A METHOD TO PRECISELY MEASURE WIND TURBINE PRESSURE DISTURBANCES, INCLUDING NOISE

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Résumé

Les sources de bruits complexes ne sont pas faciles à mesurer lorsque les conditions changent constamment. Les éoliennes sont un exemple de ces sources difficiles. Certains disent que c'est comme de la magie; maintenant vous les entendez et maintenant vous ne les entendez plus. Le son va et vient et change avec la distance, la température, l'humidité, la vitesse du vent, la direction du vent, le cisaillement du vent, l'inversion thermique, l'absorption acoustique, etc. Son bruit et sa détectabilité peuvent également être masqués par divers bruits de fond intermittents. Il y a également un bruit indésirable inhérent au système de mesure lui-même, tel que le bruit de l'écran du vent qui doit être séparé des sources d'intérêt. Celles-ci doivent être identifiées de manière à ce que seuls les enregistrements non nettoyés qui ne contiennent pas d'artefacts soient choisis et que les sources d'intérêt soient analysées. En tant que variables, beaucoup peuvent, parfois, avoir un effet cumulatif sur les sources, augmentant leur présence. Différents récepteurs (humains et animaux) réagissent différemment avec différents types de bruit. Les récepteurs qui vivent dans ces conditions ont tendance à éprouver de la gêne.

Mots clefs : bruit de turbine éolienne, infrason de turbine de vent, tonalité éolienne, modulation d'amplitude de turbine de vent, bruit de turbine éolienne

Abstract

Complex noises sources are not easily measured when the conditions constantly change. Wind turbines are an example of these challenging sources. Some say it's like magic; now you hear them and now you don't. Sound comes and goes and changes with distance, temperature, humidity, wind speed, wind direction, wind shear, thermal inversion, sound absorption, etc. Its annoyance and detectability may also be masked by various forms of intermittent background noise. There is also unwanted noise inherent with the measurement system itself, such as wind screen noise that needs to be separated from the sources of interest. These need to be identified such that only clean records where artifacts are not present are chosen and the sources of interest are analyzed. Being variables, many may, at times, have a cumulative effect on the sources, increasing their presence. Different receptors (humans and animals) react differently with different types of noise. Receptors that live under these conditions tend to experience annoyance.

Keywords: wind turbine noise, wind turbine infrasound, wind turbine tonality, wind turbine amplitude modulation, wind turbine noise

1 Introduction

So how does one measure and record fluctuating sound pressure levels according to standards and monitor the following parameters all at the same time?

- Sound Level Meter parameters including time-variant LAeq, LCeq, LAmax, LAmin, L10, L90, L50, L95, LCeqs (Far Field) etc., Instantaneous and averaged
- SLM parameters time histories
- The fluctuation strength of the modulation (whooshing)
- Time-variant Loudness
- Weather parameters such as wind speed, wind direction, temperature, humidity, light intensity, barometric pressure, etc.
- Infrasound BPFs (Blade-Pass Frequencies, 0.5-20Hz)
- Low frequency noise. (20-200 Hz)
- Audible noise (20-20,000 Hz)
- Spectral distribution of 7. 8. & 9, using Narrowband FFT analysis
- Synchronous audio and video to identify conditions
- Raw time record for playback and listening validating measurement recording
- Tonality according to Octave and Narrowband standards such as in ISO1996-2 Annex C

2 Challenges

Experientially, if one of these parameters is missed at any point in time measurement overall uncertainty can result.

Multiple turbines present the challenge of measuring all these parameters simultaneously and in different locations inside and outside receptor areas. Where there are turbines in multiple directions we expect one source to become dominant but alternating with another, for instance, if wind direction changes. However, the total pressure of all the

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turbines will always be measured at the microphone location using standard outdoor measurement microphones. Type I measurement microphones are preferred due to reliability during harsh Canadian weather. Also, higher frequencies will be absorbed more with distance than lower frequencies. Environmental noise guidelines such as MOECC NPC-350 are used to simplify this complex situation to regulate audible noise levels using A-weighting. Other techniques can be explored as listed above(1-12).

Outdoor weather conditions can deteriorate leading to instrumentation errors and failures.

3 System and setup

The SINUS Soundbook system chosen is PTB approved for the highest world standards for acoustic instrumentation. Type I GRAS 40AZ infrasound measurement microphones also measure full spectrum audible noise such that relationships between audible (20-20,000Hz), low frequency (20Hz-200Hz) and infrasound(.5-20Hz) are measured simultaneously (Fig. 2). New measurement microphones such as the GRAS 146AE are durable in the harshest conditions and can also be deployed in wet and subzero temperatures.

