NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Wind Plant Optimization and Systems Engineering

First Quarter, Fiscal Year 2015(Edition 4)

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.

In this edition:

- Integrated Design of Wind Turbines
- 3rd Wind Energy Systems Engineering Workshop
- Project Force shows benefits to system design through integrated turbine, controls and support structure design
- Sandia and NREL collaborate on a duo of studies on the impact of tip speed constraints on wind turbine design and plant cost of energy
- DAKOTA plugin for OpenMDAO released
- Stuttgart looks at controller-integrated design of offshore floating wind plants
- NREL releases Wind-Plant Integrated System Engineering and Design Model (WISDEM) which uses the Framework for Unified Systems Engineering and Design of Wind-Plants (FUSED-Wind)
- Survey of tools for integrated wind turbine modeling

Integrating Design of Wind Turbines

In this fourth edition of the Wind Plant Optimization and Systems Engineering Newsletter, we are looking at the particular theme of integrated design of wind turbines. Several studies over the last year have looked at more integrated and holistic design approaches for wind turbine technology not just at the sub-assembly level but for the entire turbine itself or even integrated turbine/support structure design for offshore wind plants. Although the fidelity of models for each piece of the system may be lower than used in actual design practice, the use of integrated design practices can yield insights into important system trade-offs that are not visible in a "siloed" and sequential design process. In addition, this newsletter surveys tools for integrated wind turbine design and discusses the features of different approaches. Such studies and tools are a featured topic for the upcoming Third Wind Energy Systems Engineering Workshop that will be held in Boulder, Colorado, USA on January 14–15, 2015.

News from Researchers and Practitioners

Third Wind Energy Systems Engineering Workshop

The Third NREL Wind Energy Systems Engineering Workshop will take place on January 14–15, 2015. NREL is partnering with DTU wind energy to co-host the third biennial event which will broaden the international perspective of the workshop. This year's theme will be on exposing interactions in wind energy systems and exploring how different wind energy stakeholders are addressing them in new, integrated and innovative ways. Highlights include a variety of expert panel sessions on topics such as:

- Cost of energy in today's wind systems
- Challenges and uncertainty in wind system design and operation
- Evolution of wind system standards and design methodologies
- Tools and methods for integrated wind system design and analysis

- Integrated design of wind systems from components to turbines to plants to operations.

For more information including a detailed agenda and registration, see the workshop website.

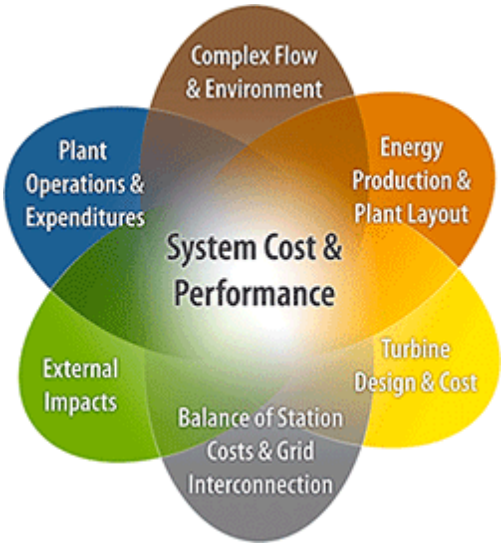

Figure 1: Workshop them of integrated design, analysis and operation of a wind plant.

Project Force shows benefits to system design through integrated turbine, controls, and support structure design

During the summer of 2014, DNV GL held an event to showcase the work performed under a novel project in integrated wind turbine system design: Project for Reduced Cost of Energy (Project FORCE). The study involved a major collaborative design effort within DNV GL's turbine engineering group to look at how various innovations could reduce offshore wind plant system costs upwards of 12%. In particular, the integration of turbine and substructure design was seen as having the potential of providing two percent of that cost of energy reduction. However, the entire study highlighted the benefits of integrated impacts via coupling of various innovations including: enhanced control systems for individual pitch control as well as LIDAR feed-forward control, refined blade design for higher speeds and the use of more slender blades, as well as frequency relaxation of the jacket design frequency constraint. The overall effort was careful to address the impact of the innovations as a collective rather than individual. Particularly novel is the way the study pursued integration of controls design with turbine design and integrated design of the turbine and substructure. Information on the effort can be found on the Project FORCE website.

