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Overview of IEEE standard development on amplitude modulation noise measurement

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Summary

The wind turbine or wind farm Amplitude Modulation (AM) noise is known to be caused by rotating Airfoil/blade broadband noise particularly trailing edge scattering noise and Doppler Effect from blade motion relative to observer [Ref: 2-8], it is also recognized as "Swish" sound. However, envelop of the sound wave appeared to be blade passing frequency; therefore it gives people impression that it is "Low Frequency" with blade passing frequency noise. The AM noise has been complained to be the most annoying to residents near wind farm, thus it has been an important topic in this conference previously. To address this issue, IEEE has started a standard development project P2400 in Oct. 2013, with the mission as below:

This standard establishes standard measurement techniques and methods of analysis to quantify wind turbine and wind farm aero acoustic noise. It can be used to understand wind turbine aero acoustic noise so called low frequency and amplitude modulation noise and potential impacts on surrounding communities. This document provides the standard measurement techniques for wind turbine aero acoustic noise including instrumentation selection, measurement setup, matrix, post-data processing and data analysis.

In this paper, we as the main contributor will report the overview and progress on the standard development, focused on the scope, definition, methodology and work plan, and reveal the post-data processing software design, data analysis using high pass filter and dB_C computation through Matlab functions, as well as theoretical comparison study. We will discuss the some of the key parameters that may affects wind turbine AM noise measurements and issues we have to overcome.

IEEE P2400 vs IEC 61400-11 and Work Plan

When a wind turbine or wind farm is installed near a populated residential community, its noise impact on the community, especially at night, is a great concern and can be a major market entry factor. International Electro-technical Commission (IEC) 61400-11 specifies the acoustic noise measurement standards, which the turbine noise is quantified as a sound power level. Although the IEC noise measurement standards works well to measure overall noise level in sound power level, it did not address the uniqueness of wind turbine aero acoustic noise so called Swishing sound, which is shown as Amplitude Modulation (AM) noise signal in time domain as its main characteristics. The envelop of AM noise has been found to be blade passing frequency, so it gives people impression of "Low Frequency" noise or perceived as "Low Frequency" noise, and was recognized the most annoying to people. Lundmark

published a new method [Ref 2] to measure and analyze the AM noise, which is the main reference for this standard. The objective of the project effort is intended to develop a more effective standardized measurement and analysis method as shown in Figure 4 that can capture the uniqueness of this AM noise then followed with modeling methodology of the noise as shown Figure 5, more detail can be found from [Ref1]. The initial definition of AM noise level is given below.

Wind Turbine Noise Amplitude Modulation Level: The absolute value of the blade passage frequency spectral level of the Fast (125 ms exponential average) Level (dB re 20 μPa) of the A-weighted or C-weighted with 150-250 Hz high-pass filtered sound pressure. The symbol is M_{WF} (dB) where W is the weighting (A or C) and F is the high-pass corner frequency.

M_{WF} quantifies the blade passage rate fluctuations in audible wind turbine noise that is often referred to as "Swish" sound, which has been identified as a major contributor to wind turbine noise annoyance.

To further illustrate the difference between the new standard IEEE P2400 vs IEC 61400-11, Figure 1 below shows the diagram of sound source assumption are fundamentally different while theoretical modeling study followed the procedure description in Figure 5 shows due to different source assumption that even the same source power based on IEC 614100-11 definition (LWA), the rotating source assumption from IEEE P2400 generate AM noise while IEC 61400-11 source assumption does not generate AM noise in the far-field. Table 1 below shows the comparison highlights of difference between the two standards, where the rotating compact source as moving source is the fundamental difference of IEEE P2400 vs IEC 61400-11, because of it, it has to treat the wind turbine aero acoustic in time domain. Also due to wind turbine aero acoustics has stronger noise directivity in the front of turbine [Ref 5, 6], so that the microphone is placed in front of testing turbine for the new standard.