The following typical setup example (Fig. 1) measures all relevant parameters. It was developed as a result of years of experience successfully measuring wind turbine noise. In this case, the 6-hour LAeq is below night time NPC-350 guidelines (35dB) yet there are BPFs (infrasound) present outside. There is low BPF penetration inside a home even though levels vary in different locations within.

4 Guidelines

It is not the intent of this short review to discuss details under which the diverse conditions exist. Ontario has guidelines for audible noise. However, guidelines for C-weighted criteria, amplitude modulation, and low frequency including infrasound have not been established. The system in Fig. 2 meets and exceeds current NPC-350, NPC-300 and other guidelines and is expandable for future changes to these guidelines.

5 Measurements

Tonality measurements can be made in two standard methods, Octave and Narrowband FFT. An example of an intermittent tonal condition is given in Fig. 4. In this case the Tone assessment is made according to ISO 1996-2 Annex C using the Soundbook SAMURAI software.

Theoretically predictable infrasound generated by wind turbines is present as Blade-Pass-Frequencies and harmonics. The example in Fig. 5 demonstrates that pressures are higher at low frequencies inside the home relative to outside the home. Identical GRAS 40AZ Type I measurement microphones were used and can be compared with less expensive micro barometers. The measurement microphones have the added capability to measure audible noise due to a .5-20,000 Hz bandwidth in the same measurement and are traceable to IEC 61094 WS3F.

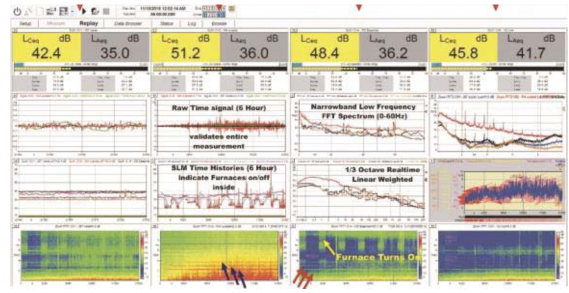

Figure 1: a) Sound level meter (SLM) - Over 100 parameters simultaneously recorded at various locations inside & outside a dwelling. b) Narrowband infrasound FFT spectrum (0-10hz) indicates blade pass frequencies inside & outside a dwelling. c) Weather station parameters. d) Inside basement BPFs are the lowest in this case. e) Inside living room indicates furnace is not interfering with BPFs. f) Outside. g) Inside kitchen BPFs are low in this case. h) SLM time histories short time records. i) Raw time signal (20 second) validates measurement.

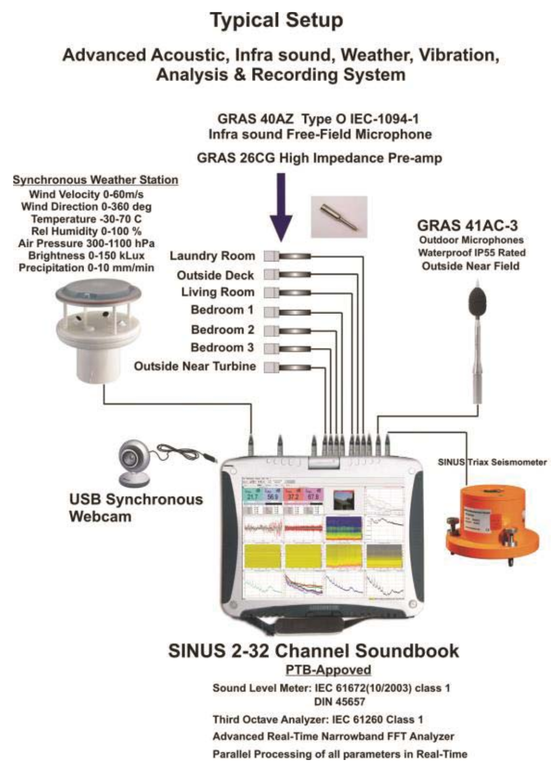

Figure 2: Advanced system setup

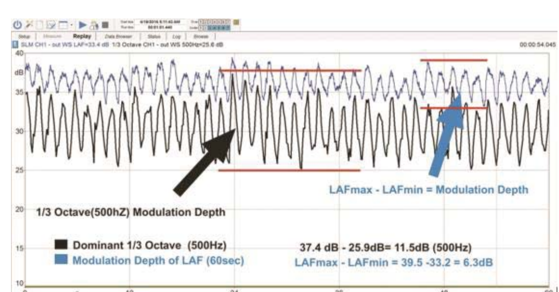

Figure 3: Modulation depth: an example of amplitude modulation or fluctuation of the LAF.

