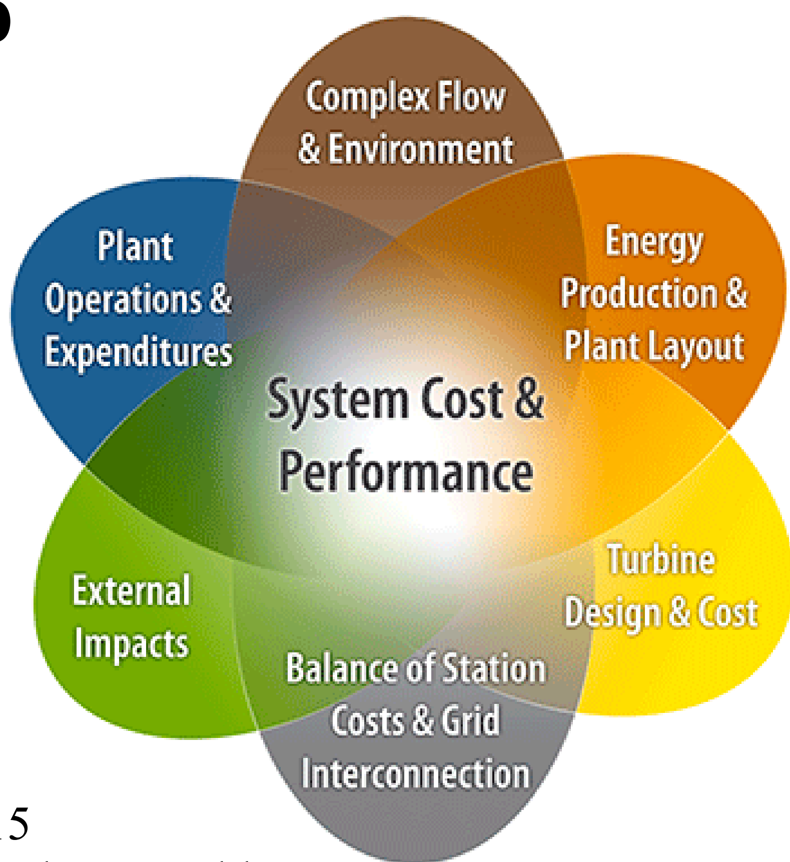
The 3rd Wind Energy Systems Engineering Workshop



January 14–15, 2015
University of Colorado at Boulder
Boulder, Colorado, USA

Sponsored by:

National Wind Technology Center at the National Renewable Energy Laboratory
DTU Wind Energy
Renewable and Sustainable Energy Institute
U.S. Department of Energy Office of Energy Efficiency & Renewable Energy

Workshop Agenda

Overview: The 3rd Wind Energy Systems Engineering Workshop will take place January 14–15 2015. The National Renewable Energy Laboratory (NREL) is partnering with DTU Wind Energy to co-host the third biennial event that 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 address them in new, integrated, and innovative ways. Workshop highlights include a variety of expert panel sessions on topics such as the 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, and integrated design of wind systems from components to turbines to plants to operations.

Short Agenda

Wednesday, January 14, 2015 (CU Boulder University Memorial Center [UMC])	
7:45 a.m.-8:30 p.m.	Registration and Breakfast
8:30 a.m.–12:00 p.m.	Morning sessions
12:00 p.m.–1:15 p.m.	Lunch (with keynote address)
1:15 p.m.–5:30 p.m.	Afternoon sessions
5:30 p.m.–7:30 p.m.	Evening reception and poster session (appetizers)
Thursday, January 15, 2015 (CU Boulder UMC)	
7:45 a.m.-8:30 p.m.	Registration and Breakfast
8:30 a.m.–1:00 p.m.	Morning sessions
1:00 p.m.–1:15 p.m.	Closing remarks
1:15 p.m.–2:00 p.m.	Lunch
2:00 p.m.–5:00 p.m.	Python 4 wind energy tutorial session (The Gallery, UMC 247)
Friday, January 16, 2015 (The Gallery, UMC 247)	
8:00 a.m.–12:00 p.m.	OpenMDAO Tutorial
12:00 p.m.–1:00 p.m.	Lunch (not provided)
1:00 p.m.–5:00 p.m.	FUSED Wind featuring WISDEM and TopFarm tutorial

Full Workshop Agenda: Day 1

Day 1: January 14, 2015	
8:30 a.m.–9:30 a.m.	**Day 1 Opening Remarks** Pierre-Elouan Réthoré, DTU Wind Energy **Opening Keynote Address:** "Challenges and Perspectives in Future Wind Turbine Technology and the Role of Systems Engineering" Flemming Rasmussen, DTU Wind Energy
Theme 1: Challenges and Uncertainty Facing Today's Wind Energy Systems	
9:30 a.m.–10:30 a.m.	**Session I: Cost of Energy for Wind Systems Today** **Moderator:** Christopher Mone, National Wind Technology Center (NWTC) at the National Renewable Energy Laboratory (NREL) Maureen Hand, NWTC Bruce Valpy, BVG Associates Ltd Todd Griffith, Sandia National Laboratories
10:30 a.m.–10:45 a.m.	**Break**
10:45 a.m.–12:00 p.m.	**Session II: Wind Plant Uncertainty – Wind Resource and Financing** **Moderator:** Patrick Moriarty, NWTC Matthew Hendrickson, 3TIER by Vaisala Inc. Taylor Geer, DNV GL – Energy Michael Brower, AWS Truepower Erik Hale, EDF Renewable Energy
12:00 p.m.–1:00 p.m.	**Lunch Keynote:** "A Vision for Systems Engineering Applied to Wind Energy" Fort Felker, NWTC
1:00 p.m.–1:15 p.m.	**Break**
1:15 p.m.–2:15 p.m.	**Session III: Wind Plant Uncertainty – Reliability and Operations** **Moderator:** Shawn Sheng, NWTC Carsten Westergaard, Sandia National Laboratories AnneMarie Graves, Upwind Solutions Keith Parks, Xcel Energy
Theme 2: System Design Methods, Tools, and Processes	
2:15 p.m.–3:15 p.m.	**Session IV: Evolution of Wind Turbine Standards and Design Methodologies** **Moderator:** Paul Veers, NWTC Sandy Butterfield, Boulder Wind Consulting Kenneth Thomson, DTU Wind Energy Graeme McCann, DNV GL - Energy
3:15 p.m.–3:30 p.m.	**Break**
3:30 p.m.–4:30 p.m.	**Session V: Tools for Integrated System Design** **Moderator:** Pierre-Elouan Réthoré, DTU Wind Energy Urs Wihlfahrt, Fraunhofer IWES Karl Merz, SINTEF Energy Research Katherine Dykes, NWTC
4:30 p.m.–5:30 p.m.	**Session VI: Addressing Uncertainty in the Design Process** **Moderator:** Peter Graf, NWTC Pierre-Elouan Réthoré, DTU Wind Energy Paul Constantine, Colorado School of Mines Paul Fleming, NWTC
5:30 p.m.–5:45 p.m.	**Break/transfer to reception location**
5:45 p.m.–7:30 p.m.	**Evening reception and poster session**

Day 1: Opening Session

Session Chair: Pierre-Elouan Réthoré, DTU Wind Energy

Keynote Speaker: Flemming Rasmussen, DTU Wind Energy

"Challenges and Perspectives in Future Wind Turbine Technology and the Role of Systems Engineering"

Abstract: Wind energy has the potential to become the backbone of a future cost-effective, secure global energy supply. This achievement will only be possible by a combined effort on the continuous development, up-scaling, and maturing of the technology in a system engineering context that is facilitated by the parallel development of research-based design tools, procedures, and standards. This presentation will provide a historical perspective on the evolution of the science and the technology and address the challenges and opportunities to reach this goal by further developing and applying an integrated system approach.

