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Wind Plant Optimization and Systems Engineering

This message contains a correction to the recently released Wind Plant Optimization and Systems Engineering Newsletter (edition 2). The article, "Toward Computation-Based Certification Using Advanced Uncertainty Quantification Methods," discussed work performed by the UQLab of Stanford University in collaboration with the DAKOTA Project at Sandia National Laboratories. NREL was not involved with the effort. The updated newsletter (below) contains the correct information.

First Quarter, Fiscal Year 2014 (Edition 2)

The Wind Plant Optimization and Systems Engineering Newsletter series from the National Renewable Energy Laboratory (NREL) Wind Energy Systems Engineering Initiative highlights current system approaches to the wind energy research, design, engineering, and development. Each quarterly edition provides short overviews of the integrated, interdisciplinary, and holistic work that is happening in this field. The wind industry community increasingly recognizes the need for a systems approach, and this newsletter serves to support stakeholders who engage with this important work.

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News from Researchers and Practitioners

Integrated System Design and Engineering Valuable for Industry

A recent article appearing in *Windpower Monthly* (September 2013, p. 56) by a wind industry veteran touted the benefits of a systems approach to wind energy research, design and development, and the explicit adoption of methods from the systems engineering discipline to industry practice.The article, boldly titled "Systems Engineering Holds Key to Next Phase" suggested that practices, such as design for full product lifecycles with an emphasis on integrated system design across suppliers and OEMS, would yield overall performance improvements and cost savings. The article also emphasizes the importance of bringing risk assessment more explicitly into the turbine product development process and looking to other industries, such as automotive and aerospace, for examples of best practices. The article represents the growing recognition by wind industry practitioners of the value of systems engineering and the potential for using the discipline's various methods and frameworks as a foundation for improvement in future wind energy technologies.

NREL Releases Modular Framework for FAST

NREL released the first version of the FAST wind turbine aero-hydro-servo-elastic Computer-Aided Engineering (CAE) tool. The new modularization framework includes:

- A merge of modules, such as *AeroDyn* and *HydroDyn*, into the framework
- A splitting out of the controls and electrical drive dynamics into a new *ServoDyn* module and structural dynamics into a new *ElastoDyn* module
- A new driver program supporting loose coupling of the modules
- Mesh-to-mesh mapping schemes between module-independent spatial discretizations
- Interfaces to the recently developed *SubDyn* module for multi-member substructure structural dynamics and *MAP* module for multi-segmented mooring quasi-statics

Toward Computation-Based Certification Using Advanced Uncertainty Quantification Methods

The DOE Office of Science funded a collaborative study by Stanford University and Sandia National Laboratories to develop and demonstrate computational strategies for uncertainty quantification with applications to wind energy. One of the most promising approaches investigated is based on compressed sensing techniques, which enable a cost-effective assessment of uncertainties induced by a large number of factors. This approach is completely non-intrusive, so it can be coupled with a variety of computational analysis tools of different complexity. The main elements of the algorithmic research include the determination of an effective sampling strategy and the ability to use gradient information obtained from the computational tools.

From the application perspective, the researchers considered the UQ analysis of a notional 5 megawatt (MW), offshore, vertical-axis wind turbine (VAWT). As a part of a broader feasibility study, these systems were designed to withstand extreme operating conditions. The quantity of interest considered in this work is the blade load impulse, a time-integrated quantity that serves as a proxy to the maximum load experienced by each blade when subject to an extreme gust event. We quantify the uncertainty of this response subject to gust and blade-geometry variability.

The gust profile is considered to be uncertain by introducing stochasticity in the arrival time, duration, and peak velocity. The research team also considered the effect of uncertainty in the geometry of the blades. This can be a consequence of manufacturing or the accretion of foreign substances such as dirt, debris, and bug splatter. The geometrical uncertainty has been modeled as introducing a perturbation in the aerodynamic lift/drag characteristics of the blade.

The results illustrate the ability of the new compressed sensing methodology to reduce the number of simulations required to quantify the uncertainty in the response. The researchers observed a cost reduction factor of 200 for the VAWT/UQ application. Moreover, indications of the most important input factors can be rigorously computed. Further information and details are available online at the UQLab Stanford website and the Dakota Project at Sandia National Laboratories website.

MIT Analyzes Wind Farm Siting Decisions Under Uncertainty

Wind farm siting processes involve many sources of uncertainty, such as wind resource variability, wake deficiency, and operational availability. These uncertainties lead to a risk of not meeting promised reliable long-term power production. At MIT, under sponsorship of the BP Academy Research program, researchers Ulker, Allaire, Deyst, and Willcox are developing a methodological approach to guide decision-making in the wind farm siting process.

The aim is to provide quantitative measures for the reliability of long-term farm power production and to mitigate the risk of not meeting performance requirements. The research team is developing algorithms for the efficient allocation of modeling and experimental resources. To demonstrate the methodology, the researchers are developing modeling capabilities for the wind resource, individual wind turbines, and wake interaction effects. With this siting modeling capability, they can estimate quantities of interest, such as the capacity factor or farm power density, with quantified uncertainty for a given farm layout. If the performance of the farm does not meet requirements, it is possible to either redesign the layout of the farm or refine the understanding of uncertainties associated with the wind farm. The team is developing approximate dynamic programming methods to efficiently handle these redesign/refine tradeoffs given constraints on modeling and experimental capabilities.