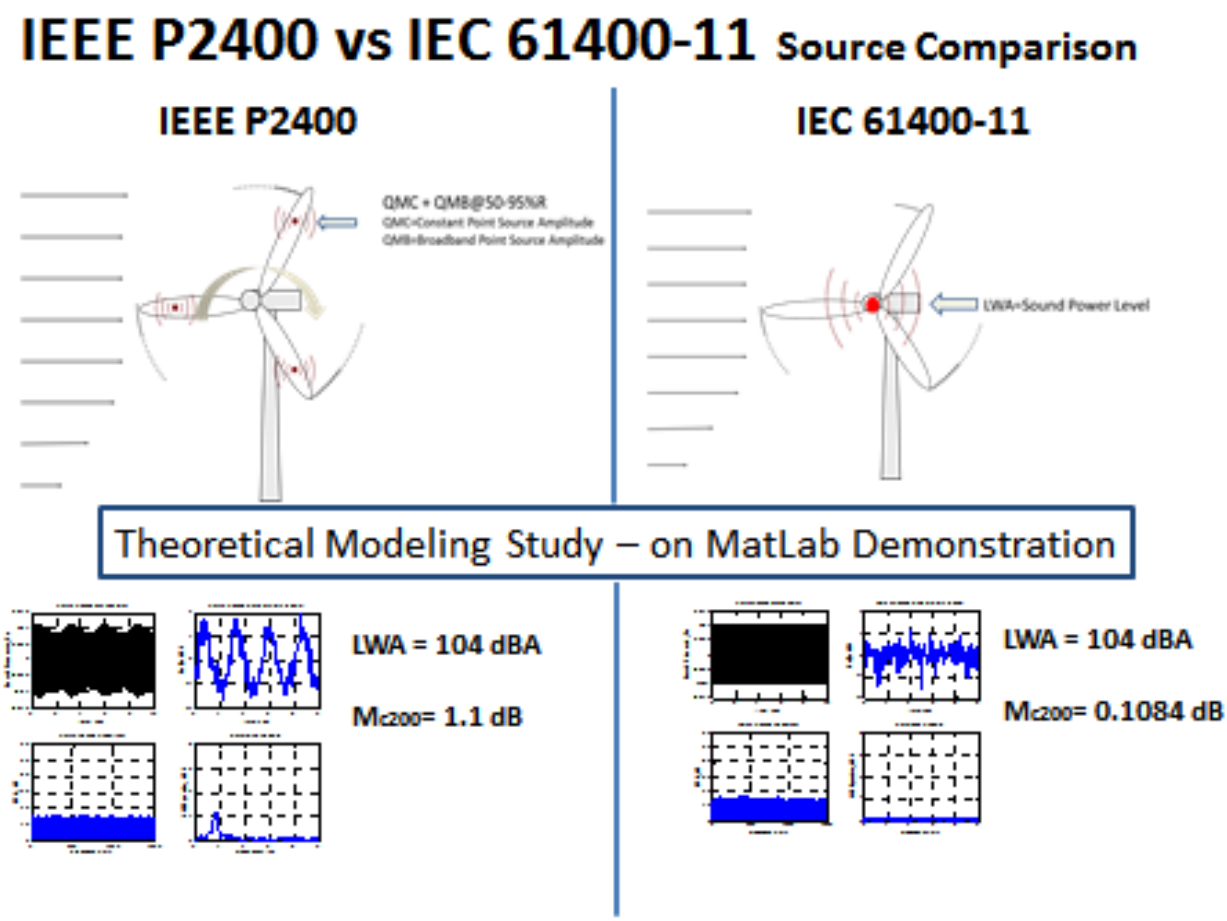

Figure 1, IEEE P2400 vs IEC 61400-11 noise source assumptions and modelling analysis result comparisons

	IEEE P2400	IEC 61400-11
Mic (near-field for WT)	Yes (in front of WT)	Yes (behind WT)
Mic (far-field for Wind Farm)	Yes	No
Sound Source Assumption	Rotating Compact	Static Point Source
Low Frequency/Infrasound	(Yes) /(yes)	(Yes) /no
Mechanical Noise	No	Yes

Table 1, IEEE P2400 and IEC 61400-11 Comparison Highlights, () indicates it's optional

Table 2 below has laid out the key tasks and milestones for the project; it has been progressing well with all the supports from sponsors and anticipators.