Biography: Flemming Rasmussen (M.S. in fluid mechanics from the Technical University of Denmark) is head of the Aeroelastic Design Section at DTU Wind Energy, focusing on the research, development, and application related to aero-servoelasticity, computational fluid dynamics, and software design tools for blades, wind turbines, and wind farms, of existing as well as new concepts. He was employed by DTU in 1978, and has been involved in nearly all aspects of wind energy research and development since then.

Theme 1:
Challenges and Uncertainty Facing Today's Wind Energy Systems
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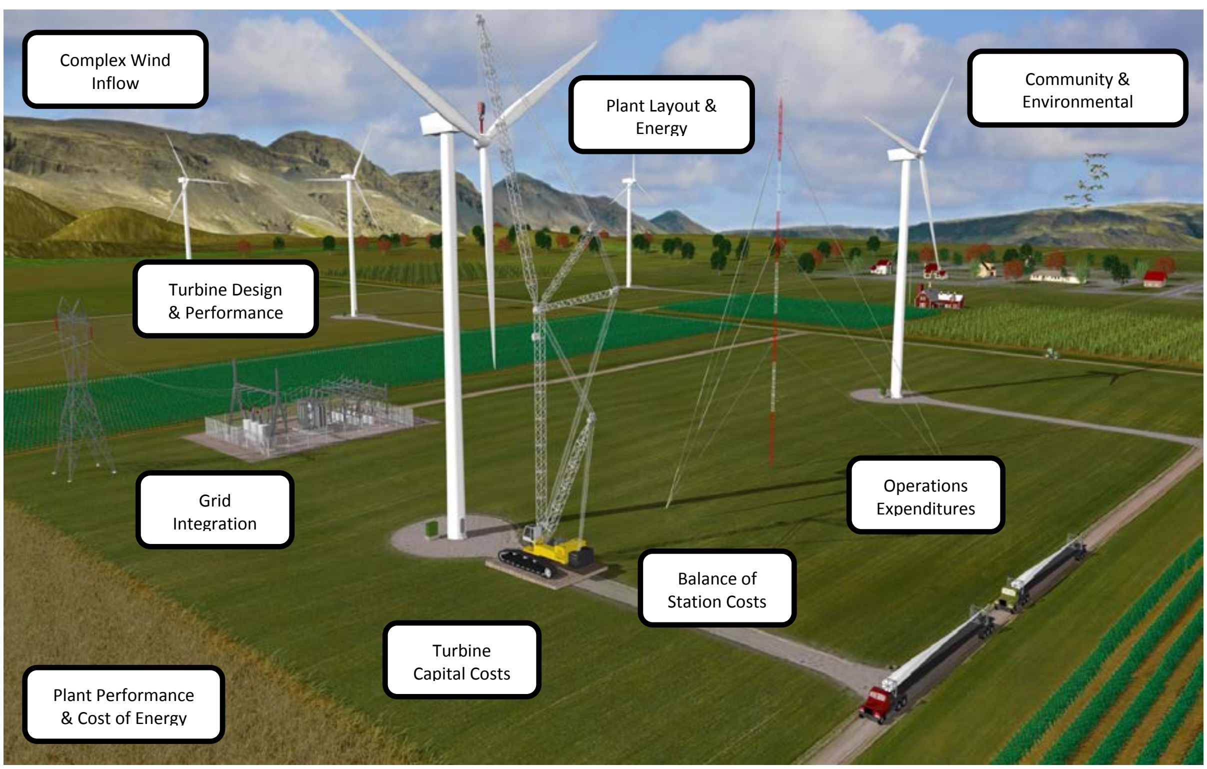


Session I: Cost of Energy for Wind Systems Today

Session Chair: Christopher Mone, National Wind Technology Center (NWTC) at the National Renewable Energy Laboratory (NREL)

First Speaker: Maureen Hand, NWTC

Abstract: Recently, wind power purchase price agreements and the corresponding cost of wind energy have reached historic lows. A number of trends have contributed to this general reduction in the cost of wind energy including larger wind turbines with larger rotors. This presentation will illustrate recent U.S. wind project technology trends, including rotor and tower size, average annual wind speed, and annual energy production. The presentation will cover design trade-offs that underlie these trends and turbine scaling trends.

Biography: Maureen Hand is a senior engineer at NREL, where she leads wind and water power analysis efforts that are focused on cost and electric sector deployment potential. She has led collaborative efforts to investigate potential renewable electricity generation scenarios in the United States including the Renewable Electricity Futures study and the U.S. Department of Energy's *20% Wind Energy by 2030* study. Hand is the operating agent for the International Energy Agency's Wind Task 26 – Cost of Wind Energy, and she served as a lead author for a special report chapter on wind energy for the Intergovernmental Panel on Climate Change. She earned a Ph.D. in mechanical engineering from the University of Colorado.

Second Speaker: Bruce Valpy, BVG Associates Ltd

Abstract: Although there is a strong industry focus on cost of energy reduction in Europe, little evidence of progress has been presented publicly. This presentation will review available data and discuss technical and supply chain factors acting in recent years, especially those related to system-level progress. From there the speaker will present and justify anticipated future cost–of-energy trends and system-level opportunities through the 2020s as well as discuss some of their main drivers.

Biography: Bruce Valpy founded BVG Associates in 2005 and has created a rapidly growing, diverse client base that includes market leaders in the wind and tidal turbine sectors, trade bodies, government institutions, multinational organizations, and private companies on five continents. He has authored much internationally recognized work on cost of energy and delivers consultancy at the operational and strategic level.

Third Speaker: Todd Griffith, Sandia National Laboratories

Abstract: It is widely recognized that cost reductions are needed to enable growth in offshore wind deployments in the United States and worldwide. This presentation highlights several offshore technology research and development projects funded by the U.S. Department of Energy at Sandia National Laboratories. The topics will include large offshore rotor development, blade manufacturing cost studies, structural health monitoring and prognostics management, and innovative offshore vertical-axis wind turbines. The presentation will emphasize system-level design trade-offs and include economics and trends analysis aimed to illustrate potential cost reductions for offshore wind via these technologies.

