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INFLUENCE OF BACKGROUND NOISE AND FREQUENCY ANALYSIS OF WIND TURBINE NOISE

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Summary

The different evaluation-methods for the wind farm noise in Switzerland – computer models (for new wind farm projects) or on-site measurements (for existing wind farms) are often discussed by the concerned authorities and organizations. In order to improve the evaluation of the wind farm noise, the first part of this study aims to compare the current Swiss calculation method with the results of in-situ measurements of a specific wind park. In the second part of this study, audio recordings are analyzed in detail. Marked amplitude modulations are highlighted in sonograms under specific meteorological conditions in particular for one of the measuring position (for head wind between 5 and 6 m/s, 10 dB variation between 40 and 50 Hz at a rate of 6 beats per second). For the other measuring position (tail wind), these beats appear at higher wind speeds (> 10 m/s) but are considerably less marked (5 dB variation between 125 and 135 Hz, with the same rhythm at 6 beats per second). These events, however, remain infrequent and difficult to assess precisely. In order to optimize the methods of measurement and calculation, the data should be completed with complementary measurements in several positions (also in the areas less exposed to wind) while the wind turbine is interrupted (« stop-and-go », procedure unfortunately not possible in the frame of this project) and to extend this research to several wind parks.

Keywords: Wind turbine noise, measurement, background noise, amplitude modulation, frequency analysis

1. Introduction

The different evaluation-methods of the wind farm noise in Switzerland – computer models (project of new wind farms) or in-situ measurements (as for existing wind farms) are often discussed by the concerned authorities and organizations (federal and cantonal public authorities, Suisse Eole …). For modeling purposes, the FOEN (Federal Office for the Environment) recommends a method based on the EMPA report "Lärmermittlung und Massnahmen zur Emissionsbegrenzung bei Windkraftanlagen" [1]. In Switzerland. There isn't yet any official measurement method for the evaluation of the wind farm noise.

In order to improve the evaluation of the wind farm noise, this research project aims to compare the current Swiss calculation method with the results of one-site measurements of a wind park. This research project is funded by the Swiss Federal Office of Energy - SFOE (project SI/501150).

The first part of this research project [2] leads to the following conclusions:

- The measurement's results allow to validate some elements concerning material and instrumentation, the duration to cover the different meteorological conditions, the parameters to be recorded, the relevant periods, as well as the measurement positions. These results show also the limits of the measurement -method. Given the particularity of the site (situation on a ridge with strong wind exposure), it is not possible to extract exactly the wind turbine noise from the background noise, even if the noise of the wind turbine is partially audible in the audio recordings. In this configuration, the measured sound level represents the noise of the wind turbine mixed with the background noise, even after the suppression of other interfering noises. The different methods tested (periods with high audibility of the wind turbine noise, third-band-analysis, statistical analysis) do not allow to isolate clearly the wind farm noise.
- Concerning the calculation's results, the Swiss method recommended to determine the wind farms noise is comparable to the ones used in neighbouring countries. All these methods are based on a simplified approach of the noise propagation, which mainly does not take into account the meteorological effects. Due to the application of a special ground-connection-factor, the results of the mandatory Swiss method (ISO-norm 9613-2 – modified according to EMPA recommendation) are usually 1 to 3 dB(A) higher than those obtained with the commonly used international norm (ISO 9613-2 [3]).
- The comparison between the results of the measurement and the modeling shows that the average global sound level (annual averaged L_{Aeq} for daytime) obtained from the measurements is 7 dB(A) higher than the values obtained by the modeling. If one takes into account the statistical index LA90, the difference is about 4 dB(A). With increasing wind speed ($v > 7$ m/s) the difference between measurement and modeling is particularly marked. This important discrepancy between measurement and calculation results is mainly due to the fact that the measured wind turbine noise is overrated by the presence of background noise (especially from wind in the vegetation).

To better assess wind turbine noise, the second part of this study is focused on third octave band and narrow band analyses using sonograms of audio recordings and measurement results.

