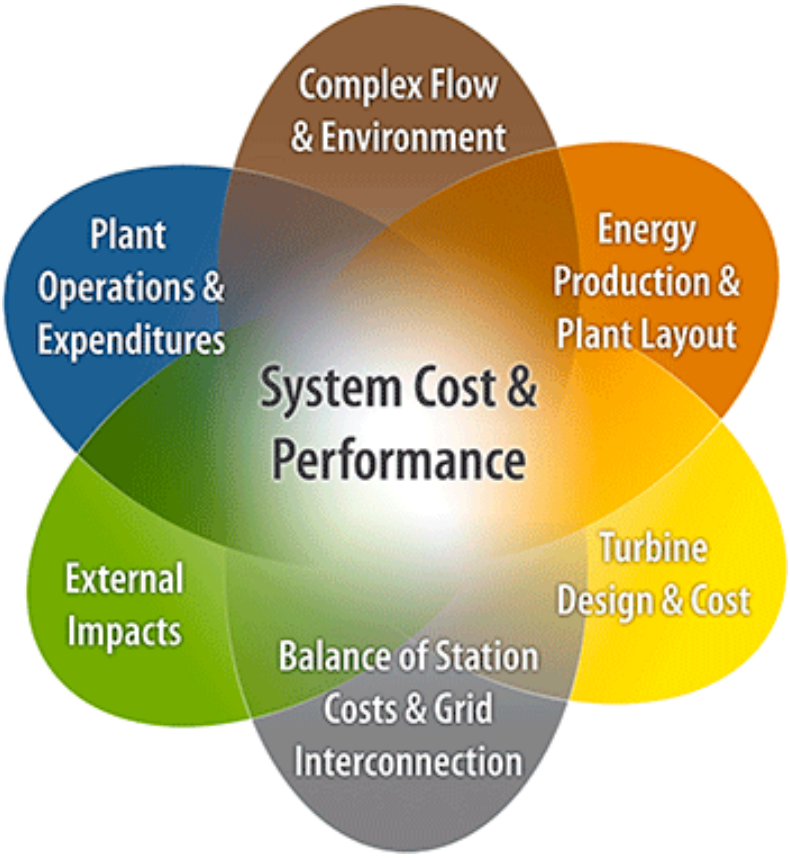
The 4th Wind Energy Systems Engineering Workshop



September 13th-14th, 2017
Risø DTU National Laboratory for Sustainable Energy
Roskilde, Denmark

Sponsored by:

DTU Wind Energy
National Renewable Energy Laboratory

Workshop Agenda

Overview: The 4th workshop on systems engineering for wind energy will take place on the 13th and 14th of September, 2017. The first workshop in December 2010 was a success in catalyzing interest in this important topic among participants from industry, the national laboratories and academia. The second and third workshops in January 2013 and 2015, respectively, with more than 100 participants each, demonstrated the significant growth in interest from the research and industry community surrounding systems engineering for wind energy and integrated approaches to wind turbine and plant design. At this fourth workshop, DTU Wind Energy and NREL will be hosting the workshop in Europe to encourage participation from European wind energy systems engineering practitioners and interested parties. This year's theme will be on exposing interactions in the system and exploring how different wind energy stakeholders addressing them in new, integrated and innovative ways.

Short Agenda

Wednesday, September 13th, 2017	
8:30 a.m. – 9:00 a.m.	Registration and Breakfast
8:30 a.m. – 12:15 p.m.	Morning sessions
12:15 p.m. – 1:00 p.m.	Lunch
1:30 p.m. – 5:45 p.m.	Afternoon sessions
5:45 p.m. – 7:30 p.m.	Evening reception and poster session (appetizers)
Thursday, September 14th, 2017	
8:00 a.m. – 8:30 a.m.	Registration and Breakfast
8:30 a.m. – 12:00 p.m.	Morning sessions
12:00 p.m. – 12: 45 p.m.	Lunch
12:45 p.m. – 3:30 p.m.	Afternoon Sessions
4:00 p.m.–5:15 p.m.	Tour of Wind Energy Facilities at DTU
Friday, January 16, 2015 (The Gallery, UMC 247)	
9:00 a.m. – 10:00 a.m.	OpenMDAO/FUSED-Wind Tutorial
10:00 a.m. – 12:00 p.m.	HAWTOpt2 Tutorial
12:00 p.m. – 1:00 p.m.	Lunch (unhosted – at DTU cantina)
1:00 p.m. – 3:00 p.m.	WISDEM Tutorial
3:00 p.m. – 5:00 p.m.	Cp-Max Tutorial

Full Workshop Agenda: Day 1

Day 1: September 13th, 2017	
9:00 a.m.–10:00 a.m.	**Day 1 Opening Remarks:** Michael McWilliam, DTU Wind Energy **Opening Keynote Address:** Anders Bavnhøj Hansen, Energinet
Theme 1: Challenges and Uncertainty Facing Today's Wind Energy Systems	
10:00 a.m.– 11:00 a.m.	**Session I: Cost of Energy for Wind Systems Today** **Moderator:** Katherine Dykes, NREL National Wind Technology Center János Hethey, Ea Energy Analysis Miriam Noonan, ORE Catapult Aaron Smith, PPI
11:00 a.m.– 11:15 a.m.	**Break**
11:15 a.m.– 12:15 p.m.	**Session II: Uncertainty Impacts on Wind Turbine Design and Performance** **Moderator:** Fleming Rasmussen, DTU Wind Energy Anand Natarajan, DTU Wind Energy David Witcher, DNV-GL Rick Damiani, NREL
12:15 p.m.–1:00 p.m.	**Lunch**
1:00 p.m.–1:45 p.m.	**Afternoon Keynote: Hanne Johansen, Vestas**
1:45 p.m.–2:30 p.m.	**Session III: Uncertainty Impacts on Plant Design and Performance** **Moderator:** Pierre-Elouan Réthoré Zachery Parker, Nordex Nicolai Gayle Nygaard, DONG Energy
Theme 2: System Design Methods, Tools, and Processes	
2:30 p.m.–3:30 p.m.	**Session IV: MDAO Applications to Wind Turbine Design** **Moderator:** Pietro Bortolotti, TUM Frederik Zahle, DTU Wind Energy Alessandro Croce, Politecnico di Milano Katherine Dykes, NREL
3:30 p.m.–3:45 p.m.	**Break**
3:45 p.m.–4:45 p.m.	**Session V: Uncertainty Quantification in MDAO for Wind Energy** **Moderator:** Michael McWilliam, DTU Wind Energy Andrew Ning, BYU Juan-Pablo Murcia, Vestas Curran Crawford, University of Victoria
4:45 p.m.–5:45 p.m.	**Session VI: Multi-fidelity Approaches to Wind Energy MDAO** **Moderator:** Frederik Zahle, DTU Wind Energy Justin Gray, NASA Mike McWilliam, DTU Wind Energy Carlo Bottasso, TUM
5:45 p.m.–7:30 p.m.	**Evening reception and poster session**