Biography: D. Todd Griffith is a principal member of the technical staff in the Wind and Water Power Technologies Department at Sandia National Laboratories. He is the technical lead for Sandia's Offshore Wind Energy Program and his recent research includes work in the areas of structural dynamics, field testing, large offshore rotor technology, and structural health monitoring methods for wind energy systems. He has served as the chairman of the Sandia Blade Workshop and as technical program chair for the American Society of Mechanical Engineer's Wind Energy Symposium. He completed his Ph.D. at Texas A&M University in aerospace engineering and is an associate fellow of the American Institute of Aeronautics and Astronautics.

Session II: Wind Plant Uncertainty – Wind Resource and Financing

Session Chair: Patrick Moriarty, NWTC

First Speaker: Matthew Hendrickson, 3TIER by Vaisala

Abstract: Improving the way we calculate uncertainty has been a topic at the forefront of the industry for several years. Questions have been raised about whether the variability we see in projects are actually related to the uncertainty we calculate. The purpose of this presentation is to highlight some of the weaknesses of the common approach that has been used for many years. To bring to light several weaknesses of the classical uncertainty approach, this presentation will first review the common methods and assumptions in the uncertainty calculation. Although there are numerous approaches that have been applied over the years to calculate specific quantities, quite a bit of commonality exists between most of the individuals who perform these calculations. Then using several key uncertainties as examples, this presentation will illustrate how complex some of the uncertainties actually are. It will examine the implication of certain assumptions and demonstrate the variability in uncertainty that can actually exist when uncertainties are propagated correctly.

Biography: Matthew Hendrickson leads 3TIER by Vaisala's premier wind, solar, and hydro energy assessment teams. Since 2003, he has managed world-class energy assessment programs, involving more than 4,000 megawatts (MW) of operating wind farms and a development pipeline of over 20,000 MW. Prior to joining 3TIER, Matthew led EDPR-NA's Energy Assessment program as director of energy assessment from 2003 to 2011. He is experienced in meteorological program management, resource assessments, project micro-siting, prospecting, power performance testing, validation research, operational assessments, feedback reconciliation, and financial due diligence. He received his B.S. in electrical engineering from the University of Houston, where he graduated magna cum laude.

Second Speaker: Taylor Geer, DNV GL – Energy

Abstract: Accurately quantifying the uncertainties in a preconstruction energy assessment allows investors, developers, and utilities to better understand and manage the risks in project development. As an industry, we have seen presentations validating the accuracy of uncertainty evaluations in preconstruction assessments when considering a portfolio of projects, but concern has been raised that we are still not capturing the true drivers of project performance. Ensuring we are accurately quantifying the drivers on individual projects will ensure that developers can focus on reducing the uncertainty in their projects; validating the accuracy of the model used to calculate the uncertainties gives the lenders the comfort they need to invest with confidence. This presentation will explore the impact of refining the uncertainty assessment to use non-normal distributions.

Biography: Taylor is the global head for the Energy and Development Services Practice at DNV GL. In this role, he manages technical aspects of land-based and offshore energy assessments for the global market, ensuring consistent and high-quality service. Taylor began work in the wind industry at Garrad Hassan in December 2004 after working in both solar and energy efficiency. He received a B.S. in both mechanical engineering and materials science engineering from U.C. Berkeley, a B.A. in philosophy from U.C. Santa Cruz, and an M.S. in mechanical engineering from the Renewable Energy Research Lab at the University of Massachusetts at Amherst.

Third Speaker: Michael Brower, AWS Truepower

Abstract: The uncertainty of wind resource and energy production estimates is a critical element in wind project financing. Although wind flow modeling uncertainty is often a large contributor to the total uncertainty, it is rarely quantified rigorously—which can lead to an underestimation or overestimation of the financial risks of the project. In addition, the variation of the wind flow modeling uncertainty across a site is generally unknown and, as a consequence, is ignored in the process of designing a wind project. Consequently, the turbine layout may not be optimal, leading to larger-than-expected errors in energy production forecasts. This presentation provides a theoretical framework for understanding wind flow modeling uncertainty and illustrates some applications of this framework in the openWind plant design software. The uncertainty model is derived from an analysis of observed wind flow modeling errors for sites spanning a range of topographic and meteorological conditions. The research shows that, with the appropriate model, it is possible to (a) quantify the variation of wind flow modeling uncertainty across a project site in a physically reasonable and statistically defensible way; (b) design monitoring campaigns to minimize the wind flow modeling uncertainty for a particular buildable area; and (c) optimize a wind project layout to maximize the power production (PXX where XX is any confidence threshold such as 75%, 90%, or 95%), as appropriate for its particular financing model. Though initially narrowly focused, the uncertainty research becomes a launching point for a comprehensive model uncertainty in wind projects. The presentation touches on aspects of this comprehensive model and points to areas requiring further research.

Biography: Michael Brower is a physicist and president of AWS Truepower, LLC, a leading renewable energy consultancy based in Albany, New York, with offices in five countries. In his nearly 20 years in the renewable energy field, Michael has made significant contributions to wind resource and energy assessment, atmospheric modeling, wind mapping, real-time forecasting, and grid integration. He has authored or co-authored three books, including most recently *Wind Resource Assessment: A Practical Guide to Developing a Wind Project* (Wiley 2012). He received his Ph.D. in physics from Harvard University in 1986, and before joining AWS Truepower was research director for the Union of Concerned Scientists.

Fourth Speaker: Erik Hale, EDF Renewable Energy

Abstract: Uncertainty estimates around the central, or P50, energy production predictions for planned wind projects play a critical role in project finance decisions. As such, it is very important that these estimates accurately capture the unknowns associated with a given project. Recent studies from leading industry organizations suggest that uncertainty estimates are not correlated to deviations in plant performance from the expected. We will review these studies and consider some project-level examples to better understand the "uncertainty around uncertainty."

Biography: Erik Hale has lead a team that is responsible for all wind energy estimates, turbine layout design, and power curve testing for projects across North America at EDF Renewable Energy since 2011. From 2006-2010 Erik worked as a meteorologist at AWS Truepower where he evaluated over 100 wind projects across the world. While at AWS, Erik authored a study published in the Wind Energy Journal detailing a proposed analytical correction to treat NRG #40 data affected by dry friction whip. Erik is serving a two year term as the program co-chair for the AWEA Wind Resource & Project Energy Assessment Seminar, and is a US delegate for the IEC 61400-15 working group on Wind Resource Assessment.

Lunch Keynote

Keynote Speaker: Fort Felker, NWTC

"A Vision for Systems Engineering Applied to Wind Energy"

Abstract: Wind plants are complex systems that lend themselves to methodologies from aerospace and other sectors for systems engineering. In 2012, the NWTC began a comprehensive program to look at systems engineering for wind energy applications. This effort led to the development of a research capability and software platform for integrated research, development, and design of wind systems. This talk highlights the importance of systems engineering to wind energy and provides an overview of some of the recent NREL research in this area.

Biography: Fort Felker is the center director of the NWTC, where he leads a team of 100 scientists, engineers, and technicians in the development of advanced wind and water power technologies. Prior to this, he was the co-founder and vice president of Winglet Technology LLC, a company that commercialized his patented design of "elliptical winglets" for business aircraft. Before his 6-year stint as an entrepreneur, Felker was an engineering analyst at Lawrence Livermore National Laboratory.

