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Quieter Wind Turbine through Integrated Aero-acoustic Simulation

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Abstracts

It is well known that noise reduction and control by design is the most effective and cost saving solution. An integrated wind turbine rotor simulation and analysis tool is required with a validated simulation process which includes both rotor aerodynamics and aero-acoustic modeling capabilities. This process can be utilized to perform turbine optimization through advanced rotor design and control. A literature review of wind turbine aero-acoustic studies with an evaluation of available approaches for simulating wind turbine aero-acoustics in the time domain and frequency domain has been conducted. The key noise generation mechanisms including airfoil, rotating blade and rotor noise have been evaluated. A strategy for an integrated wind turbine modeling including VTS (Vestas Turbine Simulation) / CFD / CAA (Computational Aero-Acoustics) utilizes the state-of-art computational modeling to model the rotor aero-acoustics has been laid out here. For the first time, the far-field aero-acoustic wind turbine noise signal at the microphone location specified was simulated which including blade tower interaction and atmospheric turbulence. This simulated noise is being compared and validated with available test data. The initial parametric study including rotor rpm, tilt, swept blade tip, shear flow and atmospheric turbulence have been evaluated to identify the key noise generation mechanisms.

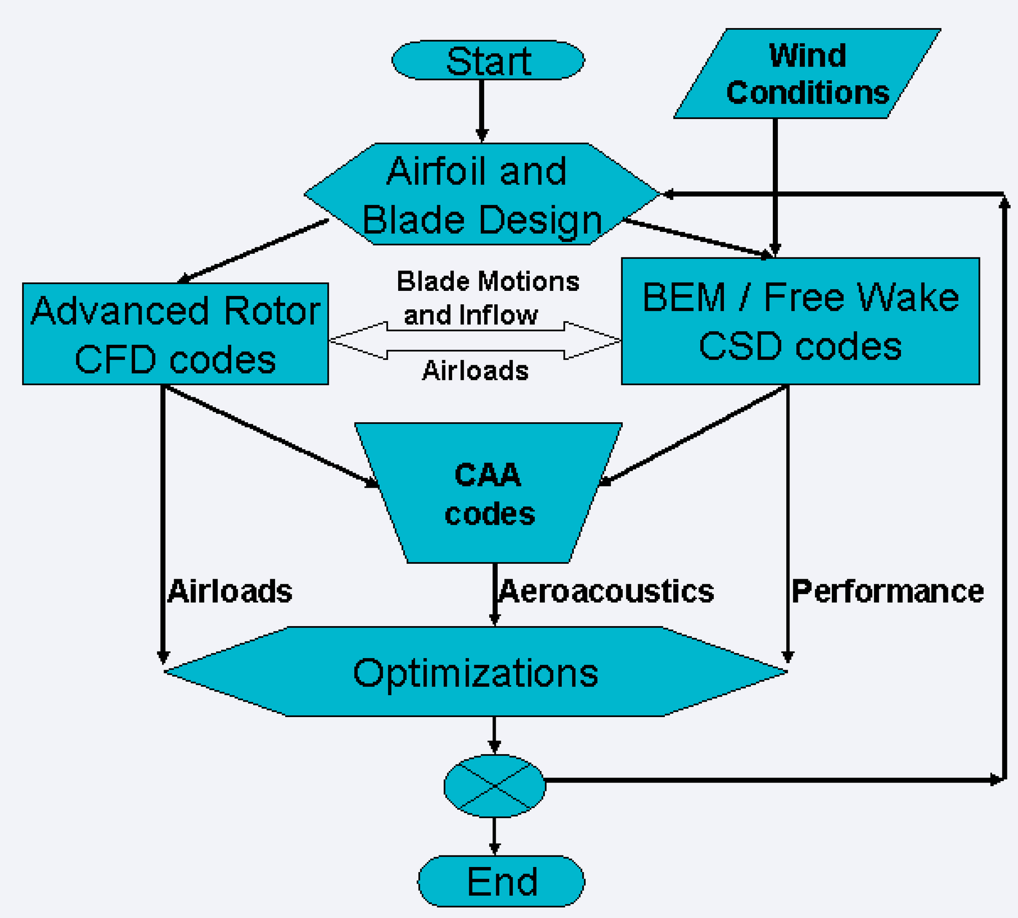
Objectives

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 specify the acoustic noise measurement standards. The objective of this research effort is to develop a validated and integrated rotor simulation with the state-of-the-art aero-acoustic model that can be utilized in rotor design and control for quieter wind turbine technology. The dominant aerodynamically generated noise for large wind turbines will be modeled and studied. The research work here also represent largely collaborated efforts with Sandia National Laboratory, National Renewable Energy Laboratory, Pennsylvania State University, commercial CFD software vendor in US and Riso DTU National Laboratory for Sustainable Energy in Denmark; together they have advanced the modeling methods with validations, and developed the advanced testing methods and measurements as well as design concepts. The ultimate goal is to develop and demonstrate how the state-of-art integrated aero-acoustic modeling/simulation technology with validation can be utilized for quieter wind turbine design and rotor control process, so that the noise generated from a wind turbine and wind farm can be reduced and controlled by an improved installation.

