Title of Proposed Research
Simulation, Measurement, Modeling, and Control of Wind Plant Power

Related Technology Fields
Renewable Electricity for Minnesota’s Future

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Declaration of Confidential Information
None
1. Project Design

1.1. Background

The most economically feasible strategies for significantly reducing global carbon emissions involve substantial, up to 8 times, increases in energy production from renewable resources, which presently contribute only 10-13% in the world’s energy portfolio (Edenhofer et al. 2011). As a fast-growing renewable energy technology, wind energy is especially appealing. Compared to other renewables, wind energy has: substantially higher ratio of energy generated to energy consumed over its lifecycle (Inman 2013); lower lifecycle CO2 emissions (Weisser 2007); and nearly zero associated water usage (Meldrum et al. 2013). Wind energy is also well positioned to become a major contributor to the nation’s electric energy production portfolio within the next decade due to the: 1) enormous capacity potential of wind energy in the U.S. (estimated to be 11,000 GW onshore and 4,200 GW offshore, much larger than the current U.S. electricity generation capacity of 1,000 GW, see Lopez et al. 2012); 2) existing wind plant infrastructure with large installed capacity; 3) substantial domestic wind energy manufacturing infrastructure already in place, including 559 manufacturers in 44 states (AWEA 2013); and 4) the fact that it can provide an effective hedge against long-term natural gas price increases or uncertainty in future carbon regulations (Bolinger 2013). Given this state of affairs, the 20% electricity from wind by 2030 roadmap laid out by the US Department of Energy (DOE) (USDOE 2008) appears today to be rather modest and many States around the Nation, including Minnesota, have already set and/or achieved more aggressive goals for integrating renewables into their electricity production portfolio (Rabe 2006; Rabe 2008). For example, the 15-state Midcontinent Independent System Operator (MISO) territory is a 130,000 MW system, with now over 13,000 MW of wind power installed. Another 12,000 MW of wind power required under current state Renewable Portfolio Standards and existing and proposed environmental regulations like the Clean Air Act’s Section 111(d) Clean Power Plan could spur more renewables development (Stephens et al. 2015).

Realizing societal and financial benefits of wind energy, however, necessitates a new research paradigm centered on optimizing the performance and improving the reliability of new and existing multi-turbine wind plants. Forecasting models used today in practice are overly simplified as, for the most part, rely on just two major parameters, weather and wind speed, to assess resource availability and variability (MISO 2014). While these models achieve reasonable answers insofar as the time-average forecast is concerned, they cannot account for the inherently intermittent, highly dynamic, multi-scale nature of atmospheric turbulence and its effects on wind plant performance over a broad range of relevant time scales. In this proposal, we present a comprehensive, multidisciplinary research program using advanced simulation, measurement, modeling, and control tools for wind plant power output optimization.

1.2. Vision Statement

As a key technology of sustainable energy, wind power has the potential to fundamentally reshape the electric energy production portfolio with substantial societal and economic benefits. A major roadblock to wind energy realizing its transformative potential, however, arises from the inherently variable nature of the wind and the challenges this poses for integrating wind resources within the power grid. Critical for power grid operators is that this variability cannot always be predicted with the same accuracy as that of the output from conventional (fossil-fuel
fire/nuclear) power plants; increasingly critical for the owners of wind plants is the ability to predict and/or control facility-level output.

Wind energy output uncertainty arises through the complex interactions among atmospheric turbulence, wind turbines, and their wakes, and the complex terrains within wind plants, which occur across a broad range of spatial and temporal scales. To address these challenges, we form a multidisciplinary team of investigators consisting of researchers from Saint Anthony Falls Laboratory and Departments of Aerospace Engineering and Mechanics, Civil, Environmental, and Geo- Engineering, and Mechanical Engineering to develop a novel and comprehensive method for the prediction and control of wind energy variability.

We propose to develop a multidisciplinary approach for the simulation, measurement, modeling, and control of wind plants to advance the sustainable development of wind energy as a major contributor to the state of Minnesota as well as the Nation’s renewable electricity portfolio. As illustrated in Figure 1, the research plan integrates four interwoven components from different disciplines: 1) high-fidelity wind plant simulations on extreme-scale supercomputers to predict wind plant performance and reliability at unprecedented levels of spatial and temporal resolution; 2) validation of simulation through wind tunnel experiments with miniature turbines (wake interactions), and utility-scale wind turbine experiments (wake evolution at realistic Reynolds numbers) in the field; 3) physics-based, dynamic reduced-order models informed by big data generated from numerical simulation and experiment measurement to enable accurate and efficient real-time forecasting; and 4) development of an active power control strategy to minimize the variability of the power output of wind plants. Note that such a multidisciplinary approach, involving high-fidelity simulation on supercomputers, laboratory and field measurements, advanced reduced-order modeling and active control, is unique in the research of renewable energy. It should also be pointed out that while the design, operation, and optimization of individual wind turbines have been extensively investigated, our proposed study of wind plants involving numerous turbines in realistic environmental setting is the first of its kind and is a significant stride in the research of wind energy.

1.3. Research Plan
The proposed project builds on our cutting-edge research approaches in high-fidelity computer simulation, laboratory and field measurements, dynamic reduced-order modeling, and advanced control of wind plants. In the following, we first review the state of the art and introduce our
enabling research advances, and the presents our research plan in each area. The interaction
and integration of the four areas of research are discussed in Section 2.

1.3.1. High-fidelity simulation of wind plants
Computational models of large wind plants must account for individual turbine interactions with
atmospheric turbulence and complex terrains. Such models typically employ large-eddy
simulation (LES) and, depending on their spatial and temporal resolution, adopt various
approaches to represent the effects of wind turbines in the flow. Recent LES of wind plants with
actuator disk models have been reported by Abkar & Porté-Agel (2014), Calaf, Parlange &
Meneveau (2011), Chivaee & Sørensen (2014), and Yang et al. (2012). LES of wind plants with
the turbines represented with a more sophisticated approach using rotating actuator lines have
been reported by Churchfield et al. (2013), Lu & Porté-Agel (2011), De Rijcke, Driesen &
Meyers (2014), and Yang et al. (2014). All of these studies have considered wind plants on flat
terrain. Computational methods capable of handling complex terrain effects have just begun to
emerge. For example, Churchfield, Lee & Moriarty (2014) used the OpenFOAM code to
simulate the flow over a simple hill terrain using a body-fitted grid. LES of offshore wind plants
with the wavy surface of ocean waves taken into account was recently performed by Yang, Meneveau &
Shen (2014).