Day 1: Opening Session

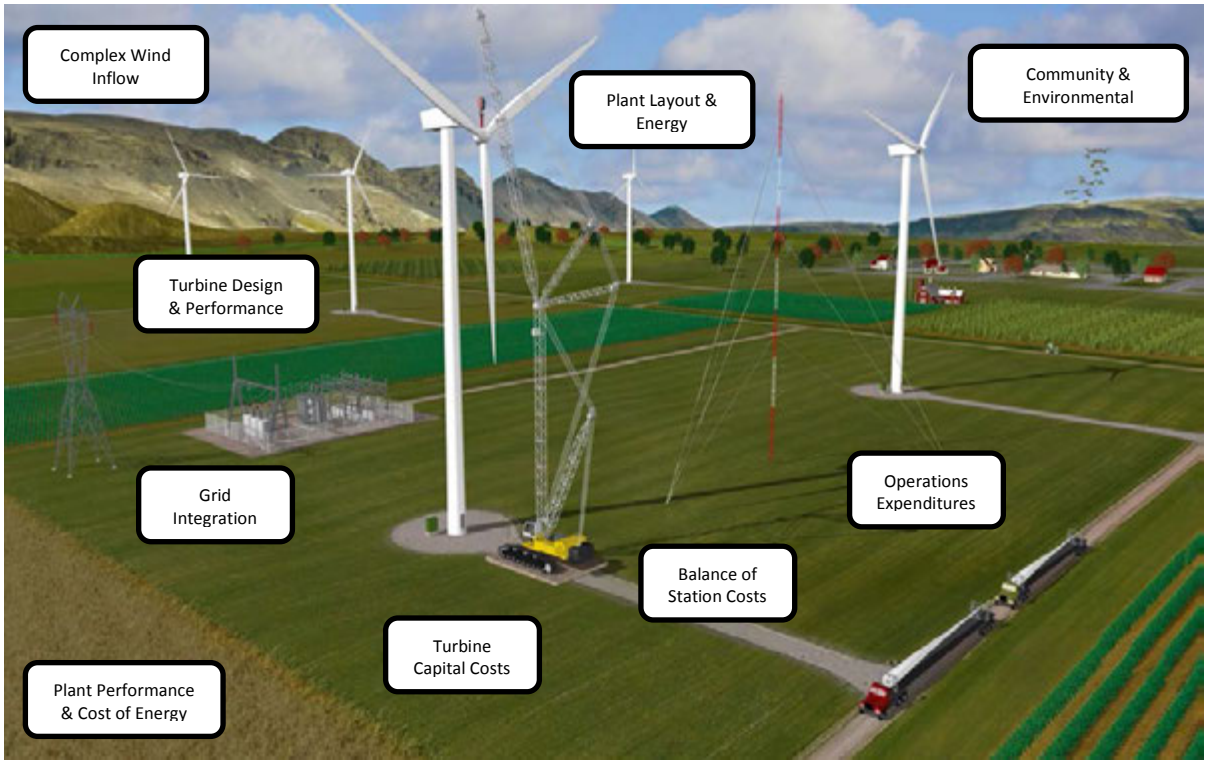
Session Chair: Michael McWilliam, DTU Wind Energy

Keynote Speaker: Anders Bavnhøj Hansen, Energinet

"Wind power in European and Danish system scenarios"

Abstract: Europe has the ambition to significant reduce the greenhouse gas emission in the coming decades, and wind power is expected to play a very central role in this European transition of the energy system. The presentation will elaborate on power-system analysis of wind power in the scenarios, with integration of very large amount of wind power. Denmark is used as a case for the system analysis, but in an international context. A number of R&D focus areas to pave the way for the power-system transition is presented.

Biography: Anders Bavnhøj Hansen is Chief engineer at Energinet.dk (Transmission and system responsible in Denmark). Fields of expertise are analysis and strategic planning of power system and integrated energy systems. Has been working at Energinet.dk for ten years with strategic system planning and before that at the Danish Energy Agency and has also been working with R&D at ABB Corporate Research.



The Complex Wind Energy System; Illustration by Al Hicks, NREL

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

Session I: Cost of Energy for Wind Systems Today

Session Chair: Katherine Dykes, NREL National Wind Technology Center

---

First Speaker: János Hethey, Ea Energy Analysis

Abstract: Wind is projected to be major contributor in power systems with large shares of renewable energy. While investment cost of land based wind energy may be reduced by up to 12% towards 2050, competitiveness of land based wind is being challenged by expectations for even stronger cost reduction for offshore wind and solar power. Technology advancements for onshore wind in terms of larger rotors and higher hub heights can further reduce levelized cost of energy and reduce system integration cost. Projections for the value of onshore wind power in the European power system show differences of up to 13% depending on the applied technology.

Biography: János Hethey, M.Sc. Engineering (Energy), Senior Consultant, Ea Energy Analyses. János has worked extensively within power system development, market analyses and scenarios for the future energy systems for more than 9 years. Key competencies include energy system modelling, analysis of renewable integration in energy systems, evaluation of power transmission projects and economic assessment of system developments. János Hethey has lead Ea Energy Analyses contribution to the IEA's Nordic Energy Technology Perspectives 2016, describing a path towards a low carbon energy system in the Nordic countries and Europe and is a key contributor to the IEA Wind Task 26 and the system integration analyses of different wind power.

Second Speaker: Miriam Noonan, ORE Catapult

Abstract: The last 12 months have seen big shifts in the Offshore Wind industry. Larger turbines, attractive financing and fierce competition in the market are contributing to rapid reductions in strike prices being awarded in auction rounds throughout Europe. Miriam will be discussing the key drivers in cost reduction in the industry, what we have seen change in the last few years and how we expect to continue this momentum in the future.

Biography: Miriam Noonan is a financial analyst at ORE Catapult, the UK's flagship technology innovation and research centre for advancing offshore wind, wave and tidal energy. Having graduated from Imperial College London in 2013 with a Masters in Civil Engineering, Miriam went on to work as a commercial analyst at BP before moving into renewables in 2016. She is responsible for delivery of the financial element of projects, maintaining internal economic models and analysis of market situations.

