WindSTAR

Wind-Energy Science, Technology, and Research
Industry/University Cooperative Research Center

2023 ANNUAL REPORT

UMass Lowell ✦ UT Dallas

MESSAGE FROM OUR CENTER DIRECTORS

Center Director
Christopher Niezrecki, Ph.D.
University of Massachusetts Lowell

Site Director
Mario Rotea, Ph.D.
University of Texas at Dallas

Dear IAB Members,

On behalf of the WindSTAR I/UCRC Directors and Faculty members, we would like to thank you for your continued support and membership. We're proud of what we've accomplished having faculty and students work side by side with company members. We have finished our fourth year as a Phase II Center having completed dozens of projects, published numerous papers, had multiple M.S. and Ph.D. students graduate (several have been hired by member companies and national labs), implemented several software and hardware systems that are in use by the WindSTAR company members, and created a new WindSTAR Webinar Series. For every dollar coming from a Full IAB member, ~20 dollars are invested in the Center from another source. For small business IAB members, the leveraging is approximately 56:1. Without operating through the National Science Foundation's I/UCRC program, this level of commitment and value to industry would not be possible.

Every year WindSTAR continues to grow and more people in the wind industry are learning that the Center is a platform that enables universities, industrial partners, and government to collaborate on developing novel solutions to wind energy problems. As we progress through our tenth year of operation (Phase II), we will continue to grow the Center, strengthen existing collaborations, and increase awareness of WindSTAR within the wind industry. In 2024, we believe there will be new growth opportunities due to increased interest in the decarbonization of the electric grid and the planned development of offshore wind energy projects.

The WindSTAR Center is working to improve the performance and availability of wind energy conversion systems. The Center's efforts will help drive down the cost of wind-generated electricity and make the use of wind energy more widespread within the United States and globally. Results from projects have provided valuable data to Center members who have acquired various multi-million dollar grants augmenting their R&D capacity. Through continued advancements in technology, we believe that wind power will be a major player in improving the sustainability of the Nation's electricity portfolio and enable new applications of this renewable source of energy. We are happy you are participating in the WindSTAR I/UCRC and look forward to working with you in the years to come.

Sincerely,
Christopher Niezrecki, Ph.D.
Distinguished University Professor, Mechanical Engineering
Co-Director, RIST Institute for Sustainability and Energy
Co-Director, Structural Dynamics and Acoustics Systems Laboratory
Director, WindSTAR I/UCRC
University of Massachusetts Lowell

Mario A. Rotea, Ph.D., F. IEEE
Professor, Mechanical Engineering
Professor (affiliate), Electrical and Computer Engineering
Director, Center for Wind Energy (UTD Wind)
Site Director, WindSTAR I/UCRC
University of Texas Dallas

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A NATIONAL SCIENCE FOUNDATION SUPPORTED INDUSTRY-UNIVERSITY COLLABORATION DRIVING DOWN THE COST OF WIND POWER

MISSION STATEMENT

The mission of WindSTAR is to bring together university and industry researchers to conduct basic and applied research on topics important to wind industry members. The Center combines capabilities, facilities, and knowledge to execute projects of interest to industry partners, train students in advanced technologies, and foster a community for industry/university networking and collaboration.

WindSTAR is an NSF-funded Industry/University Cooperative Research Center for Wind Energy, Science, Technology and Research, established in 2014. A collaboration between UMass Lowell, the University of Texas at Dallas, and its members, the Center aims to solve the pressing needs of the wind industry.

The University of Massachusetts Lowell is the lead WindSTAR site and focuses on projects that advance the materials, manufacturing, reliability, testing, modeling, and monitoring of turbines as well as energy storage, transmission and zero-carbon fuel generation. The University of Massachusetts Lowell is a public national research university in Lowell, Massachusetts.

The University of Texas at Dallas is a WindSTAR site with foci on high-fidelity simulation of wind power systems and components, LiDAR measurements and analysis of wind fields for diagnostics and model validation, wind tunnel testing, control system design for wind turbines and wind farms, large rotor design, grid integration and energy storage, data analytics for forecasting, performance and health assessment. The University of Texas at Dallas is a public research university in Richardson, Texas.

IAB MEMBER COMPANIES

WindSTAR's industry membership is diverse across the wind energy supply chain, including wind farm owner and operators; turbine, blade and tower manufacturers; material suppliers; condition monitoring & control electronics manufacturers; actuator technology developers; and other organizations with a stake in the growth of the wind energy market.

2023-2024 IAB Chair
Yi Ling (Ivan) Liang
Research Scientist
Olin Epoxy

2023-2024 IAB Vice Chair
Lauren Magin
Innovation Program Manager
Avangrid Renewables

2022-2023 IAB Chair
Brandon Fitchett
Program Manager, Wind Power R&D
Electric Power Research Institute (EPRI)

2022-2023 IAB Vice Chair
Max Peter
Technology Partnership Manager
GE Renewable Energy

Past IAB Chairs:
2021-2022: Brian Hill, Bachmann Electronic Corp
2020-2021: Nathan Bruno, Westlake Epoxy
2019-2020: Neal Fine, Arctura
2018-2019: Nicholas Althoff, GE Renewable Energy
2017-2018: Ben Rice, Pattern Energy
2016-2017: Steve Johnson, GE Renewable Energy
2015-2016: Justin Johnson, EDP Renewables
2014-2015: Steve Nolet, TPI Composites, Inc

ARCTURA
AVANGRID RENEWABLES
bachmann.
EDF renewables
edp Renewables
EPRI ELECTRIC POWER RESEARCH INSTITUTE
GE Renewable Energy
LEEWARD renewable energy
MASSACHUSETTS CLEAN ENERGY CENTER
Nikon
Olin EPOXY
Pattern
Shell
tpi
Westlake Epoxy
WindESCo
Windscape AI
Xcel Energy

New Member in 2023:
FM Global

Previous Members include:
Huntsman
Keuka Energy
LM Wind Power
Maine Composites Alliance
National Instruments
NRG Renew
Texas Wind Tower

FINANCIAL OVERVIEW: RETURN ON INVESTMENT

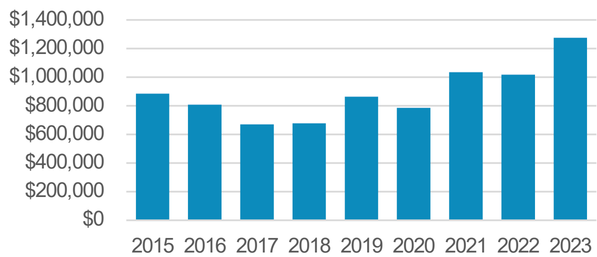
MEMBERSHIP LEVELS 2021-2022

Full Membership
$47,641 Annually

Small Business Associate
$ 17,865 Annually

CUMULATIVE INVESTMENT

TOTAL INVESTMENT: $7,484,868



NSF Awards
(Award # 1916715, 1916776, 1362022, 1362033)
$1,642,056

University Contribution (Cost Share)
$1,823,311

IAB Contributions
$4,019,501

In-Kind
$527,508

THRUST AREAS (PROJECT COUNTS ARE CUMULATIVE)

- (A) Composites and Blade Manufacturing - 29 Projects
- (B) Structural Health Monitoring, Non-Destructive Inspections, and Testing - 12 Projects
- (C) Wind Farm Modeling and Measurement Campaign - 12 Projects
- (D) Control Systems for Turbines and Farms - 3 projects
- (E) Energy Storage and Grid Intergration - 1 Project
- (F) Foundations and Towers - 6 Projects

2022-2023 PROJECTS

- Design of VARIM Process Based on A Digital Twin Approach
  Project ID: A1-22
- Long-Term Environmental Durability of Adhesive Joints
  Project ID: A2-22
- Investigation of Riblets on the Performance of Wind Turbine Blades
  Project ID: A3-22
- Improving Wind Blade Recycling
  Project ID: A4-22
- Structural Wind Blade Repair Optimization
  Project ID: A5-22
- Development and Testing of an Integral Acoustic Blade Monitoring System
  Project ID: B2-22
- Modeling Rotor-induced Effects on the Wind Resource for Onshore Wind Farms
  Project ID: C1-22
- Short-term Wind Forecasting via Surface Pressure Measurements
  Project ID: C2-22
- FAST Digital Twin Model Creation: Numerical tools for custom model creation and validation
  Project ID: C3-22
- LP-PIESC for Wake Steering via Yaw Control
  Project ID: D1-22
- Wind Farm Foundation Monitoring Using Optical Motion Magnification
  Project ID: F1-22
- Designing a Variable Angle Wind Turbine Blade Test Fixture
  Project ID: U1-23
- Design of a Rain Erosion Testing Machine for Materials and Wind Turbine Blades
  Project ID: U2-23

For a cumulative list of all center projects 2014-2023 visit uml.edu/WindSTAR

RECENT CENTER EVENTS

Webinar Series:

- Enhanced Lightning Protection for Wind Turbine Blades, Neal Fine and John Cooney, Arctura, May 11, 2022

IAB Meetings:

- University of Massachusetts Lowell, June 28-29, 2023
- University of Texas at Dallas, January 25-26, 2023

Invited Keynote Speakers for Center Banquets:

- Beyond economic competitiveness: increasing the societal value of wind energy, Dr. Carlo Bottasso, Chair of Wind Energy at the Technical University of Munich, January 25, 2023
- The low-carbon energy transformation – current state and future projections, Brandon Fitchett, EPRI, June 28, 2023

Design of VARIM Process Based on A Digital Twin Approach

Principal Investigators:
Dong Qian, Hongbing Lu (University of Texas at Dallas)

Student Researchers:
Runyu Zhang, Yingjian Liu, Guilherme Caselato Gandia (University of Texas at Dallas)

IAB Mentors:
Stephen Nolet, Shaghayegh Rezazadeh Kalehbasti, Joseph Wilson (TPI Composites)
Yi Ling Liang, Huifeng Qian (Olin Epoxy)
Paul Ubrich, Nathan Bruno, Mirna Robles (Westlake Epoxy)
Xu Chen (GE Renewable Energy)

The Vacuum-assisted Resin Infusion Mold (VARIM) process is a widely employed technique in the industrial sector for fabricating composite wind blades. However, when specific processing conditions converge, it can result in the formation of defects such as micro-distortions, voids, and resin-rich areas. These defects not only lead to the production of subpar or defective parts but also substantially inflate the overall costs associated with wind blade manufacturing. Consequently, it becomes imperative for the industry to capitalize on the advancements made in the realm of "digital twin" technology and seamlessly integrate it into the manufacturing process. In this context, we present an innovative extension of a previously developed machine learning (ML) model. This model is proposed to optimize the VARIM process for composite blades by employing inverse mapping, which yields valuable insights into the requisite processing parameters. The validation results demonstrate that the ML model based on inverse mapping can accurately predict the key temperature controlling parameters for a given temperature/curing profile of the VARIM process. Future efforts are directed to the optimization of VARIM process of non-homogeneous and spatially non-uniform laminate that is typical of wind blade.

