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Amplitude Modulation Noise Analysis and First Look at Off-Shore Wind Turbine Aeroacoustics Simulation Study

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Summary

The wind turbine aeroacoustics noise is defined as the aerodynamically generated noise from rotating blades of wind turbine also recognized as wind turbine amplitude modulation noise or Swishing sound, which is recognized as the most annoying noise to the residents nearby wind farm, sometime can cause people sleep deprivation and even mental health problem. This paper is intended to develop the technique to measure and analyse this amplitude modulation (AM) noise both through measurement with post-data processing and modelling method, which shows some good correlation in this work. The efforts will lead to further understand this noise and make the future standard measurement of this noise possible, hopefully followed with government proper regulation for effective amplitude modulation noise control. Also as Off-shore wind energy growth, we need to understand what impact of the amplitude modulation noise and rotor low frequency noise from Off-shore wind farm impact on environment since the noise can propagate very long distance, especially with thermal inversion effect. In the paper we will as first time take a look at simulation study on off-shore wind turbine aeroacoustics to see its characteristics and possible parameters might be considerable factors.

Background

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 it IEC noise measurement standards works well to control overall noise level from a wind turbine including wind turbine aeroacoustics, it did not address the uniqueness of wind turbine aeroacoustics so called Swishing sound, which is 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, and was recognized the most annoying to people. Lundmark published a new method [Ref 2] to measure the AM noise. The objective of this research effort is intended to develop a more effective measurement method as shown in Figure 1 that can capture the uniqueness of this AM noise then followed with correlation with the integrated wind turbine aeroacoustics simulation [Ref1].

The most effective and cost saving solution to control and reduce wind turbine noise is in the design stage. An integrated wind turbine rotor modeling and analysis tool validated with measured data for aero-acoustics modeling capabilities is needed. This tool will be utilized to perform turbine optimization through advanced airfoil/blade design and rotor control. A strategy

and frame work for an integrated wind turbine model, including wind turbine simulation (such as FAST, GH Bladed, or CHARM,), CFD (Computational Fluid Dynamics, such as Fluent), and CAA (Computational Aero-Acoustics) utilizing the state-of-art technology to model the airfoil/blade and rotor aero-acoustics, is laid out in Figure 2. The computed airfoil and rotor noise in both time and frequency domains due to the airfoil and rotating blade, were presented and compared to available wind tunnel data with anechoic chamber acoustic measurements and the new acoustic array field measurement for validation and correlation [Ref 7].

Methods

With extensive wind turbine rotor aeroacoustics research Ref 1 to 11, we had developed the good understanding on wind turbine aeroacoustics, AM noise and rotor noise. In Ref 2, Lundmark has defined a way to measure and quantify AM noise. Maine Department of Environmental Protection has issued a regulation with provisions for amplitude modulation noise, named Short Duration Repetitive Sounds ("SDRS"), where it defines as a sequence of repetitive sounds that occur within a 10 minute measurement interval, each clearly discernible as an event resulting from the development and causing an increase in the sound level of 5 dBA or greater on the fast meter response above the sound level observed immediately before and after the event, each typically +-1 second in duration, and which inherent to the processor operation of the development. All SDRS events characterized by event amplitude, Amplitude is defined as the peak event amplitude minus the average minima sound level immediately before and after the event, as measured at an interval of 50 milliseconds or less, A-weighted and fast time response, i.e. 125ms. For each 10 minute measurement interval SDRS events shall be reported by number of each observed amplitude integer above 5dBA. In this paper, for more effective measurement of wind turbine AM noise, we propose a new method to capture the AM noise and separate it from the rest of wind turbine noise, the following procedure in Figure 1 is developed.

Wind Turbine Amplitude Modulation Noise Measurement and Data Analysis Method

Step 1: to measure the acoustic pressure in time domain at specified location, which is about 45 degree in front of wind turbine at operation [Ref 4].

Step 2: to run the measured acoustic signal through high pass filter with cutoff frequency 200Hz to capture AM noise.