Third Speaker: Aaron Smith, PPI

Abstract: The floating market is accelerating rapidly with more than 400 MW of precommercial projects and 7,000 MW of commercial projects are under active development. The recent progress of the offshore wind in reducing costs, including the first zero-subsidy bids in Germany, creates significant opportunity for the floating industry to rapidly reduce LCOE to competitive levels. Leveraging the financial maturity, industrialization, and technology innovations that have enabled these cost reductions requires that floating technologies are designed with the constraints of the existing value chain in mind. In this presentation, Principle Power will share perspective on design drivers for successful floating concepts, design philosophy for the WindFloat, and outlook for technology/costs considering the next generation of turbines.

Biography: Aaron Smith joined Principle Power in 2016 and leads Strategy for the company. He is responsible for business planning, economics, as well as management of the WindFloat technology commercialization roadmap. Previously, Aaron was an Economist at the National Renewable Energy Laboratory, where he directed a portfolio of work for the US Department of Energy designed to identify high-value R&D opportunities for land-based and offshore wind technologies.

Session II: Uncertainty Impacts on Turbine Design and Performance

Session Chair: Fleming Rasmussen, DTU Wind Energy

First Speaker: Anand Natarajan, DTU Wind Energy

Abstract: Wind turbines are designed to meet specific ultimate load, fatigue damage and service limit states. The design driving loads are determined using the results of aeroelastic load simulations combined with several partial safety factors. These partial safety factors are usually determined based on assumed uncertainties in several inputs used in the load estimation process as well as the underlying models and physical variables themselves. This presentation explores the uncertainty levels in the extreme loads and fatigue damage on the wind turbine blade and support structure, including offshore substructures. Uncertainties in the wind turbulence model, types of pitch control and blade aerodynamic properties are considered, along with effects of limited load simulations. The results show that the impact of aerodynamic uncertainties on different extreme loads is between coefficients of variations of 5%-20%. Extreme turbulence and variation in the turbulence level can cause site specific extreme loads to exceed the levels simulated using the IEC 61400-1 extreme turbulence load case. However advanced controllers are shown to be able to mitigate the magnitude of these extreme loads and maintain required structural reliability levels. The effects of inflow turbulence model uncertainties are also shown on blade root fatigue loads, tower top fatigue loads and tower base fatigue loads as relevant for site specific load analysis.

Biography: Anand Natarajan holds a Ph.D. degree in Aerospace Engineering from Virginia Tech, U.S.A. His research focus areas include offshore wind turbine design, reliability and lifetime estimation of mechanical components. Prior to joining DTU, he worked for the wind energy industry (GE) and has overall 15 years of experience in wind energy. He is the project manager of the EU FP7 INNWIND.EU project (2012-2017) and was the secretary of the EU TPWIND working group on offshore technology (2011-2014).

Second Speaker: David Witcher, DNV-GL

Abstract: The presentation will introduce the concept of probabilistic design and how uncertainty can be quantified and accounted for in such a design approach. It will start with a brief look at the sources of uncertainty both in terms of physical uncertainty and uncertainty in measurements or knowledge and then move on to look at the quantification of uncertainty at both a component level and a system level. Some examples will be presented in the context of a large offshore wind turbine design. The presentation will end by posing a question about the future of uncertainty and what implications it has for our approach to turbine designs of the future.

Biography: David Witcher is a principal engineer at DNV GL with 15 years' experience in the development and use of software design tools to aid in the wind turbine design process and has most notably be involved in the development of Bladed, the wind turbine design software. David also spent two years at a small wave energy device developer where he championed the use of systems engineering and MDAO to solve the complex design problem.

Third Speaker: Rick Damiani, NREL

Abstract: The lead causes of fatigue-related and non-catastrophic failures in the wind industry are largely unknown because of the overall stochastic nature of the wind and wind turbine response. Structural failures can be originated by either control and protection system failures, manufacturing defects, mistakes in siting, or human errors in operations. The loading stochasticity creates important challenges for the designers, and although a systematic approach to the uncertainty modeling would be ideal, it is hard to realize.

This talk summarizes the findings of a study on the subject of uncertainty in wind turbine and power plant design as emerged from a broad analysis of the current procedures, industry best practices, design codification, and expert opinions. The topic of uncertainty is very broad and many intermingled pathways could be followed to try and

capture the most critical aspects. To organize and prioritize the various phenomena, a design criteria identification and ranking table (DCIRT) was created based on the inputs of many experts in the field. Five major categories of uncertainties were identified including: turbine loading impacts (inflow, extreme events, aero-hydro-servo-elastic response, soil-structure interaction, and load extrapolation); material behavior and strength; site suitability and due-diligence; calibration of partial safety factors and optimal reliability levels; and computational modeling. The DCIRT uses color codes (red, yellow, and green) to identify priorities (high, medium, and low) and areas in need of more research. A few highlights from the DCIRT and recommendations on suggested strategies to fill in the existing knowledge gaps are presented.

Biography: Dr. Rick Damiani is a Sr. Engineer at the National Wind Technology Center (NREL), where he focuses on aeroelastic modeling of turbines and structural design and analysis of blades and support structures. Before joining NREL, he had been working as a consultant in wind turbine design since 2000. He holds a PhD in Aeronautical Engineering and is a Licensed Professional Engineer.

Afternoon Keynote

Keynote Speaker: Hanne Johansen, Vestas

"Developing strategic roadmaps: identifying the right technologies to support future competitiveness"

Abstract: This talk will explore successful innovation processes applied to wind energy including: 1) gaining a clear perspective on the speed of adoption of technology, 2) aligning with core company objectives as well as market perspectives, and 3) keeping strategy in mind through all innovation projects.

Biography: Hanne Johansen is Vice President for Innovation Management at Vestas Wind Systems A/S - the energy industry's global partner on sustainable energy solutions with more than 83 GW of wind turbines in 75 countries on six continents. In her role, she is leading the yearly Technology Strategy and road map process, improving the innovation processes and culture within Vestas, identifying new market potential for new innovations, and leading the development of the strategy and business plan for the Vestas Power Solutions business unit. Hanne Johansen has been with Vestas since 2010. Prior to her current role she has amongst other lead smart data projects and has been responsible for the service product road maps. Before joining Vestas, Hanne Johansen has held various positions leading strategic projects in international companies. Hanne Johansen holds a bachelor's degree in Computer Science and an Executive MBA in Innovation and International Business Development from the Technical University of Denmark.

Session III: Uncertainty Impacts on Plant Design and Performance

Session Chair: Pierre-Elouan Réthoré

First Speaker: Zachery Parker, Nordex

Abstract: Nordex/Acciona Windpower presents a wind farm design process focused on reducing LCOE. The process integrates models at the wind turbine level and the wind farm level, enabling early collaboration to identify turbine configurations and locations which increase production and reduce costs. Potential enhancements regarding uncertainty are highlighted.

