative for a time range and because the analysis method reacts very sensitively to disturbances in the time series. Too long time series with disturbances and variable rotational speed of the WT would not result in a clear spectrum and thus would not allow an assignment to the acoustic emission of the WT.

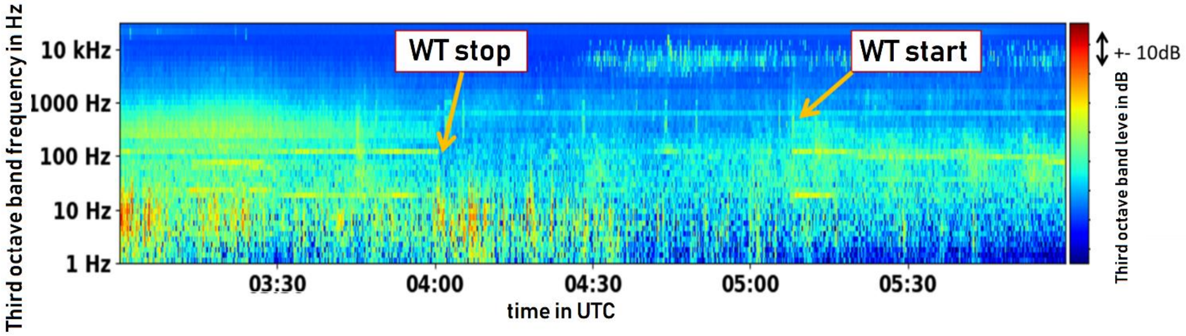

Figure 1: The spectrogram of the station SV-174 from 22.05.2017 in the period between 3:00-6:00 UTC. The color scale shows the sound pressure level of the individual one-third octave bands. WT stop and start is indicated and visible by the interruption of some one third bands.

This automatic analysis of all data sets allows to infer the number of revolutions of the WT. However, in the end the results must be summarized again.

The frequencies of the peaks were read out of the 58 spectra per hour and the frequency average for this hour was calculated. If this results in a rotational frequency that lies between 10 and 18 rpm, this analysis is considered plausible. The automatic peak detection of the resulting FFT spectrum of the third-octave band time series can be particularly difficult and error-prone. A comparison with the known rotational speed of the WT is very helpful.

THE SPECTROGRAM OF THE MEASUREMENT

A way to get a visual impression of the measurement is the presentation in form of a spectrogram. It shows all recorded one-third octave bands and their intensity (see Fig. 1). This shows at a glance at what time certain frequencies are present in a sound spectrum and when they are absent.

The spectrogram shown in figure 1 over a period of 3 hours contains one hour (from 4:00-5:00 UTC) in which the WT was switched off. The interruption of the signals is clearly visible in some one-third octave bands (> 40 Hz and < 1000 Hz). However, there are also one-third octave bands that remain when the WT is switched off. In the low-frequency range no statements can be made. In the high-frequency range > 5000 Hz, the onset of birdsong is visible from 4:30 UTC.

This form of representation shows the spectral parts of the sounds and is therefore suitable to get an impression of the plausibility of the recording. However, this temporal resolution is not sufficient to recognize individual sound situations. In single one-third octave bands displayed in very high resolution (Figure 2) the periodic variation can be recognized, which most probably represents the signal of the WT without any significant noise from other sources. This is the phenomenon of amplitude modulation, where the high-frequency sampled sound (250Hz) represents the carrier wave and the low-frequency level fluctuation (rotational speed) found in the FFT is the signal from the WT.

Such a representation of the entire measurement is not feasible. In order to detect this periodic signal in time series, a Fourier transformation of small temporal windows can be done.