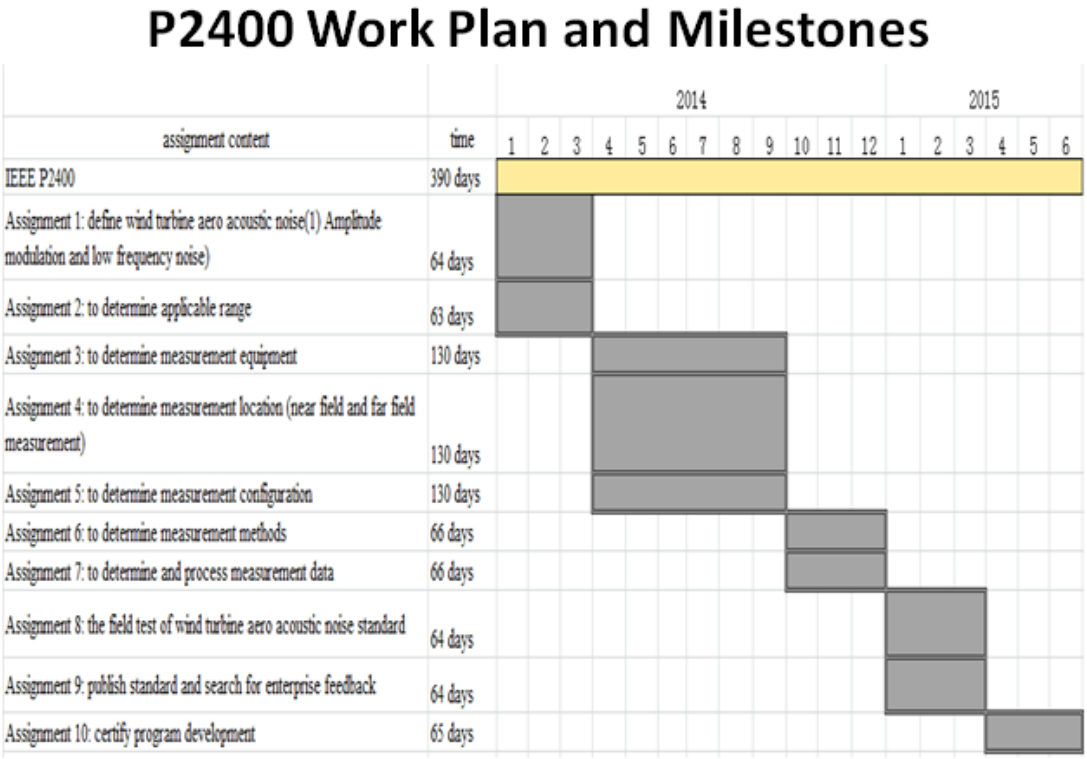

Table 2, IEEE P2400 Work Plan and Key Milestones

Measurement and Analysis Method

With extensive wind turbine rotor aero acoustic noise research from Ref 1 to 9, we had developed the good understanding on wind turbine aero acoustic noise, AM noise and rotor infrasound noise. In Ref 1 and 2, Lundmark and Xue have defined a way to measure and quantify AM noise as shown in Figure 2. It is important to know although the AM noise shall be measured +45 or -45 degree in the front of testing wind turbine, however, the microphone positions with 30 degree increment around testing wind turbine is recommended as optional measurement.

Wind Turbine Amplitude Modulation Noise Measurement and Data Analysis Method

Step 1: to mic acoustic pressure in front of test turbine [Ref 1].
Step 2: to run the acoustic signal through background noise suppression filter, currently use high pass filter with cutoff frequency ~200Hz to capture AM noise.
Step 3: to run dBC calculation to obtain instantaneous sound pressure level dBC.
Step 4: to run Lundmark method [Ref 2] of FFT
Step 5: Peak detection at blade passing frequency to get AM noise amplitude level $\mathbf{M_{wf}}$