With prior funding from NSF, DOE, and industry, researchers at SAFL
have developed a powerful computational framework for
simulating with LES the interaction of
atmospheric turbulence with wind
turbines and plants in terrestrial
environments. Our code is able to: 1)
parameterize turbines as actuator
disks or actuator lines but also resolve
their geometrical details using the
curvilinear immersed boundary
(CURVIB) approach with wall models
(Kang et al. 2014); 2) handle arbitrarily
complex terrains using the CURVIB
method with wall models or boundary-fitted grids (Yang et al. 2015, 2014b); 3) account for the
effects of atmospheric stability (Yang et al. 2014b); 4) model turbine controls (Yang et al.
2014c). Our simulations have been successfully compared with measurements from both using
laboratory experiments (Kang et al. 2014; Yang et al. 2014b; Yang et al. 2015) and field
measurements at utility-scale wind plants (Yang et al. 2014b).

In this project, we will use the SAFL wind energy LES code to perform wind plant simulations.
To the best of our knowledge, and as indicated by the brief literature review presented above,
our LES code is among the most complete, multi-physics, computational frameworks for wind
plants available today. The code is unique in its ability to parameterize or resolve the details of
wind turbines and simulate arbitrarily complex terrain effects. The code with its newly
developed unstructured Cartesian grid formulation enabling adaptive mesh refinement (AMR) will be used as the computational tool for this work. While most aspects of this code have already been developed, some major advances will still need to be implemented as part of this work, including: i) an approach for modeling wind turbines in the context of large wind plant simulations; ii) a methodology to specify site-specific inflow boundary conditions from meso-scale computational models, such as WRF; and iii) strategies to map unstructured meshes to advanced computing architecture so that efficient scaling on extreme supercomputing platforms can be achieved and demonstrated.

1.3.2. Laboratory and field measurements of wind turbines and wind plants

Turbine-turbine interactions and far wake spatial evolution have been studied experimentally in the SAFL atmospheric wind tunnel using miniature wind turbines exposed to a realistic mean wind shear (Chamorro & Porté-Agel 2009, Hu et al. 2012, Howard et al. 2015 and 2016a) and a variety of thermal and topographic boundary conditions (Howard et al. 2016a, Yang et al. 2015). In the experiment, the rotor, which was composed of three fixed-pitch blade GWS/EP-5030 and characterized by a power coefficient $C_p \approx 0.27$ and a tip-speed-ratio (TSR) of 3.2, was directly connected to a DC generator through the hub-height shaft of the turbine model, enabling the generation of a differential voltage signal proportional to the rotor angular velocity. This allowed quantifying the turbine response to various perturbation of the baseline flow, including upwind hill, vertical cylinders, and other wind turbines (Annoni et al. 2016). Integrating turbine voltage output and spatio-temporally resolved measurements of the surrounding flow (see Figure 3), we have been able to define at which height the velocity signal is more correlated, or representative, of the actual measured performance (Howard et al. 2016b). This is particularly important in the context of the proposed research because it provides an indication of the optimal input velocity, upwind of the rotor, to be used in a control strategy. Interestingly, the results were confirmed using upwind LiDAR measurements and the EOLOS turbine SCADA data, suggesting that wind tunnel and field measurements can be complementary to validate and guide numerical simulations at different scales.

Field and wind tunnel measurements will be used to validate new sets of simulation. Specifically, the field measurements will be performed around the Eolos wind turbine using a number of measurement techniques including novel super-large-scale PIV, ground-based LiDAR, meteorological tower instrumentation, turbine blade and tower instrumentation, and turbine SCADA data. The measurements will provide synchronized flow information around utility-scale turbine across a wide range of spatial and temporal scales, turbine structural information, and turbine operation information. The flow measurements will cover both incoming flows and near wake and far wake regions of the turbine. We will collect field data
systematically under different atmospheric and turbine operational conditions (e.g., different atmospheric stabilities and turbine operation regimes). The laboratory measurements will include both single turbine and turbine array experiments using the SAFL atmospheric boundary layer wind tunnel. The single turbine experiment will use a miniaturized model of the Eolos turbine. The experimental conditions will be adjusted to reproduce the conditions under which the field measurements are obtained. Specifically, the incoming turbulent flow profiles and the atmospheric stability will be controlled by varying the surface roughness and temperature in the wind tunnel, respectively. The comparison of the field measurements and single turbine lab experiments will provide key information for numerical simulation to account for the realistic operating conditions of utility-scale turbines, including specific control strategy and blade aerodynamics at high Reynolds number. The turbine array experiments will employ a 3 x 6 array of miniature turbines, focusing on providing validation data for wind plant related numerical studies. The experiments will involve turbines of different height, spacing, and operation conditions (i.e., tip speed ratio and yaw alignment) under different atmospheric stability and terrains. The measurements will offer physical insights on a number of key questions related to wind plant operation including wake-turbine interaction, terrain effects on the turbine layout optimization, and turbine control strategies.

1.3.3. Physics-based reduced-order modeling of wind plants

Reduced-order models (ROMs) provide crucial physical insight into vast datasets produced by large-scale simulations and experiments, and provide a basis on which to develop novel flow control schemes. The simplest ROM of a large wind plant is the effective roughness height model (e.g., Calaf, Meneveau & Meyers 2010; Yang, Kang & Sotiropoulos 2012; Peña & Rathmann 2014), which represents the effect of the entire wind plant as an effective roughness height. Extension of such models to finite-size wind plants has been reported by Meneveau (2012) using the internal boundary layer concept. Kinematic wake models (Lissaman 1979; Jensen 1983; Katic, Højstrup & Jensen 1986; Frandsen et al. 2006; Yang & Sotiropoulos 2015) are widely employed for wind plant design. None of these models take into account the effect of dynamic coherent structures, e.g., wake meandering, on the turbine power output and structural loads. Reduced order models that attempt to mitigate this limitation are the so-called dynamic wake meandering (DWM) models (Larsen et al. 2008; Keck et al. 2012; Keck 2014; Keck et al. 2015), which account for wake meandering effects by assuming that the wake is passively transported by the large scale lateral- and vertical motion of the atmospheric turbulence. However, a predictive DWM model does not exist yet due to the complexity of the site-specific atmospheric turbulence and the validity of the passive tracer assumption. Attempts to develop more sophisticated ROMs take into account coherent dynamics and use the Proper Orthogonal Decomposition (POD) analysis of flow fields obtained from simulation (Bastine et al. 2014; Andersen, Sørensen & Mikkelsen 2013 and 2014). In spite of these efforts, however, predictive dynamical ROMs that can incorporate the effects of site- and turbine specific large-scale coherent structures in wind plants do not exist today.