Methods

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 aero-acoustic sources have strong coupling with wind turbine aerodynamics and blade dynamics including elastic effects. Thus the following integrated rotor modeling and simulation should be utilized.

Integrated Wind Turbine Aero-Elastic-Acoustic
Performance Modelling and Design Optimization



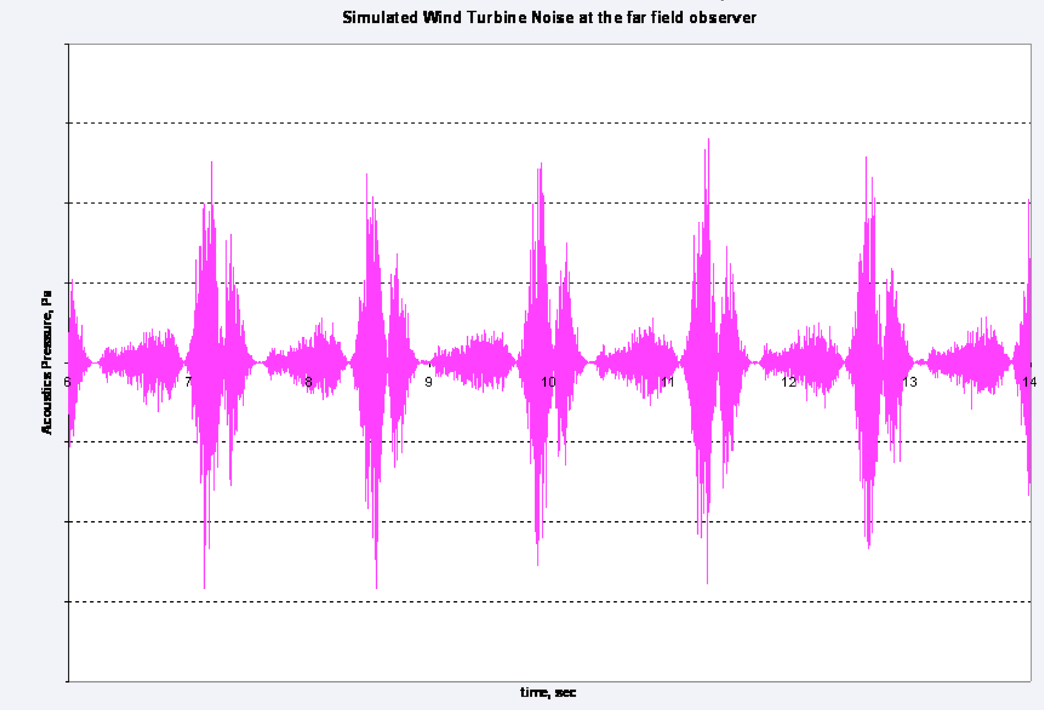
Tool selection for each module in the system is based on a rigorous literature review, trial evaluation, bench marking and validation among various commercially-available software codes or though government and university support. It is found that each software has its own advantages and limitations; therefore tool selection should depend on the specific objective.

For CFD (Computational Fluid Dynamics) tool, evaluation was based on bench marking AcuSolve, CFX/Fluent, STARCCM+, and CFD++. We found each code has significant aerodynamic modeling capabilities with its own pros and cons depending on the objective.