Step 3: to run dB(C) calculation to obtain instantaneous sound pressure level dB(C).

Step 4: to run Lundmark method [Ref 2] to get AM noise amplitude and blade passing frequency.

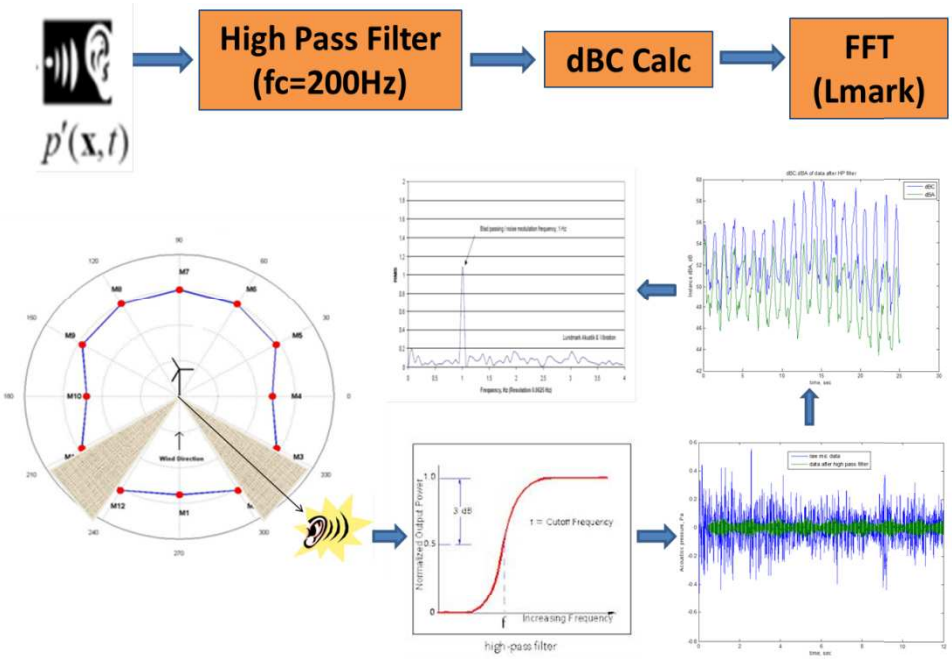

Figure 1, Wind Turbine AM noise measurement and data analysis diagram

It is expected that the wind turbine noise reduction should not be achieved through loss of wind turbine performance in term of energy production. At the same time, it is understood that wind turbine aeroacoustics sources have strong coupling with wind turbine aerodynamics and blade dynamics including elastic effects. Thus the following integrated rotor modelling and simulation 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 aeroacoustics can be validated with field test.

Wind Turbine Aeroacoustics Simulation 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 6.

Step 3: to run FWH solution to get acoustic wave at defined far–field observer locations