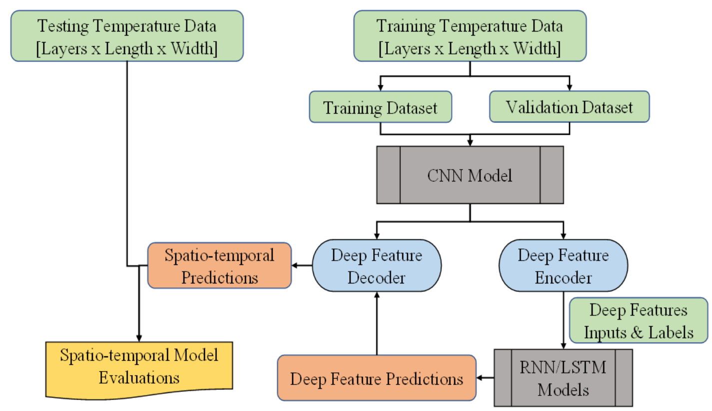


Figure 1. Framework of training and testing the CNN-RNN/LSTM-based spatio-temporal model.

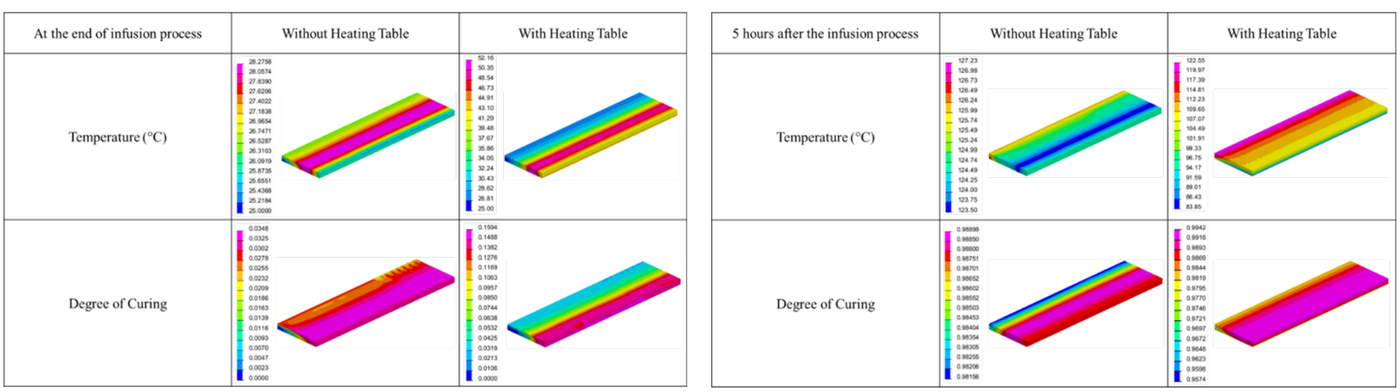


Figure 2. Evaluation of the heating table influence on temperature and degree of curing history during composite curing. (left) At the end of the infusion process. (right) Five hours after the infusion process.

PROJECT ID: A1-22

Long-Term Environmental Durability of Adhesive Joints

Principal Investigator:
Amir Ameli (University of Massachusetts Lowell)

Student Researcher:
Nahal Aliheidari (University of Massachusetts Lowell)

IAB Mentors:
Paul Ubrich, Nathan Bruno (Westlake Epoxy)
Yi Ling Liang (Olin Epoxy)
Steve Nolet (TPI Composites)

The exposure of wind turbines, especially critical blades, to the environment, can bring about inevitable damage over a long time period. Only in 2019, about USD 15 billion was spent on operations and maintenance services of WTB's where 57% was unplanned. More than 35% of the cost was for blade failure and environmental impact on the blades. Therefore, understanding and quantification of long-term durability in adhesive joints of wind turbine blades (WTB) are vital. This research focuses on the establishment of a framework that will enable the lifetime prediction of in-service joints or the optimization of new joint designs. The residual fracture toughness is correlated to the aging condition (time, temperature, and relative humidity) using an Environmental Index (EI). The framework unites fracture mechanics, open-faced accelerated hygrothermal aging, exposure EI, and finite element modeling. The open-faced specimen method significantly reduces the aging times.

This was a two-year project with multiple tasks including: a) substrate surface preparation, b) hygrothermal aging characterization by gravimetric measurement and diffusion modeling, c) evaluation of the mechanical performance of the aged adhesives, and d) establishment of the fracture specimen making e) Aging and testing for fresh and aged joints f) Measuring properties needed for FE CZM model g) FE CZM modeling integrated with hydrothermal exposure data h) Aging & testing closed joints to verify FE model.

Following the results and progress from the first year, in second year, the fracture testing protocol was finalized and open-faced and closed joints were fabricated. Then, the aging experiments were performed considering various times periods and three different levels of RH (43, 75, and 96%) and three temperatures (40, 50, and 60°C). A MATLAB code was fully developed for Exposure Index (EI) concept for absorption and desorption. Then, a cohesive zone finite element model was created that integrates the fracture envelopes of aged joints with the adhesive's absorption/desorption dataset to predict the fracture toughness of adhesive joints over time, exposed to actual environmental conditions. Closed-joint specimens were also prepared, aged, and they will be tested to verify the model prediction capability.

Further, the EI values were calculated for long time of the exposure until there was no significant drop in fracture toughness at 9 exposure conditions. The fitting curve for GIIC vs. EI was performed and an R-sq of 93% was achieved. There is a minimum of 31 and maximum of 44% of the drop in fracture toughness for mild and sever conditions. These results incorporate fracture toughness data from aged, degraded open-faced ENF specimens, adhesive water diffusion characteristics which obtained from diffusion modeling, and the concept of the exposure index to estimate the residual strength of degraded closed joints directly.

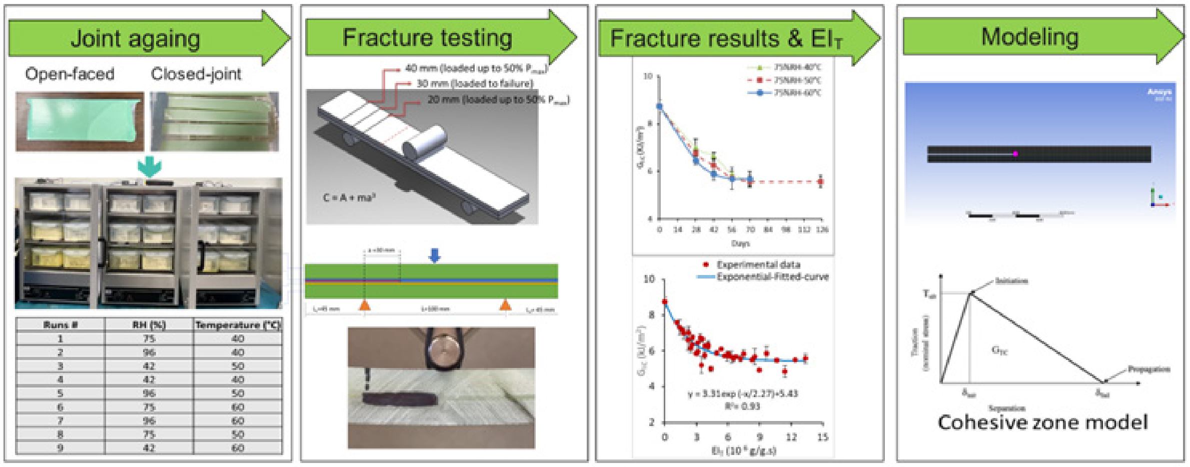


Figure 1. Project overview.