Session III: Wind Plant Uncertainty – Reliability and Operations

Session Chair: Shawn Sheng, NWTC

First Speaker: Carsten Westergaard, Sandia National Laboratories

Abstract: Sandia National Laboratories have been investigating reliability of wind farms through the Continuous Reliability Enhancement Wind project since 2007 through the use of supervisory control and data acquisition (SCADA) data from multiple wind farms in the U.S. fleet. In 2014, we investigated various aspects of wind plant reliability and attempted to quantify a simple and meaningful high-level average of the U.S. fleet for guidance purposes to the U.S. Department of Energy's Atmosphere to Electrons initiative. In this process, it has become evident that there are many examples and situations in which average benchmark data cannot be presented in a meaningful way because of discrete events, especially when the data is only based on small samples. Further, it has been challenging to compare data as the tagging methods of components, failure modes, and corrective actions are in development with owner/operators; whereas the tags, at the same time, are used inconsistently from organization to organization. The discrete events and tagging issues contribute significantly to the uncertainty of a fleet average and impair the way we communicate reliability. Further, we speculate that reliability can be understood much better through simple SCADA data-mining techniques.

Biography: Carsten H. Westergaard is a senior advisor to Sandia National Laboratories on wind energy and a professor of practice at Texas Tech University supported by the Emerging Technology Fund of Texas from the Governor's office. He is the president and owner of NextraTEC, Inc., a consulting company to renewable energy companies and suppliers developing exciting new technologies and market approaches. Westergaard has served in numerous advisory board positions and chaired international reviews of large, multiyear government research programs in several countries. He earned his Ph.D. from the Danish Technical University with a thesis on optical computing and laser-based turbulent flow measurements. During his student years he was at the University of Illinois, CREN in Switzerland, and Baker Oil Tools in Houston. He has been holding a variety of management roles, including technology, sales, and marketing. Westergaard has worked for LM Wind Power, Dantec Dynamics, Force Technology, and Vestas Wind Systems in Denmark and the United States. During his industrial career he published more than 50 publications and 20 patents/pending.

Second Speaker: AnneMarie Graves, Upwind Solutions

Abstract: Wind energy becomes more cost effective when the costs of building or operating the projects are reduced. On the operations side, cost reductions are achieved by building a reliability-centered maintenance program for these projects. A key element to building this type of program is bringing many different data sets together, such as parts usage, parts age, production, parts condition, and failure causes. This presentation will describe what a reliability-centered maintenance program looks like for wind projects, and what information needs to be assembled to implement such a program. Actual operating experiences and examples will be provided to support wind turbine designers and wind project developers in designing more reliable and cost-effective wind projects.

Biography: AnneMarie Graves brings 11 years of engineering and management experience to assessing the performance and reliability of wind projects. She is the director of performance engineering at Upwind Solutions and is directly involved in analyzing their 3 gigawatts of operation and maintenance (O&M) projects to reduce cost, increase production, and improve reliability over the lifetime of the asset. She previously led the Operations Services team with DNV GL (formerly Garrad Hassan), advising 20% of North American wind projects on assessing performance, predicting wind project production, and modeling turbine life. Prior to joining DNV GL, Graves worked at GE Wind Energy assessing the suitability of new wind project locations in North America. She has presented and chaired sessions at AWEA WINDPOWER and Wind Energy Update's O&M Summits and co-chaired conferences with Women of Wind Energy. Graves has a B.S. in mechanical engineering and science and technology studies from Rensselaer Polytechnic Institute.

Third Speaker: Keith Parks, Xcel Energy

Abstract: Wind uncertainty for power system optimization spans multiple time horizons—next hour, next day, and next year, to 20 years. The short-term uncertainty is driven by synoptic weather conditions that greatly affect the optimal dispatch of balance resources, deteriorate the value of renewables, and reliability. For systems with a large penetration of wind energy, wind curtailment is an effective tool used to both manage exposure to wholesale markets and balance the power system. Long-term uncertainty affects resource acquisition, but is largely hedged through pay-for-performance power purchase agreements, that is, the producer takes the risk for underperformance. The use of storage technology to mitigate uncertainty is discussed.

Biography: Keith Parks is a senior analyst at Xcel Energy. He is an expert in power system optimization and wind integration. For 5 years, Keith managed Xcel Energy's wind portfolio—the largest of any utility in the United States for the last 10 years (American Wind Energy Association).

Theme 2:
System Design Methods, Tools, and Processes

Session IV: Evolution of Wind Turbine Standards and Design Methodologies

Session Chair: Paul Veers, NWTC

First Speaker: Sandy Butterfield, Boulder Wind Consulting

Abstract: Over the past 25 years, a suite of international standards has evolved under the International Electrotechnical Commission's (IEC's) TC88 Technical Committee. These standards have mainly focused on design requirements and testing for wind turbines and have helped support the maturation of the current design process and contributed to the success we see today. But are these standards or the way we develop standards all we need to support a world-class energy source? Wind turbines have grown in scale and complexity. They are parts of much larger wind plant systems ranging up to 1,000 MW. They have significant impact on utility grids which are also large systems. In order for wind plants to be successful in supplying reliable, low-cost energy at ever-increasing penetration levels they must be designed and optimized as a system. There are gaps in our suit of standards, which must be reorganized for easier and faster development, and allowing for an improved ability to react to commercial project development needs and certification needs. Ultimately, these standards must also be harmonized with national requirements if they are to capitalize on the advantages of international trade. But perhaps the most important realization is that our future standards must address the system aspects of wind plant design and operations if we expect them to facilitate a global solution. This presentation will explore the future of international standards, research and development's role in evolving them, and what is needed to assist the system aspects of wind plant design.

Biography: Sandy Butterfield was a wind energy entrepreneur. He co-founded ESI, a wind turbine manufacturing company in 1980, where he was vice president of engineering and responsible for all aspects of design and manufacturing. He then worked at NREL as the director of the NWTC for a number of years. Butterfield is currently chairman of IEC's TC88 Technical Committee, which is responsible for international wind turbine standards. He chairs the IEC Renewable Energy Conformity Assessment System (www.IECRE.Org) and served on the American Wind Energy Association's board. Butterfield has authored or co-authored more than 100 papers. He graduated from the University of Massachusetts with an M.S. in mechanical engineering in 1977, where he studied under Bill Heronemous, famous for his floating offshore wind farm proposals in the early 1970s.

Second Speaker: Kenneth Thomson, DTU Wind Energy

Abstract: An overview of the evolution of load simulation methods is presented as well as the technical challenges that triggered the development of some of the components. The complexity of the simulation methods depend significantly on the scope of the task at hand. If a full design process is carried out, the needed level of detail in both model elements and output is higher than if a product scoping optimization is carried out in which main design parameters (e.g., rated power and rotor diameter) are determined. For the latter case, a compromise between model complexity and computational effort is needed. It is illustrated that the overall loads for a wind turbine can be simulated with an extremely simplified approach and the results of this are compared with a full set of IEC 61400-1 design loads for a 5-MW turbine. Based on this, load simulation needs in a systems engineering perspective are discussed. Possible future development trends are considered for load simulation methods to be used either in a system optimization context or for detailed component designs.