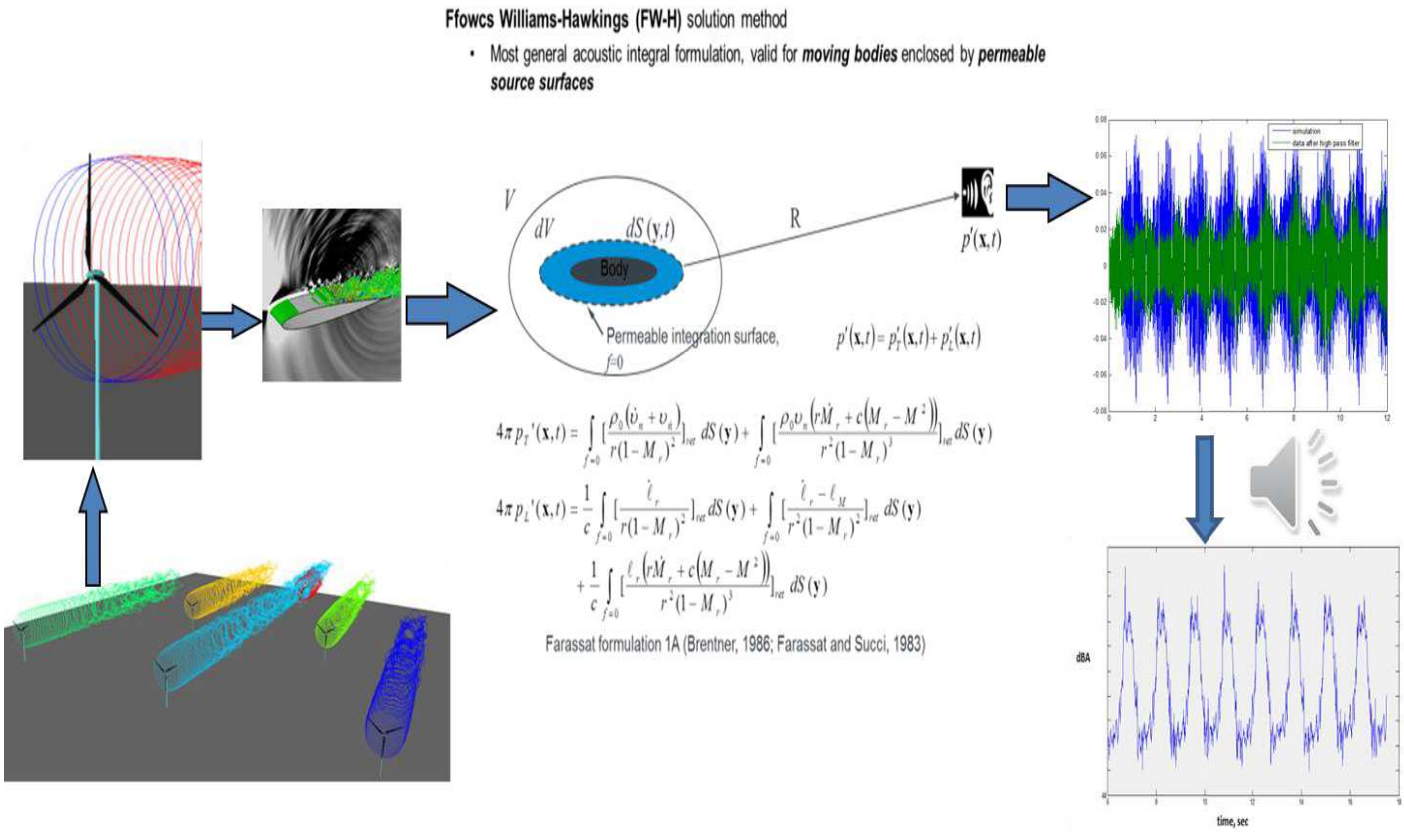

Figure 2, Wind Turbine Aeroacoustics Simulation Method and Process

Results

Following the measurement and modelling methods stated above, below are examples of typical results. Figure 3 the figure on left shows the high pass filter is effective in capturing the AM noise from measured wind turbine total noise, while right figure shows pretty good correlation in key characteristics between measured data and simulation. The measured data has some variations in amplitude might be related the unsteady wind with atmospheric turbulence effect.