PROJECT ID: A2-22

Investigation of Riblets on the Aerodynamic Performance of Wind Turbine Blades

Principal Investigator:
Yaqing Jin (University of Texas at Dallas)

Co-Principal Investigator:
Stefano Leonardi (University of Texas at Dallas)

Student Researchers:
Nir Saar Maor, John Michael Bustamante Tubije (University of Texas at Dallas)

IAB Mentors:
Takashi Yuito, Shintaro Tsuchihashi, Takaya Higashino (Nikon)
Neal Fine (Arctura)
Wouter Haans (Shell)

Improving the aerodynamic performance of blades, such as increasing the lift force and reducing the drag, plays a significant role for increasing the power output of wind turbines. During the last decades, surface treatment with micro-scale riblets has proven to effectively reduce turbulent drag on flat plates. Based on the recent studies by new (2022) IAB member, this project investigated the aerodynamic performance of wind turbine blades with riblet treatment via systematically designed wind tunnel experiments. A DU91-W2-250 airfoil section with aspect ratio of 2 was vertically mounted on an ATI Delta sensor to measure the lift and drag loads under chord-based Reynolds number of 650K under various angle of attacks. The surface of airfoil was covered by a riblet film with pitch distance between 180 to 240 microns on the suction side to evaluate its effectiveness in modulating airfoil aerodynamic performance. The results highlighted that when compared to a smooth airfoil surface, the riblet film allowed to reduce drag coefficients across a wide range of angle of attacks. This resulted in the maximum enhancement of airfoil lift to drag ratio by approximately 2% when the angle of attack is within 5 to 8 degrees. Further investigation with particle image velocimetry measurement of near-wall flow profiles indicated that the riblet film allows to reduce the boundary layer velocity shear and therefore mitigate the friction velocity. To assess the impacts of riblet film on power output of a wind turbine, the experimental results were used as input in numerical simulations with actuator disk model. The results indicate that with the improved aerodynamic performance of blade sections, the wind turbine with the designed riblet film allows to enhance the torque acting on the generator and therefore produce more power under turbulent incoming flows when compared to smooth blades.

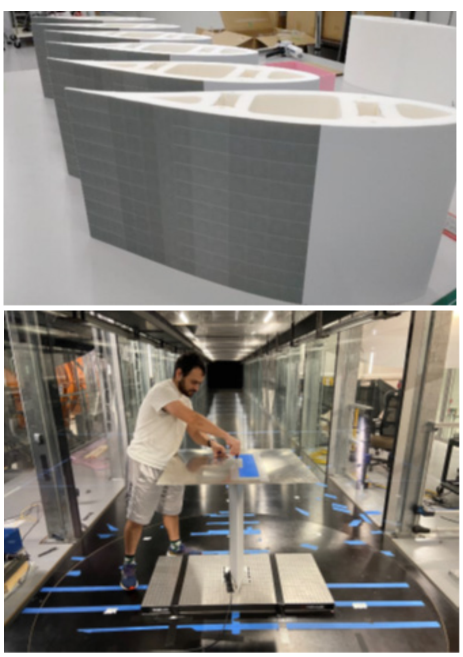


Figure 1. (top) Photograph of model blade sections with riblet films; (bottom) Photograph of model blade with force sensor in wind tunnel.

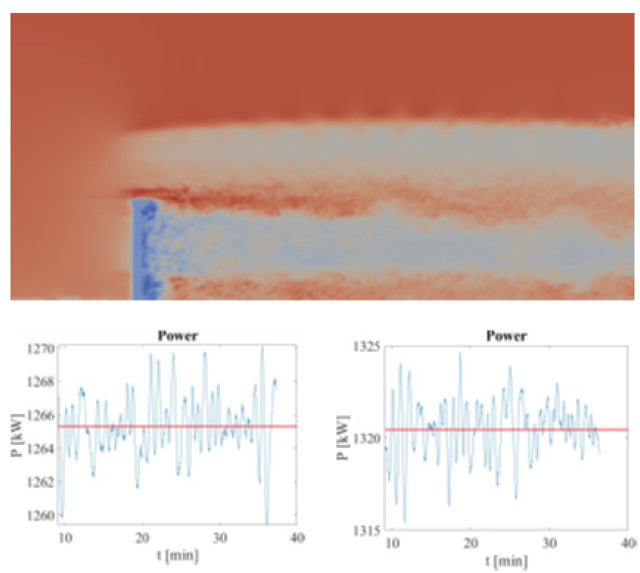


Figure 2. (top) Numerical simulations with actuator disk model for flow over wind turbines; (bottom) time series of turbine power output with smooth (left) and riblet-treated (right) surfaces.

PROJECT ID: A3-22

Improving Wind Blade Recycling

Principal Investigator:
Stephen B. Johnson (University of Massachusetts Lowell)

Co-Principal Investigator:
Todd Griffith (University of Texas at Dallas)

Student Researchers:
Mohammed Al-Evan Chowdhury (University of Texas at Dallas)
Rodrigo Palominos (University of Massachusetts Lowell)

IAB Mentors:
Ivan Liang, Huifeng (Olin Epoxy)
Allie Peters (EDP Renewables)
Stephen Nolet (TPI Composites)
Wounter Haans–Wouter (Shell)

Wind Turbine installations have grown rapidly which has led to decommissioning rates increasing and landfill disposal prohibitions starting. The latter has resulted in landfill becoming a wind energy black eye. This project has investigated the role thermoplastic resins will potentially have in improving the recyclability of wind blades, and in particular structural performance versus initial cost versus recycling value. It is also generating an integrated cost model including the time discounted value of invested initially in blade cost versus future costs of disposal. The project relies on a high-fidelity tool (NuMAD, WISDEM, and UML's Wind Blade Cost Estimator) to evaluate the performance of the thermoplastic blade. The life cycle cost of the new redesigned blade consists of six components of which four costs (Recyclability, Manufacturing, Material, Decommissioning) are positive costs and two costs (Recouped value of the recycled blade materials or reuse of blade, Environmental value proposition) are negative costs. The approach is to make a determination of the mechanical properties of the Glass fiber laminates (by replacing Epoxy with thermoplastic polymer like Elium, Vitrimax, Recyclamine) and perform structural analysis and cost analysis of recycling of the blade after blade decommissioning. The next process included mapping of recycling process options from blade removal to recycling completion in order to determine costs, CO2 generation and energy use in the available multiple recycling options.

Results of this study support two main outcomes, (1) resin cost is the key cost in manufacturing thermoplastic blade, though due to low temperature demand and faster cooling rate of thermoplastic and low tooling cost the cost can be offset [1] and (2), due to 2-3% lower density of the laminate overall blade is lighter than the baseline blade even in optimized condition. Ultimately, Thermoplastics are highly recyclable materials that can be melted and reprocessed multiple times without significant loss of properties. This characteristic makes it easier to recycle wind turbine blades compared to traditional thermoset resin-based blades, which are more challenging to recycle. The thermoplastic-based blades enable a more sustainable and environmentally friendly approach to wind turbine blade disposal instead of landfills or incineration and can be processed and transformed into new products or raw materials for various industries which promotes a circular economy.

[1] Murray, R. E., Jenne, S., Snowberg, D., Berry, D., & Cousins, D. (2019). Techno-economic analysis of a megawatt-scale thermoplastic resin wind turbine blade. Renewable Energy, 131, 111–119. https://doi.org/10.1016/j.renene.2018.07.032

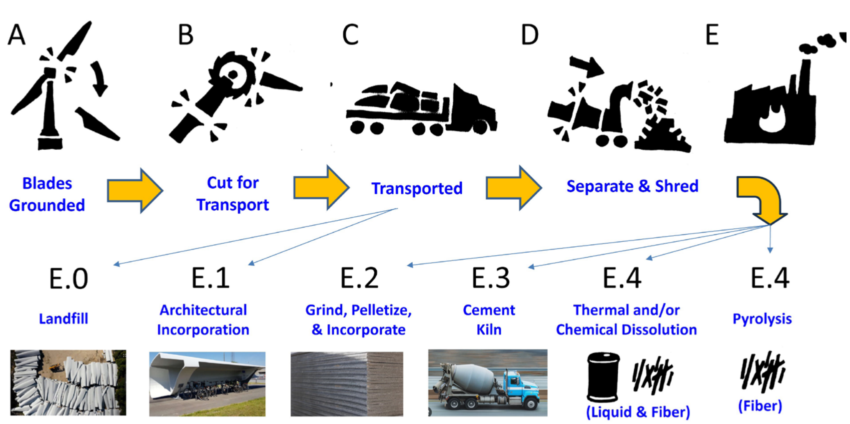


Figure 1. Wind blade life-cycle framework.

PROJECT ID: A4-22

Structural Wind Blade Repair Optimization

Principal Investigator:
Marianna Maiaru (University of Massachusetts Lowell)

Co-Principal Investigator:
Christopher Hansen (University of Massachusetts Lowell)

Student Researchers:
Evgenia Plaka , Michael Olaya, Joseph McDonald, Sagar Shah (University of Massachusetts Lowell)

IAB Mentors:
Steve Nolet, Amir Salimi, Alexander Krimmer (TPI Composites)
Paul Ubrich, Nathan Bruno, Mirna Robles (Westlake Epoxy)
Ben Rice (Pattern Energy)
Jian Lahir (EDP Renewables)
Ron Grife (Leeward Renewable Energy)
Rajesh Turakhia, Yi Ling Liang (Olin Epoxy)

Damaged wind turbine blades are typically repaired on-site and up-tower, which can take several days to complete. The time-consuming repair process can be attributed to the complexity and difficulty in accessing the damaged sections, as well as the need to replace and cure the fiber-reinforced composite (FRC) materials used in state-of-the-art blade design. As repairs are performed on-site, environmental conditions such as the temperature and relative humidity can have an impact on the steps necessary to rehabilitate the blade, and ultimately on the final properties of the restored structure. Currently, there are no best practices to repair damaged blades effectively, and each repair varies with respect to environmental conditions as well as the unique geometry and FRC materials used in each repair. Insights on the effect of these parameters thus presents opportunities for repair optimization to reduce the turbine downtime.

Figure 1. Image of the sandwich panel to be cured under a heat blanket set to 80°C.

