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Ear Training on Wind Turbine Noise Emissions

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Abstract

Internationally accepted methods are available for the characterisation of acoustic noise of wind turbines but, whereas the designers of wind turbines are convinced that their machines are acoustically all right and the independent acoustic consultants rely on acoustic indicators leading to reproducible results, some wind farm neighbours keep complaining about disturbing noise, tones or other sound effects.

Whereas most fields of engineering refer to physical quantities which can be measured, they seldom have to refer to the field of human perception. The acoustician however must relate his measurements to human hearing. Whereas the unpleasantness of wind farm noise is first dependent on loudness and second to tonality, other more subtle effects, e.g. fluctuation strength, play also a significant role. Some robust indicators are available for the assessment of the loudness and the tonality but they are still missing for the later effects.

In parallel to the development of dedicated measuring procedures, ear-training by listening and identifying particular wind turbine sounds helps improving the quality of the description and of the diagnostic which can be made about individual wind turbine noise conditions.

This paper is illustrated by selected wind turbine noise samples ranging from the legacy Monopetros 50 sound to inconspicuous acoustic problems which could turn out to be disturbing on the long term.

Acoustic noise emission measurements

The most widely applied measurement methods of acoustic noise emission from wind turbines are currently the international standard IEC 61400-11 [1] and the technical guideline TR1 [2].

These standards specify the measurement set-up, the operating conditions, the evaluation procedures as well as the reporting of the results. At a first glance, they give the impression that the task of producing a measurement report is within the realm of a skilled person with technical background.

Whereas the standards mainly describe objective assessment methods, they give the opportunity to the operator to make use of his listening skills. This is the case for example in section 7.2.4 of the IEC standard which recommends “other optional measurements” or in the TR1: “the described methods should contribute to a unified assessment of the noise, its tonality for example. They cannot however replace the

subjective evaluation by the expert. As a consequence, the results of the frequency analysis must be confronted to the audible impression at the time of the measurement and must also be reported."

Applications of acoustic noise measurements

The introduction of TR1 reminds that "the acoustic noise measurement reports are meant to improve the reliability of the permiting process. This is of interest to the administrations, the operators, the project engineer as well as the manufacturer" [2].

Among other interest groups, the administration represents the neighbours of the wind farm projects who are not directly sensitive to the amplitude of physical parameters but on their perception. To a large extent, the perception is related to psychoacoustic parameters and the standards on acoustic noise measurements specify how to assess these parameters. However some effects are still difficult to quantify and the final judge is the human ear. This is the main reason why the ear of the operator at the test site has still an important role to play.

Subjective evaluation

The engineer performing acoustic noise measurements should be able to assess the peculiarities of the noise of the turbine under test in order to adapt the measurement protocol if necessary. Furthermore he should be able to communicate to other persons about his impression. The preferred way of communication is textual since it can be included in the measurement report. Translating an audible impression into a textual description is however not an easy task and it has to be trained. To prevent misunderstandings it is recommended to complement the textual description by short audio samples which can be played back at the office.

Onomatopoeia is a way of imitating the sounds associated with the objects or actions they refer to. A set of terms is proposed by the IEC standard such as "whine, hiss, screech, hum, bangs, clatters, clicks, thump" but it can be extended at will.

Surrounding noise sources

The sound sources surrounding the wind turbine under test must be carefully documented and their effect on the measurement assessed in order to decide about the best measurement setup and conditions.

This is especially the case when a wind turbine under test is surrounded by other wind turbines. Only the person at the test site can reasonably assess where the noise is coming from.

Wind-induced noise in the vegetation, animal noise, noise from the next industrial plant, traffic noise (cars, planes, farm machines etc…) belong to the usual potentially disturbing noise sources.

Wind-induced noise at the measurement microphone should be differentiated from the surrounding noise and eventually avoided by using state-of-the art wind screens.

The tools of the trade

The acoustician at the site has usually a high quality sound level meter which can help assessing the various noise sources. However, the ear of the operator can be considered as the most talented tool. The measurement microphone must be

protected from wind-induced noise by suitable wind screens. In a similar fashion, the human ear can be protected using wind screens. During strong wind conditions, these ear wind screens definitely improve the capability of the ear to segregate the various noise sources. Further tools are a high quality headphone amplifier as well as a closed headphone.