Biography: Zach has been active in the wind energy sector since 2008, beginning with DOE funded research at Boise State University and continuing to roles with Gamesa, Nordex, and NREL. Since 2015 he has focused on deploying software to optimize turbine performance at the headquarters of Nordex/Acciona Windpower in Hamburg, Germany.

Second Speaker: Nicolai Gayle Nygaard, DONG Energy

Abstract: What is the cost of uncertainty in the wind plant design process? How can we systematically quantify the uncertainty, understand its components and determine the best path for reducing it? I will focus on uncertainties related to wind resource assessment and layout optimization. Does uncertainty influence the wind plant design?

Biography: Nicolai Gayle Nygaard is lead wind energy analyst at DONG Energy. He works on wake modelling, wind resource assessment, remote sensing as well as performance assessment of wind turbines and wind power plants. He holds a Ph.D. in chemical physics from University of Maryland, College Park.

Theme 2: System Design Methods, Tools, and Processes

Session IV: MDAO Applications to Wind Turbine Design

Session Chair: Pietro Bortolotti, TUM

First Speaker: Frederik Zahle, DTU Wind Energy

Abstract: Design of a wind turbine rotor is an inherently multidiscplinary problem. The balance between on one side material strength and stiffness and loads versus on the other side aerodynamic efficiency continues to be a challenge to blade designers in the quest to lowering cost of wind energy. The use of integrated design tools that couple the aerodynamic and structural design of the blade has greatly helped improving the efficiency of wind turbine blades over the last decades, driving down cost of energy with it. This presentation will introduce one such design tool and through examples seek to demonstrate the strength of multidisciplinary numerical optimization.

Biography: Frederik Zahle completed his masters in aeronautical engineering at Imperial College, London in 2003, and earned a Ph.D. jointly from Imperial College and Risø DTU in the field of computational fluid dynamics (CFD) of wind turbines, which he completed in 2007. He is currently holding a position as a senior scientist in the Aerodynamic Design Section (AER) at the Department of Wind Energy, Risø Campus, DTU. His current research activities are within aerodynamics of airfoils and rotors, computational fluid dynamics, and multi-disciplinary design of wind turbines.

Second Speaker: Alessandro Croce, Politecnico di Milano

Abstract: In this talk is presented an application of Multidisciplinary Design Analysis and Optimization (MDAO) to a rotor blade design for an Italian industrial project. In this analysis, the rotor blade has been design for re-blading existing wind turbines so that loads on the other components, such that hub, drive train and tower have been constrained. The presentation will describe both the complete design process, based on the comprehensive multi-disciplinary design tool Cp-Max, as well as the test for the certification which have followed the design itself.

Biography: Alessandro Croce holds a Ph.D. in Aerospace Engineering from the Politecnico di Milano in Italy in 2004, became assistant professor in 2011 and is now Associate Professor of Flight Mechanics at the Department of Aerospace Science and Technology of the PoliMI. His areas of expertise include wind turbine design, multidisciplinary optimization of rotor systems, wind turbine active and passive load alleviation systems and wind tunnel testing. On these topics he has co-authored about 100 publications in peer-reviewed international journal papers, book chapters and conference proceedings. He is coordinating the POLI-Wind Laboratory (i.e. the wind energy laboratory within the Aerospace Department) and is representative of Politecnico di Milano within the European Academy of Wind Energy (EAWE).

Third Speaker: Katherine Dykes, NREL

Abstract: This presentation will survey case studies that looked at holistic wind turbine optimization using multi-disciplinary techniques and a cost of energy objective function. Particularly, the trade-offs in the design between turbine sub-systems will be high-lighted to showcase the benefits of MDAO compared to a more traditional, sequential optimization approach.

Biography: Katherine Dykes is a Senior Engineer at the National Renewable Energy Laboratory and the Team Lead for Systems Engineering in the wind energy center. She holds a Ph.D. from MIT in Engineering Systems with a dual-MS from the Ohio State University in Electrical Engineering and Applied Economics.

Session V: Uncertainty Quantification in MDAO for Wind Energy

Session Chair: Mike McWilliam, DTU Wind Energy

First Speaker: Andrew Ning, BYU

Abstract: We use polynomial chaos (PC), an uncertainty quantification method, to construct a polynomial approximation of wind farm power production and to efficiently compute the expected power (AEP). We explore both regression and quadrature approaches to compute the PC coefficients. Regression-based PC is significantly more efficient than the rectangle rule (the method most commonly used in practice), and reduces the number of simulations required by as much as an order of magnitude. This UQ method is applied to optimization under uncertainty studies of wind farm layout design. Finally, some initial results on multi-fidelity UQ methods will be discussed.

Biography: Andrew Ning is an Assistant Professor in the Mechanical Engineering Department of Brigham Young University. His research focuses on multidisciplinary design optimization and aerodynamics with applications in wind energy and aircraft. He received his PhD and MS degrees from Stanford University in Aeronautics & Astronautics with a focus on aircraft formation flight aerodynamics. Prior to joining BYU he worked at the National Renewable Energy Laboratory on wind turbine design optimization and aeroelastic analysis.

Second Speaker: Juan-Pablo Murcia, Vestas

Abstract: Polynomial surrogates are used to characterize the energy production and lifetime equivalent fatigue loads for different components of the DTU 10 MW reference wind turbine under realistic atmospheric conditions. The variability caused by different turbulent inflow fields are captured by creating independent surrogates for the mean and standard deviation of each output with respect to the inflow realizations. A global sensitivity analysis shows that the turbulent inflow realization has a bigger impact on the total distribution of equivalent fatigue loads than the shear coefficient or yaw misalignment. The methodology presented extends the deterministic power and thrust coefficient curves to uncertainty models and adds new variables like damage equivalent fatigue loads in different components of the turbine. These surrogate models can then be implemented inside other workflows such as: estimation of the uncertainty in annual energy production due to wind resource variability and/or robust wind power plant layout optimization. It can be concluded that it is possible to capture the global behavior of a modern wind turbine and its uncertainty under realistic inflow conditions using polynomial response surfaces. The surrogates are a way to obtain power and load estimation under site-specific characteristics without sharing the proprietary aeroelastic design.

Biography: Juan Pablo Murcia works in Vestas as a Specialist in Mathematical modeling and statistics. He finished his PhD in Uncertainty Quantification in wind farm flow models for both power production and load estimation at DTU Wind Energy. He specializes in Model Validation based on operational (SCADA) data of turbines/wind plants and in the use of machine learning surrogates for aeroelastic response inside systems engineering setups.