This work builds upon the material characterization of resin systems (infusion, hand lamination, bonding paste) commonly used in turbine blade repairs and the computational tools developed in the previous years of this project. Five tasks including both experimental and computational work were executed during this year's project. A larger and more complex lab-scale experiment was performed, involving a balsa core as a repair material and heat blanket as the curing source, and validation of the computational tools developed in previous years and advanced in this years' work was performed. An additional laminate repair scenario which considered the hot plate as the heat source, was experimentally performed and modeled by finite element methods, to enhance the on-site repair application's portfolio. Experimental investigation of the thermal properties (thermal conductivity and specific heat capacity) of a commonly used epoxy resin was performed to determine the change in thermal properties

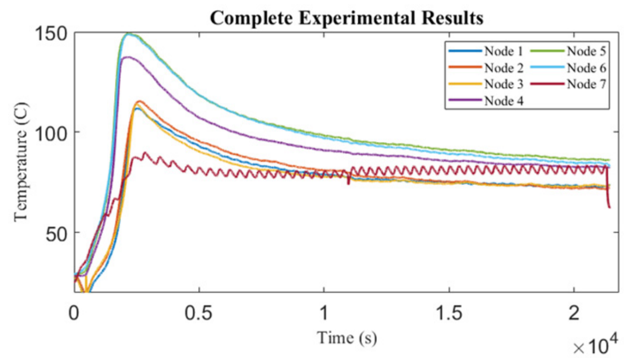


Figure 2. Temperature profile of various positions in the panel as recorded by the thermocouples (sketch in the bottom of the plot shows the thermocouple positions).

as a function of cure upon resin gelation. The knowledge gleaned from these tasks has been studied and implemented in ongoing development of the on-site repair tool/application for on-demand cure cycle optimization. The app now features a preliminary graphical user interface (GUI) designed for ease-of-use by repair personnel, and work continues on migration to an open-source platform more mobile device usage. This work continues to address and contribute to providing insight into factors which influence every repair, including environmental conditions, extent of the damaged area, and material systems used in state-of-the-art blade rehabilitation efforts. Ultimately, an understanding of these critical parameters offers a way to analyze and optimize each repair in a way that has never been done before. Through computation and experiment, the potential of extended repair season and thus cost savings for owners and operators is possible.

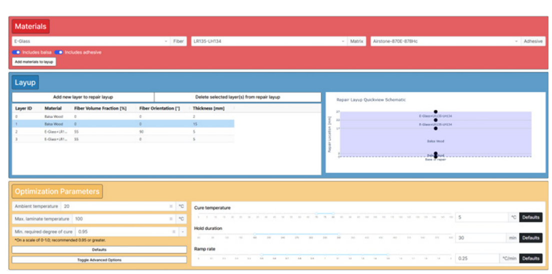


Figure 3. Prototype web-based GUI developed for interacting with the on-site repair analysis showcasing simplistic user inputs and cure cycle optimization.

PROJECT ID: A5-22

Development and Testing of an Integral Acoustic Blade Monitoring System

Principal Investigator:
Murat Inalpolat (University of Massachusetts Lowell)

Co-Principal Investigators:
Christopher Niezrecki, Yan Luo
(University of Massachusetts Lowell)

Student Researchers:
Connor Pozzi, Calvin Ng
(University of Massachusetts Lowell)

IAB Mentors:
Lothar Breuss (Bachmann Electronic Corp)
Adam Johs, Jian Lahir, Aditya Krishna (EDP Renewables)
Danian Zheng (WindEsco)
Max Peter (GE Renewable Energy)
Wouter Haans (Shell)
Carly Lavender (MassCEC)

This project has enabled the development and testing of an integral acoustics-based structural health monitoring system for wind turbine blades, building off work in previous projects. In previous projects, the team developed a low-cost, yet highly capable acoustics-based monitoring system for real-time surveillance of wind turbine blades. To date, a few system prototypes (including sensors, enclosures, power converters, and wiring) have been developed, and tested at the subscale in the laboratory, through blade fatigue tests, as well as in the field at NREL and Pattern Energy wind farms with significant success. The primary task of this project consisted of the development of hardware and software interfaces necessary for connecting the already developed sensing system to a commercially available wind turbine data acquisition and controls system (Bachmann) to construct an integral acoustic monitoring system. This system utilizes a Can-BUS based hardwired connection for fast and robust data collection with no wireless data transmission. A specific PLC programming platform, provided by Bachmann Electronics, was leveraged to develop a new PLC program that utilizes the logic of the wireless sensor software to successfully trigger recordings at specified intervals in an autonomous loop. In-lab bench tests, presented in this final report, validate the ability to connect the already developed wireless sensors to the Bachmann controller via a wired connection. Overall, this project enabled the creation of a wired sensing platform for wind turbine blades in addition to the already existing wireless sensing platform.

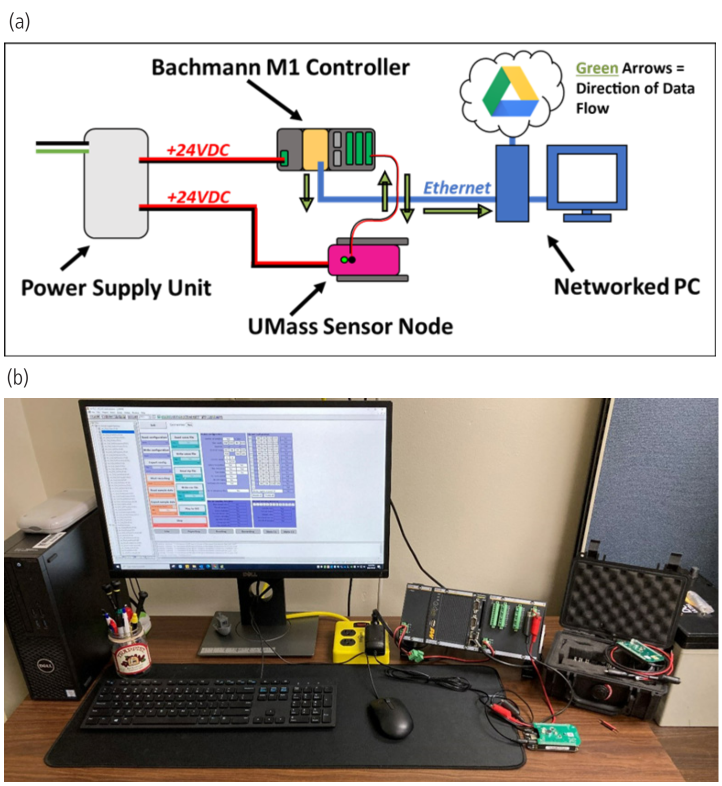


Figure 1. In-lab test setup, (a) Diagram with data flows, (b) Picture of system with M-PLC3 open on the monitor

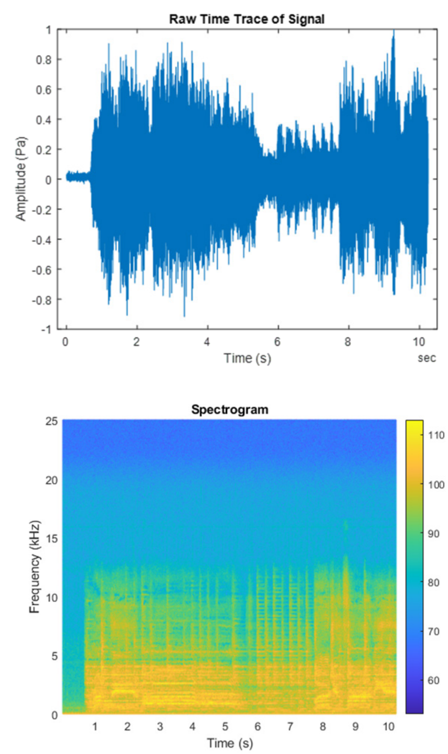


Figure 2. Spectrogram of the raw signal shown in Figure 1 using an STFT

PROJECT ID: B2-22

Modeling Rotor-induced Effects on the Wind Resource for Onshore Wind Farms

Principal Investigator:
Giacomo Valerio Iungo (University of Texas at Dallas)

Student Researchers:
Matteo Puccioni, Coleman Moss
(University of Texas at Dallas)

IAB Mentors:
Clément Jaquet (GE Renewable Energy)
Nick Smith (Shell)
Daniel Cabezon (EDP Renewables)
Teja Dasari (Xcel Energy)
Jason Dubois (EDF Renewables)
Chi Qiao (WindESCo)

The interaction between operating wind turbines and the incoming wind field can produce effects that include the reduction of velocity downstream of the turbines, referred to as wakes, as well as upstream of the turbine, referred to as induction. When turbines are installed in arrays, additional reductions in front of the turbines can occur, termed blockage. Wakes, induction, and blockage effects are here studied, along with the corresponding speedup effects in between rotors and wakes. These phenomena are characterized with respect to atmospheric stability variability and the spacing between turbines. It is demonstrated that current induction region models underestimate the total wind reduction, potentially due to blockage effects that result from an array of turbines as opposed to a single turbine. The induction zone appears to have little relationship with atmospheric stability but, as turbulence intensity increases, the wake recovery increases while the speedup magnitude decreases. Due to changing wind directions, increasing the spacing between turbines is seen to reduce the magnitude of the speedup while having little impact on the induction or wake recovery. While these results are determined from continued analysis of data gathered during the C2-20 project campaign, the WindFluX mobile LiDAR station is deployed in this project as part of the American wake experiment (AWAKEN) campaign and additional data is gathered. The wake and blockage effects are noted in the preliminary analysis of this data, with more analysis to be done after the campaign concludes. SCADA data from wind farms involved in the AWAKEN campaign is used to develop novel data-driven wake detection methods. These methods can improve upon existing wake detection methods, such as the IEC standard, or be used as entirely new, model-free detection methods.