Typical wind-turbine sounds

A method for developing listening skills is to listen to typical wind turbine noise. We give in the following a set of examples to start with. Most of these sound samples are derived from measurements at the IEC reference position 1 [1].

Monopteros 50

Wind turbine opponents often complain about the thump noise produced by the blade while passing the tower. One of the best examples of an objectionable wind turbine noise is given by the Monopteros 50. This one-blade downwind wind turbine has been in operation from the late 80's to the late 90's. It had a rated power of 640 kW, a rotor diameter of 56 m and a 60-m hub height. The rotational speed ranged from 32 to 43 rpm. The measured sound power level reached 113 dB(A) [3]. The vibrations of this wind turbine type where not only objectionable for the neighbours but they also contributed to a premature wear of the mechanical components.

The time plot of the sound pressure level (arbitrary dB scale) shows maxima when the blade is passing by the tower and most of the acoustic energy is radiated at low frequencies (Fig. 1).

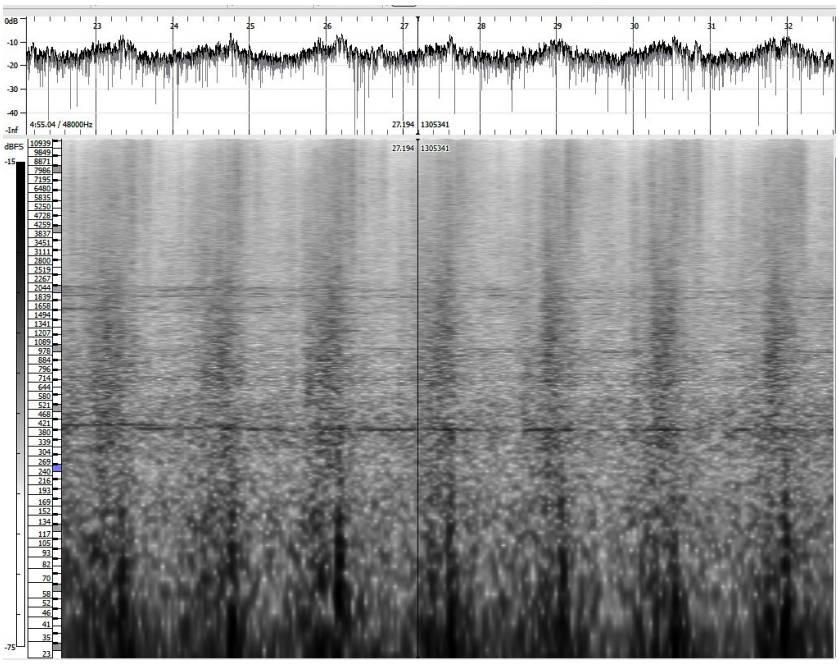


Fig. 1: Monopteros 50

Two-blade downwind

A two-blade downwind wind turbine has typically a binary rhythm where a low frequency thump alternates with a high frequency swish (Fig. 2).