In the context of wake-meandering, the predictive power of POD-based models is limited because they focus only on the most energetic flow structures that develop far downstream of individual turbines. Such models cannot capture the processes by which these energetic motions developed from lower-energy flow perturbations upstream closer to turbines. By focusing on coherent dynamics instead of energetics, Balanced-POD (BPOD) (Rowley 2005) and Dynamic Mode Decomposition (DMD) (Schmid 2010) are two recent advances in reduced
order modeling especially appropriate for convection-dominated flows. While POD modes can be ordered by decreasing energy, however, dynamics-centered ROMs unfortunately lose this natural organization. In collaboration with Prof. Jovanovic in the Electrical Engineering Dept. of UMN, co-PI Nichols helped develop a variant of DMD that recovers this information through the application of sparsity-promoting convex optimization algorithms (Jovanovic et al. 2014). Recently, co-PI's Seiler and Nichols applied BPOD and DMD to preliminary simulation data of a multi-turbine wind plant, with very promising results (Annoni et al. 2016).

In this project, physics-based ROMs will be developed to produce predictions in real time. The goal of our multi-fidelity approach is to utilize computationally intensive high-fidelity simulations to inform accurate dynamic ROMs that can run at a low computational cost for fast prediction of the wake-meandering instability responsible for reduced efficiency of power extraction and increased wear of downstream turbines. We will leverage high-fidelity data sets produced by the proposed experimental measurements and corresponding large-eddy simulations to extract physics relevant to wake-meandering and its connection to wind plant output variability. We envision a robust ROM-infrastructure in which libraries of site-specific ROMs can be developed for a variety of atmospheric states, which will provide information required for advanced control schemes. A major challenge for data-driven decomposition techniques is developing algorithms that handle extremely large matrices (so called “Big Data”). For example, a typical high-fidelity simulation can produce a snapshot matrix exceeding 1 TB in storage requirements. We will leverage the MapReduce framework originally developed by Google to implement DMD on massive tall-and-skinny matrices, based on a communication avoiding tall-and-skinny QR algorithm (Constantine & Gleich 2011). We will utilize the Red node Hadoop cluster at the Minnesota Supercomputing Institute for this purpose.

1.3.4. Advanced control of wind plants

Traditionally, wind plants are controlled in a decentralized fashion where each turbine is operated to maximize power extraction locally without consideration of aerodynamic interactions between neighboring turbines within a wind plant. Essentially, this amounts to a greedy control algorithm where each turbine is operated at its peak efficiency according to Betz' Law (Burton et al. 2001). In practice however, the energy extracted from the free stream flow at a leading turbine will generate a wake with reduced energy content, thereby mitigating the power extractable by nearby downstream turbines. There have been several papers in the recent literature that have examined advanced control for the entire wind plant. Johnson & Thomas (2009) presented several simulation-based results demonstrating sub-optimality in power capture when individual turbines are operated at their peak efficiencies. Marden, Ruben & Pao (2012, 2013) used a game-theoretic learning approach to solve the control problem. The approach does not require an explicit model of the aerodynamic interactions. However, the achievable performance may be limited in practice if the wind velocity varies more rapidly than the time required to converge to the optimal policy.

Designing wind plant control strategies requires a model of the wind plant that has a low computational complexity, but retains the necessary dynamics. A variety of wake models exist in literature that are useful for studying wind plant control. Low- and high-fidelity models have been used to evaluate wind plant control strategies. The analysis provides conflicting results based on the wake model chosen for control design. For example, control strategies designed using simple static models may report significant improvements in wind plant performance, but
an analysis of such control strategies using high-fidelity simulations can result in minimal to no improvements in wind plant performance. An example of a comparison between control predictions given by a high-fidelity and simplified model is given in Annoni (2015), where constant offsets of pitch and torque are used to change wake deficits. It is shown that extensions to the low-fidelity Park model are needed to match the results of high-fidelity models. The reduced order models developed in this research will be critical for the design of wind plant control laws.

In this project, Active Power Control (APC), which refers to a mode of operation where the wind turbine tracks a desired power reference command, will be developed to enable wind plants to perform frequency regulation and to provide ancillary services in the energy markets. APC can also be used to minimize the variability in the total power produced by wind plants. We have previously designed advanced gain-scheduled and Linear Parameter Varying (LPV) controllers for a single turbine to provide APC. These designs are multiple-input, multiple-output controllers that coordinate the blade pitch angle, generator torque, and standard inputs on a utility scale turbine. The objective is to track a given power reference command while also minimizing the structural loads. The controller is scheduled to adapt to changing wind speed and desired power commands. The performance of this LPV design is evaluated using high fidelity simulations. A limitation of these previous designs is that they focused on the control design for a single turbine. In reality the turbines in wind plants are coupled by the wind flow and complex wake dynamics. For example, reducing the power output at an upstream turbine will increase the power generated by a downstream turbine. Hence it is important for an APC to be coordinated across the entire wind plant. The objective of this subtask is to use the validated wind plant models (generated as part of the preceding three subtasks) to design such a coordinated wind plant APC. The benefit of this approach is that it will reduce the variability in the total power produced by the wind plant. To our knowledge, such whole-plant control method will be the first of its kind.

2. Project Management

2.1. Monitoring and Evaluation Scheme

2.1.1. Research team and interaction among different research components

The research team includes six investigators from three departments and one center at UMN. While all active and experienced in wind energy research, they possess different skill sets to contribute to various aspects of this multidisciplinary project. PI Shen (ME & SAFL) specializes in computational fluid dynamics with applications in wind energy. He holds the positions of Associate Director for Research of SAFL and Director of the Eolos Wind Energy Consortium. He will oversee the entire project and lead the efforts in simulation. Co-PI Guala (CEGE & SAFL) specializes in laboratory measurement of wind turbine model arrays. Co-PI Hong (ME & SAFL) is an expert in field measurement of utility-scale turbines. Co-PI Marr is the Associate Director for Engineering and Facilities of SAFL and has extensive experience in applied research and project management. Guala, Hong, and Marr will lead the efforts in measurement. Co-PI Nichols (AEM) is an expert in large-scale scientific computing and reduced-order modeling, and will lead the efforts in modeling. Co-PI Seiler specializes in control. He has worked extensively in wind energy control strategy, and will lead the efforts in wind plant control.
Figure 4 summarizes the role of each investigator and the interactions among different research components. It should be emphasized that for such a multidisciplinary project, it is important to have close interactions among different disciplines. We will:

(1) Have close comparisons and cross-validation between simulation and measurement. These two aspects will be complementary. Measurement will provide flow conditions and validation for the simulation, while simulation will provide a more complete physical picture of wind plants for interpretation of the acquired data.

(2) Use reduced-order modeling to substantially reduce the complexity of simulation and measurement data, while capturing the essential physics of wind plants. The reduced-order modeling also provides a mathematical framework for development of control algorithms.