Third Speaker: Curran Crawford, University of Victoria

Abstract: This talk will overview three probabilistic approaches being developed in the Sustainable Systems Design Lab (SSDL) with the unifying end-goal of creating optimization toolsets capable of directly handling system variability to enhance overall wind energy system value while minimizing computational cost. The first approach employs Bayesian techniques to better predict the range of structural performance from composite blades, using a micromechanics model for greatest flexibility in material choice. The second research effort is aimed at developing blade-element-momentum (BEM) and Lagrangian vortex aerodynamic models (and

eventually coupled aero-structural-control models) using chaos expansion formulations to implicitly handle unsteady inflows and directly provide full statistical knowledge of loading and power production. The third research effort employs cumulant-based formulations of the grid power flow equations to examine stochastic wind power injections and electrical loads.

Biography: Dr. Curran Crawford works at the University of Victoria (UVic), Department of Mechanical Engineering, Sustainable Systems Design Lab (SSDL). Dr. Crawford has worked on wind turbine system multidisciplinary optimization since 2002, starting with his SM thesis at MIT connecting FAST to a CAD-based turbine parameterization and PhD at Cambridge developing optimization tools for a coning rotor concept. Building up over the past decade as a professor at UVic, his SSDL research group now works on a portfolio of optimization frameworks across wind (onshore/offshore/airborne), tidal and wave energy devices, as well as electrical grid system integration using demand response and green aircraft design. This body of work makes of use of range of model fidelities and multidisciplinary optimization frameworks, with a particular emphasis on developing probabilistic toolsets.

Session VI: Multi-fidelity approaches to Wind Energy MDAO

Session Chair: Frederik Zahle, DTU Wind Energy

First Speaker: Justin Gray, NASA

Abstract: In order to extract the best performance out of our systems, we're seeking tighter integration and greater synergy between sub-systems. Designing these increasingly coupled systems requires building increasingly multidisciplinary models. These models tend to have longer run times and include large design spaces, which motivates the use of gradient based optimization with analytic derivatives as a more efficient method for solving these design problems. NASA's OpenMDAO framework provides the tools for quickly building multidisciplinary models with analytic derivatives and optimizing them. It has been applied to a wide range of relevant problems including aero-propulsive aircraft concepts and aero-structural wind turbine blade design.

Biography: Justin Gray has worked at NASA's Glenn Research Center for 15 years as a propulsion systems analyst and MDO specialist. Justin has served as the OpenMDAO Development Team Lead since 2010, and worked on MDO applications including aircraft propulsion, satellite design, and wind energy. He is currently working toward his PhD in MDO at the University of Michigan.

Second Speaker: Michael McWilliam, DTU Wind Energy

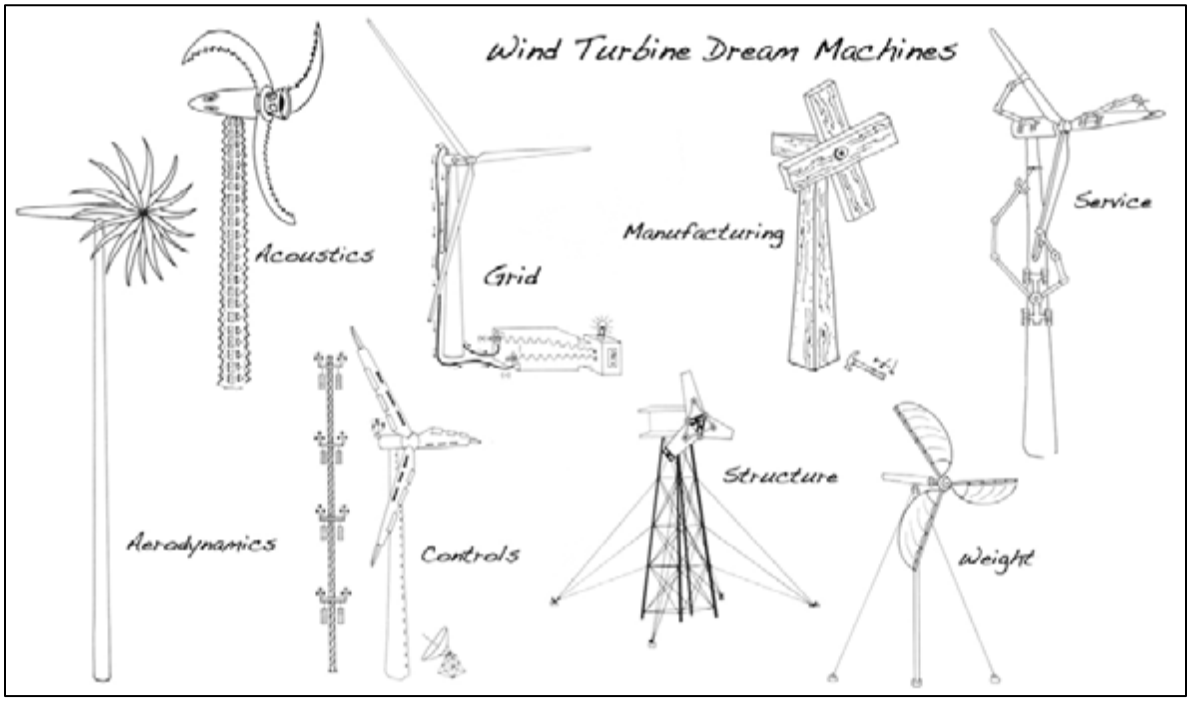
Abstract: Typically wind turbine design optimization frameworks are based on simple tools for computational efficiency making it suitable only for basic design early in the design process. Yet, many interesting design innovations require higher fidelity analysis. This talk will present two ways of incorporating higher fidelity analysis into the optimization, the first is the traditional approach of coupling the high fidelity analysis directly into the analysis. This typically requires a redevelopment of the methods to make them more suitable for design optimization. A second, is based on using multi-fidelity surrogate based approaches that can work with existing codes to sample the design space only when needed. Thus, potentially achieving more efficient optimization.

Biography: Michael K. McWilliam received his bachelors and masters in Mechanical Engineering from the University of Waterloo specializing in wind turbine aerodynamics. After, he pursued a PhD, supervised by Prof. Curran Crawford in Multidisciplinary Design Optimization (MDO) of wind turbine blades with medium fidelity tools, like vortex methods, nonlinear beams and anisotropic cross analysis. He successfully defended his thesis in 2015. Currently, he is a Research in the DTU wind energy department.

Third Speaker: Carlo Bottasso, TUM

Abstract: The presentation describes an algorithmic framework for the comprehensive multi-disciplinary design of wind turbines. The design problem is formulated as a constrained optimization. Design variables parameterizing aerodynamics, structures, controls, and systems are computed that minimize a cost of energy model, while satisfying an extensive number of constraints expressing all desired design conditions, including performance, manufacturing, safety, operation and others. This multi-physics optimization poses several challenges. In fact, there is a need to limit the computational cost while not sacrificing accuracy. In addition, there is a need to faithfully capture all existing subtle couplings existing among the various disciplines and the sub-components of the overall wind turbine system. The problem is further complicated by the fact that some design variables have only a very modest effect on the overall cost of energy. This means that a naïve one-shot monolithic formulation is in most cases ill posed, and the overall design problem should be reformulated as a collection of coupled well-posed sub-optimization problems. The presentation will describe the automated wind turbine design approach developed by our research group, and it will present examples of its application to the integration of multiple passive load mitigation technologies on board multi-MW machines.