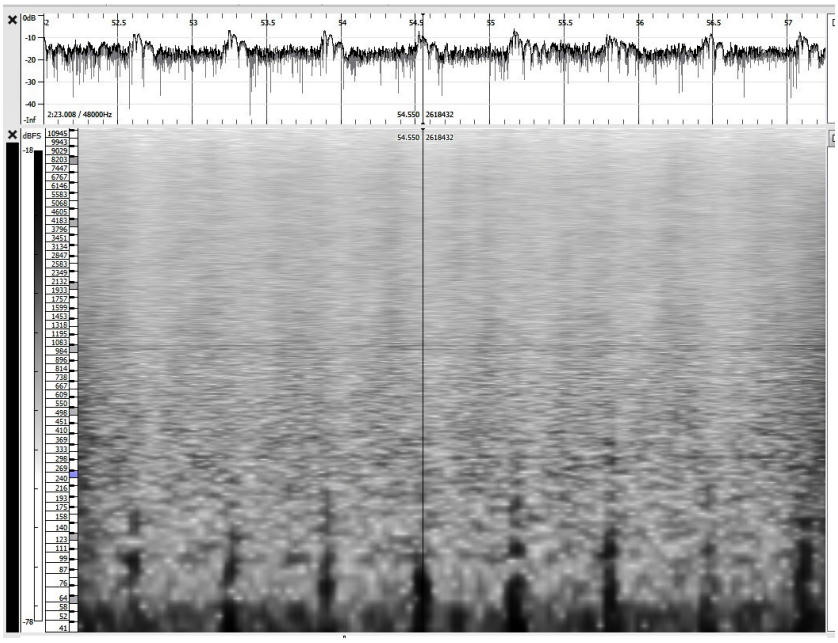


Fig. 2: Two-blade downwind wind turbine

Three-blade wind turbine

The former two examples had the salient characteristic of thump noise at tower passing which is typical for downwind wind turbine types. An old-fashioned upwind three-blade wind turbine has a significantly smoother sound (Fig. 3). Amplitude variations can be noticed on the time plot of the sound pressure level but the rhythm is not as regular as with the former examples. Individual tonal components can be heard and with the help of the spectrogram can be identified to be in the range of 450 Hz and 2400 Hz.

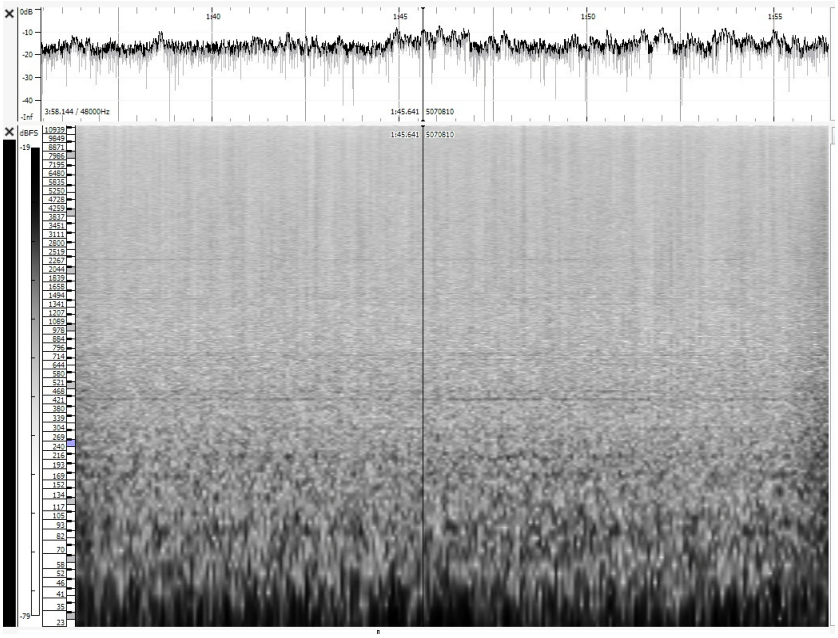


Fig. 3: An old-fashioned three-blade wind turbine

Four-blade wind turbine

A four-blade rotor is more difficult to balance than a three-blade one. That can be heard in the sound example where the whip of the blades is varying in amplitude. The unsteady amplitude can also be seen on the time-plot of the sound pressure level in Fig. 4.