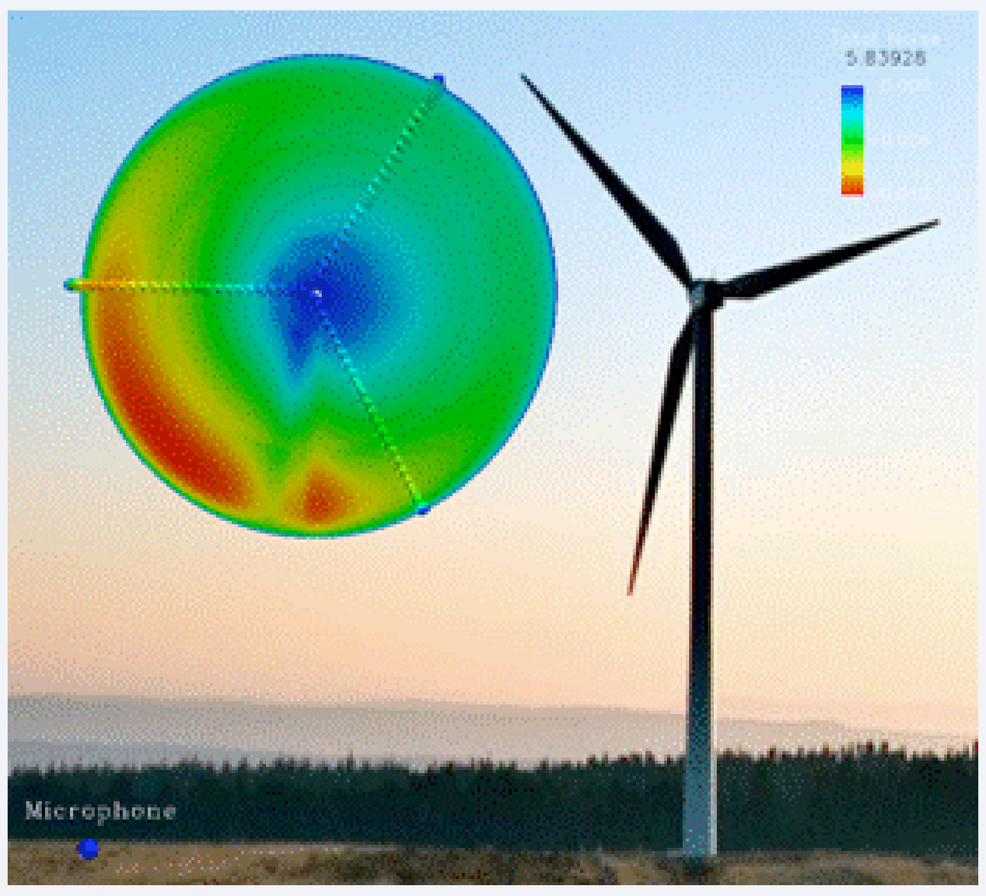
For CAA (Computational Aero-Acoustics) tool, we have evaluated Fluent-CAA, CFD++/CAA++, PSU-WOPWOP, NREL-NAFNoise and FAST, and Riso-HAWTOPT. It is found that using PSU-WOPWOP code is a very efficient way to compute the far-field low frequency noise when it is coupled with a rotor aerodynamics and dynamic modeling based on Blade-Element Method (BEM), while NREL-NAFNoise is a very efficient tool in evaluating typical airfoil broadband noise, such as laminar/turbulence boundary layer noise, separated flow noise, trailing edge bluntness vortex shedding noise, and turbulence inflow noise, which are very important wind turbine aerodynamically generated noise. It should be noted that NAFNoise for airfoil and FAST for 3D rotor are the semi-empirical aero-acoustic noise prediction codes that compute the noise in frequency domain. On the other hand, the CAA code such as PSU-WOPWOP, based on Ffowcs Williams-Hawkings (FWH) equation solution method, is a time domain aero-acoustic noise prediction code, and is more deterministic solution that can be high fidelity modeling when it is coupled with CFD using LES turbulence model or NLAS (Non-Linear Acoustic Solver) model. VTS (Vestas Turbine Simulation code) is an efficient comprehensive wind turbine simulation code which includes airfoil/rotating blade aerodynamics, dynamic with elastic modes, nacelle and tower that includes transmission, generator and rotor controller. VTS was utilized in this study to couple with PSU-WOPWOP for the far-field aero-acoustic noise simulation, followed by parametric study to identify the key wind turbine aero-acoustic noise sources.

Results

Simulated typical Wind Turbine Rotor Aero-acoustic Noise at the far-field observer in 8m/s wind speed



Simulated typical Wind Turbine Rotor Aero-acoustic Sources at Rotor Plan with Tower Interaction Effects



Conclusions

A comprehensive wind turbine aero-acoustic simulation system is developed and implemented. The key wind turbine aero-acoustic noise generation mechanisms including RPM, blade-tower interaction, airfoil broadband noise, blade design such as swept tip, rotor control inputs, and atmospheric turbulence were evaluated through subsequent parametric studies. It is found that wind turbine aero-acoustic noise has strong coupling with aerodynamics and rotor dynamics including elastic modes necessitating the use of integrated wind turbine simulation that includes both wind turbine aerodynamic performance and aero-acoustics noise. Thus the wind turbine aero-acoustic noise reduction can be achieved with rotor design and control optimization while considering both wind turbine performance and noise at the same time.

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