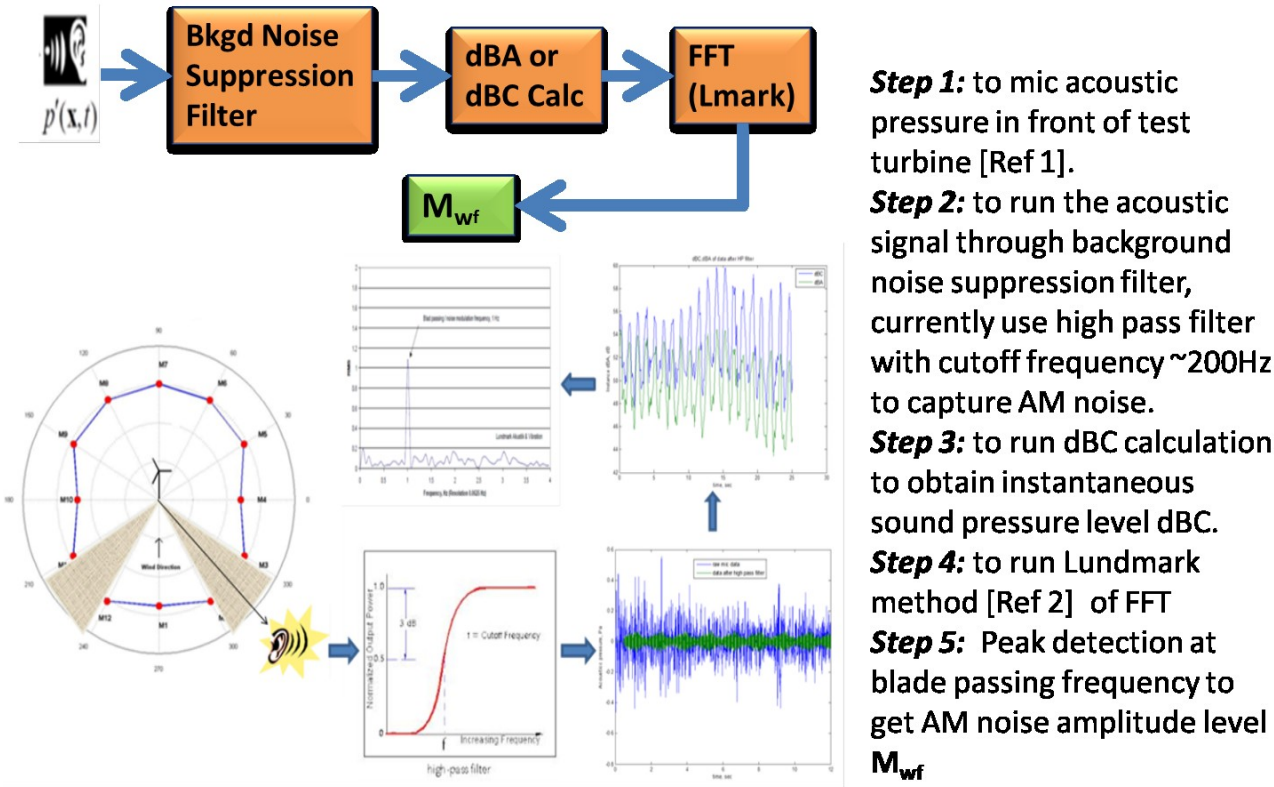

Figure 2, Wind Turbine AM noise measurement and data analysis diagram

While the new standard method is focused on measurement, but it important to understand the modelling method that associated with wind turbine aero acoustic noise is established in Ref 1 and more complete theoretical details can be found in Ref 9. It is understood that wind turbine aero acoustic sources have strong coupling with wind turbine aerodynamics and blade dynamics including elastic effects. Thus the following integrated rotor modelling approach should be utilized and validated with various fidelity models [Ref 1]. The Figure 2 shows the frame work and process where it is shown that airfoil noise should be validated by wind tunnel test inside anechoic chamber, and wind turbine rotor aero acoustic can be validated with field test.