(3) Control algorithms built upon the reduced-order model based on the physical data from simulation and measurement, will realize the ultimate goal of this project, optimization of wind plant power. The advanced control strategy developed in this project will then be tested using measurement and simulation.

2.1.2. External collaborators
In addition to our Eolos field station, we have secured commitments of two key external collaborators who will provide us with access to other field data for model validation: 1) The Sandia National Laboratories will provide us access to unique data sets from SNLs’ SWIFT facility in Lubbock, Texas (see letter of collaboration); and 2) Professor Leonardo Chamorro from the University of Illinois at Urbana Champaign will provide us access to data from his small-scale wind plant experimental facility (see letter of collaboration). In addition, we will collaborate with a key local stakeholder, WindLogics (see the collaboration letter) to ensure the research has close connection to wind energy industry.

2.1.3. Team coordination
The success of this inherently interdisciplinary project will hinge on our ability to tightly integrate the efforts of our diverse team. We will coordinate our efforts and ensure integration of various disciplinary research components through the following plan:

• A project kick-off meeting will be held at SAFL. In this meeting, the PIs will lay out expected outcomes of the project, timelines, and deliverables in much greater detail than is possible to present in the proposal. Subsequent annual PI and partner meetings will be used to evaluate progress towards the goals and coordinate the research and educational efforts.

• Following the kick-off meeting, there will be a meeting to communicate the overall strategy for future research and emphasize areas where integration across disciplines is critical.

• We will have quarterly research meetings, whereby project information sharing will take place

![Figure 4. Roles of components in the project and interactions among different disciplines.](image-url)
through: 1) planning and coordinating different components; 2) synthesizing results across disciplines; 3) presentations to discuss research findings; 4) discussion of research objectives, goals, and paths to fulfillment of these prerogatives. Such research meetings will promote regular communication and facilitate cross-disciplinary integration.

- A special section of the SAFL web page, which will be dedicated to reporting project results, will provide an interface to communicate results amongst the group and to the public along with up to date posts to SAFL’s social media.

2.2. Year-to-Year Milestones

Year 1:
- The measurement team will provide field validation data for numerical simulation of a single utility-scale wind turbine under specific conditions and develop laboratory instrumentation for simulating different atmospheric and turbulence conditions.
- Simulations will be performed for the miniature turbine arrays in the SAFL atmospheric wind tunnel, and will be validated against experimental measurements.
- A Hadoop implementation of the sparsity-promoting DMD algorithm will be developed for reduced-order modeling and control.

Year 2:
- The measurements will provide field validation data for a utility-scale turbine simulation over a wide range of wind conditions and provide laboratory validation data for wind plant simulation under specific conditions.
- Simulations will be performed at field scale, and will be compared and validated with measurements. The simulation dataset will be provided to the reduced-order modeling study.
- The high-throughput ROM extraction algorithm will be applied to experimental and high-fidelity simulation wind plant data, and interfaced to the advanced control effort.
- An active power control algorithm will be developed for wind plants using ROM’s constructed from wind plant data. This control will be designed at one wind condition.

Year 3:
- The measurements will provide validation data for wind plant simulation over a wide range of atmospheric and terrain conditions.
- Simulations will be performed for a range of conditions based on the data from SAFL wind tunnel, Eolos station, Sandia National Laboratories, and University of Illinois. An extensive dataset will be provided to modeling study. Simulations will test the new control strategy.
- The ROM’s will be extended to a range of wind directions and atmospheric turbulence levels.
- The active power control algorithm will be extended to a range of wind conditions (speed/direction) using gain scheduling, and be tested using simulation and experiment.

2.3. Broader Impacts and Beyond This Project

2.3.1. Multidisciplinary education

A salient feature of the proposed study is its strong interdisciplinary focus, with researchers from three departments and a center who have backgrounds across computational science, control, fluid mechanics, mathematical modeling, and wind energy. This project will provide students
and a postdoctoral associate with a rich experience in cross-disciplinary education and training. Three graduate students will be supported for their PhD study, co-advised by faculty members from different disciplines.

2.3.2. Potential commercial impacts
This study will take a critical and transformative step towards lowering the variability in wind energy output and improving the efficiency and reliability of the wind energy for existing and future wind plants. Recent studies have shown that enhancing long-term wind turbine reliability, reducing forecasting uncertainty, and effectively managing wind resources could save wind plant operators up to $1B nationwide in annual operating costs for high wind penetration scenarios (Lew et al. 2011). The proposed project will have tremendous commercial impact.

2.3.3. Obtaining other funding
As shown in their CV’s, the investigators in this project have excellent record in obtaining external funding in wind energy research. For example, Shen is currently supported by NSF to study wind energy. Shen and Guala were co-PIs on a DOE wind energy project that has just successfully completed. Hong, Guala, and Seiler all have NSF Early Faculty Career awards in wind energy research. Marr has several projects on applied wind energy. If this proposal gets funded, it is highly likely that continued support can be obtained from external sources.

3. Detailed Project Budget
The project budgeted is detailed in the table below. Note that besides a small amount of cost for supplies (such as computer auxiliaries and lab materials), travel, publication, and salary of PIs (10 days per year) and engineer staff, the majority of the funding (near 80%) is used to support one post-doctoral associate and three graduate student RAs.

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TOTAL SALARIES AND WAGES | 147,618 | 152,047 | 156,608 | 456,274 |

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TOTAL FRINGE BENEFITS | 76,512 | 77,460 | 78,436 | 232,408 |

TOTAL PERSONNEL | 224,131 | 229,507 | 235,044 | 688,682 |

OTHER EXPENSE

| Travel | 5,000 |
| Computer and Experiment Supplies | 20,869 |
| Publication Cost | 2,000 |

TOTAL PROJECT BUDGET | 250,000 | 250,000 | 250,000 | 750,000 |
References


Biographical Sketch

Lian Shen
Benjamin Mayhugh Associate Professor, Department of Mechanical Engineering
& Associate Director for Research, St. Anthony Falls Laboratory
& Director, Eolos Wind Energy Research Consortium
University of Minnesota

A) Professional Preparation
Massachusetts Institute of Technology, Doctor of Science in Fluid Mechanics, 2001
University of Science and Technology of China, Bachelor of Science in Mechanical Engineering, 1993

B) Academic Appointments
Benjamin Mayhugh Associate Professor with tenure (2012 – present)
University of Minnesota, Department of Mechanical Engineering & St. Anthony Falls Laboratory
Assistant Professor and Visiting Associate Professor (2004 – 2015)
Johns Hopkins University, Department of Civil Engineering

C) Products
Five Publications Most Closely Related to Proposal


Five Other Significant Publications


**D) Synergistic Activities**


Organized mini-symposiums “Advancement in numerical and physical modeling of free-surface flows” and “Potential-flow and viscous-flow simulations of interfacial flows, waves and free-surface turbulence” at the World Congress on Computational Mechanics.