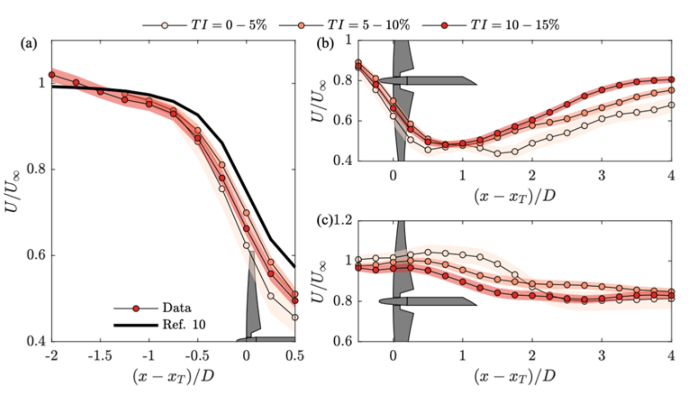


Figure 1. The variability of the induction region (a), the wake region (b), and the speedup region in between two turbines (c) for varying turbulence intensity levels.

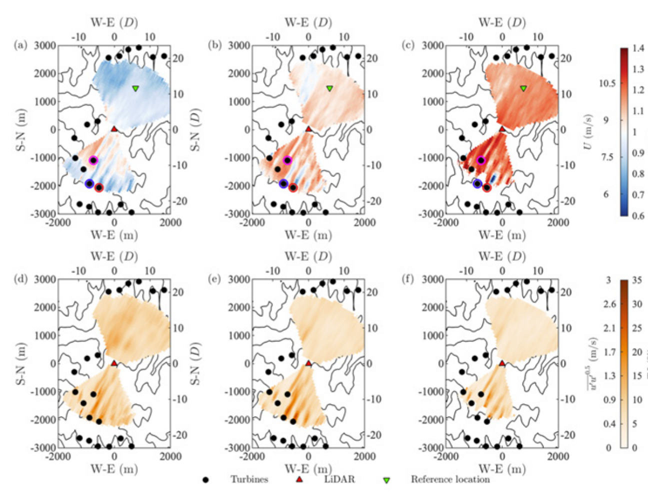


Figure 2. Mean wind speed and TI of preliminary data from the WindFluX mobile LiDAR station collected at the AWAKEN campaign for the heights of (z-H)/D=-0.25 (a, d); 0 (b, e); and 0.25 (c, f).

PROJECT ID: C1-22

Short-term forecasting via surface pressure measurements: a stochastic approach

Principal Investigator:
Armin Zare (University of Texas at Dallas)

Co-Principal Investigators:
Mario Rotea, Stefano Leonardi
(University of Texas at Dallas)

Student Researchers:
Aditya H. Bhatt, Mireille Rodrigues, Seyedalireza Abootorabi, Michael V. Lingad (University of Texas at Dallas)

IAB Mentors:
Jason Yosinski (Windscape AI)
Nick Smith (Shell)
Phillip Gauthier (EDF Renewables)
Teja Dasari (Xcel Energy)

In the absence of effective forecasting tools that would inform wind turbine controllers about the short-term variability in the incoming flow, almost all modern-day plants rely on data collected at or just behind the rotor to adjust their settings and can consequently lag optimal operating conditions. To address this challenge, we proposed a short-term wind forecasting framework that would enable model-based control systems to preemptively adapt ahead of atmospheric variations by estimating changes to the rotor effective velocity. Our approach relies on the sequential self-correcting property of the Kalman filter in assimilating real-time measurements from ground-level air-pressure sensors and nacelle-mounted anemometers into the predictions of a reduced-order model given by the stochastically forced linearized Navier-Stokes equations around the predictions of static engineering wake models. The choice of pressure sensors is motivated by a desire for inexpensive distributed sensing capabilities that could present a viable alternative to doppler LiDAR. On the other hand, the choice of flow model is justified by the predictive capability of the linearized dynamics and the possibility of shaping colored-noise processes for achieving statistical consistency with the result of high-fidelity codes, e.g., large-eddy simulations.

We focused on predicting changes in hub-height wind velocity due to atmospheric variations simulated by high-fidelity large-eddy simulations. To this end, we restricted our stochastic reduced-order models to the hub-height and relied on a data-driven projection strategy for mapping predicted pressure changes to the ground. We also complemented our proposed estimation framework with an optimization-based sensor selection strategy that allowed us to drop pressure sensors with the least contribution to the performance of the Kalman filter. This approach identified sensors within the near-wake region of the leading row of a wind farm as the most significant in detecting atmospheric changes using ground-pressure sensors, which agrees with the dynamic relevance of the fluid mechanics within those regions. Given this subset of crucial sensors, we evaluated the performance of conventional Kalman filtering algorithms in estimating the wind velocity and its variance relative to the result of a high-fidelity simulation. Our results serve as a proof of concept for short-term wind forecasting based on ground-level pressure measurements and identify the extended Kalman filter as a viable option for further development of our envisioned forecasting tools.

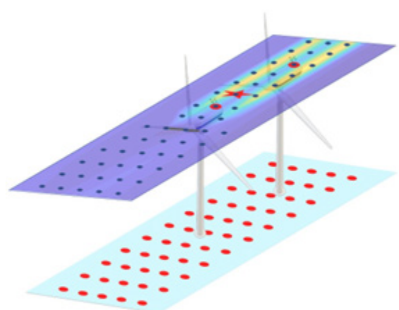


Figure 1. Training/computation (top) and sensing (bottom) planes in our estimation framework with training and sensor locations marked by blue and red dots, respectively, and an estimation point marked by the red star.

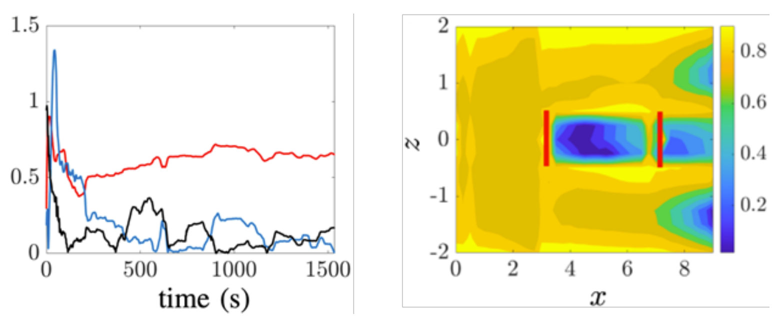


Figure 2. (left) Relative error in estimating the velocity variance one diameter behind the leading turbine: linerized Kalman filter (red), extended Kalman filter (blue), and unscented Kalman filter (black). (right) Colormap of relative statistical error at the final time point across the 2D domain obtained by extended Kalman filter.

PROJECT ID: C2-22

FAST Digital Twin Model Creation: Numerical tools for custom model creation and validation

Principal Investigator:
Todd Griffith (University of Texas at Dallas)

Co-Principal Investigator:
Mario Rotea (University of Texas at Dallas)

Student Researchers:
Rakesh Reddy Kondam, Rohit Gajjala, Dan Bouzolin (University of Texas at Dallas)

IAB Mentors:
Neal Fine (Arctura)
Lothar Breuss (Bachmann Electronic Corp)
Phillip Gauthier (EDF Renewables)
Adam Johs, Alberto Llana Hernanz, Jian Lahir (EDP Renewables)
Brandon Fitchett, Liliana Haus, Noah Myrent (EPRI)
Peter Ireland, Venkat Valdamudi (WindESCo)

This project is delivering a toolkit for customizable creation of wind turbine digital twin models, in OpenFAST aero-servo-elastic model format. Development of a customizable model creation toolkit provides industry users the ability to create their own OpenFAST digital twin models, for each turbine in their fleets, and to tailor the models to their own needs or site conditions. Digital twin models are emerging as a valuable and viable tool for decision support in operations and maintenance for a variety of applications. For wind energy systems, aero-servo-elastic digital twin models for actual, operating wind turbines offer capabilities to perform "what-if" studies that provide decision support to wind farm operators for turbine trouble shooting, maintenance decisions, life-extension studies, performance upgrades, and many other uses.

Prior work in WindSTAR has produced a methodology to create digital twin models based on limited datasets, and this methodology has been applied to develop digital twins for the GE 1.5sle and Gamesa 3.465 MW machines. However, there was a need to widely deploy the numerical tools for creation of wind turbine digital twins, thus this project focused on creation of a user-friendly toolkit, with the following major results: (1) Toolkit for Customizable Model Creation with capability to create models in the 1.5MW to 15+MW range, (2) Matlab-based GUI to provide user-friendly features for input of target data and technical specifications, and for post-processing, model accuracy checks, and (3) User Guide and Starter Kits to help new users get started using the toolkit.

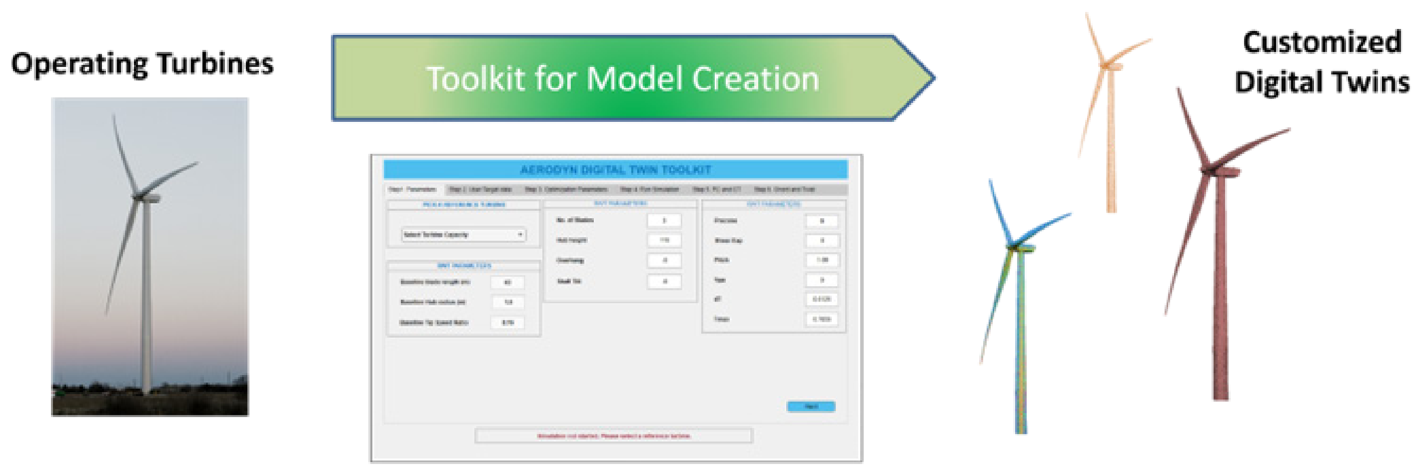


Figure 1. Digital Twin Creation Toolkit: Graphic representation of the toolkit concept for the digital twin model development process: (1) Operating Turbines: experimental data, technical specifications and other data are gathered for an actual, operating turbine, (2) Toolkit: Aerodynamic, structural, and control systems models are created for the target, customized digital twin, and (3) Customized Digital Twin: a digital twin model is produced in OpenFAST format that matches target data and target properties.