2. Measurement

2.1 Methodology

The main objective of the measurement method proposed in this research project is to remain simple (equipment, parameter...) and efficient. In order to take into account all the interfering noises (from rain, wind at the microphone and in the trees) and to improve the representativeness of the results, we use a statistical approach over a long measurement period. The on-site measurement performed over one month (May-June 2015) covers varied weather conditions, which are representative of those usually found in this area.

For on-site measurement, the two locations are selected on both sides of a wind turbine at a distance of approximately 200 m in the direction of the prevailing winds (South-West, North- East). These positions, however, dictated by local constraints (plot boundary, presence of isolated trees), fulfil the ISO 1996-2: 2007 [4] requirements (in the direction of the prevailing winds) and remain relatively distant from disturbing noise sources as forests and other wind turbines present in the area. Moreover, choosing a position relatively close to the wind turbine allows to reduce the uncertainties related to long distance propagation and the influence of background noise (increase of S/N ratio).

2.2 Results

In a first stage, short term on-site measurements are grouped in a single figure for each measuring position (see Figure 1 for position 1). Measured sound levels take into account all sound events that occur near the microphones.

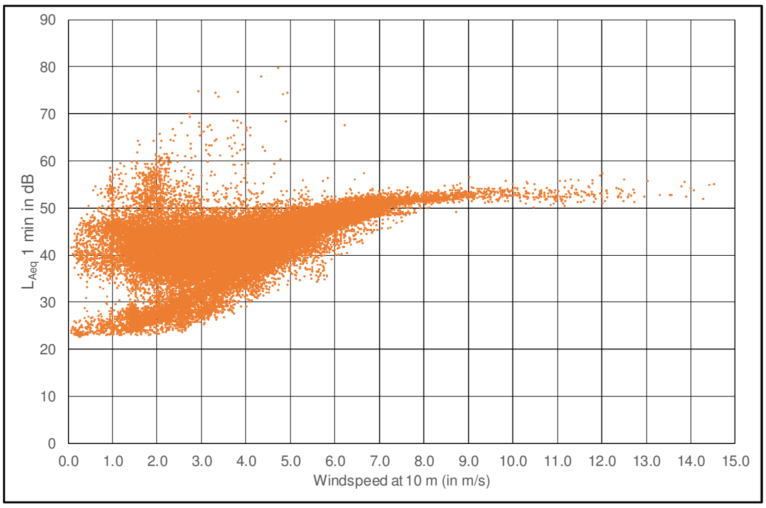

Figure 1: Raw data of sound level (L_{Aeq}) measured at position 1

In a second stage, in order to extract the useful information, it is necessary to remove disturbing noises due to:

- Unfavorable weather condition (rain, wind gust at the microphone)
- Human activities (tractor, forestry work, construction sites in the vicinity)
- Noise from animals (cow bells, birds, crickets)

Based on post processing analysis of audio recordings, the samples containing such disturbing noises have been removed. The suppression of disturbing noise led us to consider only the measurement results during nighttime (from 22h00 to 4h00) for the rest of this research project (see Figure 2).

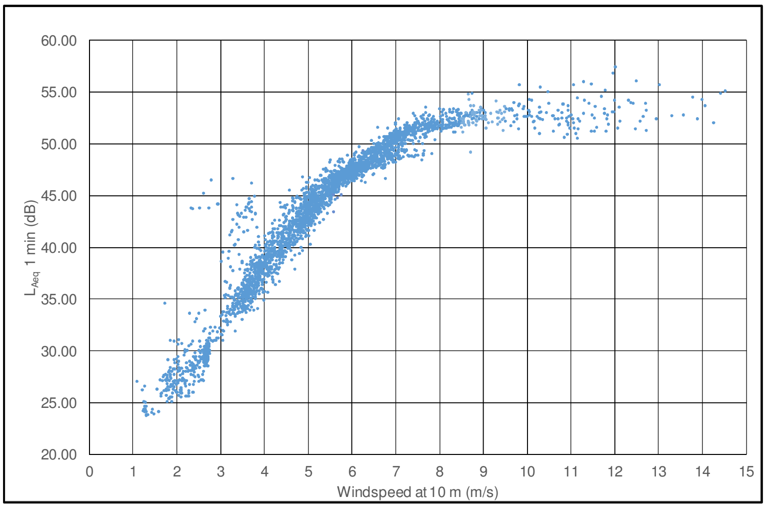

Figure 2 : Selected data (after suppression of disturbing noise) of sound level (L_{Aeq}) measured during nighttime (22h-4h) at position 1 for main wind direction

Based on these selected data, trend curves (third order polynomial) are plotted in order to determine the sound levels for each wind class. Then, the annual average sound levels for day and night periods are calculated based on these trend curves and according to the different wind classes' occurrences (see Table 1).