Biography: Carlo L. Bottasso holds the Chair of Wind Energy at the Technical University of Munich, Germany, where he directs the Wind Energy Institute. His research interests are in wind energy and rotorcraft technology, with particular reference to modeling and simulation, aeroservoelasticity and control. On these topics he has co-authored over 350 publications, including more than 100 peer reviewed journal papers.



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

Workshop Agenda: Day 2

Day 2: September 14th, 2017	
8:30 a.m.–9:30 a.m.	**Day 2 Opening Remarks:** Katherine Dykes **Opening Keynote Address:** Peter Fuglsang, Siemens Gamesa Renewable Energy
Theme 3: Integrated Design for Wind Energy Systems in Practice	
9:30 a.m.–10:30 a.m.	**Session VII: Turbine MDAO in Industry Practice** **Moderator:** Rick Damiani, NREL Kristian Dixon, Envision Energy Christian Frank Andersen, LM Wind Power Francesco Grasso, Vestas
10:30 a.m.–10:45 a.m.	**Break**
10:45 a.m.–12:00 p.m.	**Session VIII: Plant MDAO in Industry Practice** **Moderator:** Karl Merz, Sintef Pieter Gebraad, Siemens Gamesa Renewable Energy Ervin Bossanyi, DNV-GL Nick Robinson, AWS Truepower Gregor Giebel, DTU Wind Energy
12:00 p.m.–12:45 p.m.	**Lunch**
12:45 p.m.–1:45 p.m.	**Session IX: IEA Wind Task 37 Update** **Moderator:** Frederik Zahle, DTU Wind Energy Katherine Dykes, NREL Pietro Bortolotti, TUM Sebastian Sanchez Perez-Moreno, TU Delft Mike McWilliam, DTU Wind Energy
1:45 p.m. – 2:00 p.m.	**Break**
2:00 p.m. – 3:15 p.m.	**Panel: Public-Private Partnership in Wind Energy System Research** **Moderator:** Kenneth Thomsen, DTU Wind Energy Mikel Iribas Latour, CENER Anand Natarajan, DTU Wind Energy Mersudin Bajric, DNV GL – Energy Yavor V. Hristov, Vestas
3:15 p.m. – 3:30 p.m.	**Closing Remarks**
3:30 p.m. – 3:45 p.m.	**Break**
3:45 p.m. – 5:15 p.m.	**Tour of DTU Wind Energy Facilities**

Day 2: Opening Session

Opening Remarks: Katherine Dykes, NREL

Keynote Speaker: Peter Fuglsang, Siemens Gamesa Renewable Energy

"Design Drivers"

Abstract: This presentation conveys an outside-in view on the design drivers for wind turbines. Starting point is the market and the Customer and how to come to the development of the right products in the end. This requires understanding on how to translate Customer value into design requirements and new technologies. One important part in this is the understanding of the value chain and how to properly have the right simultaneous focus on product and manufacturing targets, also fitting into a global footprint. The design approach is important and more than having the right design tools. The design philosophy, modularization, design knowledge and also design for manufacture are fields that play an important role during product design to arrive at a successful product in the end.

Biography: Peter Fuglsang is Head of Blades in the Technology Department in the Offshore Business Unit of Siemens Gamesa Renewable Energy. He graduated in 1994 as Mechanical Engineer from Aalborg University, Denmark. From 1994 to 2004 he worked at Risø National Lab as a researcher in the fields of wind turbine aerodynamics, aeroelasticity, aeroacoustics, numerical optimization, cost modelling, wind tunnel testing and wind turbine blade design. In 2004 he joined LM Wind Power A/S as Manager of the Aerodynamics Team doing wind turbine blade design, airfoil design, passive & active flow control being responsible for strategy and innovation in area. He was responsible for establishing the LM Wind tunnel. In 2011 he joined Siemens Wind Power A/S and currently he has the full responsibility for design, prototyping, certification and validation of new blades and upgrades for Siemens Gamesa Offshore wind turbines.

Theme 3: Integrated Design for Wind Energy Systems in Practice

Session VII: Turbine MDAO in Industry Practice

Session Chair: Rick Damiani, NWTC

First Speaker: Kristian Dixon, Envision Energy

Abstract: The rotor is the most influential component in the turbine system in terms of overall performance, cost and ultimately LCOE. A clear understanding of rotor tradeoffs and how these interact with and influence other turbine components is critical to the success of a product. The rotor system design problem is summarized in the context of the needs of a fast-moving Chinese OEM. The impact on methodology and model development choices is explored by examining the tradeoff between fidelity and computational/implementation effort. The chosen design philosophy must be matched to a given market climate and its influence on internal expectations and targets. Increased pressure for reduced time to market combined with reduced cost as a market entry threshold forces a different and in some a ways more focused approach to innovation and technology development.

Biography: Kristian Dixon completed his B.A.Sc. in engineering science at the University of Toronto and his M.Sc. in aerospace engineering at TU Delft (Netherlands). Kristian joined Siemens Wind Power a few months after graduating in 2008, working in both Denmark and Boulder Colorado and spent nearly 8 years with SWP before joining Envision Energy in mid-2016. Kristian has worked on several blade design efforts and developed numerous frameworks, tools, and models for use in design and optimization. Kristian is currently the technical

lead for Envision's in-house blade design projects. His interests have expanded to include turbine system level modelling in support of better trade-space analysis and decision making at the product level.

Second Speaker: Christian Frank Andersen, LM Wind Power

Abstract: Having design and manufacturing under one roof gives you some benefits when optimizing for the best blades. At LM Wind Power we have stored our more than 30 years of layup experience in the design specification: "The standard Laminate Plan". Furthermore, we have implemented these manufacturing constraints in our blade optimizer: RotorOpt. This means that RotorOpt outputs a layup plan ready to be produced in a LM Wind Power factory. This presentation gives an introduction to "The Standard Laminate Plan" and RotorOpt.

Biography: Mr. Christian Frank Andersen has been working in the wind industry since 1998. He is currently Director of Conceptual Design at LM Wind Power. He studied Mechanical Engineering specialized in Energy Technology and Fluid Dynamics at Aalborg University. After his studies he has held different positions at LM Wind Power (Research Specialist, Chief Engineer) and has mainly been involved in designing blades and development of design tools.