Biography: From 1990 to 2007 Kenneth Thomson worked as a research engineer and senior scientist at the Wind Energy Department, Riso National Laboratory. Then, from 2007 to 2014, he served as a department head at Siemens Wind Power A/S. In 2014 he returned to DTU Wind Energy as the organization's innovation manager. His technical fields of work include dynamic behavior of wind turbines, aero-elasticity for wind turbines, design load bases for wind turbines, wind turbine fatigue and extreme load analysis, control design, rotor design, and overall wind turbine design.

Third Speaker: Graeme McCann, DNV GL - Energy

Abstract: This presentation will look at how the integration of various numerical submodels may be used to optimize the initial layout design, and subsequent control, of a large modern wind plant. Specifically, we will look at how engineering models of inflow, wakes, ground conditions, water depths (offshore), turbine loading, and turbine performance may be unified within an overarching cost model that includes balance-of-plant and O&M aspects to inform optimization of turbine positioning before construction, and plant-wide control policies postconstruction. The model synthesis will be illustrated by means of an example offshore wind plant with both regular and irregular layout strategies, including an engineering-based cost model for the support structures. Sensitivity analyses of the system model will be presented, and further development avenues discussed.

Biography: Graeme McCann is the deputy head of turbine engineering at DNV GL, based in Bristol, United Kingdom. He holds a degree in mechanical engineering and has over 12 years of experience working in the field of renewable energy. His specific areas of technical interest include integrated numerical modeling of offshore wind turbines and their support structures, simulation of horizontal-axis tidal turbines, and analyzing wind farm wake loading effects and probabilistic design methodologies for wind turbines. He is a member of the TC88 MT-01 and MT-03 committees, which are responsible for the development of the IEC 61400-1 (onshore) and -3 (offshore) international wind turbine design standards, respectively.

Session V: Tools for Integrated System Design

Session Chair: Pierre-Elouan Réthoré, DTU Wind Energy

First Speaker: Urs Wihlfahrt, Fraunhofer IWES

Abstract: OneWind is a system that combines all components of a wind plant into one model with different levels of detail. The completeness of the model is ensured by introducing the concepts model transformation and model generation. This structure enables users to combine the models from different tools in different domains within the design process of a turbine. OneWind consists of 1) the OneWind Modelica Library, a simulation tool for load simulations in the Modelica language, and 2) the OneWind-Framework, an Eclipse/Java-based software framework for models (of parts or the whole turbine), the workflow of a design process like model transformation, generators (for external simulators), and a set of post-processing tools for the models. Various OneWind products are based on the framework (e.g., OneWindLoads provides load simulation including load cases management and the OneWind Modelica Library for dynamic simulation. The presentation illustrates the concepts and uses of OneWind. In addition, the aspects of the verification, functional capabilities and the extension of the system to future work will be covered.

Biography: Urs Wihlfahrt studied civil engineering with a strong focus on information technology in civil engineering at the Technical University Berlin/Germany (Diploma Thesis 12-1999.) Afterwards, from 2000 to 2005, he worked as a scientific staff member at the department of information technology in civil engineering. Wihlfahrt worked in software development for Airbus CAE system including plugin development for assessments of fiber composite metal parts and connections. Since 2009 he has worked at Fraunhofer IWES on the OneWind project and has served as the project group manager of the OneWind projects and successor Project Wind MuSE since 2012.

Second Speaker: Karl Merz, SINTEF Energy Research

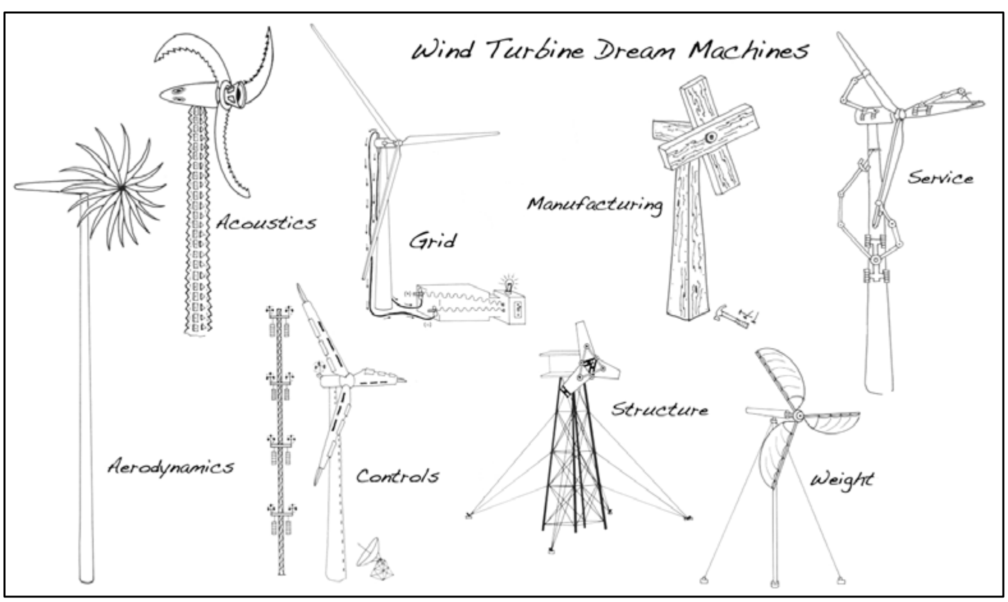
Abstract: If a system can be modeled as linear, then powerful mathematical and computational techniques, in either the time or frequency domain, can be used to analyze and control the system. Recent investigations into the linearization of wind turbine systems will be discussed, along with plans for further developments. In addition, an overview of the Dogger Bank Reference Wind Farm will be given.

Biography: Karl Merz has been working with offshore wind energy since 2008, first as a Ph.D. student and postdoc at the Norwegian University of Science and Technology, and presently as an employee of SINTEF Energy Research. His present research goal is to understand and control a large offshore wind farm, like the Dogger Bank, and he is interested in the validation of simple, intuitive methods that can help in this regard. Prior to becoming a 'propellerhead,' Karl developed composite structure analysis methods for Boeing Commercial Airplanes.

Third Speaker: Katherine Dykes, NWTC

Abstract: The NWTC wind energy systems engineering initiative has developed an analysis platform to leverage its research capabilities toward integrating wind energy engineering and cost models across wind plants. This Wind-Plant Integrated System Design & Engineering Model (WISDEM™) platform captures the important interactions between various subsystems to achieve a better understanding of how to improve system-level performance and achieve system-level cost reductions. This work illustrates a few case studies with WISDEM that focus on the design and analysis of wind turbines and plants at different system levels.

Biography: Katherine Dykes joined NREL in 2011 to support an NWTC initiative for systems engineering methods applied to wind energy. The project is undergoing initial development and involves integrating engineering and cost-based analysis tools to analyze overall wind energy system performance. Katherine is a Ph.D. candidate in engineering systems at the Massachusetts Institute of Technology. Her background in wind energy began while working as a wind program analyst for Green Energy Ohio in 2005 and later as a data analyst for The Renaissance Group.