Wind speed m/s	Sound Level L_{Aeq}	Day occurrence %	Weighted Day L_{Aeq}	Night Occurrence %	Weighted Night L_{Aeq}
<4.5	--	42.9	--	31.0	--
4.5-5.5	43	11.4	34	10.9	34
5.5-6.5	48	9.3	37	10.8	37
6.5-7.5	50	8.2	39	10.1	40
7.5-8.5	52	7.0	40	8.7	41
8.5-9.5	53	6.1	41	8.1	42
>9.5	54	15.1	46	20.4	47
Total		100	**L_{day}=49**	100	**L_{night}=50**

Table 1: Day and night annual average level calculation (L_{Aeq} from sound levels and wind occurrence in each wind speed class, position 1)

Results show that the annual average level is 1 dB(A) higher for nighttime than for daytime. Even with an average occurrence (15 -20%), the highest wind speed class (>9.5 m/s) represents the essential contribution to noise (50%).

However, a detailed analysis of the different periods shows that wind noise at the microphone is always significant when the wind turbine operates at high speed. The only periods when wind noise is low are of course limited to weak wind periods when the wind turbine operates with a relatively low power or is off and thus with reduced noise emissions. The values obtained in Table 1 therefore constitute the measured noise levels of wind turbine noise combined with wind noise at the microphone and residual background noise (especially from wind in the vegetation, even at long distance). Unfortunately, it is not possible, in our specific situation, to extract noise data only due to wind turbine (without any disturbance from background noise) even if such noise is audible in the audio recordings.

According to the methodology adopted in some countries, the use of statistical indicators such as L_{A90} (which represents the A-weighted sound level exceeded for 90% of the measurement period) makes it possible to deduce part of the remaining disturbing noises.

The same calculation is then carried out on the basis of statistical indices L_{A90} level to determine the annual average sound levels for day (46) and night periods (47). Results with L_{A90} lead to same conclusion as for L_{Aeq} but with values 3 dB lower.

3. Comparison between measurement and calculation

The comparison between measurements and modeling is illustrated in Figure 3 and Table 2 for position 1.

The average sound levels (annual L_{Aeq} for daytime) obtained by measurements are 7 dB(A) higher than the calculated results. When taking into account the L_{A90}, the difference is only 4 dB(A). The difference between measurements and modeling increases with the wind speed and becomes very significant at high wind speed (v> 7 m/s).

This large discrepancy between measured and calculated results is mainly due to the fact that the measurements results include not only wind turbine noise but also some residual background noise (mainly due to wind noise in the vegetation), which cannot be extracted.

4. Frequency analysis of audio recordings

In order to highlight specific aspects of wind turbine noise, further analyzes are carried out on audio recordings.

4.1 Analysis of particular periods

A detailed analysis of certain periods when wind turbine noise is audible allows us to highlight more marked emergence of this noise from background noise. Using only these selected data, the average sound level values for wind speed and annual average are slightly lower, especially for high wind speeds (> 8 m / s, see Figure 3).