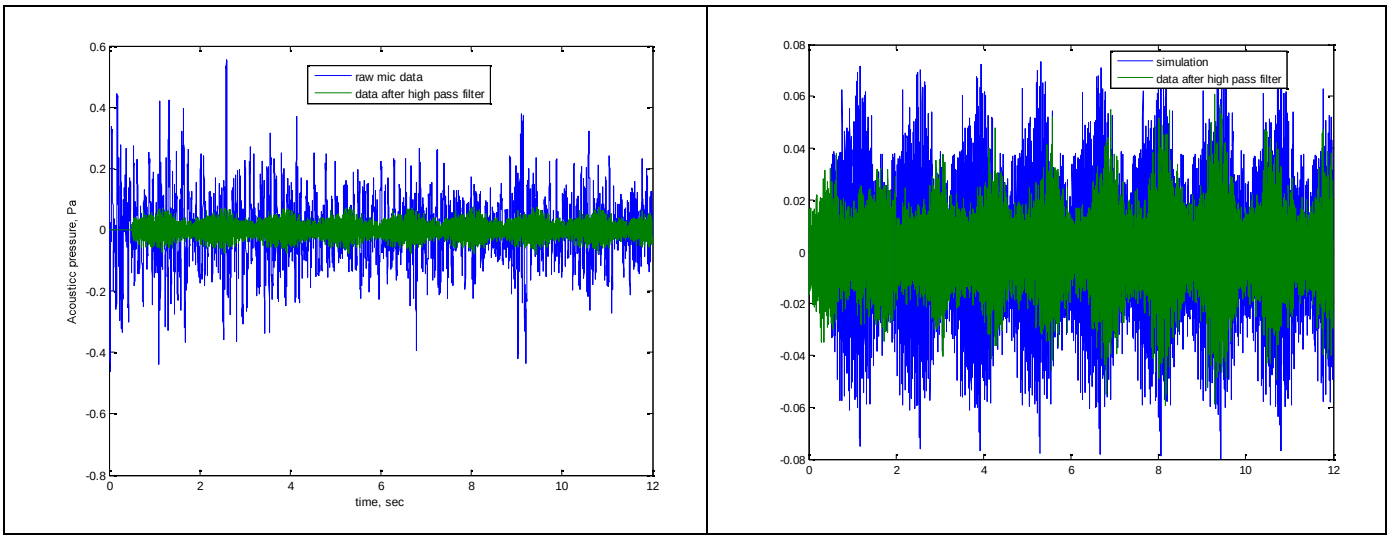

Figure 3, data after high pass filter and correlation with simulation result

The figure on left in Figure 4 shows the time domain spectrum of measured data after 200 Hz high pass filter, it is clearly shown the modulation in time where the low frequency spectrum dominated the energy. Thus, the figure on right is shown that dBC Criteria is better fit to evaluate the modulation signal.

