SIMULIA CO-SIMULATION ENGINE PROVIDES NEW INSIGHTS INTO THE MULTIPHYSICS OF WINDPOWER

Abaqus structural analysis couples with fluid and control software to model complex signal-field interaction for many industries

Unlike a tree, a towering wind turbine should only bend slightly with the wind to avoid any collisions between its components. Its blades—now as long as 100 meters in some commercial designs—must withstand, yet also change pitch in response to the onslaught of variable wind speeds, transforming rotational velocity into electrical power.

If the wind gets too strong the turbine must be stopped as quickly as possible without damaging its expensive components. Understanding the multiphysics that result when blades, tower, generator, gearbox and wind interact is an exercise in extreme complexity for windpower engineers. But it's also a critically important exercise in terms of helping the wind industry optimize turbine performance to reduce the overall cost of this increasingly prevalent source of clean, alternative energy.

"Modeling flow conditions for wind turbines is especially challenging," says Stefan Sicklinger, whose Ph.D. thesis [https://mediatum.ub.tum.de/download/1223319/1223319.pdf], written at the Technical University of Munich, Germany, explores the topic in great depth. "Scalable multiphysics simulation tools are required in order to design and predict the performance, durability and safety of these machines. Such simulations are highly complex because they involve multiple disciplines, but it pays off for a product like a wind turbine for which testing is very expensive—or even not possible at all. The next generations of larger wind turbines are very nice candidates for this kind of modeling because you can't do any testing on them at the real scale."

Sicklinger's Ph.D. work focused on developing new methods and algorithms for co-simulation. In collaboration with Dassault Systèmes, he took on the problem of developing highly realistic models of wind turbine function by investigating new numerical methods. His thesis solved several industrial examples, ranging from a fully coupled fluid-structural-signal interaction with closed-loop control to a fully coupled emergency brake maneuver of a wind turbine with flexible blades. He presented much of his work at the 2014 SIMULIA Community Conference; this case study reflects updates from his recently finished thesis.

The simulation of the emergency brake maneuver of the NREL wind turbine involves the interaction of the generator/gearbox, flexible composite blades, control unit and the three-dimensional flow field. These recently developed co-simulation methods also have potential applications in a number of areas besides wind, Sicklinger is quick to point out.

"This type of field co-simulation can benefit many different industries," he says. "You could model the relationship between an automobile tire and its anti-lock braking system. You could investigate the active shape change of a wing—from an aircraft to a turbine blade—under different flow conditions. Or you could explore the ways in which a duct control unit shapes air inflow to reach a preset temperature. With co-simulation it is possible to analyze and optimize the interaction of control units (signals) with the technical product (fields & signals)."

ALWAYS START WITH GOOD DATA

To begin his wind turbine research, Sicklinger wanted to start from CAD models that were based on real-world data. "Clearly, an experiment needed to be the basis for my simulations in order to validate them fully," he says.

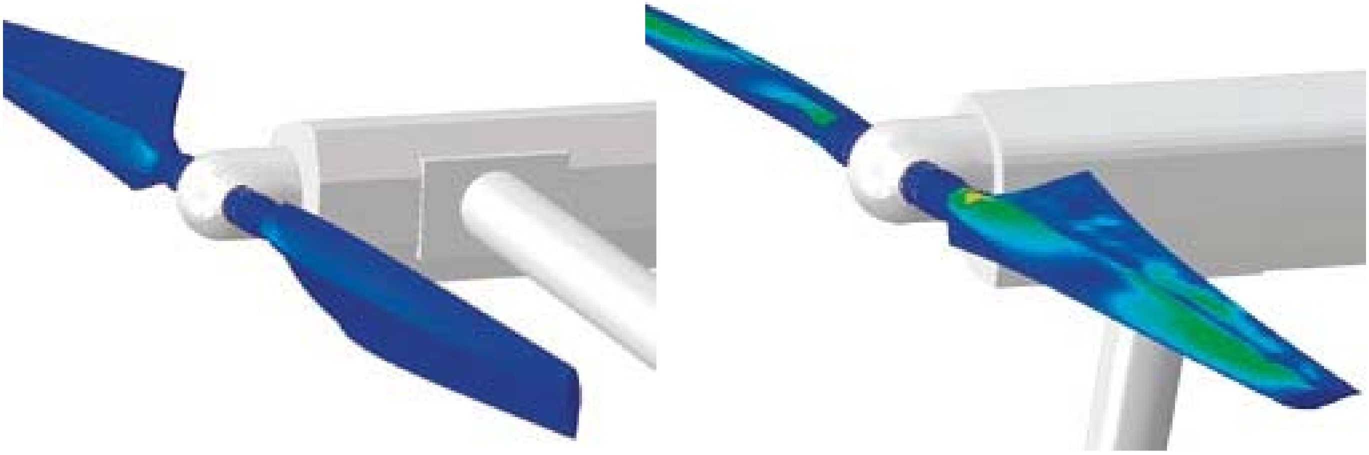

Figure 1. Stresses on outer composite layer of flexible wind turbine blades at different points in time during the emergency brake maneuver. Images courtesy Stefan Sicklinger.