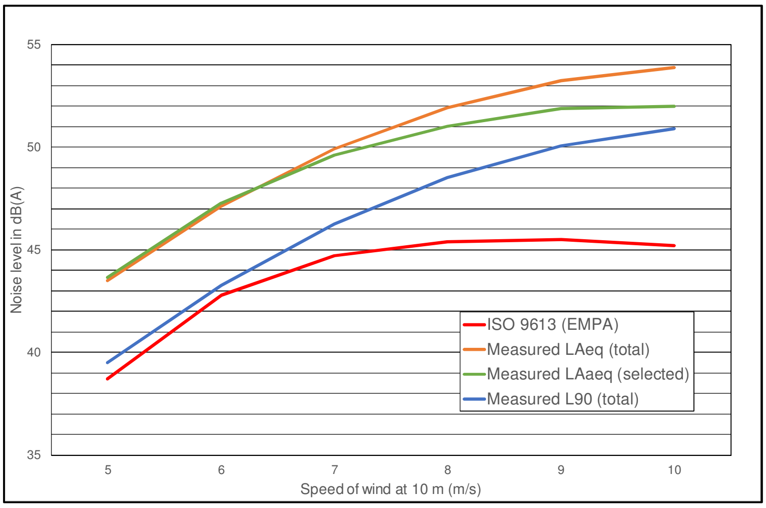

Figure 3: Calculated and measured sound level according to wind speed and direction with selected data

Daytime	dB(A)
Measurement, annual L_{Aeq} (total)	49
Measurement, annual L_{Aeq} (selected)	48
Measurement, annual L_{A90} (total)	46
Calculated L_{Aeq} (ISO 9613-2 including Empa correction)	42

Table 2: Summary of measured and calculated annual average daytime levels

The average sound levels (annual L_{Aeq} for daytime for selected data) obtained by measurements (1 dB(A) lower than for all the data) are still 6 dB(A) higher than the calculated results.

4.2 Narrow band analysis

For the measuring point located 200 meters head wind from the turbine, these different analyzes show that:

- Most of the time, the wind turbine noise doesn't emerge from the background noise, nor to audio recording listening, nor to time-frequency analysis (sonogram ...).
- During certain wind phases, a slight emergence between 63 Hz and 250 Hz of the wind turbine noise can be observed in sonograms and in third octave band analysis (see Figure 4)
- In some particular cases (wind speed between 5 and 6 m/s) and over relatively short durations, a clear signature of wind turbine noise can be observed between 40 Hz and 50 Hz; This signature presents a stable frequency behavior (figure 4) or some modulations (see Figure 5)

- The amplitude modulation is about 10 dB and the main frequency varies from 40 Hz to 50 Hz with a "rhythm" of approx. 6 beats per second.

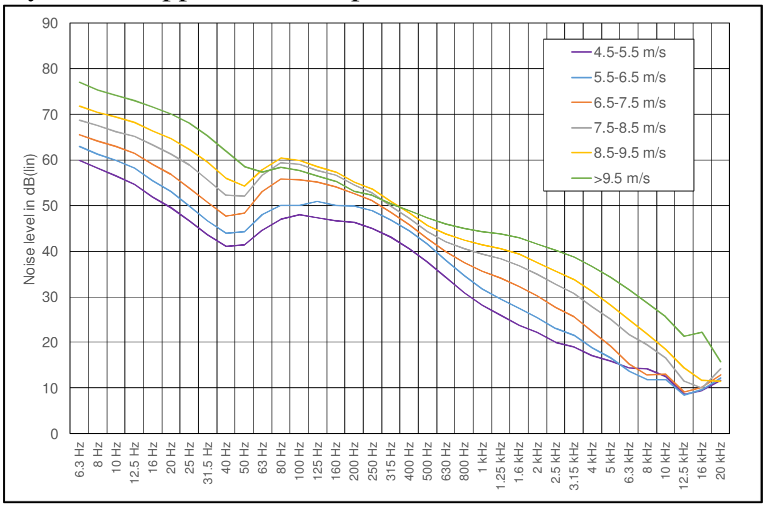

Figure 4: Third octave band analysis according to wind speed with slight emergence of wind turbine noise between 63 and 250 Hz