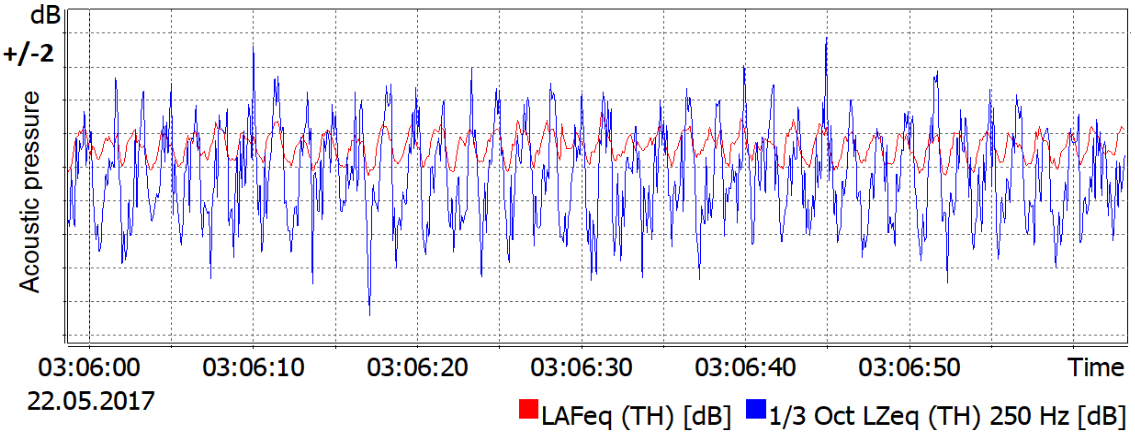

Figure 2: Sound pressure level curve of the 250 Hz one-third octave band (black) and the LAeq (red) on 22.05.2017 at 03:06 UTC for the duration of one minute with 36 periodic signals, corresponding to a frequency of 0.6 Hz and a rotational speed of 12 rpm.

FOURIER TRANSFORMATION

Using an FFT of small temporal windows within individual one-third octave bands, the entire measurement can be sampled for signals that are likely to come from the WT. The acoustic spectra with a very high temporal resolution show a periodic signal of 0.4 - 0.9 Hz within the one-third octave bands between 40 Hz and 315 Hz. Signals found in this way are classified as true WT signal, if the hourly average of the found frequency is equal to the declared rotation of the WT. This hour is then counted for later statistics as a detected signal. Figure 3 shows the result of an FFT of the 125 Hz one-third octave band of the station SV-174 in high temporal resolution. It shows the course of the detected signal within one hour on 22.05.2017 from 3:00 to 4:00 UTC as well as two undertones which can be recognized by integer fractions of the fundamental.

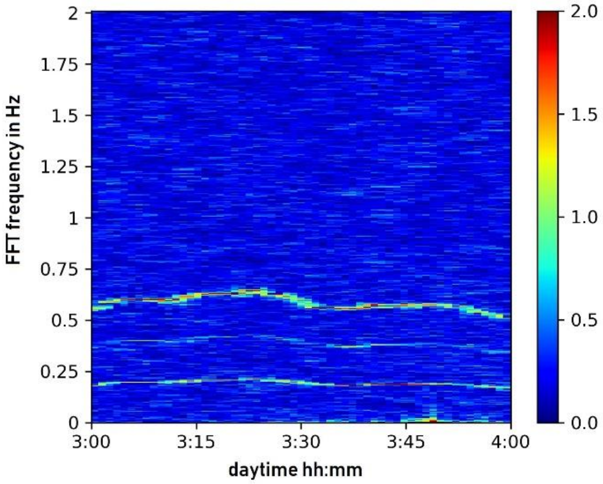

Figure 3: Result of the FFT of the 125 Hz third-octave band of station SV-174 on 22.05.2017 3:00-4:00 UTC. The rotation signal of the WT at about 0.60 Hz (corresponds to 12 rpm) with a temporal variation and two undertones can be recognized.

RESULTS

Various statistics can be calculated from about 10000 data records per microphone. Figure 4 shows the summary of the previously described FFT analyses of 8 third frequency bands and their signals of the WT for the three microphones. It can be seen that the microphones with a smaller distance to the WT have a higher detection rate for these periodic signals than the microphone (SV-181), which is positioned in 965m distance. Furthermore, the detection rate is better with increasing frequency of the one-third octave bands.

The dependency of the detection rate on noise but also on the propagation conditions, i.e. the meteorology, is shown in a summary of all FFT results averaged over one day in figure 5. Here we assume that within one day the meteorological conditions vary sufficiently strongly, but are comparable on average and are repeated accordingly during the day. The detection rate varies significantly over the course of the day across all one-third octave bands. In sum, the result is a diurnal cycle that has a minimum around noon. During this time the sound propagation conditions are more difficult from a meteorological point of view (unstable stratification, turbulent flow and higher wind speed near the ground). In addition, there is increased noise from animal and human activities.