Wind Turbine Aeroacoustics Prediction Method

Step 1: to run BEM-Panel (such as FAST, CHARM or GH Bladed) to get section blade inflow, run CFD to get pressure on airfoil/blade surface.
Step 2: to generate inputs to Flows Williams Hawking (FWH) solution method, the details of methodology and implementation can be found in Ref 9.
Step 3: to run FWH solution to get acoustic wave at defined far–field observer locations
Step 4: to run Lundmark method [Ref 2] of FFT
Step 5: Peak detection at blade passing frequency to get AM noise amplitude level $\mathbf{M_{wf}}$

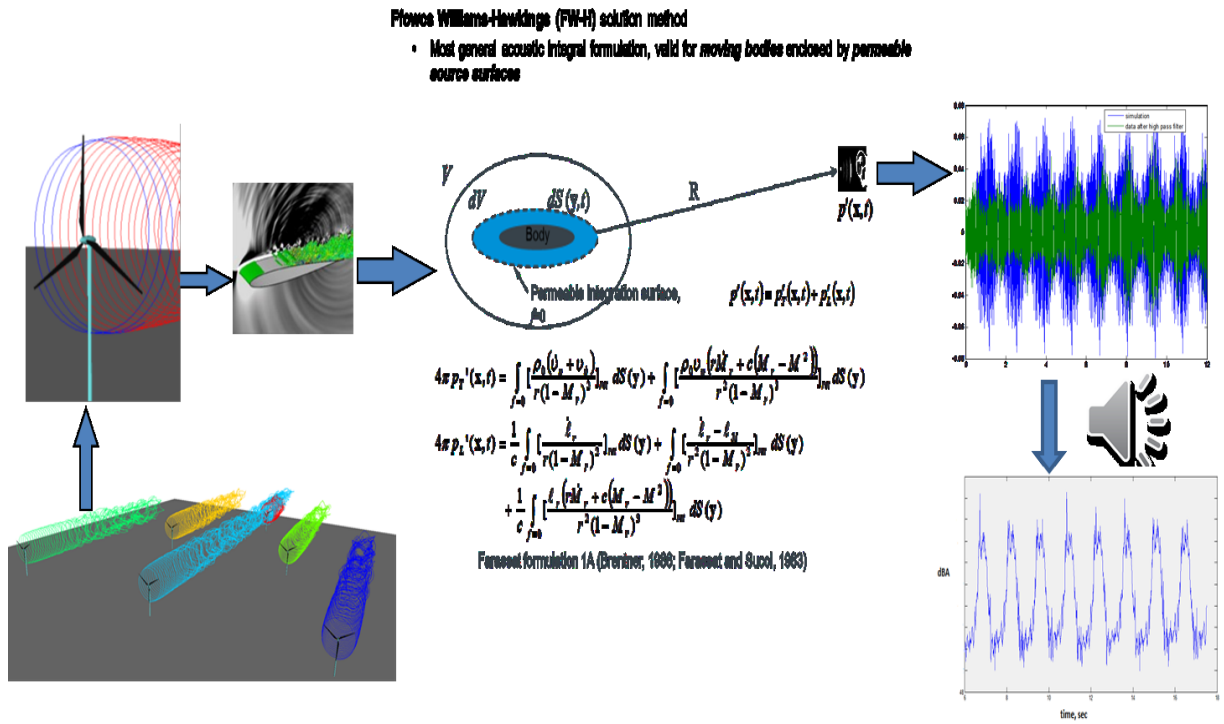

Figure 3, Wind Turbine aero acoustics Prediction Method and Process

Field Test Near-Field Measurement and Analysis Demonstration

To verify and demonstrate the measurement and analysis method stated above, we conducted a near field measurement as shown below left in Figure 4 at Jiao Nan wind farm.

The figure on right in Figure 4 [Ref11] show the microphone raw data in time history in 30 seconds with wind turbine in operation and non operation, then use P2400 post data processor to compute the AM noise level, which show when WT in operation, the AM noise level M_{c200} is about 2dB while WT in non-operation mode, the AM noise level M_{c200} is about 0.5dB, mostly caused by background noise.