Serving on the editorial board of Ocean Systems Engineering.

Served as judge for Historically Black Colleges and Universities Undergraduate Program (HBCU-UP) National Research Conference.

Participated in outreach project with Native American community as part of the NSF project “Broader impact from graduate students transferring engineering principles (BIGSTEP) to K–12 education.”

**E) Collaborators and Other Affiliations**

Collaborators
R.A. Dalryme (Johns Hopkins University), T. Dicky (University of California, Santa Barbara), W. Drennan (University of Miami), M. Guala (University of Minnesota), J. Gulliver (University of Minnesota), C. Hogan (University of Minnesota), J. Hong (University of Minnesota), T. Igusa (Johns Hopkins University), C. Meneveau (Johns Hopkins University), J. Nichols (University of Minnesota), P. Seiler (University of Minnesota), F. Sotiropoulos (University of Minnesota), K. Voss (University of Miami), Q. Wang (Naval Postgraduate School), D.K.P. Yue (Massachusetts Institute of Technology)

Graduate Advisor and Postdoctoral Sponsor
D.K.P. Yue (Massachusetts Institute of Technology)

Thesis Advisees and Postgraduate Scholars
Graduate Students: *Graduated:* Nourah Almashan, Antoni Calderer, Xin Guo, Alireza Kermani, Hamid Khakpour, Guotu Li, Yi Liu, Adam Witt, Shengbai Xie, Di Yang
*Current:* Tao Cao, Danniell Foti, Qiang Gao, Xuanting Hao, Sida He, Ming Li, Tianyi Li, Lin Liu, Jie Wu, Anqing Xuan

Postdoctoral Associates: *Previous:* Xin Guo, Di Yang
*Current:* Antoni Calderer, Bingqing Deng, Zixuan Yang

**F) Selected Recent External Funding**

1. *Computation of marine atmospheric boundary layer and nonlinear ocean wavefield for energy for sustainability*
2. *High-resolution computational algorithms for simulating offshore wind turbines and farms: model development and validation*
   PI: Fotis Sotiropoulos; co-PIs: Michele Guala, Lian Shen.
   $780,000.

3. *MURI: Coupled air sea processes and EM ducting research (CASPER)*
   PI: Qing Wang; co-PIs: Robert Burkholder, Joe Fernando, Djamal Khelif, Kipp Shearman, Lian Shen.
   $7,437,924.

4. *Model development for particle deposition by sieving*
   PI: Christopher Hogan; co-PI: Lian Shen.
   $33,000.

5. *Permeability theories for depth loaded liquid filter media*
   PI: Christopher Hogan; co-PI: Lian Shen.
   $41,319.

6. *Dynamic simulations of realistic upper-ocean flow processes to support measurement and data analysis*
   PI: Lian Shen. $525,000.

7. *Quantifying the dynamic ocean surface using underwater radiometric measurements*
   PI: Lian Shen.
   $300,000.

8. *Direct phase-resolved simulation of wind-waves*
   PI: Lian Shen.
   $293,843.

9. *A multiscale nested modeling framework to simulate the interaction of surface gravity waves with nonlinear internal gravity waves*
   PI: Lian Shen.
   $450,000.
Dr. Michele Guala

Address: St. Anthony Falls Laboratory (SAFL), Department of Civil Environmental and Geo-Environmental Engineering CEGE, University of Minnesota, Minneapolis, 55414, MN, USA
Phone: + 612 625-9108 (office) Email: mguala@umn.edu

Professional Preparation
Laurea Civil and Environmental Engineering, 1998, University of Genova, Italy
Ph.D. Hydraulic Engineering, 2003, University of Padova, Italy
PhD Advisor: Seminara G. (University of Genova), Co-advisors: Adrian R.J. (ASU) and Garcia M.H. (UIUC)

Appointments:
Jan 10 -- Now : Assistant professor, Department of Civil Environmental and Geo-Engineering, CEGE, UMN.
Feb 08 -- Oct 10 : Postdoc at GALCIT, Caltech, Pasadena, CA, USA (BJ McKeon)
Jan 07 -- Dec 07 : Research scientist at the SLF, Davos, CH (M Lehning)
May 03 -- Dec 06 : Postdoctoral fellow at the Institute of Hydromechanics ETH Zurich, CH (W Kinzelbach, A Tsinober)
May 01 -- Aug 02 : Visiting scholar at Laboratory of Turbulence and Complex Flows
Department of Theoretical and Applied Mechanics, UIUC (RJ Adrian) & Hydrosystem Laboratory, Civil and Environmental Eng, UIUC (MH Garcia)

Products most closely related to the proposed research activities

Other Significant Products

**Synergistic Activities**
3) Recipient of the IREE Early Career Award (UMN) “Evaluating wind farm performance under realistic thermal and complex terrain conditions: the first path towards optimization”
4) Member of: the EOLOS Wind Energy Consortium, the National Center for Earth Dynamics (NCED) University of Minnesota, American Physical Society (APS), American Geophysical Society (AGU)

**Collaborators**
Miki Hondzo, Fotis Sotiropoulos, Lian Shen, Jiarong Hong, Efi Foufoula-Georgiou(UMN), Arvind Singh (UCF) Leonardo Chamorro (UIUC) Beverley McKeon (Caltech), Meredith Metzger (University of Utah), Ronald Adrian (ASU), Kenneth Christensen (ND), Marcus Holzner, Annunziato Siviglia (ETH Zurich, CH), Michael Lehning, Charles Fierz, Henning Lowe (SLF Davos, CH), Alex Liberzon, (Tel Aviv University, Israel), Alessandro Stocchino, (Università di Genova, Italy), Costantino Manes (University of Southampton, GB), Sergij Gerashenko, Chris Tomkins (Los Alamos Nat Lab), Federico Toschi (Technische Universiteit Eindhoven).

**Graduate advisees (current research group)**
Mirko Musa (PhD student 2014- ), Anne Wilkinson (PhD students 2013- ) , Michael Heisel (PhD students 2015 - ) CEGE., University of Minnesota.