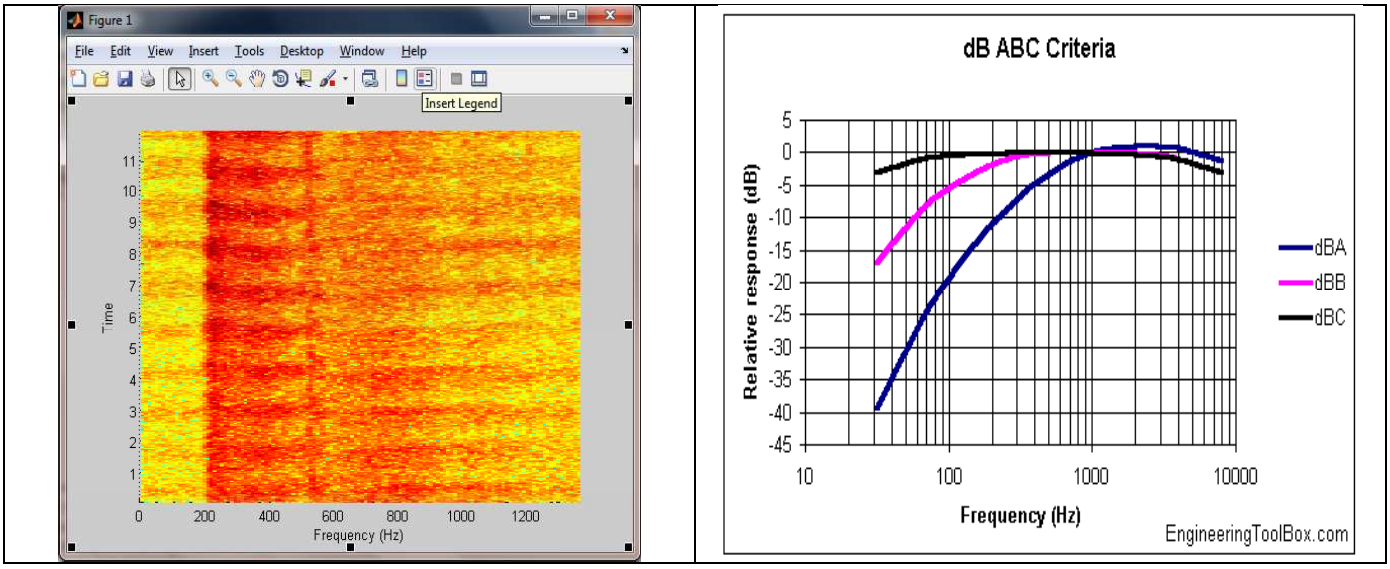

Figure 4, Spectrum of data after HP filter in time domain

The figure on left in Figure 5 shows that the dBC is quite noisy and not as good as dBA to evaluate the AM noise before filter data, however, the figure on right show the dBC works better than dBA to evaluate the AM noise.

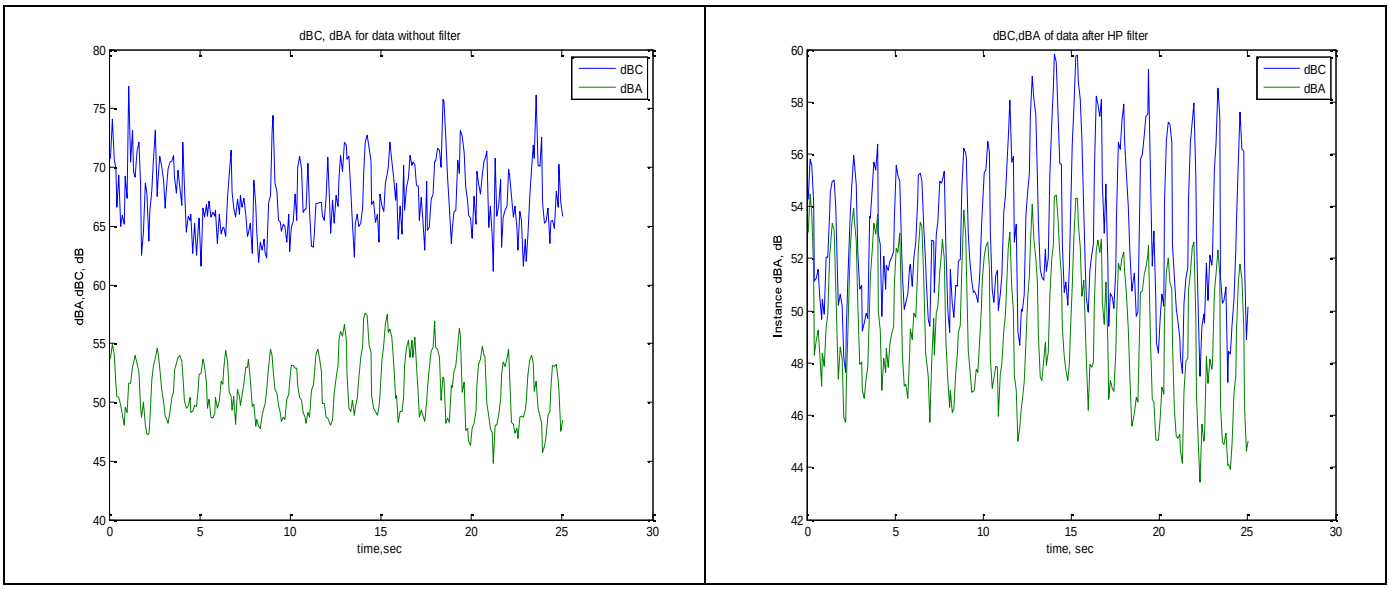

Figure 5, the instantanours sound pressure level (A and C) before and after high pass filter

The figure on left in Figure 6 shows the correlation between measured data and simulation, which shows good correlation in term of the main characteristics, but we also noticed that measured data has more variations due to unsteady wind and turbulence that caused variable rpm. The figure on right shows the spectrum of both measured data and simulation, where the simulation lost some high frequency energy due to relative low resolution in simulation.