Sandia and NREL collaborate on a duo of studies on the impact of tip speed constraints on wind turbine design and plant cost of energy

NREL and Sandia recently published two reports on their collaborative effort to study the effects of increased maximum allowable blade tip velocities on overall system cost and performance. The maximum rotor rotation speed for utility-scale wind turbines is generally constricted by noise considerations. Even so, innovations in acoustics and/or siting in remote locations could enable future wind turbine designs to operate with higher tip speeds which may allow for reduced overall system cost.

In the first study, *Understanding the Benefits and Limitations of Increasing Maximum Rotor Tip Speed for Utility-Scale Wind Turbines*, NREL and Sandia performed a sequential optimization of the turbine rotor, nacelle, and tower under two different tip velocity limits of 80 meters per second (m/s) and 100 m/s. In this study, Sandia used a very detailed set of rotor models for the blade structural design [1]. The research team investigated the effect of tip-velocity constraints on system levelized cost of energy (LCOE). The results indicated that a change in maximum tip-velocity from 80 to 100 m/s could produce a 32% decrease in gearbox weight and a 33% reduction in gearbox cost. In the study, the significant reduction in gearbox weight due to the higher tip velocity and lower overall gear ratio was counterbalanced by increased weights for the rotor and/or other drivetrain components and tower. As a result, the increased costs of either the rotor or drivetrain components offset the overall reduction in turbine costs from down-sizing the gearbox. Overall, the team found several design trade-offs and design constraints that come into play when seeking to maximize the benefits of higher tip velocity constraints.

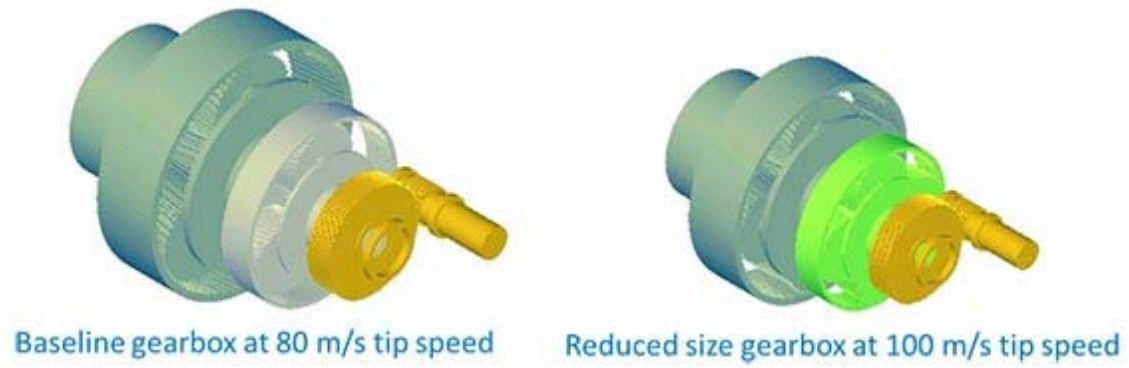

Figure 2: Gearbox sizing for different speed ratio requirements driven by different maximum allowable tip speed constraints.

In the second study, *Effect of Tip Velocity Constraints on the Optimized Design of a Wind Turbine*, which was presented at the Science of Making Torque from Wind Conference in June, NREL used the new system tool, Wind-Plant Integrated System Design and Engineering Model (WISDEM), to perform a full integrated optimization of the turbine and plant for overall system cost of energy over a range of tip velocity limits and site conditions [2]. The research team developed a multidisciplinary, system-level framework to facilitate wind turbine and wind plant analysis and optimization where a global optimization was performed for overall LCOE. As expected, almost all of the cost savings could be attributed to the decrease in gearbox mass because of the reduced maximum rotor torque. Furthermore, the team discovered that extreme increases in tip speed were unnecessary; benefits for maximum tip speeds greater than 100-110 m/s were small to nonexistent.

[1] Dykes, K.; Resor, B.; Platt, A.; Guo, Y.; Ning, A.; King, R.; Parsons, T.; Petch, D.; Veers, P. (2014). Effect of Tip-Speed Constraints on the Optimized Design of a Wind Turbine. 77 pp.; NREL Report No. TP-5000-61726. http://www.nrel.gov/docs/fy15osti/61726.pdf

[2] Ning, A.; Dykes, K. (2014). Understanding the Benefits and Limitations of Increasing Maximum Rotor Tip Speed for Utility-Scale Wind Turbines. Article No. 012087. Journal of Physics: Conference Series. Vol. 524(1), 2014; 10 pp.; NREL Report No. JA-5000-61729. http://dx.doi.org/10.1088/1742-6596/524/1/012087