PROJECT ID: C3-22

LP-PIESC for wake steering via yaw control

Principal Investigator:
Mario Rotea (University of Texas at Dallas)

Co-Principal Investigator:
Yaqing Jin (University of Texas at Dallas)

Student Researchers:
Devesh Kumar, Emmanuvel Joseph Aju, Yujie Zhang (University of Texas at Dallas)

IAB Mentors:
Lothar Breuss (Bachmann Electronic Corp)
Neal Fine (Arctura)
Nick Smith, Bart Doekemeijer (Shell)

Wake steering via yaw control reduces wake losses and increases power production. Our team has developed hardware & software infrastructure to test autonomous wake steering algorithms, measure power outputs, wind loading and wake statistics for scaled wind farms (Fig. 1).

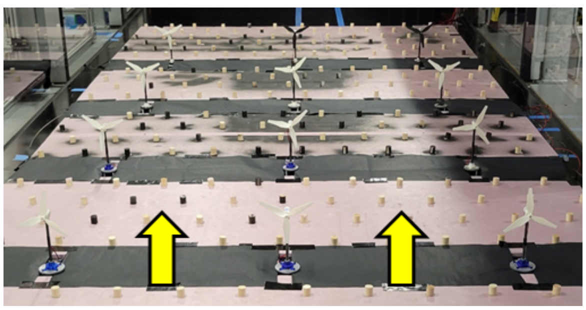


Figure 1. Scaled wind farm in the wind tunnel; arrows indicate wind direction.

In prior projects we demonstrated cluster-based log-of-power proportional-integral extremum seeking control (LP-PIESC) for wind plant power maximization in flat terrain [1,2]. We also demonstrated this approach in complex terrain emulating the layout of an actual wind farm [3]. Prior work has been limited to yawing only the most upstream rows in each cluster.

This project investigates multi-row cluster-based LP-PIESC in 4 x 3 wind farm array with and without consecutive gusts. Two configurations are considered. The first configuration allows yaw angle variation of the first two upstream rows only, this configuration is defined as "consecutive row wake steering." The second configuration, defined as "alternating row wake steering," allows yaw angle variation for the most upstream row and the third row behind. Figure 2 shows the static power maps for each case obtained by selecting various yaw angles and measuring the power of each turbine to calculate the total wind farm power. The optimal yaw angles for each configuration are shown with black dots: $\gamma_1 \approx$ **-30** deg and $\gamma_2 \approx$ **-20** deg for consecutive rows producing 9% power increase and $\gamma_1 \approx$ **-30** deg and $\gamma_3 \approx$ **-10** deg for the alternating row case with a power increase of 5.5%.

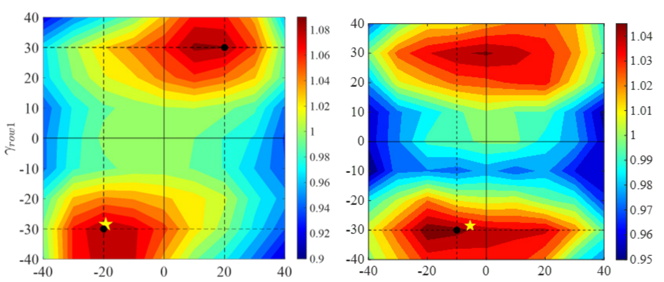


Figure 2. Static power maps of consecutive row wake steering (left) and alternating row wake steering. The black dots indicate the optimal yaw angles. The 5-point yellow stars show the convergence points for cluster-based LP-PIESC from Fig. 3.

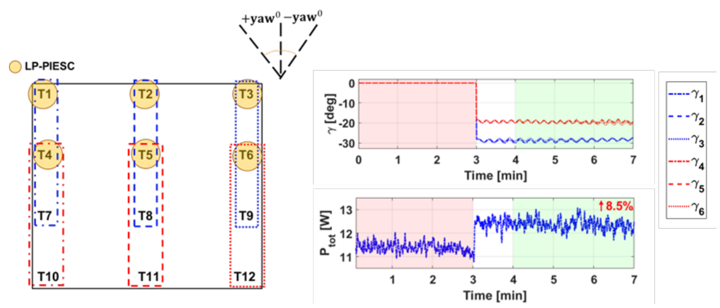


Figure 3. Cluster-based LP-PIESC for consecutive rows. Yellow circles show the turbines with LP-PIESC. The blue (red) rectangles represent the clusters optimized by T1, T2 and T3 (T4, T5 and T6). LP-PIESC is on at 3 minutes. First row yaw angles converge to -28.5 deg while second row yaw angles converge to -19 deg. Average power (4 to 7 minutes) increases 8.5%.

The cluster-based LP-PIESC for the consecutive row configuration is shown in Fig. 3. This algorithm converges almost instantaneously to yaw angles producing nearly optimal power increase (8.9%), as can been from the static power map in Fig. 2, which shows the convergence point with a yellow 5-point star.

Results to date support the following:

- Cluster-based LP-PIESC can find nearly optimal yaw angles to maximize total farm power without requiring detailed flow models.
- Total farm power can be maximized by optimizing the power of separate clusters defined using the wind farm layout and wind direction.
- The LP-PIESC response does not appear sensitive to variations in wind conditions (including gusts) and unknown yaw misalignments.

[1] Kumar, D., et al. (2023). Wind plant power maximization via extremum seeking yaw control: A wind tunnel experiment. Wind Energy.
[2] Aju, E. J., et al. (2023). The influence of yaw misalignment on turbine power output fluctuations and unsteady aerodynamic loads within wind farms. Renewable Energy.
[3] Rotea, M. A., et al. Wake steering via extremum seeking yaw control for power maximization: wind tunnel experiments. Wind Energy Science Conference, 23 – 26 May 2023, Glasgow, UK

PROJECT ID: D1-22

Wind Farm Foundation Monitoring Using Optical Motion Magnification

Principal Investigator:
Alessandro Sabato (University of Massachusetts Lowell)

Co-Principal Investigator:
Christopher Niezrecki (University of Massachusetts Lowell)

Student Researchers:
Tymon Nieduzak, Nitin N. Kulkarni
(University of Massachusetts Lowell)

IAB Mentors:
Adam Johs, Aditya Krishna, Alvaro Marquez Garcia (EDP Renewables)
Ron Grife, Mike Purcell (Leeward Renewable Energy)

An inexpensive, quick, and robust condition monitoring (CM) technique to assess the integrity of wind turbine foundations and components remains elusive. The most common techniques used to inspect the integrity of a foundation rely on destructive methods such as concrete cores or contact-based approaches that combine strain gauges, accelerometers, and tiltmeter measurements. Because of the complexity of the inspection and the high cost per turbine, widespread interrogation and CM is not financially attractive or practical to implement. Due to the heavy dynamic loading conditions and the severe hazards of wind turbine failure, material testing of components during fabrication and active monitoring during turbine operation is necessary. Flaws or imperfections in the turbine components can increase fatigue stresses and the potential for catastrophic failure. Optical motion magnification (OMM) is a vision-based monitoring technique that is growing in popularity in the structural health monitoring (SHM) and modal analysis research communities. OMM algorithms take ordinary video, extract and magnify imperceptible motion of part of the structure, and highlight issues that may lead to failure. OMM can produce qualitative magnified motion videos revealing the points of largest displacements in the object, and quantitative analyses of displacement time histories and vibrational frequency spectra can be generated. Based on the initial WindSTAR study, OMM has shown the capability of quantifying the motion of WT foundations that are consistent with traditional measurements. The current work achieved to (1) identify the minimum wind speed needed to detect damage, (2) determine best practices for wind farm operators to run effective foundation inspection campaigns, and (3) provide the final validation of OMM for monitoring WT foundations. A comparative blind study was implemented on 27 operating wind turbines to classify their conditions without prior knowledge of their physical integrity and validate the accuracy of OMM on a wind farm. OMM-measured displacements to rank the condition of the tested turbines have shown up to 83% correlation with the ranking provided by accelerometer-based measures. In addition, the field tests provided insights and indications on how to inspect real-world wind farms. The outcomes of this project indicate that OMM can be used to replace existing foundation interrogating methods and provides an approach that is quick (<15 min/turbine), inexpensive, and can inspect turbines without any service interruption.