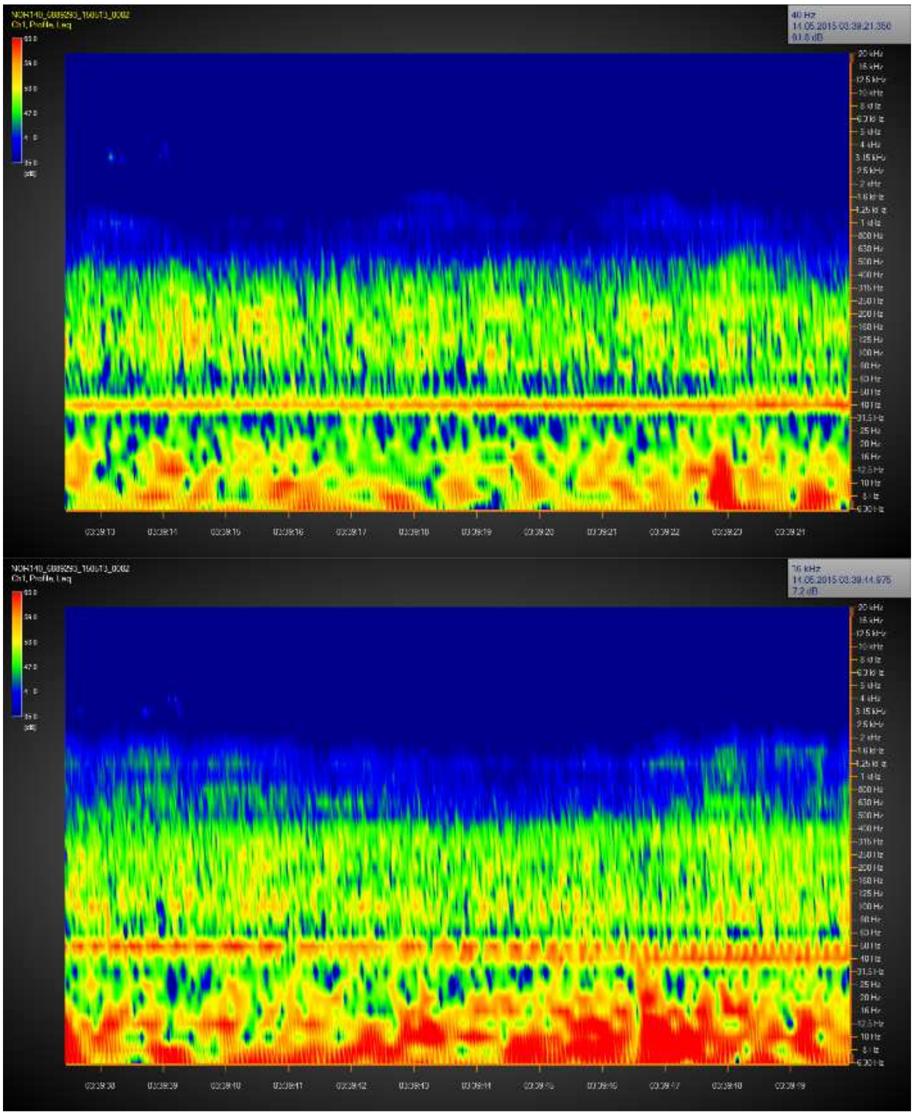

Figure 5: Sonogram with clear emergence of wind turbine noise at 40 Hz and 50 Hz and amplitude modulation

For the other measuring point, located 200 meters tail wind from the turbine these different analyzes show that:

- Most of the time, the wind turbine noise doesn’t emerge from the background noise, nor to audio recording listening, nor to time-frequency analysis (sonogram ...).
- During certain wind phases (wind speed > 10 m/s), a slight emergence at 130 Hz of the wind turbine noise can be observed in sonograms (see Figure 6)
- The amplitude modulation is about 5 dB and the main frequency varies from 125 Hz to 135 Hz with a "rhythm" of approx. 6 beats per second.
- This frequency peak in 125 Hz third octave band is also found in emission spectrum of this type of wind turbine (see Figure 7).
- •The emergence of wind turbine noise is lower at this measurement position probably because of the higher background noise in the area (close to the forest).