DAKOTA plugin for OpenMDAO released

DAKOTA, a powerful optimization package from SANDIA National Laboratory, has been integrated into the OpenMDAO framework. This work was done through a collaboration between the NREL Wind Plant Systems Engineering developers, NASA's OpenMDAO developers, and SANDIA's DAKOTA developers. The DAKOTA plugin allows OpenMDAO users to apply DAKOTA optimizers and optimization strategies to their models quickly and easily as well as use a large variety of DAKOTA's methods for uncertainty quantification, sensitivity analysis, design of experiments and more. Two versions of the DAKOTA python wrapper are available, for versions 5.3 and 6.0 of the software. Work continues to integrate the wrappers into the DAKOTA code base, but initial versions of the wrappers for Windows and Linux are available on the OpenMDAO website at http://openmdao.org/downloads/recent/. The DAKOTA driver plugin for OpenMDAO is available at https://github.com/OpenMDAO-Plugins/dakota_driver.

Stuttgart looks at controller-integrated design of offshore floating wind plants

A team at the University of Stuttgart has developed an approach for conceptual design of floating offshore wind turbines that take advantage of controller design though an integrated model [1]. The work, which is sponsored by the EU funded INNWIND.EU project, brings a simplified controller up front into the conceptual design process for a floating turbine which is optimized for performance from an energy and loads perspective subject to stability and other constraints. The study was a first step in a larger effort to look at a much closer coupling of the aerodynamics, structure, and controls design in a floating wind system. For a look at more research on co-design (integrating controls into the system design process), see the Edition 3 newsletter which highlighted this topic.

[1] Sandner, F.; Schlipf, D.; Matha, D.; and Cheng, P.W. (2014). Integrated Optimization

Floating Wind Turbine Systems. Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering. San Francisco, California, USA, June 8-13, 2014. http://elib.uni-stuttgart.de/opus/volltexte/2014/9120/pdf/OMAE2014_sandner.pdf

NREL releases Wind-Plant Integrated System Engineering and Design Model (WISDEM) which uses the Framework for Unified Systems Engineering and Design of Wind-Plants (FUSED-Wind)

This week, the National Wind Technology Center at NREL released a beta version 1.0 of the new WISDEM software. For the first time, this software brings together a publicly available and comprehensive set of wind turbine and plant engineering and cost models that enable design and analysis of entire wind plant systems. The model set includes engineering design tools for the full range of wind turbine components from blades to drivetrains to towers and offshore substructures, as well as plant energy production models and turbine and plant costs for balance of station and operations. The possibilities for research using the new WISDEM tool include assessment of various sources of uncertainty on wind system performance and cost, assessment of new technologies, scenario modeling, multidisciplinary design analysis and optimization, and many more possibilities. In addition, different fidelity models for each sub-system (turbine design, plant cost, energy production, etc) are provided or could be integrated with WISDEM for a great degree of flexibility and scalability of the tool. Over time, additional models will be developed in different areas of the model to provide even more sophisticated analysis capability.

The overall software has been released as open source using the system modeling tool OpenMDAO in a modular framework that has been co-developed by NREL and DTU Wind Energy called the Framework for Unified Systems Engineering and Design of Wind-Plants (FUSED-Wind). OpenMDAO is a software package out of NASA Glenn Laboratories designed specifically for supporting complex multidisciplinary design, analysis, and optimization (MDAO) with a large number of different types of models. FUSED-Wind is a software framework built into OpenMDAO that provides standards for integrating wind turbine and plant models so that models can be easily substituted for one another. The software is in the early stages of development and new functionality will continuously be added over the next year. The development of the framework is open and others are welcome to contact us about contributing and interfacing their own models.