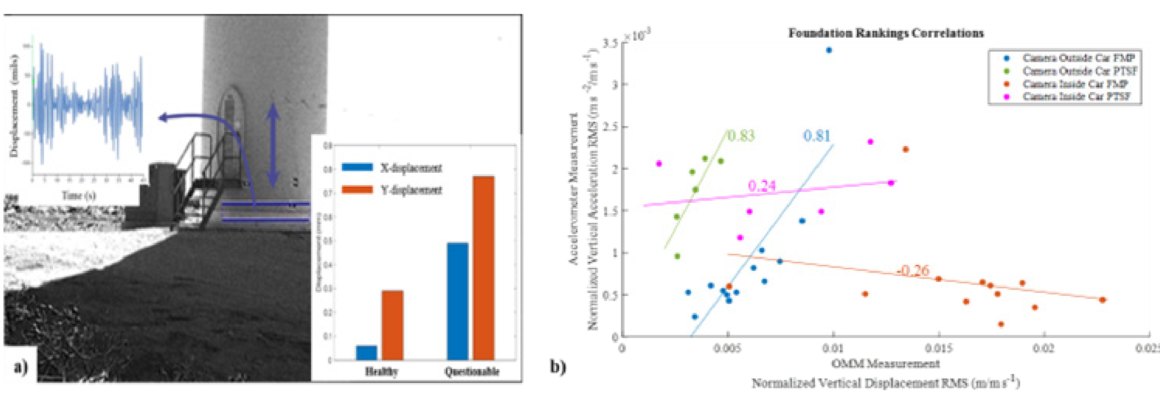


Figure 1. Outcomes of project F1-22: (a) Use of OMM for measuring the vertical and horizontal displacements of a wind turbine foundation for detecting healthy and questionable structures; and b) correlation between optical and accelerometer datasets collected during the blind tests with different experimental setups used to identify best practices.

PROJECT ID: F1-22

Designing a Variable Angle Wind Turbine Blade Test Fixture

Project Instructor:
Christopher Niezrecki (University of Massachusetts Lowell)

IAB Mentor:
George Blagdon (Wind Technology Testing Center)

Student Researchers:
Ashley Caiado, Kevin Hallerman, Kyle Fielder, Michael Jones (University of Massachusetts Lowell)

The Wind Technology Testing Center is exploring the possibility of developing a variable tilt fixture for the testing of ultra-long wind turbine blades. This fixture would mount to the existing concrete test stand structure and be used to tilt the blades from 0 degrees horizontal to 15 degrees horizontal. The desire is to keep the blade at 0 degrees for installation and test setup and tilted to the desired test angle prior to the test. The fixture would need to transmit all loads appropriately into the concrete stand structure. The capstone students successfully designed and modeled a hydraulically actuated fixture that could meet this goal.

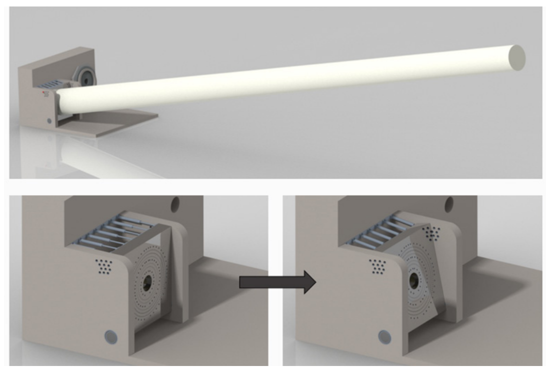


Figure 1. Wind turbine blade test stand with the designed variable angle mounting plate.

PROJECT ID: U1-23

Design of a Rain Erosion Testing Machine for Materials and Wind Turbine Blades

Project Instructor:
Christopher Niezrecki (University of Massachusetts Lowell)

IAB Mentor:
Shintaro Tsuchihashi (Nikon)

Student Researchers:
Alexander Brown, Connor Tower, James Bartram, Rachel Dolan (University of Massachusetts Lowell)

Figure 1. Wind turbine blade erosion test stand

A typical rain erosion testing machine is large in scale and can be expensive, making it unsuitable for easily examining the durability of materials. This Capstone project surveyed existing commercially available designs and standards, and then designed an inexpensive machine that can provide rain erosion durability evaluation for test samples exposed to a variety of wind speeds and rain flows.

PROJECT ID: U2-23

2022-2023 OUTCOMES

Through August 31, 2023. For a cumulative list of all center outcomes visit uml.edu/WindSTAR

Products:

1. Patent Filing or Awarded: Invention Disclosure Application UML# 2023-011, “Wind Turbine Blade and Internal Cavity Structural Health Monitoring System”, Inalpolat, M., Niezrecki, N., Luo, Y., Submitted (1/6/2023).
2. Formulations: UTD, M. Rotea: Formulation of a SCADA data index to determine when to apply wake steering in wind farms (invention disclosure under development)
3. Software: OpenFAST digital twin model developed for Gamesa 3.465MW turbine
4. Software: Multiphysical computational model for predicting process-induced residual stress and distortion in fiber-reinforced composites
5. Software: FAST Model V1.0: Aero-elastic Model
6. Software: Matlab code for cure optimization as a function of the repair thickness, kinetic of two resin systems as a function of temperature and humidity.
7. Software: A user-based subroutine written in Fortran for use in the finite-element software Abaqus, to calculate the degree of cure and temperature of an adhesive under exothermic curing reaction.
8. Software: A tool to simulate blade active load control systems using NREL FAST and any actuation system (plasma actuators in particular) that can command changes in the local lift coefficient along the blade span.
9. Software: A Matlab-based GUI that can predict the axial, transverse, and shear properties of composite laminates used in wind turbine blades based on CPFM advanced micromechanics model
10. Software: A Matlab based GUI for prediction of power production and wind turbine wakes for the Panhandle Phase II wind farm.
11. Software: Simulink code for Extremum Seeking Control of NREL CART3 (Controls Advanced Research Turbine, 3-bladed).
12. Patent: Foundation and Deflection Monitoring Device #10808374, Awarded 10/20/20.
13. Hardware: Fiber Optic Interrogator for Strain Monitoring
14. Hardware: Passive Acoustic Damage Detection System for Blades
15. Hardware: Active Acoustic Damage Detection System for Blades

Journal Papers:

1. Cimorelli, J., Hammerstrom, B., Niezrecki, C., Jin, X., “Estimate of the Wind Energy Needed to Replace Natural Gas with Hydrogen, and Electrify Heat Pumps and Automobiles in Massachusetts,” Wind Engineering, July 2023.
2. Aliheidari, N., Ameli, A. “Retaining high fracture toughness in aged polymer Composite/Adhesive joints through optimization of plasma surface treatment,” Composites Part A Applied Science and Manufacturing, Volume 176, January 2024, 107835.
3. S. P. Shah, M. N. Olaya, E. Plaka, J. McDonald, C. J. Hansen, and M. Maiarù, “Effect of moisture absorption on curing of wind blades during repair,” Compos. Part Appl. Sci. Manuf., vol. 173, p. 107706, Oct. 2023.
4. Aju, E. J., Kumar, D., Leffingwell, M., Rotea, M. A., & Jin, Y. (2023). The influence of yaw misalignment on turbine power output fluctuations and unsteady aerodynamic loads within wind farms. Renewable Energy, 215, 118894.
5. Kumar, D., Rotea, M. A., Aju, E. J., & Jin, Y. (2023). Wind plant power maximization via extremum seeking yaw control: A wind tunnel experiment. Wind Energy, 26(3), 283–309.
6. Li, H. and Zhang, J., Towards Sustainable Integration: Techno-Economic Analysis and Future Perspectives of Co-located Wind and Hydrogen Energy Systems, Journal of Mechanical Design, 2023.
7. Cao, Dongyang; Bouzolin, Dan; Lu, Hongbing; Griffith, D. Todd. (2023). Bending and shear improvements in 3D-printed core sandwich composites through modification of resin uptake in the skin/core interphase region, Composites Part B.
8. Zhang, Runyu, Yingjian Liu, Thomas Zheng, Sarah Eddin, Steven Nolet, Yi-Ling Liang, Shaghayegh Rezazadeh, Joseph Wilson, Hongbing Lu, and Dong Qian. “A fast spatio-temporal temperature predictor for vacuum assisted resin infusion molding process based on deep machine learning modeling.” Journal of Intelligent Manufacturing (2023): 1-28.
9. Devesh, K., Rotea, M.A., Aju, E., & Jin, Y (2022). Wind plant power maximization via extremum seeking yaw control: a wind tunnel experiment. Wind Energy.

Conference Papers:

1. Nieduzak, T., Kulkarni, N. N., Niezrecki, C., and Sabato, A., “Wind turbine monitoring using optical motion magnification: challenges and opportunities,” Proceedings of the 14th International Workshop on Structural Health Monitoring (IWSHM 2023), Stanford, CA, September 14-16, 2023.
2. Nieduzak, T., Valente, N. A., Niezrecki, C., and Sabato, A., “Optical Motion Magnification: A Comparative Study and Application for Vibration Analysis,” Proceedings of the IMAC XLI, A Conference on Structural Dynamics, February 13-16, Austin TX, 2023.
3. Aliheidari, N., Ameli, A., “Hygrothermal Aging of Structural Epoxy Adhesives Used in Wind Turbine Blade Composite Joints,” Proc Am Soc Compos Tech Conf 2023;0. https://doi.org/10.12783/asc38/36687
4. Aliheidari, N, Ameli, A., “Effects of Bondline and Substrate Thicknesses on the Mode I Fracture Toughness of Composite/Adhesive Joints,” Proc Am Soc Compos Tech Conf 2023;0. https://doi.org/10.12783/asc38/36688
5. Letizia, S., Moss, C., Puccioni, M., Jacquet, C., Apgar, D., & Iungo, G.V. (2022). Effects of the thrust force induced by wind turbine rotors on the incoming wind field: A wind lidar experiment. Journal of Physics: Conference Series, 2265(2), 022033.
6. Li, H., Rahman, J., & Zhang, J. (2022). Optimal planning of co-located wind energy and hydrogen plants: A techno-economic analysis. Journal of Physics: Conference Series, 2265(4), 042063.