Wind Turbine Dream Machines; Illustration by Rick Hinrichs, PWT Communications

Session VI: Addressing Uncertainty in the Design Process

Session Chair: Peter Graf, NWTC

First Speaker: Pierre-Elouan Réthoré, DTU Wind Energy

Abstract: This presentation is about TOPFARM, an open-source framework that helps optimize wind farm layouts built using OpenMDAO (a framework for multidisciplinary optimization and analysis) and FUSED-Wind (a framework for unified system engineering and design for wind energy). First, the lessons learned during the EU-FP6 TOPFARM project will be presented. Next, the new framework will be covered. Finally, the roadmap of TOPFARM will be discussed with a special emphasis on how to address multifidelity and optimization under uncertainty.

Biography: Pierre-Elouan Réthoré earned an M.S. in computer science from Centrale Marseille, an M.S. in wind energy from DTU, and a Ph.D. in wind energy from Aalborg University and Risø National Laboratory. He has worked for 10 years at Risø, now known as DTU-Wind Energy. His areas of research are mainly wind farm layout optimization and wind farm flow modeling.

Second Speaker: Paul Constantine, Colorado School of Mines

Abstract: NREL's FAST model predicts several measures of long-term fatigue for offshore wind turbine components. These predictions depend on many input parameters—such as speed and direction of winds hitting the turbine. Understanding the relationships between inputs and predictions is critical for thorough uncertainty quantification, but this understanding becomes more challenging as the number of input parameters increases. We employ recently developed active subspace methods to analyze sensitivity and build easy-to-use, low-dimensional models that represent the relationship between inputs and predictions. Also, the sensitivity analysis provides insights into the FAST model that can be exploited for future studies.

Biography: Paul Constantine is the Ben L. Fryrear assistant professor of applied math and statistics at Colorado School of Mines. He received his Ph.D. in 2009 from Stanford's Institute for Computational and Mathematical Engineering and spent 2 years at Sandia National Laboratories as the John von Neumann Fellow. His interests include uncertainty quantification and dimension reduction for large-scale computational simulations.

Third Speaker: Paul Fleming, NWTC

Abstract: Wind plant controls is an area of research in which the control actions of individual turbines are coordinated to produce improved wind plant performance. Researchers at NREL have been designing wind plant control systems and analyzing their potential using high-fidelity simulations. Additionally, recent work has researched the potential of combining wind plant controls with system engineering techniques. In this work, a wind plant layout is optimized while accounting for the use of wind plant controls. This proof-of-concept study demonstrates the increased potential of wind plant controls, when these control capabilities are incorporated into the design of the wind plant.

Biography: Paul Fleming is a senior engineer at the NWTC. His areas of research focus on control systems for wind energy, including wind turbines and wind plants. He received his Ph.D. in electrical engineering from Vanderbilt University in 2009.

Poster Session Presentations

Poster Title	First Author Biography
Data-driven modeling and analysis for load characterization, condition monitoring, adaptive predictions and wake effect quantification	Eunshin Byon is an assistant professor in the Department of Industrial and Operations Engineering at the University of Michigan, Ann Arbor, USA. She received her Ph.D. degree in industrial and systems engineering from the Texas A&M University, College Station, USA, and joined the University of Michigan in 2011. Byon's research interests include reliability evaluation and optimal control for stochastic systems, predictive modeling, and data analytics. Her recent research focuses on load modeling, O&M optimization, and condition monitoring in wind power systems. Her research has been supported by the National Science Foundation.
Integrated Design of Wind Turbine Layout and Controls using the FLOw Redirection and Induction in Steady-State (FLORIS) model	Pieter Gebraad is a postdoctoral researcher at the NWTC. His research aims at applying control techniques in wind plants that mitigate wake effects to increase production and reduce turbine fatigue loads. In December 2014, he obtained his Ph.D. at Delft University of Technology (TU Delft) with his dissertation *Data-Driven Wind Plant Control*.
Forecastability as a Design Criterion in Wind Resource Assessment	Jie Zhang is currently working at NR EL as a research engineer. Zhang received his Ph.D. (2012) from the Department of Mechanical, Aeronautical, and Nuclear Engineering at Rensselaer Polytechnic Institute. His research expertise and interests are multidisciplinary design optimization, complex engineered systems, big data analytics, wind energy, renewable integration, and power and energy systems.
An Interactive Parametric Design-Through-Analysis Platform for Wind Turbine Blades	Austin Herrema is an Integrated Graduate Education Research and Traineeship fellow pursuing a co-major Ph.D. at Iowa State University's Wind Energy Science, Engineering, and Policy Program and Mechanical Engineering. He received a B.S. in mechanical engineering from Dordt College in May 2014. His current research is in the field of computational mechanics, specifically regarding the computational design and analysis workflow.
A New Yaw System for a 6-MW Downwind Two-Bladed Offshore Wind Turbine	Edwin van Solingen was born in Abbenbroek, the Netherlands. He received a B.S. in electrical engineering and an M.S. in systems and control from the Delft University of Technology, the Netherlands. He is currently pursuing a Ph.D. at the Delft Center for Systems and Control in the same university where his focus is on integrated control design of two-bladed wind turbines.
Wind turbine blade failure, safety and quality assurance (WINDRISC)	Hamid Sarlak Chivaee is a postdoctoral research associate at the Department of Wind Energy, Technical University of Denmark. Chivaee's research interests include in the area of wind energy are numerical and experimental fluid mechanics and turbulence modeling.
Application of WISDEM models to tower design optimization—the influence of tower height and RNA weight	Braulio Barahona Garzón earned his M.S. (2008) and Ph.D. (2012) from DTU Wind Energy, and joined NREL as a postdoctoral researcher in 2014. His research interests revolve around wind turbine integrated dynamics analysis and control, and the integration of wind power to the power system.
Co-Design for Wind Turbines	Anand Deshmukh is a doctoral student in systems engineering at the University of Illinois at Urbana-Champaign. His research interests span mathematical optimization and control theory and their application to wind turbine system design.
A New CFD-Based Optimization Framework for Wind Plant Layouts	Ryan King is a PhD student at the University of Colorado, Boulder and joined NREL's Wind Energy Systems Engineering group in 2012 to work on drivetrain modeling. His current research focuses on turbulence modeling, Large Eddy Simulations (LES) and adjoint optimization of wind farm layouts.