Luckily, substantial measurement data resources were available from the NASA AMES' National Renewable Energy Laboratory (NREL) in Mountain View, California, where the world's largest wind tunnel is located. Commonly used for determining low- and medium-speed aerodynamic characteristics of full-scale aircraft and rotorcraft, a wind tunnel also provides the perfect setting for exploring full-scale, 3D aerodynamic behavior of wind turbines.

NREL, a facility of the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, developed its windpower test objectives to meet recommendations of an international science panel of wind-turbine aerodynamics experts; the data is made available to researchers like Sicklinger to help improve and validate enhanced engineering models for designing and analyzing advanced wind-energy machines.

During the "Unsteady Aerodynamics Experiment Phase VI" at NASA AMES, a research wind turbine with lightweight carbon-fiber blades that measured 10 meters (33 feet) in diameter was set up in the 24-by-37-meter wind tunnel and operated at different angles during wind speeds up to 90 kilometers per hour generated by six huge fans. Probes integrated into the blade surfaces and other turbine structures recorded the pressure coefficients generated on the turbine at different wind speeds.

"The NREL data provided a major advantage for validation of my research because, unlike measurements taken in the field, a wind tunnel can deliver a constant inlet velocity profile," says Sicklinger.

LINKING IT ALL TOGETHER WITH THE SIMULIA CO-SIMULATION ENGINE

To solve the coupled physics challenge of linking four model types—CFD, structure, multibody dynamics and control—into a full-picture solution of an operating wind turbine, Sicklinger employed the SIMULIA Co-simulation Engine (CSE) and a research tool called EMPIRE. This allowed him to explore in great detail how the components of the structure respond to the fluid (wind), are influenced by each other's presence and react to feedback (from the control unit) by adjusting blade pitch.

Due to the research nature of his work, Sicklinger used OpenFOAM, an open-source finite-volume based solver, to analyze the three-dimensional turbulent flow field of air around the blades and rotor. The flexible composite blades (modeled with Abaqus/Standard) and the generator/gearbox (modeled with an in-house code) were connected to the CFD solver through SIMULIA's CSE. To extend the co-simulation to a fluid-structure-signal interaction, MATLAB was added to model the pitch control unit, which varies the angle of the blades in response to the strength of wind flow (Figure 1).

To Sicklinger's knowledge, his work represents a "first" in terms of combining four physics in a wind turbine simulation with such a high level of model fidelity. "We've now got a fluid-structure simulation where the turbine startup procedure is truly physically accurate," he says. His analyses depict the realistic behavior of a turbine startup, run, and emergency stop procedure employed when winds exceed the generator's capabilities.

"You see the turbine going up to speed, pitching its wings very slowly, because it's rotating," he says. "Then once the simulation is running at full speed you can investigate phenomena like local flutter of the flexible blades during unusual events like emergency brake maneuvers. You really need a high-fidelity model like this for such situations."

MODELING THE EMERGENCY BRAKE MANEUVER

So what exactly happens when a wind turbine has to execute an emergency stop maneuver?

"You can't really brake a big turbine the same way you would a car," says Sicklinger. "There is so much energy being generated that in a high wind a sudden stop could completely melt down the whole gearbox. There have also been situations where turbines have overheated and caught fire when they spin too fast in high winds."

In a properly designed wind turbine, when the wind exceeds a preset velocity, sensors provide feedback to the control unit, which automatically slows the rotation down by pitching the wings 90 degrees to reach 100% stall. The blades can no longer extract any energy from the wind flow and slowly come to a standstill. Sicklinger's finished models predict this entire cycle with a high degree of realism [http://youtu.be/vDDsAljF0ug].

Sicklinger ran his massive simulations on a 184 Intel Sandy-Bridge supercomputer; there were approximately 62 million unknowns solved per time step (10,000 steps in total). "It was important that the analyses could be carried out in parallel, because mine was a fairly large model, around one million degrees of freedom on the structure," he says. The analysis was performed with a new co-simulation algorithm that was developed within a research project between SIMULIA R&D and Stefan Sicklinger [http://dx.doi.org/10.1002/nme.4637].

OPENNESS AND ROBUST SOLUTIONS FROM SIMULIA

"My work concentrated on those features that directly influenced the fully coupled simulation," he says. "We found that the CSE is truly as open as they say: it's easy to use and it adapts to a lot of different hardware and software environments, allowing us to develop interfaces to these different simulation tools very easily."

"Abaqus/Standard also proved to be a very robust solver, extremely capable with geometric nonlinearities. Handling the large rotation of a wind turbine was no problem from the point of view of accuracy."

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