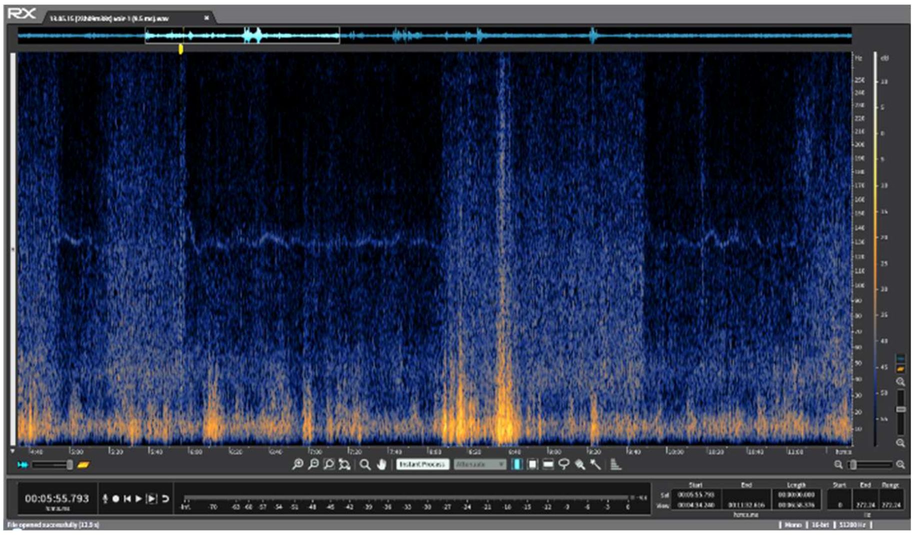

Figure 6: Sonogram with slight emergence of wind turbine noise between at 130 Hz

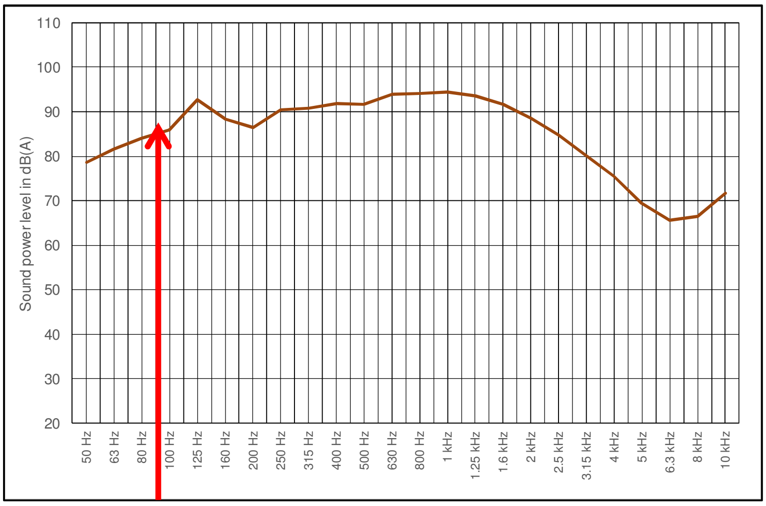

Figure 7: Sound power level of wind turbine noise in 1/3 octave band (manufacturer’s data)

Narrow band analysis allows to highlight amplitude modulation. However, their occurrence during the measurement period is not sufficient to obtain a reliable statistic and to determine with certainty their main characteristics (occurrence condition, amplitude, frequency, etc.).

5. Conclusions

The comparison between the results of the measurement and the modeling shows that the average global sound level (annual averaged L_{Aeq} for daytime) obtained from the measurements is 7 dB(A) higher than the values obtained by the modelling (6 dB(A) with selected data). If one takes into account the statistical index L_{A90}, the difference is about 4 dB(A). With increasing wind speed (v > 7 m/s) the difference between measurement and modeling is particularly marked. This important discrepancy between measurement and calculation results is mainly due to the fact that the measured wind turbine noise is overrated by the presence of background noise (especially from wind in the vegetation).

Sonograms based on audio recordings show marked amplitude modulations are highlighted under specific meteorological conditions in particular for one measuring position (for head wind between 5 and 6 m/s, 10 dB amplitude variation between 40 and 50 Hz at a rate of 6 beats per second). For the other measuring position (tail wind), these beats appear at higher wind speeds (> 10 m/s) but are considerably less marked (5 dB amplitude variation between 125 and 135 Hz, with the same rhythm at 6 beats per second). These events, however, remain infrequent and difficult to assess precisely.

In order to optimize the methods of measurement and calculation, the data should be completed with complementary measurements in several positions (also in the areas less exposed to wind) while the wind turbine is interrupted (« stop-and-go », procedure not possible in the frame of this project) and to extend this research to several wind parks.

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