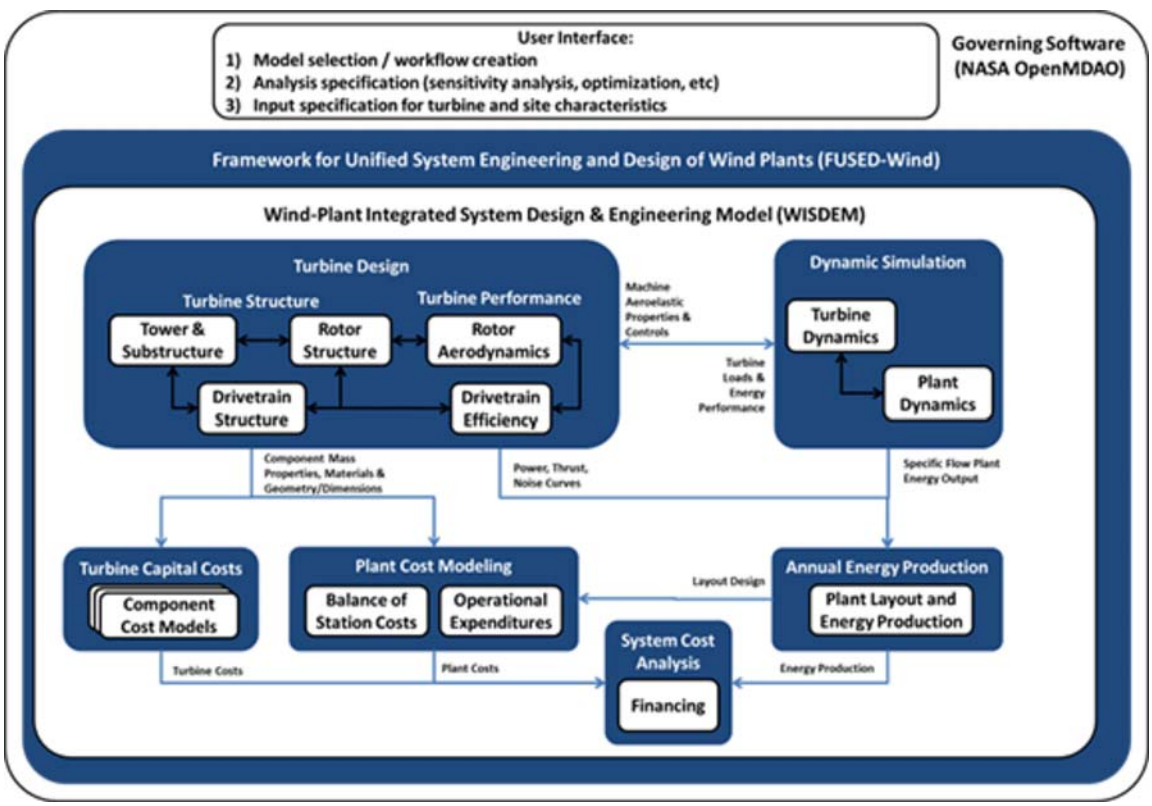

Figure 3: WISDEM and FUSED-Wind on top of the OpenMDAO framework.

A webinar held on Wednesday October 8, 2014, demonstrated the software to interested parties from industry, the DOE community, and academic researchers. The webinar and software are

available for download from the NWTC Information Portal. For more information on the WISDEM software, contact the NREL systems engineering team at systems.engineering@nrel.gov.

Survey of tools for integrated wind turbine modeling

In addition to WISDEM, various other efforts have been developed over the last several years to look at integrated modeling of wind energy systems. There are many traditional tools for modeling wind turbine components and overall system dynamics along with various tools for modeling wind plant performance, cost, and supporting wind plant design. The survey here focuses on tools that go beyond the system boundaries of traditional tools to look at wind turbines and plants in more integrated ways.

Name	Organization	Description
Cp-Lambda	TU Munich, Politechnico di Milano	Integrated design of wind turbine components with system dynamics analysis. Has also been integrated with cost models for cost optimization.
FOCUS6	ECN	Integrated design of wind turbine components with system dynamics analysis.
LMS Samtech Samcef Wind Turbines	Siemens LMS Samtech Subsidiary	Integrated design of wind turbine components with system dynamics analysis.
OneWind and OneWindStudent*	Fraunhofer	Integrated design of wind turbine components with system dynamics analysis at the turbine and plant level.
QBlade*	TU Berlin	Combines airfoil design with performance analysis for HAWT and VAWT rotor design that can be coupled with the FAST aeroelastic code for dynamic simulation.
SOWFA*	NREL	Integrates dynamic wind turbine model with computational fluid dynamics (CFD) software to simulate complex flows within a wind plant.
TOPFARM	DTU Wind Energy	An optimization platform for wind plant layout that accounts for wind turbine controls and operational costs for the plant over time by integrating the cost models with dynamic models for the turbine and wind flow in the plant.

* Indicates model sets that are currently open source.

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.

If you have any questions or comments about this email bulletin, please contact the Systems Engineering webmaster. You can subscribe to this mailing list using our online form, and you can also unsubscribe online.

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.