**Graduated students**
Craig Hill PhD, August 2015 (now at University of Washington)
Kevin Howard PhD, August 2014 (now at Ford Aerodynamics Group),
Chris Feist (MS, 2015), Nicholas Bad Heart Bull (MS, 2013), Chao Sun (MS, 2012) , CEGE Stephen Hu (MS, 2012) coadvised AEM, University of Minnesota.
Jiarong Hong

Professional Preparation

- Johns Hopkins University, Baltimore, Maryland, the United States
  
  **Ph.D. in Mechanical Engineering, December, 2011**
  
  **M.S. in Mechanical Engineering, May, 2008**

- University of Science and Technology of China (USTC), Hefei, P. R. China
  
  **B.S. in Thermal Science and Energy Engineering, July, 2005**

Professional Appointments

- University of Minnesota, Twin Cities 8/2012–present
  
  *Assistant Professor at Department of Mechanical Engineering and Saint Anthony Falls Laboratory*

- Johns Hopkins University 1/2012–7/2012
  
  *Postdoctoral Researcher for Dr. Joseph Katz, Laboratory for Experimental fluid Dynamics*

Products

**Products Related to Proposed Projects**

- **Hong, J., Toloui, M., Chamorro, L. P., Guala, M., Howard, K., Riley, S., ... & Sotiropoulos, F.** (2014). Natural snowfall reveals large-scale flow structures in the wake of a 2.5-MW wind turbine. *Nature Communications*, 5. doi: 10.1038/ncomms5216


**Other significant products**


**Synergistic Activities**

**Public Dissemination**
• Research work on “super-large-scale particle image velocimetry for wind wake measurements” is widely disseminated by international media including *Nature*, *National Geographic*, *Yahoo News*, *Phys.org*, *Science 2.0*, *Nanowek*, *Science Codex*, *LiveScience*, and many others.
• The videos and images of the research have been widely published by worldwide magazines and popular science journals such as New Scientists, Thomson Reuters, Wind System Magazine (Editor’s pick).
• Invited talk about wind energy research during a daily science program on "Deutschlandfunk", one of Germany's largest nationwide radio stations.
• Invited talk about atmospheric vortex power generation and field wind energy research on National Public Radio.

**Awards**
• 2016: McKnight Land-Grant Award
• 2015: National Science Foundation CAREER Award.
• 2012: Corrsin-Kovasznay Outstanding Paper Award.
• 2011: Robert T. Knapp Award from ASME Fluids Engineering Division for the best paper on analytical, numerical, or laboratory research.

**Affiliations**
• Members of American Physical Society, American Society of Mechanical Engineers and American Institute of Aeronautics and Astronautics

**Collaborators**
*Collaborators*: Charles Meneveau (Johns Hopkins Univ.), Michael Schultz (U.S. Naval Academy), Patricia Tester (National Ocean Service, NOAA), Allen Place (Univ. Maryland), Rebecca Waggett (Univ. Tampa), Fotis Sotiropoulos (Univ. Minnesota), Michele Guala (Univ. Minnesota), Xiang Cheng (Univ. Minnesota), Nikolaos Papanikolopoulos (Univ. Minnesota), Yannis Ekaterinaris (Embry-Riddle Aeronautical University), Leonardo Chamorro (Univ. of Illinois, Urbana-Champaign), Miki Hondzo (Univ. Minnesota), Roger Arndt (Univ. Minnesota)
*Graduate Advisor*: Joseph Katz (Johns Hopkins Univ.)
*Postdoc Advisor*: Joseph Katz (Johns Hopkins Univ.)
*Graduate Advisee*: Mostafa Toloui (Ph.D.), Ashish Karn (Ph.D.), Teja Dasari (Ph.D.), Santosh Kumar (Ph.D.), Kevin Mallery (Ph.D.), David Brajkovic (M.S.).

**Recent External Funding**
• 2015-2020: NSF CAREER funding on “Tackling Fluid Dynamics at Full Scale for Wind Energy Applications”; Role: PI; total award amount $505,000
• 2014-2017: NSF National Robotics Initiative funding on “Robotics 2.0 for Disaster Response and Relief Operations”; Role: Co-PI (with Nikolaos Papanikolopoulos and Miki Hondzo); total award amount $1,000,000.
Jeffrey DG Marr, MS PE
Associate Director of Engineering and Facilities
St. Anthony Falls Laboratory, University of Minnesota
2-Third Avenue SE, Minneapolis, MN;
marrx003@umn.edu, voice: 612-624-4427

EDUCATION AND TRAINING
B.S., Civil Engineering, University of Minnesota, 1996
M.S., Civil Engineering, University of Minnesota, 1999
Professional Engineering License – Minnesota, 2004

WORK EXPERIENCE
1/31/10-present  Associate Director of the Eolos Wind Energy Research Consortium
1/5/09-present  Associate Director of Engineering and Facilities, St. Anthony Falls Laboratory, University of Minnesota
8/06-12/08  Director of Knowledge Transfer, National Center for Earth-surface Dynamics (NCED)
8/02-6/05  NCED Engineer, National Center for Earth-surface Dynamics
7/99-8/02  Research Fellow, St. Anthony Falls Laboratory
7/96-2/99  Graduate Research Assistant, University of Minnesota

- Project Manager for several multi-investigator, multi-institution research studies. Experience with federal, state, and private sponsors, contracts, intellectual property issues, confidentiality.
- Technical expertise in wind energy engineering; wind plant design, construction operation; wind turbine generated noise; and wind resource measurement technologies; river engineer; river restoration; open channel hydraulics; sediment transport; transportation hydraulics.
- Special interest in projects with important public application that require blending fundamental and applied research and communicating results to broader community.

REFERRED PAPERS


Singh, Arvind; Czuba, Jonathan A.; Foufoula-georgiou, Efi; Marr, Jeffrey D. G.; Hill, Craig; Johnson, Sara; Ellis, Chris; Mullin, James; Orr, Cailin H. Wilcock, Peter R.; Hondzo, Miki; Paola, Chris, StreamLab Collaboratory: Experiments, data sets, and research synthesis, Water Resources Research, 2013, Vol.49(3), pp.1746-1752.

PROJECT REPORTS


Marr, Jeff; Johnson, Sara; Busch, Dennis; Performance assessment of H Flumes under extreme approach flow conditions., St. Anthony Falls Laboratory Project Reports 538, March 2010.

Marr, Jeffrey; Hill, Craig; Johnson, Sara; Grant, Gordon; Campbell, Karen; Mohseni, Omid; Physical Model Study of Marmot Dam Removal: Cofferdam Notch Location and Resulting Fluvial Responses. St. Anthony Falls Laboratory Project report #508, September 2007.

FUNDED PROJECTS

Minnesota Culvert Manual to Accommodate Aquatic Species Passage, $164,353, Minnesota Department of Transportation and Local Road Research Board. Award date: in progress. Role on project: Principal Investigator.

Field Demonstration and Validation of Advanced Blade Control. $96,175. [Confidential sponsor] Award date: December 2015. Role on project: Principal Investigator.