Workshop Agenda: Day 2

Day 2: January 15, 2015	
8:30 a.m.–9:30 a.m.	**Day 2 Opening Remarks** Shreyas Ananthan, U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) **Opening Keynote Address: "A New Vision for United States Wind Power"** Jose Zayas, DOE EERE
Theme 3: Integrated Design for Wind Energy Systems in Practice	
9:30 a.m.–10:30 a.m.	**Session VII: Component-Level Design in System Contexts** **Moderator:** Rick Damiani, NWTC Tristan Dhert, University of Michigan Kristian Dixon, Siemens Energy Inc. Peter Bæk, LM Wind Power
10:30 a.m.–10:45 a.m.	**Break**
10:45 a.m.–11:45 a.m.	**Session VIII: Turbine-Level Integrated Design Approaches I** **Moderator:** Katherine Dykes, NWTC Frederik Zahle, DTU Wind Energy Brian Resor, Sandia National Laboratories Andrew Ning, Brigham Young University
11:45 a.m.–12:00 p.m.	**Break**
12:00 p.m.–1:00 p.m.	**Session IX: Turbine-Level Integrated Design Approaches II** **Moderator:** Daniel Laird, Sandia National Laboratories Patrick Riley, GE Global Research Jon Campbell, Alstom Power Inc. James Allison, University of Illinois
1:00 p.m.–1:15 p.m.	**Closing Remarks** Paul Veers, NWTC

Day 2: Opening Session

Opening Remarks: Shreyas Ananthan, DOE EERE

Abstract: DOE's Wind Program launched a new research and development initiative, Atmosphere to Electrons, to approach wind plant optimization holistically—identifying the underlying performance barriers and adopting innovative component and system technology options to improve the cost and performance of utility-scale wind plants. This talk will provide a brief overview of this long-term research program, including the management structure, key research focus areas, and ongoing near-term (FY15-16) research activities.

Biography: Shreyas Ananthan has been with DOE's Wind and Water Power Technologies Office since 2013, but has been involved in rotary wind technology research and development throughout his career. Before joining the program, Shreyas applied his expertise in designing aerodynamic wind turbine blades at Vestas Global Research Office and developing high-performance computing tools for wind farm optimization. He brings to the program technical expertise in wind technology development, including aerodynamics and aeroacoustics, coupled multidisciplinary physics modeling and simulations, and high-performance computing experience that are key to the design and operation of next-generation wind plants. Shreyas received his Ph.D. and M.S. in aerospace engineering from the University of Maryland, College Park, and his B.T. in aerospace engineering from Indian Institutes of Technology in Madras, India.

Keynote Speaker: Jose Zayas, DOE EERE

"A New Vision for United States Wind Power"

Abstract: DOE's Wind Program, in close cooperation with the wind industry, has launched a new initiative to revisit the findings of the 2008 DOE *20% Wind Energy by 2030* report, and to develop a renewed vision for U.S. wind power research, development, and deployment. The wind vision effort includes the following: 1) a characterization of industry progress and how recent developments and trends impact the 2008 conclusions, 2) a discussion of the costs and benefits to the nation arising from more wind power, and 3) a roadmap addressing the challenges to achieving high levels of wind within a sustainable national energy mix.

Biography: Jose Zayas is the director of the DOE's Wind and Water Power Technologies Office. In this role, he manages efforts to improve performance, lower costs, and accelerate deployment of wind and water power technologies, which can play a significant role in America's clean energy future. In working with DOE's national laboratories, academia, and industry, the program funds research, development, and deployment of wind and water power systems through competitively selected, cost-shared projects with businesses, federal, state, and other stakeholder groups.

Theme 3:
Integrated Design for Wind Energy Systems in Practice

Session VII: Component-Level Design in System Contexts

Session Chair: Rick Damiani, NWTC

First Speaker: Tristan Dhert, University of Michigan

Abstract: Wind-generated electricity is increasing and is expected to account for up to 18% of the global electricity by 2050. Improvements in wind turbine performance with no penalty in capital cost would make it possible to reach this goal sooner. In this presentation, we demonstrate that the aerodynamic performance of wind turbines can be improved with subtle changes in shape that do not affect the cost. Quantifying the effect of these changes requires at least RANS-based computational fluid dynamics. To find the best possible shape requires hundreds of design variables. To address these needs, we developed a framework for the aerodynamic shape optimization of wind turbines based on a RANS computational fluid dynamics model. To perform design optimization, we use a gradient-based optimization algorithm with a method that efficiently computes the gradients with respect to large numbers of design variables. We demonstrate the design optimization capability by maximizing the torque of the NREL IV turbine with respect to 496 airfoil shape and twist variables, resulting in a 22.4% torque increase.

Biography: Tristan Dhert is interested in the development of computational models and algorithms with application to fluid dynamics of rotating flow problems, gradient-based optimization, and finance. He is graduating from the Delft University of Technology with an M.S. in aerospace engineering specialized in aerodynamics. Currently, he is a research scholar at the University of Michigan.

Second Speaker: Kristian Dixon, Siemens Energy Inc.

Abstract: Multiobjective global optimization using genetic algorithms can be a powerful approach in rotor system design particularly when confronted by a design problem that is substantially different from past experience, such that conventional manual design methods and rules of thumb may not work. The utility of

multiobjective optimization will be shown through the comparison of multiobjective pareto fronts as a means to quantitatively compare the total system impact of various technology changes on rotor design. A redesign of the NREL 5-MW rotor will serve as an example design space.

Biography: Kristian Dixon completed his B.S. in engineering science/aerospace at the University of Toronto and his M.S. in aerospace engineering at the Delft University of Technology (TU Delft) in the Netherlands. His M.S. thesis work was on the modeling of the near-wake structures of vertical-axis wind turbines. Kristian joined Siemens Wind Power a few months after graduating from TU Delft in 2008. In his 6 years with Siemens, Kristian has worked on several blade design campaigns and driven the development of the optimization framework, tools, and models used for all current blade design and optimization efforts.

Third Speaker: Peter Bæk, LM Wind Power

Abstract: Not a single formula exists to produce the optimal blade. The design philosophy of each turbine manufacturer determines the shape of the blade that is optimal for their given turbine. In this talk, we will go through the components that are used to design blades at LM Wind Power (i.e., the LM Materials Database, the LM Standard Laminate Plan, and the LM Airfoil Families). These components are joined in LM's in-house developed software tools, which are combined in a numerical optimization framework called RotorOpt. A design example will be presented.

Biography: Peter Baek has a mechanical engineering degree from the Technical University of Denmark (DTU). He has worked at LM Wind Power for 7 years, during which he obtained an industrial Ph.D. in collaboration with DTU on the topic of advanced control concepts with active aerodynamics devices on wind turbine blades. He has worked with airfoil development and wind tunnel testing, blade sensor system development and field testing, and is currently working with aero-structural blade optimization.

Session VIII: Turbine-Level Integrated Design Approaches I

Session Chair: Katherine Dykes, NWTC

First Speaker: Frederik Zahle, DTU Wind Energy

Abstract: This work presents the multidisciplinary wind turbine analysis and optimization tool HawtOpt2 that is based on the open-source frameworks OpenMDAO and FUSED-Wind, and interfaces to several state-of-the art simulation codes, which allows for a wide variety of problem formulations and combinations of models. In this presentation, the simultaneous aerodynamic and structural optimization of a 10-MW wind turbine rotor is discussed with respect to material distribution and outer shape. A set of optimal designs with respect to mass and annual energy production (AEP) are presented, which shows that an AEP-biased design can increase AEP by 1.5%, whereas a mass-biased design can achieve mass savings of up to 20% compared to the baseline DTU 10-MW reference wind turbine. A newly developed frequency-domain-based fatigue model is used to minimize fatigue damage, which achieves up to an 8% reduction in the tower bottom fore-aft fatigue damage, with only limited reductions of the aerodynamic performance or increased mass.