Selected Presentations:

1. Nieduzak, T., Niezrecki, C., and Sabato, A., “Wind turbine monitoring using optical motion magnification,” presented at the SEM Northeast regional symposium, University of Rhode Island, April 22, 2023.
2. S Abootorabi, S Leonardi, M Rotea, A Zare (2023), “Short-term wind forecasting via surface pressure measurements: stochastic modeling and optimal sensor placement,” 76th Annual Meeting of the Division of Fluid Dynamics, Bulletin of the American Physical Society.
3. EJ Aju, P Gong, D Kumar, RS Wale, M Rotea, Y Jin (2023), “The Influence of Consecutive Gust on Turbine Under Yaw Misalignment, 76th Annual Meeting of the Division of Fluid Dynamics, Bulletin of the American Physical Society.
4. Rotea, M. A., Kumar D., E.J. Aju, Y. Jin (2023), “Wake steering via extremum seeking yaw control for power maximization: wind tunnel experiments.” Wind Energy Science Conference, 23 – 26 May 2023, Glasgow, UK
5. Li, H. and Zhang, J., Economic Feasibility and Decarbonization Potential of Hybrid Wind and Hydrogen Systems in Texas, North American Wind Energy Academy (NAWEA)/WindTech 2023 Conference, Denver, CO, Oct. 30–Nov. 1, 2023.
6. Li, H. and Zhang, J., “Assessing The Economic Feasibility and Decarbonization Potential of Wind Energy-based Hydrogen Production in Texas”, Wind Energy Science Conference, Glasgow, United Kingdom, May 23–26, 2023.
7. Aju, E., Kumar, D., Rotea, M., & Jin, Y. Wake steering of wind farm over complex terrain, APS Division of Fluid Dynamics Meeting 2022, Indianapolis, Nov 20-22, 2022
8. Hammerstrom, B., Niezrecki, C., Jin, X., Cimorelli, J., “Estimate of the Wind Energy Needed to Replace Natural Gas with Hydrogen and Electrify Heat Pumps and Automobiles in Massachusetts,” NAWEA/WindTech 2022 Conference, University of Delaware, DE, USA, September 20-22, 2022.
9. Diltz, N., Avitabile, P., and Niezrecki, C., “Assessment of Wind Turbine Foundation Degradation from Dynamic Measurements Made at the

Nacelle," NAWEA/WindTech 2022 Conference, University of Delaware, DE, USA, September 20-22, 2022.

10. Yujie Zhang, Mario Rotea, Federico Bernardoni, and Stefano Leonardi, Wind Direction Estimation using Neural Networks , NAWEA/WindTech 2022 Conference, Newark, Delaware, September 20-22, 2022.
11. Moss, C., Puccioni, M., Maulik, R., Jacquet, C., Apgar, D., & Iungo, G.V., Machine Learning Analysis of Profiling Wind LiDAR Data to Quantify Blockage for Onshore Wind Turbines, NAWEA/WindTech 2022 Conference, Newark, Delaware, September 20-22, 2022.

Master of Science Thesis:

1. Tymon Nieduzak, "Wind Turbine Foundation Monitoring using Optical Motion Magnification" UMass Lowell, May 2023.

PhD Dissertations:

1. Devesh Kumar, "Advanced log-of-power extremum seeking control for wind power maximization," Mechanical Engineering, University of Texas at Dallas, May 2023. (
2. Chang Liu, "Active load control of wind turbines using plasma actuation," Mechanical Engineering, University of Texas at Dallas, May 2023. (Chair: Mario Rotea)
3. Ning Bian, "Using nanofillers to enhance the mechanical properties of fiber-reinforced composites," Ph.D. in Mechanical Engineering, UT Dallas, August 2023.
4. Runyu Zhang, "Data-driven predictive models for manufacturing glass fiber composites and 3D-printed metals using neural networks and x-ray imaging, Ph.D. in Mechanical Engineering, UT Dallas, May 2023.
5. Yingjian Liu, "Hierarchical deep-learning neural network and its application to non-linear finite element method," November 2023.
6. Chang Liu, "Active Load Control of Wind Turbines Using Plasma Actuation," Ph.D. in Mechanical Engineering, University of Texas at Dallas, Fall 2022.
7. Caleb Traylor, "Computational Investigation into the Aeroacoustics of Wind Turbine Blades for Structural Health Monitoring," Ph.D. in Energy Engineering, UMass Lowell, August 2022.
8. Joshua Morris, "Design, Characterization, and Analysis Methods for Low Frequency Mechanical Metamaterials" Ph.D. in Mechanical Engineering, UMass Lowell, August 2022.
9. Sagar Shah, "Transverse Property Prediction of Thermosetpolymer Matrix Composites," Ph.D. in Mechanical Engineering, UMass Lowell, November 2022.
10. Federico Bernardoni, "Identification of wind turbine clusters for effective real time yaw control optimization," Ph.D. in Mechanical Engineering, University of Texas at Dallas, Fall 2022.
11. Matteo Puccioni, "Investigation on the organization of turbulence for high Reynolds-number boundary-layers through LiDAR experiments," Ph.D. in Mechanical Engineering, University of Texas at Dallas, Fall 2022.

Interns at Member Companies:

1. Research Project: Vivianne J. Snell, "Fiber-optic Resin Cure Sensor for Wind Turbine blades, Spring 2023.
2. Undergraduate research project: Reillan Sawyer, "Modeling and Control of an Experimental Scaled Wind Turbine," Summer 2023, NSF REU site on Wind Energy Systems.
3. Undergraduate research project: Joan Matutes, "Techno-Economic Analysis of Hybrid Offshore Wind and Hydrogen Systems," Summer 2023.

Students Hired at Member Companies:

1. Liliana Haus, MS,University of Texas at Dallas, EPRI
2. Sara Najafian, PhD, University of Massachusetts Lowell, TPI Composites

ACTIVE PROJECTS: 2023-2024

» **Data-Driven Curing Cycle Optimization in Wind Blade Manufacturing**
Project ID: A1-23
PIs: Dong Qian, Hongbing Lu (University of Texas at Dallas)Mentors: GE, Olin Epoxy, TPI Composites, Westlake Epoxy

» **Riblet Treatments on Energy Production and Loads of Turbines**
Project ID: A2-23
PIs: Yaqing Jin, Stefano Leonardi, Mario Rotea (University of Texas at Dallas)
Mentors: Arctura, Nikon Corporation, Pattern, Xcel Energy

» **Structural Wind Blade Repair Optimization**
Project ID: A3-23
PIs: Marianna Maiaru, Christopher Hansen (University Of Massachusetts Lowell)
EDF Renewables, EDP Renewables, TPI Composites, Westlake Epoxy

» **Mechanical Properties Enhancement Prediction for Matrix Materials**
Project ID: A4-23
PIs: Marianna Maiaru, Margaret Sobkowicz-Kline (University Of Massachusetts Lowell)
Mentors: EPRI, GE/LM, Olin Epoxy, TPI Composites, Westlake Epoxy

» **Machine Learning-enabled Condition Monitoring of Wind Turbines Using High-Resolution Voltage and Current Signals**
Project ID: B2-23
PI: Jie Zhang (University of Texas at Dallas)
Mentors: Bachmann Electronic Corp., EDF Renewables, EDP Renewables, EPRI, Leeward Renewable Energy, Windscape AI, Xcel Energy

» **Detecting the Onset of Icing in Wind Turbine Blades using SCADA Data and Strategies to Reduce Power Losses**
Project ID: B3-23
PIs: Nasser Kehtarnavaz, Mario Rotea (University of Texas at Dallas)
Mentors: Bachmann Electronic Corp., EDP Renewables, EPRI, Leeward Renewable Energy, Windscap AI, Xcel Energy

» **Feature-based Identification of Data Collected Using Acoustic Blade Monitoring System**
Project ID: B4-23
PI: Murat Inalpolat, Christopher Niezrecki (University Of Massachusetts Lowell)
Mentors: Arctura, Bachmann Electronic Corp., EDF Renewables, EDP Renewables, EPRI, Nikon Corporation, Pattern Energy, TPI Composites

» **Farm-to-Farm Interactions: Field-data Analysis, Modeling, and Improved AEP Estimates**
Project ID: C1-23
PI: Giacomo Valerio Iungo (University of Texas at Dallas)
Mentors: Avangrid, EDP Renewables, EPRI, GE, Windscape AI, Xcel Energy

» **Wind Turbine Loads on the Main Shaft, Main Bearing and Tower Under Wake Steering**
Project ID: D1-23
PIs: Mario Rotea, Yaqing Jin (University of Texas at Dallas)
Mentors: Arctura, Bachmann Electronic Corp., EDF Renewables, EDP Renewables, EPRI, Xcel Energy

» **Short-term wind forecasting via surface pressure measurements**
Project ID: D2-23
PIs: Armin Zare, Stefano Leonardi, Mario Rotea (University of Texas at Dallas)
Mentors: EDF Renewables, EDP Renewables, GE, Windscape AI, Xcel Energy

» **Foundation Stiffness Monitoring Using Optical Motion Magnification for Land-based and Offshore Wind Turbines**
Project ID: F1-23
PIs: Alessandro Sabato, Christopher Niezrecki (University Of Massachusetts Lowell)
Mentors: EDF Renewables, EDP Renewables, GE, Leeward Renewable Energy, Pattern Energy

» **Wind Plant Design for Repowering**
Project ID: F2-23
PI: D. Todd Griffith (University of Texas at Dallas)
Mentors: Bachmann Electronic Corp., EDP Renewables, EPRI

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