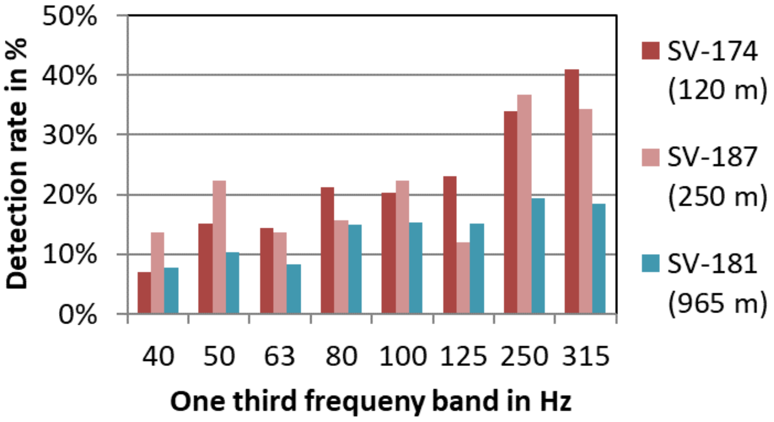

Figure 4: Frequency of detectability within individual one-third octave bands at different microphones

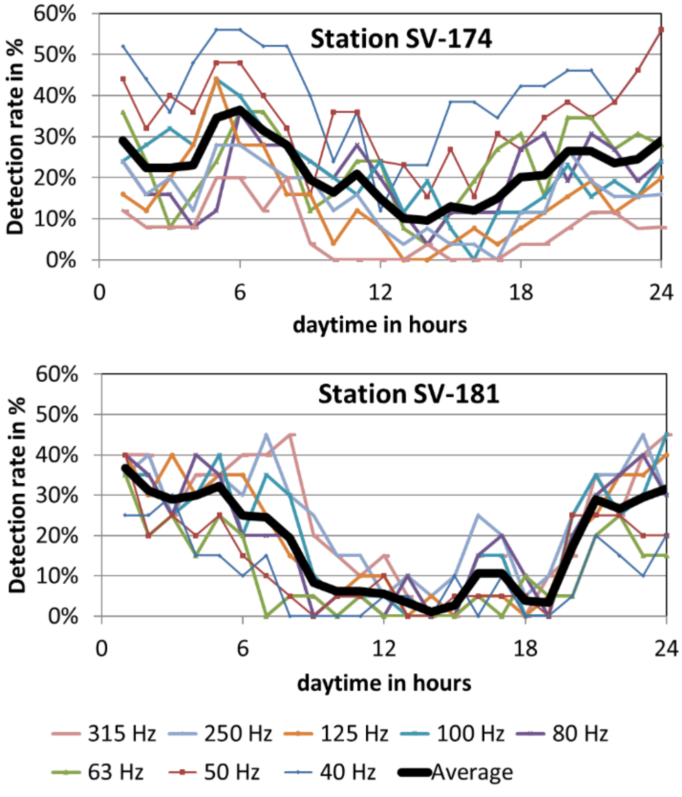

Figure 5: Frequency of detectability in the mean diurnal cycle over all one-third octave bands between 40 and 315 Hz at station 174 at a distance of 120 m from the WT (top) and station 181 at a distance of 965 m (bottom)

CONCLUSION

Acoustic long-term measurements in the vicinity of a wind turbine show the typical daily course of the audible sound even in positions further away from the turbine. This is characterized by ambient noises such as the twittering of birds, the barking of dogs and the rustling of leaves and the wind that comes up near the ground. The sound signal of the wind turbine is visible in one-minute sections within a few one-third octave bands. There, periodic signals are visible, from which the signal of the 3-blade rotor with its rotational frequency can be determined by means of an FFT. The diurnal cycle represents a first approximation to summarize regular changes of the weather influence relatively easy. Therefore, the dependence on the weather, such as atmospheric stratification, and wind speed is indicated by the FFT results in daily cycles. The detection rate, which can reach up to 55% depending on the microphone, was determined very conservatively. The automatic procedure to pick out the peak in the FFT analysis and then averaging these found values of the 58 FFT-spectra over one hour have an influence on the detection rate. Downtimes of the WT or times with a rotational frequency lower than 10 rpm were evaluated as not detected. In these cases, the FFT result can of course not show any signals in the spectrum. Dividing only the found signals that are similar to the declared rotational speed of the WT by the sum of all analyzed hours the detection rate results as a relatively small value.

It should also not be forgotten that the measurement is also influenced by the meteorological particularity of the site. During the 40 days of measurement, north-east wind directions occurred unexpectedly often. During the night time, the measuring station 181 in the valley was often upstream of the WT, whereas during the day it was in the wake of the WT.

A special filtering of the data could significantly improve the evaluation of these results. The large amount of data sets has to be reduced in such a way that only relevant cases for a specific question are included in the analysis or evaluation.

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