Wind Turbine Generated Sound, $625,102, Xcel Energy Renewable Development Fund Project RD4-12. Award Date: June 2015. Role on Project: Principal Investigator.


Minnesota Steel Culvert Pipe Service Life Map, $60,678, MN Department of Transportation. Award date: July 2013. Role on Project: Principal Investigator.

Design Consideration for Embankment Protection during Roadway Overtopping, $194,787. MN Department of Transportation. Award date: September 2012. Role on Project: Principal Investigator.

Scour Monitoring Technology Implementation, $38,233, MN Department of Transportation. Award date: April 2011. Role on Project: Principal Investigator.

Matrix (Partially grouted) Riprap Lab Flume Study, $124,831. MN Department of Transportation. Award date: November 2011. Role on Project: Principal Investigator.


Renovation of the St. Anthony Falls Laboratory, $7,104,536. National Science Foundation. Award date: October 2010. Role on Project: Project Manager.


Joseph W. Nichols  
Assistant Professor, Department of Aerospace Engineering and Mechanics  
University of Minnesota, Minneapolis, MN  
(612)-626-5496; Email: jwn@umn.edu

a. Professional Preparation:
University of Washington, Mechanical Engineering, PhD, 2005.  
Pacific Lutheran University, Computer Science, BS, Computer Engineering, BS, 1999.  
Massachusetts Institute of Technology, Undergraduate studies, 1995-1997.  

b. Appointments:
Academic Research and Teaching Positions
University of Minnesota, Department of Aerospace Engineering and Mechanics  
Assistant Professor 2013-present  
Stanford University, Center for Turbulence Research  
Research Associate 2011-2013  
Postdoctoral Fellow 2009-2011  
École Polytechnique, Laboratoire d'Hydrodynamique (LadHyX)  
Postdoctoral Research Associate 2006-2008  
University of Washington, Department of Mechanical Engineering  
Instructor 2005  
Research Assistant 2001-2005

Government and Industry Positions
Cascade Technologies, Inc., Palo Alto, CA  
Consultant 2011-2013  
American Physical Society, Division of Fluid Dynamics  
Website developer and coordinator 2004  
University of Washington, Department of Mechanical Engineering  
Systems administrator 1999-2001  
Engineered Software, Inc., Lacey, WA  
Programmer 1998-2001

c. Publications:
Five closely related publications
Five other significant publications


d. Educational Activities

Instructor, High Performance Computing (ME599), Mechanical Engineering, U. Washington 2005
Instructor, Intro to Fluid Mechanics (AEM4201), Aerospace Engineering & Mechanics, U. Minnesota 2013
Instructor, Fluid Mechanics II (AEM8202), Aerospace Engineering & Mechanics, U. Minnesota 2014
Instructor, Intro to Fluid Mechanics (AEM4201), Aerospace Engineering & Mechanics, U. Minnesota 2014
Instructor, Fluid Mechanics II (AEM8202), Aerospace Engineering & Mechanics, U. Minnesota 2015
Instructor, Hydrodynamic Stability (AEM8207), Aerospace Engineering & Mechanics, U. Minnesota 2015

e. Synergistic Activities

Helped develop and scale an unstructured large eddy simulation code to more than one million cores during an “Early Science” testing period of the IBM BG/Q machine “Sequoia” and the Lawrence Livermore National Laboratory. Currently routinely running on a similar system at Argonne National Laboratory, and have trained several UMN grad students to do the same.

f. Collaborators and Other Affiliations

Recent Collaborators (past 48 months)
F. Alvi (FSU); M. Andersen (Stanford); B. Barney (LLNL); A. Bassetti (DLR); I. Bermejo-Moreno (Stanford); M. Bernardini (U Roma); J. Bodart (ISAE); G. Brès (Cascade Tech.); J. Bridges (NASA GRC); L. Cattafesta (FSU); G. Chandler (Bristol); S. Chumakov (Bosch); P. Constantine (Colorado Mines); C. Druzhgalski (Stanford); S. Davidson (Stanford); D. Gleich (Purdue); F. Ham (Cascade Tech.); I. Jang (Stanford); S. Jones (Stanford); M. Jovanović (UMN); M. Juniper (Cambridge); Y. Khalighi (Altair Eng.); R. Kumar (FSU); J. Larsson (UMD); S. Lele (Stanford); A. Mani (Stanford); S. Martens (GE); P. Moin (Stanford); S. Pirozzoli (U Roma); R. Reba (UTRC); T. Sayadi (Imperial College); R. Schlinker (UTRC); P. Schmid (Imperial College); J. Simonich (UTRC); J. Spyropoulos (NavAir); K. Taira (FSU)

g. External Funding

Office of Naval Research
Analysis and Simulation of the Structure and Dynamics of Transitional Shock/Boundary Layer Interactions
Funding: $1,063,008 (5/19/2015 - 5/31/2018)
Joint with: G. Candler (PI, UMN AEM), M. Jovanovic (ECE UMN)
Peter J. Seiler, Biographical Sketch

Aerospace Engineering and Mechanics
110 Union St. SE
University of Minnesota
Minneapolis, MN 55455 USA

Tel. Office: (612)625-6561
email: seiler@aem.umn.edu

Professional Preparation
- University of Illinois, Urbana-Champaign Mechanical Engineering B.S. 1996
- University of Illinois, Urbana-Champaign Mathematics B.S. 1996
- University of California, Berkeley Mechanical Engineering Ph.D. 2001

Professional Experience
- 2011- Assistant Professor, Aerospace Engineering and Mechanics, University of Minnesota.
- 2008-2011 Research Associate, Aerospace Engineering and Mechanics, University of Minnesota.
- 2004-2008 Senior Research Scientist, Honeywell Labs, Honeywell.
- 2002-2004 Assistant Professor, Mechanical and Industrial Engineering, University of Illinois, Urbana-Champaign.

Products Related to Proposed Project:

Other Significant Products:
Synergistic Activities

2004-2008 Managed a joint project between the Honeywell Labs and the Air Transport business unit to develop the redundancy management architecture for the Boeing 787 flight control electronics.

2002- Consultant on the development of the “μ-Analysis and Synthesis Toolbox,” and new “Robust Control Toolbox” software products distributed worldwide by The Mathworks for analysis and design of feedback systems in the presence of uncertainty.