Near Field Measurement at Jiao Nan

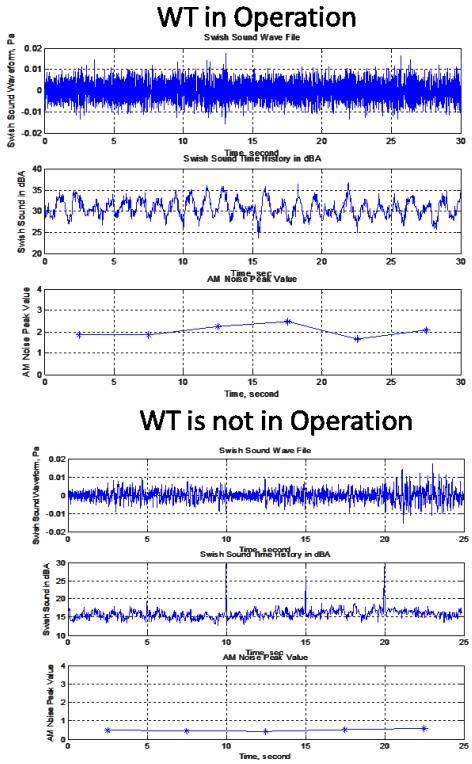

Figure 4, P2400 AM noise near field measurement demonstration

Further measurement and data collection with different wind speeds for AM noise level are shown below in Figure 5 [Ref 11], while the background noise AM level were measured during WT in non-operation mode are shown in the same Figure for comparison. The scattering in the data may be are caused by incoming wind turbulence, gust, wind shear and background noise.

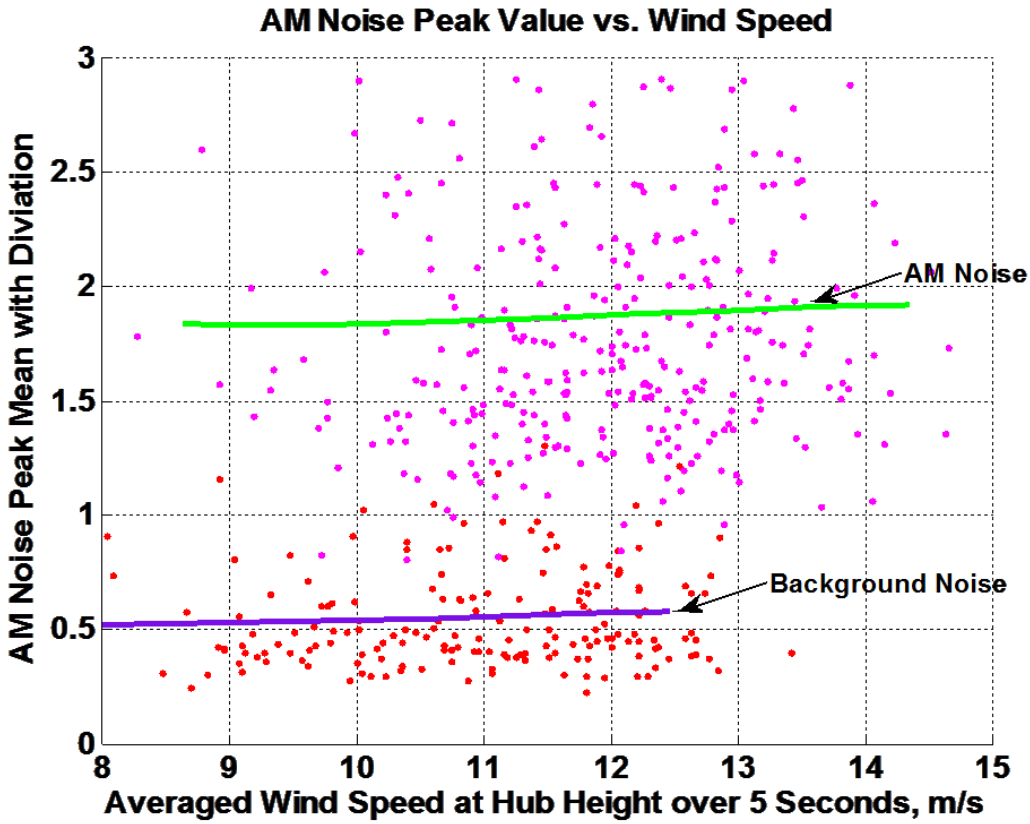

Figure 5, Wind Turbine AM noise measurement and data analysis results

Field Test Far-Field Measurement and Analysis Demonstration

To verify and demonstrate the measurement and analysis method stated above, Figure 6 shows a far-field measurement setup illustration. Figure 7 shows a far-field AM noise measurement at about 1250 meter away from a wind farm, more details can found from Ref 2.