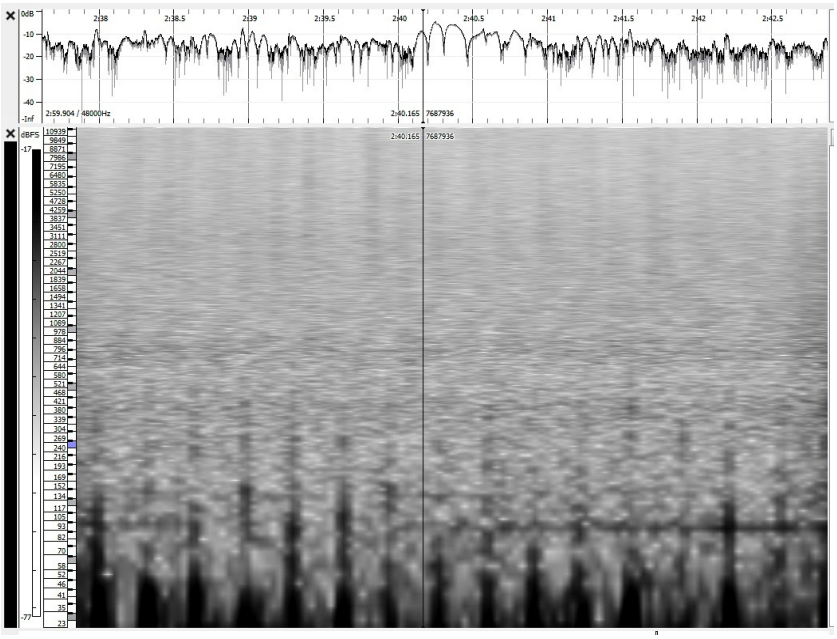


Fig. 4: A four-blade wind turbine

Blade whistling and machinery noise

An old-fashioned two-blade wind turbine gives an example of problems which have to be avoided: the whistling of the blade tips as well as the fixed-frequency machinery noise (Fig. 5). By refining the mechanical design and maintaining the blades these problems can be effectively reduced.

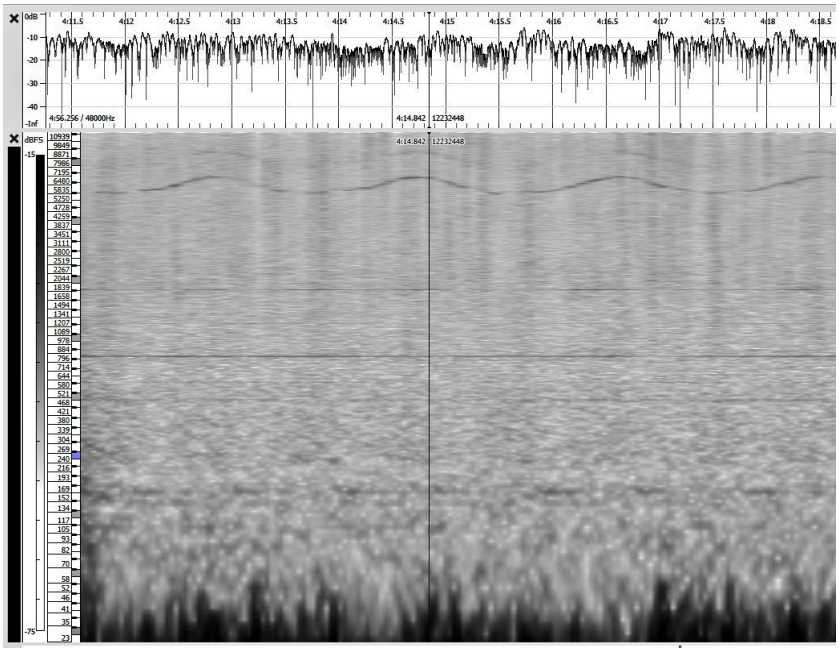


Fig. 5: Blade whistling and machinery noise

Fans and wind turbine stop

For the sake of dependability, the measurements according to IEC or TR1 have to be performed during fairly steady operational conditions in each wind-speed bin.

Measuring during transition phases (stop/start of the wind turbine) would lead to unreliable results but listening at these periods can reveal many details about the wind turbine, its auxiliary components as well as its acoustic integration in the environment. Listening to the recording of the start and stop phases while reading the measurement report provides a vivid illustration of the acoustic scenery.

Figure 6 illustrates the stop phase of a wind turbine whose cooling fans stop with a few seconds delay. The acoustic level drops from the operating level down to the background noise level but shows an intermediate level when only the fans are in operation. The investigation of the individual spectral lines would allow differentiating between acoustic signature of the wind turbine and that of the fans.