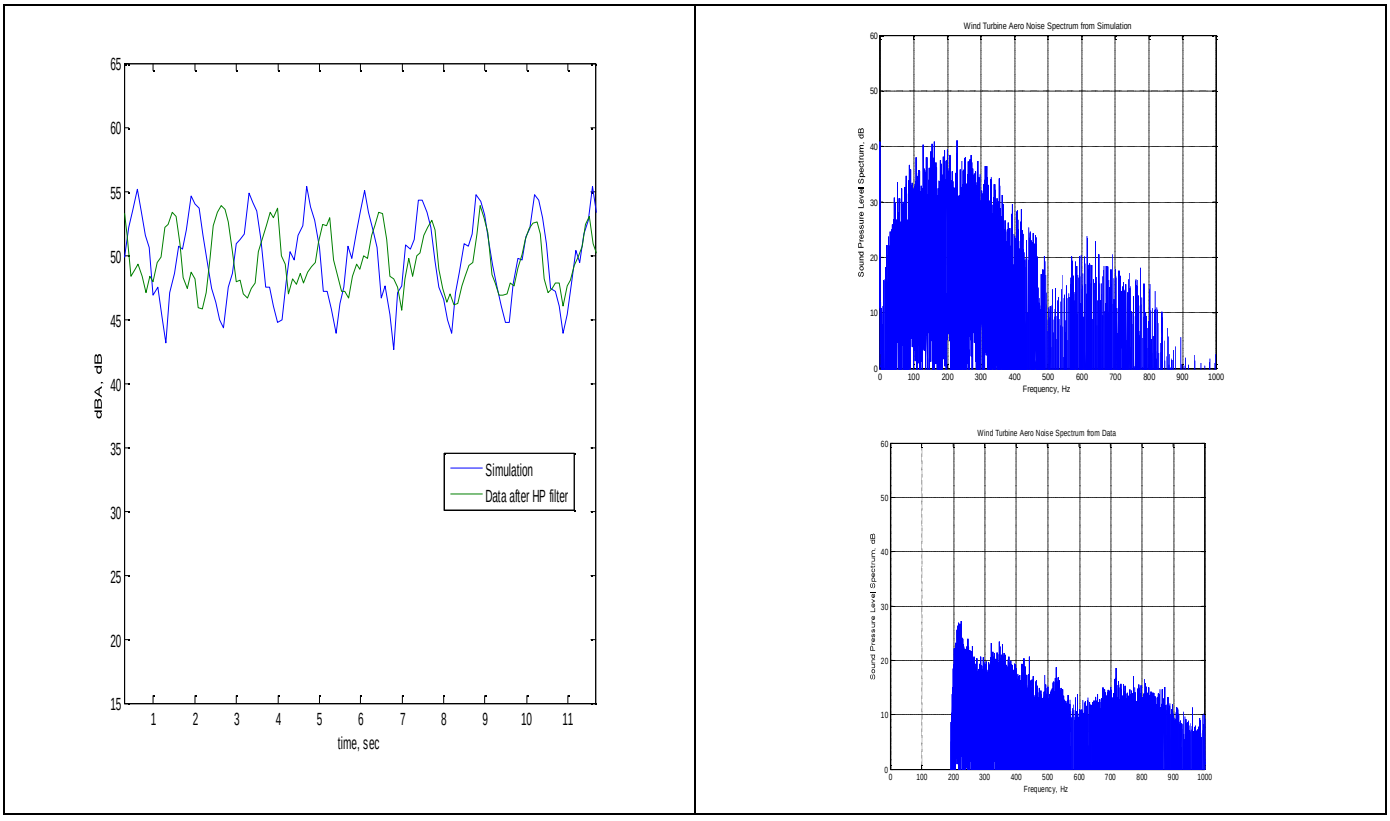

Figure 6, AM noise correlation between measured after high pass filter and simulation

In order to understand the offshore wind turbine aeroacoustics simulation study, the two turbine models have been studied in this paper, one offshore, other onshore for comparison.