Biography: Frederik Zahle completed his masters in aeronautical engineering at Imperial College, London, in 2003, and earned a Ph.D. jointly between the Imperial College and Risø DTU in the field of computational fluid dynamics of wind turbines in 2007. He is currently holding a position as a senior scientist in the aeroelastic design section at DTU Wind Energy, Risø Campus. His current research activities focus on aerodynamics of airfoils and rotors, computational fluid dynamics, and development of multidisciplinary design tools for wind turbines.

Second Speaker: Brian Resor, Sandia National Laboratories

Abstract: This talk will show an example of multidisciplinary aerodynamic and structural optimization of wind turbine rotor designs. A simple design problem is used: quantify the effect of increasing the maximum allowable rotor tip speed on rotor design. The importance of rotor optimization within the full turbine system is demonstrated. Additionally, motivation for adequate component cost models is shown. NREL's Harp_Opt and Sandia's NuMAD tools were integrated and enable this work. Genetic algorithms were used as the global optimization algorithm. Results showed that although rotor torque decreases for higher rotor speeds, the rotor can become heavier and more expensive because the optimal high-speed rotor tends toward lower solidity and lower blade absolute thickness (requiring more material to maintain stiffness). The design of a truly optimal rotor cannot be done in isolation, i.e., it cannot be done without consideration for the full set of turbine system parameters.

Biography: Brian Resor joined the Wind Energy Technologies Department in 2008 and focuses his work on wind turbine rotor design and aeroelastic system dynamics simulation. He began working at Sandia National Laboratories in 2002 in the Engineering Sciences Center where he specialized in structural dynamics research, experimental dynamic environments testing, and model validation. Resor received a B.S. in mechanical engineering from the University of Illinois at Urbana-Champaign in 2000, and an M.S. in mechanical engineering from Pennsylvania State University in 2002.

Third Speaker: Andrew Ning, Brigham Young University

Abstract: Large wind turbine rotor blades are often constrained by the stiffness required to prevent a tower strike. The mass of these rotor blades may be reducible by utilizing a downwind configuration in which the constraints on tower strike are less restrictive. Large upwind and downwind rotors are compared using nonlinear optimization to minimize cost of energy. The large turbines of this study range in power rating from 5 to 7 MW and in diameter from 105 to 175 meters. Although the focus is on the rotor design, the drivetrain and tower are also optimized. Coupled derivatives are derived to allow for efficient and robust comparisons between designs.

Biography: Andrew Ning is an assistant professor of mechanical engineering at Brigham Young University. His research group works in the areas of wind energy, multidisciplinary design optimization, and aeronautics. Prior to joining the university he was a senior engineer and postdoctoral researcher at NREL. At NREL, he helped develop the WISDEM tool set and led a variety of wind turbine and wind plant optimization studies. Ning received his Ph.D. from Stanford University working on aircraft formation flight in the Aeronautics and Astronautics Department.

Session VIII: Turbine-Level Integrated Design Approaches II

Session Chair: Daniel Laird, Sandia National Laboratories

First Speaker: Patrick Riley, GE Global Research

Abstract: GE uses systems engineering tools and methods to evaluate and optimize new technology and the subsequent impact on wind turbine product designs. Different technologies, environmental, and market conditions will result in different turbine designs. For example, hub-height optimization and the impact of the space frame tower technology is examined.

Biography: Patrick Riley is an energy systems research engineer in the Aero, Thermal & Mechanical Systems organization at GE Global Research based in Niskayuna, New York. Since joining GE Global Research in 2005, he has provided system-level technical and value analysis of various energy technologies including wind turbines, industrial-scale energy storage technologies, gas turbines, and fuel cells. Specifically for the past 7 years, he has been focused on conceptual analysis, systems engineering, and techno-economic analysis for advanced wind technologies. Prior to GE, he was a systems and performance engineer at UTC Fuel Cells. Riley received his B.S. (2000) and M.S. (2002) in chemical engineering from Rensselaer Polytechnic Institute and was awarded the Rensselaer Alumni Association Director's Award in 2009.

Second Speaker: Jon Campbell, Alstom Power Inc.

Abstract: This presentation describes Alstom's methodology for the integrated design and optimization of wind turbine systems. The benefits of systems-level design are supported with key examples from offshore drivetrain and foundation design, wind farm layout, and with an overview of Alstom's systems-level approach to economic value analysis. Although Alstom uses several tools concurrently to meet design objectives, various options are being explored to implement a more holistic application in a single platform. Recommendations are also provided in the areas of software selection and management, with an emphasis on meeting organizational goals.

Biography: Jon Campbell is a program manager at Alstom Power's North American wind headquarters in Richmond, Virginia. He is responsible for managing research and development projects to test and validate Alstom's wind turbine technology at NREL and is a member of the Virginia Offshore Wind Technology Advancement Project team. Campbell has more than 15 years of experience in the power generation industry. His prior roles include test engineer, test director, and system integration leader, managing international projects at Pratt & Whitney, UTC Power, and GE Energy. He earned a B.S. in mechanical engineering from Virginia Tech, an M.S. in management from Rensselaer Polytechnic Institute, and an M.B.A. from the University of South Carolina, Moore School of Business.

Third Speaker: James Allison, University of Illinois

Abstract: Designing actively controlled engineering systems involves both physical and control system design decisions. These two sets of decisions are coupled; i.e., physical system design decisions influence what the best control system design decisions are, and vice versa. Optimization-based design methods that account for this coupling explicitly are known as co-design methods, and are a subclass of multidisciplinary design optimization. Co-design methods exploit physical-control design synergies to produce system-optimal designs. This presentation will review important concepts from co-design, including recent developments that support comprehensive physical system design models. Initial findings based on co-design studies of horizontal-axis wind turbines will be presented, along with a discussion of how co-design can fit within the larger systems engineering process to enhance design integration for wind energy systems.

Biography: James Allison is the director of the Engineering System Design Lab at the University of Illinois at Urbana-Champaign. The lab concentrates on the development and investigation of quantitative design methodologies for engineering systems, with an emphasis on the design of complex dynamic systems. Application domains studied by Allison's research group include sustainable energy systems (wind and wave energy), electric and hybrid electric powertrains, robotics, structural systems, space-based observatories, material design, and synthetic biology. He holds a Ph.D. in mechanical engineering from the University of Michigan (2008), is the co-author of over 30 publications, and has received several awards, including the 2013 American Society of Mechanical Engineer's Design Automation Young Investigator Award and National Science Foundation Graduate Research Fellowship. Allison's previous experience includes several years of industry experience in the automotive (Ford and GM) and engineering software (MathWorks) industries, as well as other academic positions (part-time faculty at Tufts University, postdoctoral research fellow at the University of Michigan).