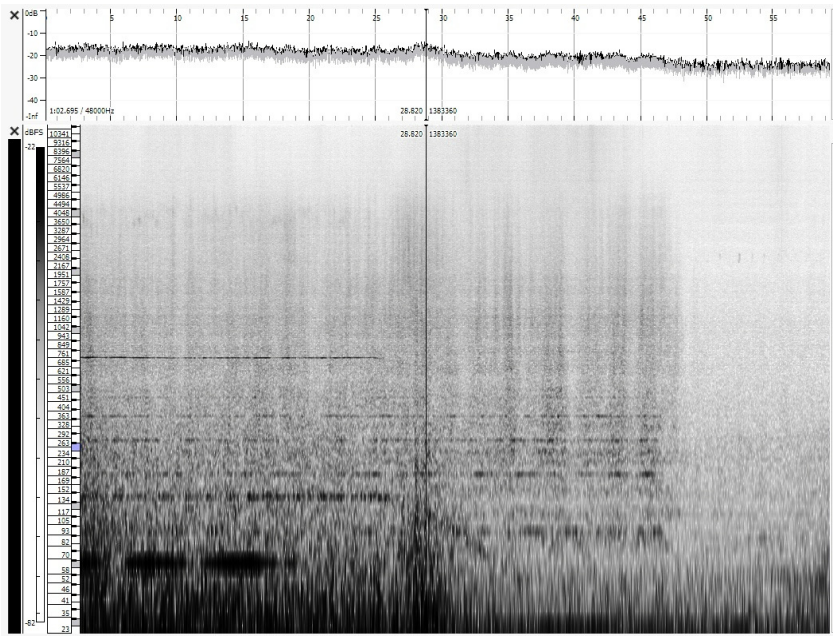


Fig. 6: Machinery, fans, surroundings

Gearbox and bearings

Gearbox and bearings are powerful sources of vibrations which can be transmitted and sometimes even amplified by the mechanical structure on which they are mounted. The sound pattern is very characteristic and can be extremely annoying for the neighbours of the wind farm.

The mechanical engineer works at avoiding vibrations because they have a negative impact on the expected life-time of the mechanical components. As a by-product, he expects that the level of the vibrations will be acceptable also for the neighbours of the wind farm. However, assessing the audibility of the vibrations by a human ear often requires the feedback from field testing.

Figures 7.1 and 7.2 show the example of a gearbox and bearing noise in a typical prototype wind turbine at an early stage of testing. In the shown time excerpt, the rotational speed was steady enough so that the IEC tonal assessment delivered a significant and consistent value ΔL_a = 1.6 dB.

During unsteady operational conditions the result of the IEC tonal assessment might have been blurred because of the time averaging of spectra originating from slightly differing rotational speeds. This remark points to a shortcoming of the tonal assessment method according to IEC 61400-11 ed.2.1. From the perspective of human hearing, the noise would be as objectionable during unsteady as during steady operational conditions.