1. Offshore turbine: 5Mw with 140 meter diameter with 13 rpm at 8 m/s wind
2. Onshore turbine: 2MW with 100 meter diameter with 15 rpm at 8 m/s wind

For simplicity, we did not include blade tower effects in this study, but focus on rotor low frequency noise and AM noise both at IEC microphone location and 10000 meter far-field. As figure 7 shows below that both AM and low frequency rotor noise that the typical offshore wind turbine has much higher acoustic amplitude than onshore wind turbine at IEC defined microphone location, however, at far-field 10k meter away as we know offshore wind turbine should be at least 10k meter away from the shore, both noise are negligible for offshore wind turbine. Thus, from this study, it shows that offshore wind turbine at least 10k meter away is not big concern for on shore acoustic environment. However, the following thermal inversion effects on sound propagation as shown in Figure 8 might be significant consideration when it happens.

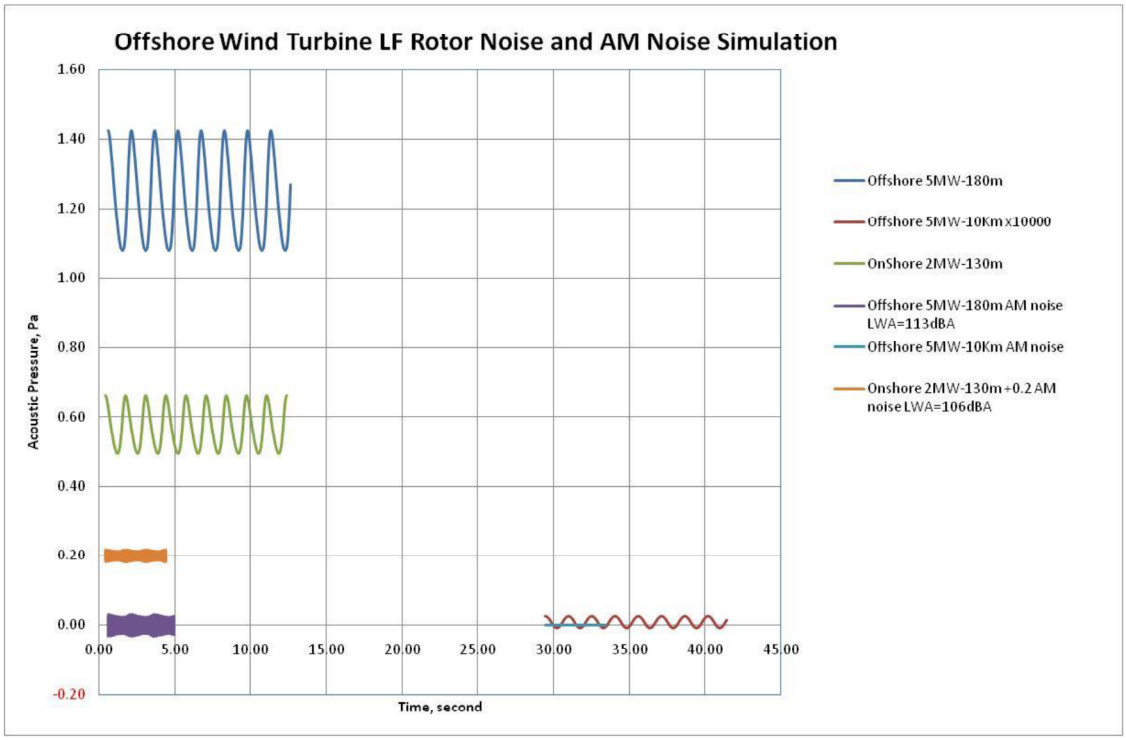

Figure 7, Off-shore wind turbine AM noise and LF rotor noise simulation

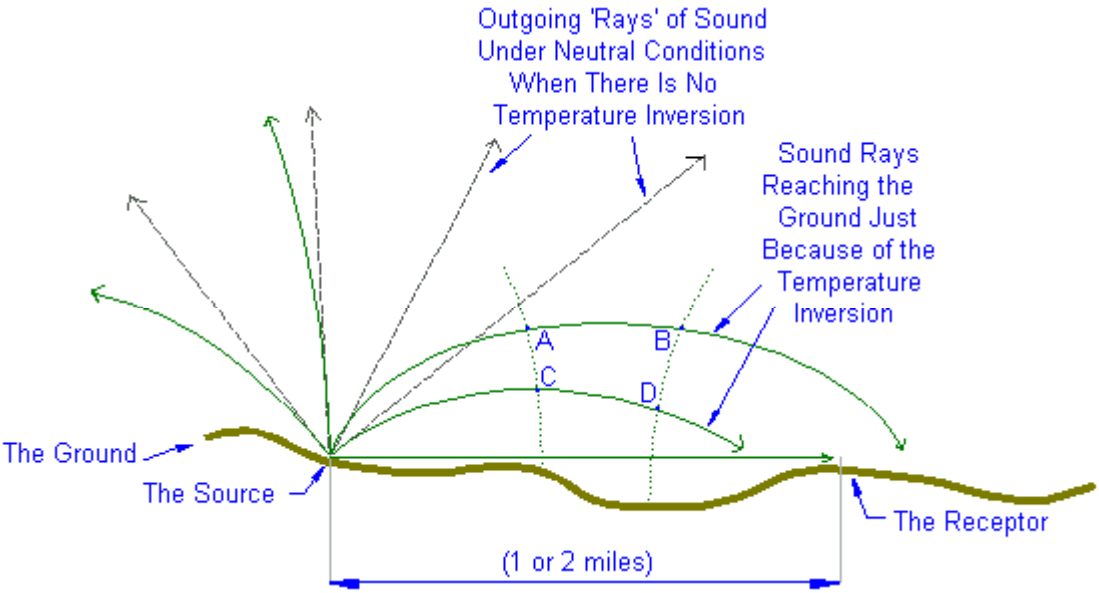

Figure 8, Temperature Inversions & Sound Propagation by Mike O'Connor

The above conceptual diagram shows how the influence of a temperature inversion can sometimes cause distant sources of noise to sound much closer than they really are. All of the curved lines on the diagram, those drawn in green, pertain to atmospheric conditions when an inversion is present; the straight, gray dotted lines depict sound propagation during 'neutral' atmospheric conditions when there is no inversion. The diagram does not pertain to windy conditions, as wind has other effects on sound and inversions don't exist near the ground when wind speeds are high.

Conclusions

A new method with high pass filter followed with instantaneous dBC computation has been shown good results in capturing wind turbine amplitude modulation noise. Also different from IEC microphone location, it is recommended to measure AM noise at 45 degree in the front of wind turbine. Comprehensive wind turbine aero-acoustic simulation system is laid out and shown good correlation with the measured data after 200Hz high pass filter for this case. It is found that wind turbine aeroacoustics AM noise has strong coupling with in coming unsteady wind with atmospheric turbulence. Hopefully this new method may help to establish the standard measurement method of wind turbine AM noise for the industry, followed with government proper regulation for better control of wind turbine AM noise. For the offshore wind turbine aeroacoustics simulation in this study, It is also found the offshore wind turbine aeroacoustics should have minimum impact to far-field on shore acoustic environment, unless the temperature inversion effect on sound propagation might be strong factor when it happens, but is not simulated in this study. Both temperature inversion effect and atmospheric attenuation on offshore wind turbine aeroacoustics should be studied in future.

Acknowledgement

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