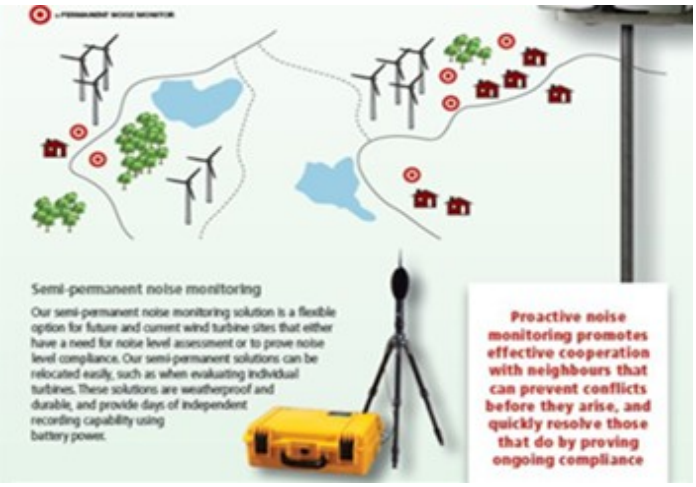

Figure 6, Far-field wind farm noise measurement setup [Ref 10]

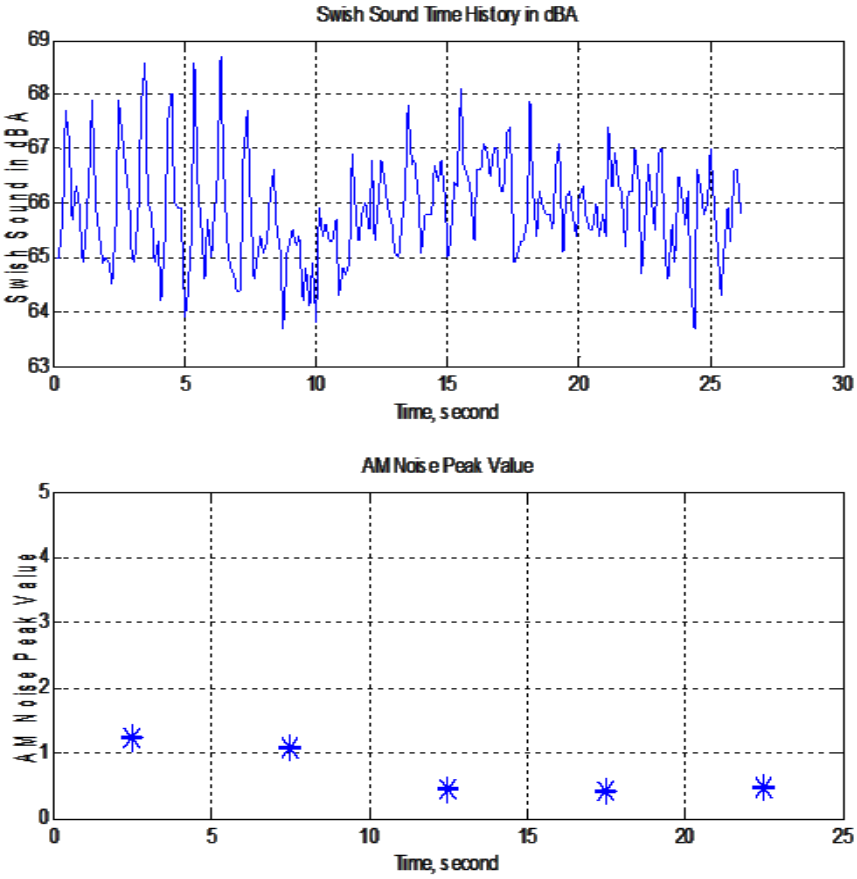

Figure 7, P2400 AM noise far field measurement demonstration [Ref 2]

Although the wind turbine and wind farm AM noise is the focus of IEEE P2400 standard development, it should be noted that the wind turbine rotor induced low frequency including infrasound noise measurement guideline is provided as an optional measurement in the standard. Figure 8 below shows the wind turbine infrasound measurement setup, the more details can be found from Ref 4 from Dr. Walker.