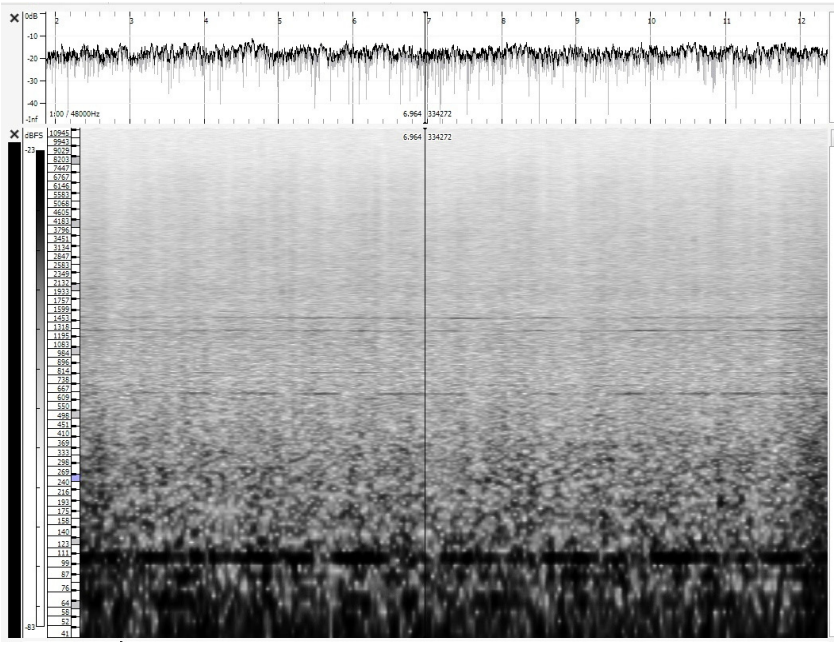


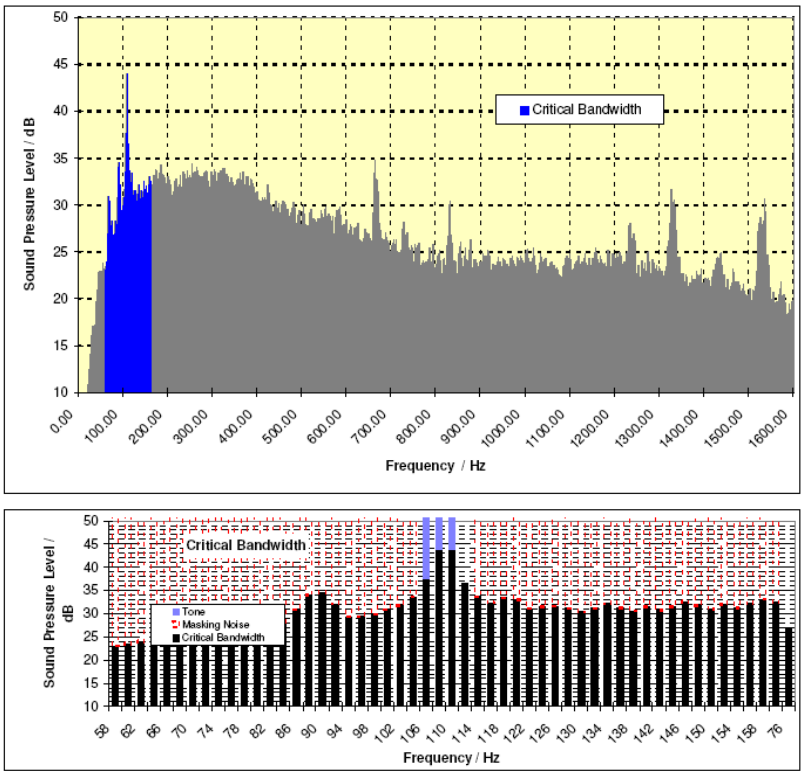
Fig. 7.1: A prototype wind turbine: spectrogram

Spectrum: 806 **8 m/s** TON_IEC_22

frequency: A- weighted

f_t	delta f_c	f1	f2	delta f	$L_{pn,avg,c}$	L_{pn}	L_{pt}	delta L_{tn}	delta L_a
108	101	58	159	2	**30.7**	**46.0**	**45.6**	**-0.4**	**1.6**

	$L_{70\%}$ = 30.0	$L_{navg\text{ - tone}}$ = 31.3		L_a =	-2.0
Correction for Background noise:	L_n = 19.1	$L_{pn,avg}$ = 31.0		Correction:	0.3



Example of Tonal Assessement for a Standardised Wind Speed of 8 m/s (108 Hz)

Fig. 7.2: A prototype wind turbine: tonality assessment. Source: DEWI.

Unusual sounds

The IEC standard [1] recommends documenting the “unusual sounds” or “noise that is irregular enough in character to attract attention”.

Such sounds might occasionally appear during short periods of time and are usually not significant for the assessment of the sound power level or of the tonality of the wind turbine. They must however be documented because they could give a hint about the condition of individual wind turbine components or be decisive for the acceptance of the wind farm project by the neighbours of the wind farm.

An example is given by a yaw geared-motor noise which is usually not objectionable but which might become a problem for the neighbours of the wind farm if, e.g. during calm nights with continuously changing wind directions, the wind turbine would correct its orientation every now and then. Figure 8 shows a spectrogram of the yawing period before and after start of operation of a wind turbine.