For more information, please contact F. Demet Ulker, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology.

University of Michigan MDO Work Evaluates Potential for Reduction in Wind System Costs

Multidisciplinary design optimization (MDO) provides powerful methods that can help in the design of the next generation of low cost wind turbines. The application of MDO to redesign the 5 MW NREL wind turbine based on low-fidelity aeroelastic and aeroservoelastic models has shown 2.3% and 4.2% reduction in the levelized cost of energy [1, 2]. In both studies, the rotor and tower were optimized simultaneously with stresses, fatigue damage, modal frequencies, and blade-tower clearance as the design constraints. Mass and cost models were used to preserve the entire wind turbine dynamics and life time costs, respectively. High-fidelity models can potentially result in even better designs, and currently the Multidisciplinary Design Optimization Laboratory (MDOlab) at the University of Michigan, Ann Arbor, is developing a CFD -FEM optimization framework using coupled analytical gradient-based algorithms to optimize the rotor with respect to large numbers of aerodynamic shape and structural variables. This effort aims to achieve the best design using optimal aeroelastic tailoring of a composite turbine blade.

[1] Turaj Ashuri, Michiel B. Zaaijer, Joaquim R.R.A. Martins, Gerard J.W. van Bussel and Gijs A.M. van Kuik. Multidisciplinary Design Optimization of Offshore Wind Turbines for Minimum Levelized Cost of Energy, Renewable Energy (In press), 2014. Preprint available online from http://mdolab.engin.umich.edu/content/multidisciplinary-design-optimization-offshore-wind-turbines-minimum-levelized-cost-energy
[2] Turaj Ashuri. Beyond Classical Upscaling: Integrated Aeroservoelastic Design Optimization of Large Offshore Wind Turbines. PhD Thesis, Delft University of Technology, the Netherlands, 2012. Available online from http://repository.tudelft.nl/view/ir/uuid%3Ad10726c1-693c-408e-8505-dfca1810a59a/

Conferences and Workshops

Several conferences and workshops from this past year highlighted wind plant optimization and systems engineering work, including:

- The North American Wind Energy Academy (NAWEA) 2013 Symposium took place on August 6–7, 2013, in Boulder, Colorado. Several of the invited talks focused on systems engineering concepts in wind energy, with a particular focus on integrated turbine-plant modeling and wind farm wake simulations, including those by Jayanarayanan Sitaraman (University of Wyoming), Matthew Churchfield (NREL), Hui Hu (Iowa State University), and Richard Stevens (Johns Hopkins University).
- 2013 Wind Plant Reliability Workshop took place on August 13–14, 2013, in Albuquerque, New Mexico. Reliability is inherently a complex system property of wind plants and a few sessions focused in particular on the influence of upfront design on long-term plant reliability and costs. The slides of the workshop are available on the website.
- AIAA SciTech 2014; the 10th AIAA Multidisciplinary Design Optimization Specialist Conference/32nd ASME Wind Energy Symposium took place form January 13–17, 2014, in National Harbor, Maryland. Complex flow and high-fidelity simulation of wind turbines (rotor design in particular) were emphasized during the week of sessions. The FAST framework was featured in two talks by Qi Wang (NREL) and Michael Sprague (NREL) while the first use of new Wind-Plant Integrated System Design and Engineering Model (WISDEM) was presented by Katherine Dykes (NREL).

Several upcoming conferences feature opportunities to present and attend presentations on wind plant optimization and systems engineering. To organize a meet-up for interested persons at one of the upcoming events or to notify us about relevant upcoming events, please e-mail the Systems Engineering Initiative.

- The European Wind Energy Association (EWEA) 2014: March 10–13, 2014, in Barcelona, Spain. Call for abstracts closed.
- AWEA Windpower 2014 Conference and Exhibition: May 5–8, 2014, in Las Vegas, Nevada. Call for abstracts closed.
- 15th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference: June 16–20, 2014, in Atlanta, Georgia, USA. Call for papers closed.
- The Science of Making Torque from Wind 2014: June 18–20, 2014, in Copenhagen, Denmark. Call for abstracts closed.

Contribute to this Newsletter

We invite all researchers and practitioners to submit their own contributions (up to 100 words along with any weblinks) to share with the greater community. The key requirements are that the work represents a true integrated, interdisciplinary, and preferably holistic approach to wind energy research, design, engineering, and development. Contributions highlighting research, software, or technology development are all welcome. We recognize that, for our industry colleagues in particular, sharing information via this forum may be difficult. However, if there is a recent press release or publication that can be highlighted and referred to, we are happy to share that information as well. We would also like to highlight upcoming relevant conferences and workshops. Please send contributions to systems.engineering@nrel.gov.

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