Optional Infrasound Noise (Dr. Walker) measurement configuration

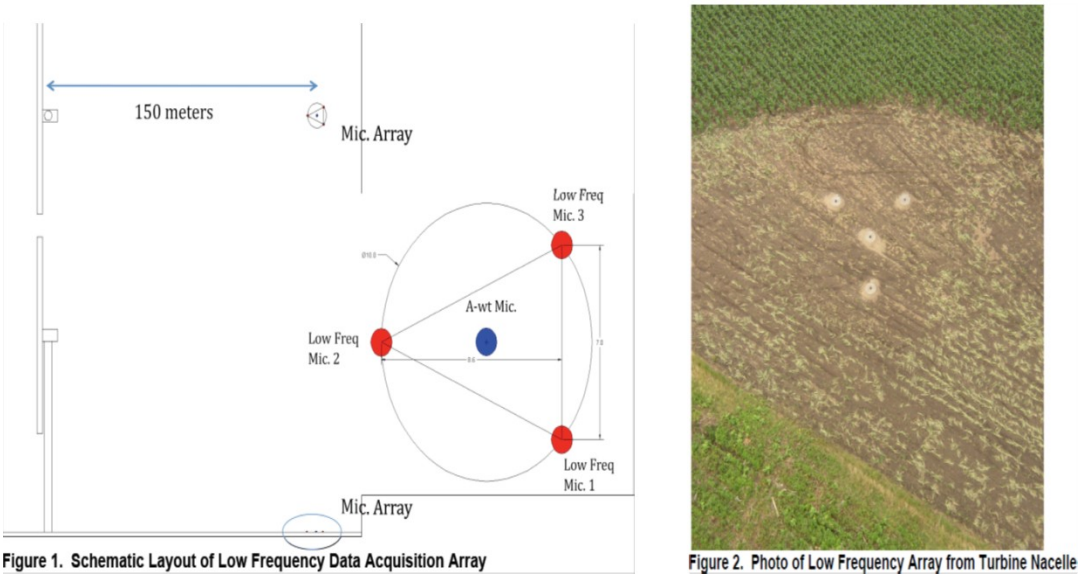

Figure 8, Low frequency Infrasound noise measurement demonstration [Ref 4]

Conclusions

An overview of new wind turbine aero noise standard measurement IEEE P2400 is presented with focus on wind turbine amplitude modulation noise. The key differences between the new standard IEEE P2400 vs. existing standard IEC 61400-11 is presented in detail, where the rotating compact source as moving source is the fundamental difference between IEEE P2400 vs. IEC 61400-11, because of it, it has to treat the aero noise in time domain. Also due to wind turbine aero acoustics has stronger noise directivity in the front of turbine, so that the microphone is placed in front of testing turbine for the new standard. The overview of new standard measurement and analysis with AM noise level definition were given in this paper with preliminary field test as demonstration. From the field test results, it seems the current method uses high pass filter followed with instantaneous dB_C computation has been shown good results in capturing wind turbine amplitude modulation noise; however, still have room to improve to suppress the background, so it will have less requirement on background noise requirements. It is found that wind turbine aero acoustics AM noise has strong coupling with in coming unsteady wind with atmospheric turbulence. The new standard method is intended to establish the standard measurement method with quantified wind turbine AM noise level for the industry, followed with government proper regulation for better control of wind turbine AM noise. Further improvement study will be focused on microphone locations, background noise suppression filter and how to quantify AM noise time history as better way to quantify its impact on annoyance to people nearby wind farm.

Acknowledgement

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