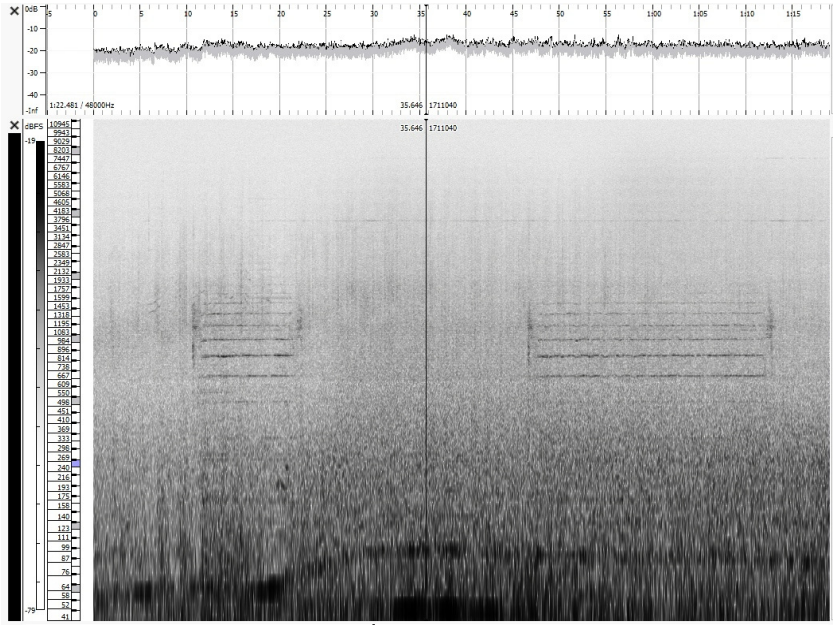


Fig. 8: Yaw geared-motor noise

Unexpected noise

Unexpected noise components can give a hint that the wind turbine runs in an unusual operational mode or that a component or a setting deviates from the specifications. In such a situation, double checking with the client is recommended before proceeding with the acoustic noise measurements.

A sample recording was made on the ground in the vicinity of a wind turbine at about 30 m distance. The spectrogram in figure 9 shows a low rumble tone (50 Hz) which was not expected and turned out to be related to an unusual type of gearbox. The high frequency components around 2.5 kHz which could be heard close to the wind turbine are due to the electrical power converter. At a larger distance of the wind turbine they were less of an issue than the rumble tone.

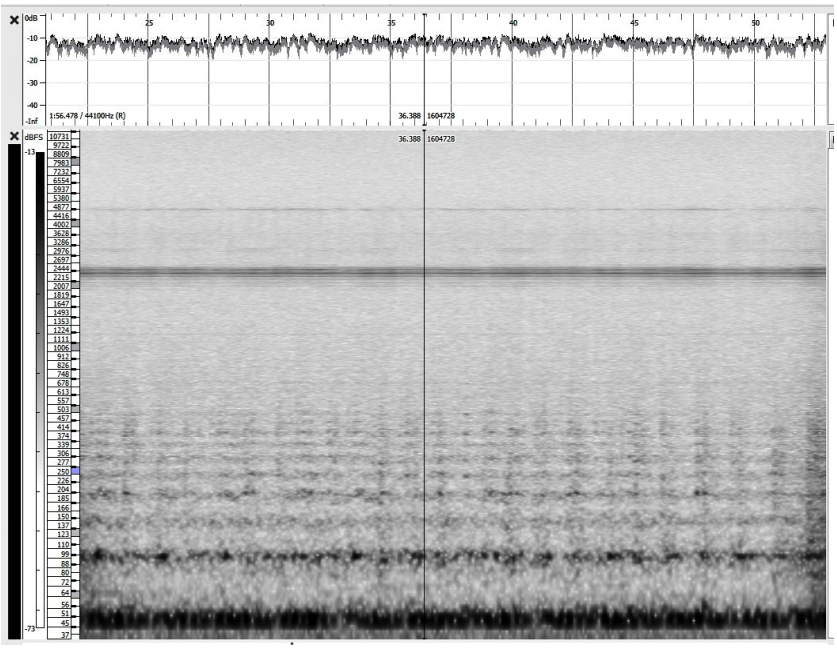


Fig. 9: Unexpected very low frequency noise

State of the art

The sound of a modern three-blade wind turbine has almost no salient features. The very slight amplitude variations over time which can be seen on figure 10 are more likely dependent on the instabilities of the wind field than on the wind turbine itself. Some spectral lines can be identified on the spectrogram but most listeners will not complain about these tones because they are below the hearing threshold. This is in agreement with the results of the standardised IEC tonality assessment method.