Collaborators and Other Affiliations

Collaborators and Co-Editors: Eilyan Bitar (Cornell University), Jozsef Bokor (Hungarian Computer and Automation Research Institute), Joaquim Carrasco (Manchester) Sairaj Dhople (University of Minnesota), Demoz Gebre-Egziabher (University of Minnesota), Michele Guala (University of Minnesota), Vijay Gupta (Notre Dame) Sue Mantell (University of Minnesota), Andrew Packard (University of California, Berkeley), Tamas Peni (Hungarian Computer and Automation Research Institute), Jorge Sofrony (National University of Columbia), Fotis Sotiropoulos (SUNY-Stony Brook), Tim Smith (University of Minnesota), Ufuk Topcu (University of Texas, Austin), Balint Vanek (Hungarian Computer and Automation Research Institute), Elizabeth Wilson (University of Minnesota), Rusen Yang (University of Minnesota).

Graduate Advisors: Karl Hedrick (University of California, Berkeley) and Raja Sengupta (University of California, Berkeley).

Postdoctoral Sponsor: Andrew Packard (University of California, Berkeley).

Graduate Advisees (8 Graduated Students): Andrei Dorobantu (Cymer), David Escobar Sanabria (U. of Minnesota), Paul Freeman (Northrup Grumman) Dongwong Lim (Northrup Grumman), Will Thorson (Seagate) Timothy Wheeler (GMO Investing), Jen Annoni (Current), Shu Wang (Current), Aditya Kotikalpudi (Current), Parul Singh (Current), Raghu Venkataraman (Current), Shu Wang (Current), Postdoctoral Advisee (3 Total Scholars): Marcio Lacerda (Current), Harald Pfifer (Current), Daniel Ossmann (Current).

Recent External Funding

- National Science Foundation: CAREER Program
  CAREER: Probabilistic Tools for High Reliability Monitoring and Control of Wind Farms

- National Science Foundation: Cyberphysical Systems Program
  CPS: Synergy: Collaborative: Managing Uncertainty in the Design of Safety-Critical Aviation Systems
  Funding: $473,560 (UMN) and $316,000 (Tufts) (9/1/2013 - 8/31/2016)
  Joint with: D. Gebre-Egziabher (UMN), J. Rife (Tufts), and S. Guyer (Tufts)

- NASA: Vehicle Systems Safety Technologies Topic 1-9
  Funding: $1,059,842 (9/1/2012 V 8/31/2015)
  Joint with: G. Balas (PI) and A. Packard
January 6, 2016

Dear IonE Renewable Electricity for Minnesota’s Future Program Reviewers,

A primary function of the Sandia National Laboratories’ Wind Energy Technologies group is to act as the U.S. Department of Energy’s research and field testing resource for subscale wind turbine arrays in ambient atmospheric flow. The SWiFT site – located in Lubbock, Texas – consists of a specially-designed array of three 27 meter diameter, 225 kW rated turbines along with multiple meteorological towers, and a vast array of signal conditioning and data acquisition equipment for collection of large, high-quality data sets describing physics of wind turbines and arrays of wind turbines. The University of Minnesota team has been instrumental in high fidelity numerical simulation of these physical interactions. I see Sandia’s relationship with your team in this topic as valuable and fruitful.

With this letter I am expressing my desire to collaborate with the Renewable Electricity for Minnesota’s Future project “Simulation, Modeling, Measurement, and Control of Wind Plant Power” supported by the Institute on the Environment of the University of Minnesota. As part of this collaboration, Sandia will provide the team access to the vast array of experimental measurements from our SWiFT site.

We enthusiastically support this proposal and look forward to collaborating on these topics.

Sincerely,

David G. Minster
Manager, Wind Energy Technologies Department
Sandia National Laboratories
Prof. Lian Shen, Sc.D.
Benjamin Mayhugh Associate Professor, Department of Mechanical Engineering
& Associate Director for Research, St. Anthony Falls Laboratory
University of Minnesota

Dear Lian,

I am delighted to offer my collaboration on the proposal ‘Simulation, Modeling, Measurement, and Control of Wind Plant Power’. This letter represents my commitment to collaborate with your group as detailed below.

Your proposed work addresses a very relevant and timely topic related to the wind farm optimization using a state-of-the-art computational framework. High-resolution numerical simulations with high-fidelity parametrizations of wind turbines are necessary conditions to advance towards this complex problem.

Detailed tests of the proposed computational infrastructure in realistic and controlled conditions are essential for validation purposes. I offer my collaboration by providing detailed data set of high-temporal resolution from our small-scale wind farm including flow turbulence within the wind farm and individual turbine power output. The small wind farm consists of 16 units of 3.2 m rotor diameter, 3-4 m hub height, and 1kW rated power. Turbine layout is customizable and all flow and turbine data are synchronously gathered.

My collaboration is not limited to providing dataset but to technical assistance of field test, and joint research activities.

I wish you success in this proposal submission, and please do not hesitate to contact me at 217-300-7023 or lpchamo@illinois.edu if you need any further assistance.

Yours sincerely,

Leonardo P Chamorro
Assistant Professor
Department of Mechanical Science and Engineering
Department of Civil and Environmental Engineering (Affiliate)
University of Illinois at Urbana-Champaign
Office: 3009 Mechanical Engineering Laboratory
105 South Mathews Avenue, Urbana, IL, 61801
http://chamorro.mechse.illinois.edu/
January 4, 2016

Dear IonE Renewable Electricity for Minnesota’s Future Program Reviewers,

As CEO of WindLogics over the past fifteen years, I helped the company become an authority in applied meteorology, wind and solar energy analysis, wind forecasting and utility integration of wind and solar energy. I frequently participate in and speak at events for the American Wind Energy Association, Utility Wind Integration Group, IEEE, NERC and other industry and government groups.

WindLogics became a subsidiary of NextEra Energy (nexteraenergy.com) in 2006 and directly supports the development and operation of NextEra’s wind and solar power plants. NextEra is the largest developer, owner and operator of wind power in North America with an installed base that exceeds 10,000 MW of wind turbines. In addition to owning clean energy projects across North America, NextEra includes one of the largest regulated utilities (Florida Power & Light) and has announced an agreement to combine with Hawaiian Electric, so we have very strong interests in clean and renewable energy.

With this letter I am expressing my desire to collaborate with the Renewable Electricity for Minnesota’s Future project “Simulation, Modeling, Measurement, and Control of Wind Plant Power” supported by the Institute on the Environment of the University of Minnesota.

I feel strongly that the challenges of integrating variable renewables like wind power into electricity systems is a crucial issue for sustainability. This project can help bridge the gap between how electricity systems are managed today and a future with high penetrations of variable resources like wind energy. I commit to being an active member of the project advisory board, where I will aid the researchers in ensuring that they understand the problems faced by utilities and system operators and the future needs of the energy system.

I sincerely support this proposal and look forward to contributing to its success.

Best regards,

Mark Ahlstrom
VP, Renewable Energy Policy
NextEra Energy Resources, WindLogics