Third Speaker: Francesco Grasso, Vestas

Abstract: The selection of the aerofoils plays a crucial role to obtain high wind turbine performance, which include not only aerodynamics, but also noise, structure and manufacturing. Multi-disciplinary optimization offers a design methodology that should naturally mimic the complete physics of the problem.
The presentation gives an introduction about the latest work done in Vestas on aerofoil development.

Biography: Francesco has an MSc in aeronautical engineering in 2005 at University of Napoli "Federico II" and obtained a PhD in 2008 in aerospace engineering on multi-disciplinary optimization applied to aircraft design. He is an aerodynamicist researcher at ECN from 2009 to 2014. Since 2015, aerodynamic specialist at Vestas for blades and aerofoils development.

Session VIII: Plant MDAO in Industry Practice

Session Chair: Karl Merz, Sintef

First Speaker: Pieter Gebraad, Siemens Gamesa Renewable Energy

Abstract: Optimizing turbine layouts for the levelized cost of energy (LCOE) has been shown to yield significant savings in balance of plant (BOP) costs when compared to turbine layouts that have been optimized for net annual energy production (AEP) alone. The reduction in BOP costs is achieved by trading off one-time capital costs against recurring energy revenue. We looked at the potential advantages of optimizing for internal rate of return (IRR) compared to LCOE and AEP.

Biography: Nick Robinson has 20 years of experience in the wind industry and is the lead author of OpenWind, developed by AWS Truepower. Before joining AWS Truepower in 2007, Nick worked in consultancy and development in Quebec. Prior developments include WINDOPS which later became GH WindFarmer. Currently, Nick enjoys working out of his home office in British Columbia where he stays busy developing new features of OpenWind in response to requests from both internal and external users.

Second Speaker: Pieter Gebraad, Siemens Gamesa Renewable Energy

Abstract: This talk will discuss some of the industrial design practices for wind turbine and wind farm control research and development, the interface with system engineering research in academics and national labs, and a vision for wind farm control development in the coming years.

Biography: Pieter Gebraad is a Wind Farm Control and Optimization Engineer at Siemens Gamesa Renewable Energy. He joined Siemens Gamesa in March 2016 after having been in controls research positions at Delft University of Technology and the National Renewable Energy Laboratory.

Third Speaker: Ervin Bossanyi, DNV-GL

Abstract: The potential of wind farm control for manipulating wake interactions to optimize wind plant economic performance depends on subtle trade-offs between energy production, fatigue loads and provision of grid ancillary services. Understanding this requires modelling of a broad range of effects, but to achieve a sufficient level of detail with manageable computer resources needs careful marshalling of different types of models. The presentation explains how different tools are being brought together for DNV GL's current research in this area, covering atmospheric turbulence, wake flows, turbine control, fatigue loading, and grid interaction.

Biography: Ervin Bossanyi has a physics degree and a PhD in energy economics, and has been working on many aspects of wind energy and other renewables in the academic, industrial and consultancy sectors since 1978. Main contributions include development of detailed simulation models and advanced control concepts for commercial wind turbines. He is a co-author of Wiley's widely-used Wind Energy Handbook, and was given the European Academy of Wind Energy's Scientific Award in 2014. He is currently senior principal researcher in renewables at consultants DNV GL, and has a visiting professorship at Bristol University.

Forth Speaker: Gregor Giebel, DTU Wind Energy

Abstract: The European Energy Research Alliance (EERA) Joint Programme Wind worked 3, 5 years on bringing together their partners' in-house software to create the Design Tool for Offshore Clusters (DTOC). The talk describes the tool, the design process, the challenges of integration, and the additional bits which make a software framework usable for industry. The DTOC tool (see eera-dtoc.eu) and its commercial version, Wind & Economy (wind-and-economy.com) enable the calculation of annual energy production and levelized cost of energy of offshore wind farms and clusters of wind farms in a scenario based comparative approach.

Biography: Dr. Gregor Giebel is a Senior Scientist at DTU Wind Energy at Risø. He has worked for more than 20 years with energy meteorology, especially short-term forecasting of wind power, wind farm control and large-scale integration of wind power into electricity grids. He is Operating Agent of IEA Wind Task 36 Forecasting for Wind Power.

Session IX: IEA Wind Task 37 Update

Session Chair: Frederik Zahle, DTU Wind Energy

First Speaker: Katherine Dykes, NREL

Abstract: This talk provides an overall overview of the IEA Wind Task 37 on wind energy systems engineering and an update on Work Package 1 which focuses on the development of guidelines for integrated system modeling / MDAO frameworks for wind energy.

Biography: Katherine Dykes is a Senior Engineer at the National Renewable Energy Laboratory and the Team Lead for Systems Engineering in the wind energy center. She holds a Ph.D. from MIT in Engineering Systems with a dual-MS from the Ohio State University in Electrical Engineering and Applied Economics.

Second Speaker: Pietro Bortolotti, TUM

Abstract: This talk will give an update on activity in the IEA Wind Task 37 Work Package 2.1 on reference wind turbines and the development of two reference turbines – an offshore 10 MW wind turbine and land-based 3.X MW wind turbine (with an emphasis on the latter).

Biography: Pietro Bortolotti graduated from TU Delft in 2012 and after one year of work at DTU joined the Wind Energy Institute of the Technical University of Munich. Here he is currently completing his PhD studies on multi-disciplinary design optimization of wind turbines under the supervision of Prof. Carlo Bottasso. Pietro is involved in several public and industrial research projects related to design and he has been the contact person at TUM for IEA Task 37.

Third Speaker: Sebastian Sanchez Perez-Moreno, TU Delft

Abstract: This talk will focus on the progress made thus far on the ongoing WP 2.2: Reference wind plants (RWP) of the IEA Wind Task 37. Results of a survey for the use cases of RWP in academia and industry, the definition of wind plant components to be designed, both onshore and offshore, and a preliminary design workflow will be presented.

Biography: Sebastian Sanchez Perez-Moreno is a PhD researcher at the Wind Energy Institute of the Delft University of Technology. His research aims at improving the application of MDAO in the domain of offshore wind farms. He holds a BS in Physics from UNAM and MS in Renewable Energy from Durham University.

Fourth Speaker: Michael McWilliam, DTU Wind Energy

Abstract: Design optimization is a critical tool in Systems Engineer because it can deterministically navigate all the disciplinary interactions to achieve optimal designs. The IEA task aims to conduct a set of case studies to develop a set of best practices for design optimization. Since the full multidisciplinary problem is complicated, the first case study is focusing on aerodynamic optimization with some structural considerations. Multiple institutions around the world have applied their tools to this problem. The results of this comparison will be presented in this talk.