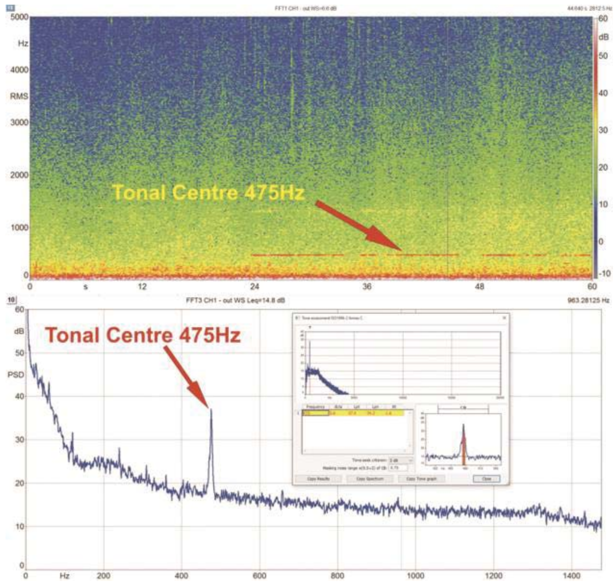

Figure 4: Tonality.

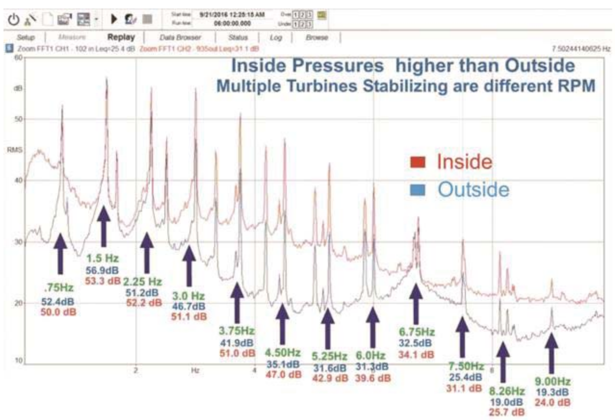

Figure 5: Wind Turbine BPFs (infrasound) Measured simultaneously Inside and Outside a Home.

Wind speed is a primary factor for both power generation and turbine RPM stability. The graph in Fig. 6a and 6b indicate the turbines stabilize at constant 14.4 RPM at wind speeds above 3.5m/s. Colourized arrows in Fig. 6a indicate wind direction. Measurements of temperature, relative humidity, light intensity and barometric pressure are also recorded. Both the sonogram in Fig. 6b and the windspeed in Fig. 6a indicate varying BPF RPMs at 4320 seconds in the 6-Hour LAeq. After 12,000 seconds, the BPFs become stable at 15RPM.

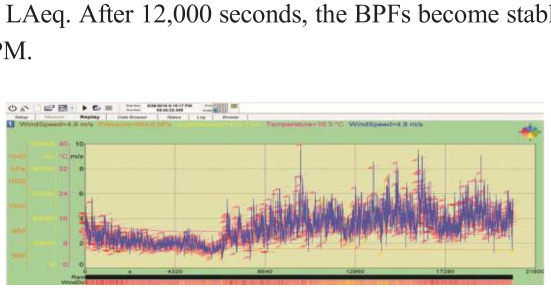

Figure 6a: BPFs Changing with Wind Speed and Wind Direction.

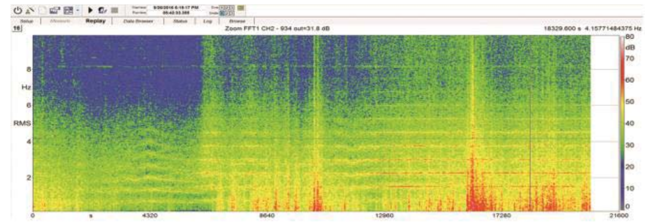

Figure 6b: 3D Sonogram of Wind Turbine Speed Transition by measuring Sub-Audible Pressures (BPFs).

Conclusion

Complex dynamic sources such as multiple wind turbines require advanced measurement solutions and concepts to eliminate measurement uncertainty.

Constant speed wind turbines have stationary and very stable signatures allowing them to be easily measured and separated from random, naturally occurring infrasound using Advanced Narrowband FFT analysis and multi-processing with validation techniques for eliminating measurement uncertainty.

Real-time Analysis is a superior method to produce valid recordings vs. record collection and post-processing off-site. This significantly streamlines the entire measurement process and allows for validation through the constant review of multiple measurement results. This method requires no data editing by third parties if implemented properly and minimizes human error with multiple file handling. The real-time analysis method used also identifies instrumentation setup problems that may occur during long term monitoring as well as other interfering noise sources.

FFT sonograms show fingerprints of turbine BPF's that appear simultaneously at many locations inside and outside homes. These require proper validation before any further calculations are applied.

References

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[2] Acoustic Interaction a Primary Cause of Infrasonic Spinning Mode Generation and Propagation from Wind Turbines, 166th Meeting ASA San Francisco Dec 2013 Kevin A. Dooley and Andy Metelka