Under particular listening conditions these individual frequencies might become clearly audible. This is especially the case when playing back the recording in a room where the low-frequency modes amplify the objectionable tones.

Under open field propagation, this amplification of the low frequency components is not expected to happen but during a long-term exposition to the low-frequency steady frequency components, the complaining neighbour might develop an enhanced sensitivity to this noise.

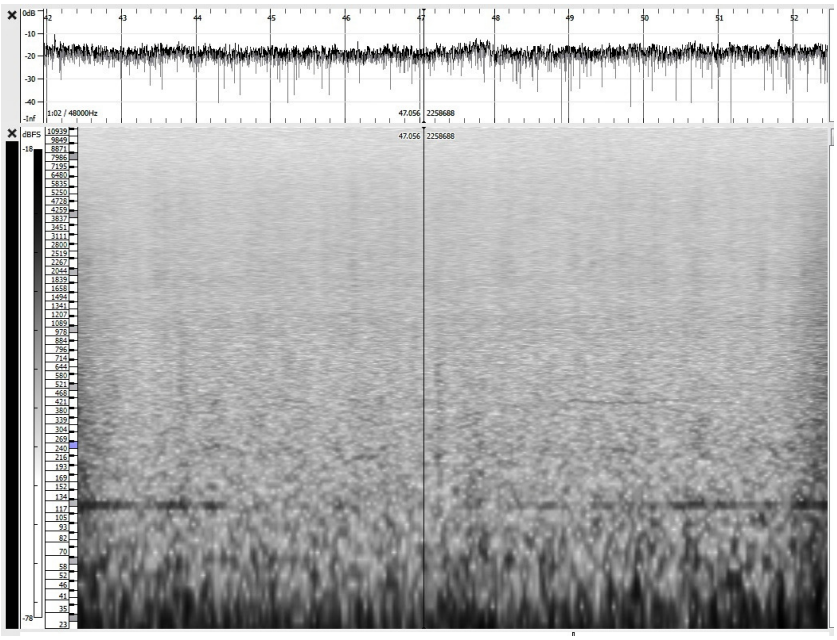


Fig. 10: A modern three-blade wind turbine

Disclaimer

The presented sound samples are derived from experimental or prototype measurements. They are representative of potential acoustic noise problems but are not representative of the final acoustic characteristics of the wind turbine types once their designs have been finalized by the wind turbine manufacturers.

Conclusion

The application of the standard measurement methods leads to reproducible results but the tiny interesting details might get blurred by a large amount of average data.

By carefull listening and identification of individual sound sources, the measurement sequence can be focused on the most relevant operating conditions. Experience shows that trained listening skills help better assess the situation at the test site and the conditions of the measurement.

This helps improve the signal to noise ratio, reduce the measurements uncertainties and identify exception conditions when a correction or a repair of the wind turbine should be performed before the measurement can proceed.

When the measurement report is made available along with a description of the peculiar noise issues, the potential problems can be better understood by the design engineers and the operator of the wind farm. This can open the way to a faster improvement of the acoustic characteristics of the wind turbine or to a better acceptance of the wind farm project.

This presentation has dealt with the wind turbine as a source of noise. At the receptor location, other phenomena should be taken into account which might affect the hearing perception such as the acoustic propagation and the accumulation of the

contributions from several similar wind turbines operating at an almost synchronous speed.

Acknowledgments

This presentation builds up on the experience gained by the author throughout the past years spent at various positions in sound design, wind farm project development, wind turbine trouble shooting, project due diligence before financial close, wind farm acoustic due diligence after commissioning, measurements for certification purposes, training workshops and specification of working procedures. Many thanks to my clients who did not only challenged me but also trusted me. Special thanks to DEWI where I could trace back the history of wind turbine noise analysis and measurement as well as set training and evaluation procedures [4].

References

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