Biography: Michael K. McWilliam received his bachelors and masters in Mechanical Engineering from the University of Waterloo specializing in wind turbine aerodynamics. After, he pursued a PhD, supervised by Prof. Curran Crawford in Multidisciplinary Design Optimization (MDO) of wind turbine blades with medium fidelity tools, like vortex methods, nonlinear beams and anisotropic cross analysis. He successfully defended his thesis in 2015. Currently, he is a Research in the DTU wind energy department.

Panel: Creating Successful Collaborative Wind Energy System Research

Panel Moderator: Kenneth Thomsen, DTU Wind Energy

First Speaker: Mikel Iribas Latour, CENER

Abstract: CL-Windcon (Closed Loop Wind Farm Control) will put forward new innovative solutions based on wind farm multi-fidelity dynamic modelling, and open- and closed-loop advanced control algorithms, which will enable to treat the entire wind farm as a single integrated real-time optimization problem. Extensive validation will be performed through simulations and wind tunnel tests, as well as some open-loop field tests. The suggested approach is expected to reduce LCoE and O&M costs, improving turbine and farm-level reliability and availability for existing and future, onshore and offshore, wind farms. An economic, environmental and standards impact analysis will also be performed.

Biography: Coordinator of CL-Windcon H2020 project, Mikel is Head of R&D of Wind Energy Department at CENER (Spain). Master on "Control Systems and Industrial Engineer" at Universidad Pública de Navarra, he held the leadership of Control Area at CENER for 12 years. He is author of several patents in the field of wind turbine system identification. He has also been Associate Professor at Universidad Pública de Navarra, at the Automatic Control department, and invited as lecturer for several Master and PhD programs at EU level. Throughout his career, he has participated in numerous customer-oriented, and national and EU-funded R&D projects.

Second Speaker: Anand Natarajan, DTU Wind Energy

Abstract: The proposed project is an ambitious successor for the UpWind project, where the vision of a 20MW wind turbine was put forth with specific technology advances that are required to make it happen. This project builds on the results from the UpWind project and will further utilize various national projects in different European countries to accelerate the development of innovations that help realize the 20MW wind turbine. DTU is the coordinator of this large project of 5 years duration and with a total of 27 European partners. The overall objectives of the INNWIND.EU project are the high performance innovative design of a beyond-state-of-the-art 10-20MW offshore wind turbine and hardware demonstrators of some of the critical components. The progress beyond the state of the art is envisaged as an integrated wind turbine concept with: The proposal addresses the heart of the Long Term R&D Programme of the New Turbines and Components strand of the European Wind Initiative (EWI) established under SET-Plan, the Common European Policy for Energy Technologies. The consortium comprises of leading Industrial Partners and Research Establishments.

Biography: Anand Natarajan holds a Ph.D. degree in Aerospace Engineering from Virginia Tech, U.S.A. His research focus areas include offshore wind turbine design, reliability and lifetime estimation of mechanical components. Prior to joining DTU, he worked for the wind energy industry (GE) and has overall 15 years of experience in wind energy. He is the project manager of the EU FP7 INNWIND.EU project (2012-2017) and was the secretary of the EU TPWIND working group on offshore technology (2011-2014).

Third Speaker: Mersudin Bajric and Gireesh Ramachandran, DNV GL – Energy

Abstract: Together with global partners, DNV GL, the world's largest resource of independent energy experts and renewables certification body is running a Joint Industry Project (JIP) to develop a new Best Practice for the validation of turbulence models. The JIP "Validation of Turbulence Models" aims to create a better understanding of turbulence modelling to reduce uncertainty in the design of wind farms. By jointly developing guidelines in the form of a Best Practice document the project will improve accuracy on site-specific load assessments, leading to a reduction in the cost of wind energy. To design wind turbines and wind farms, the industry currently relies on wind turbulence models that were developed decades ago when wind turbines were smaller than modern

turbine types. With the increased size of wind turbines, the current turbulence models could result in large fatigue load variations with differences of up to 20% (based on internal investigation). Furthermore, existing turbulence models may not be sufficiently applicable to other site-conditions beyond flat terrain and neutral atmospheric stability.

By providing a platform to discuss challenges such as the most appropriate turbulence model parameters and whether parameters should differ onshore and offshore, stakeholders are developing a mutual alignment on key questions that are vital to moving the industry forward. The JIP will collect onshore and offshore high frequency wind measurement data from more than 15 sites across the globe, considering onshore, offshore and coastal influences in the analysis. By validating key turbulence parameters and evaluating their load impact, the JIP will provide guidance for optimal wind turbulence parameters / models for design and site assessments in a new Best Practice document. The participants include a global range of wind farm developers, wind turbine manufactures and research institutes.

Biography: Mersudin Bajric: Focus on certification development and project management. Principal Project Manager at DNV GL, Dipl. Ing. Mechanical Engineering Technical University Hamburg-Harburg. Mersudin has worked for a computational fluid dynamics software development company before he joined DNV GL. Since 2007 he has worked for DNV GL where he has participated in and been Project Manager for several large type certification projects. He has large knowledge on Type Certification and Project Certification of wind turbines.

Gireesh K V Ramachandran: Focus on aero-hydro-servo-elastic loads at wind turbine and support structures in relation to wind turbine type and project certification, wind turbine (covering onshore, offshore – bottom-fixed and floating wind turbines) research, development, and innovation projects at DNV GL. Senior Engineer at DNV GL, Ph.D. from DTU Wind Energy. Gireesh has been with DNV GL since 2013, working for Site conditions and Loads department focusing on aero-hydro-servo-elastic load calculations for wind turbines and support structures (covering onshore, offshore – bottom-fixed and floating wind turbines). Previous to the current position, he has been working with NWTC-NREL, USA, DTU Wind Energy, Denmark, NIWE, India, and a couple of other research organizations.

Fourth Speaker: Yavor V. Hristov, Vestas

Abstract: "Wind. It means the world to us.™ Vestas is the only global energy company dedicated exclusively to wind energy. Wind is our business and our passion. Founded in 1898 as a blacksmith shop in western Denmark, we started producing wind turbines in 1979, and have since gained a market-leading position with 83 GW of installed wind power and more than 71 GW under service across the globe, including close to 7 GW of non-Vestas turbines. Today, everyone at Vestas works to ensure that we deliver best-in-class wind energy solutions and set the pace in our industry to the benefit of our customers and our planet. If we continue to do this every day we will be the undisputed global wind leader." Vestas.com

Biography: Yavor has worked at Vestas Wind Systems A/S since 2003 (first 5 years as Specialist, last 5 as Manager of Plant Simulations group). He holds a PhD in Fluid Dynamics from Sofia University and an MSc in Applied Mathematics from the same.