WindSTAR

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

2024 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 fifth year as a Phase II Center having completed dozens of projects, published numerous papers, had multiple M.S. and Ph.D. students graduate, several hired by member companies and national labs. Software and hardware systems are in use by the WindSTAR company members and the WindSTAR Webinar Series continues to disseminate important information. In 2024, for every dollar that came from a Full IAB member, ~20 dollars was invested in the Center from another source. For small business IAB members, the leveraging was 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 eleventh year of operation (Phase II), we will continue to grow the Center, strengthen existing collaborations, and increase awareness of WindSTAR within the wind industry .

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 strong player in improving the resilience of the Nation's electricity portfolio and enable new applications of this 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, Department of Mechanical Engineering
Professor (affiliate), Department of Electrical and Computer Engineering
Director, Center for Wind Energy (UTD Wind)
Site Director, WindSTAR I/UCRC
University of Texas Dallas

TABLE OF CONTENTS

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.

2024-2025 IAB Chair
Lauren Magin
Innovation Program Manager
Avangrid Renewables

2024-2025 IAB Vice Chair
Phil Gauthier
Sr. Mgr., Innovation and Technology Commercialization, EDF Renewables

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

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

Past IAB Chairs:
2022-2023: Brandon Fitchett, EPRI
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

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

FINANCIAL OVERVIEW: RETURN ON INVESTMENT

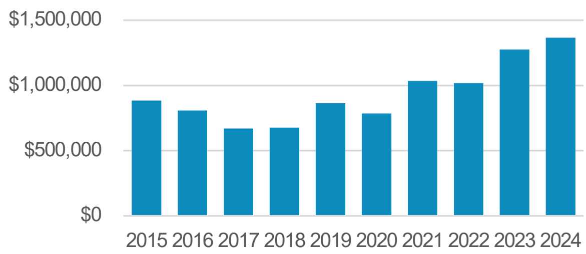
MEMBERSHIP LEVELS 2023-2024

Full Membership
$47,641 Annually

Small Business Associate
$ 17,865 Annually

CUMULATIVE INVESTMENT

TOTAL INVESTMENT: $8,850,968



NSF Awards
(Award # 1916715, 1916776, 1362022, 1362033)
$1,917,611

University Contribution (Cost Share)
$2,169,456

IAB Contributions
$4,763,901

In-Kind
$ 527,508

THRUST AREAS (PROJECT COUNTS ARE CUMULATIVE)

- (A) Composites and Blade Manufacturing - 33 Projects
- (B) Structural Health Monitoring, Non-Destructive Inspections, and Testing - 18 Projects
- (C) Wind Farm Modeling and Measurement Campaign - 13 Projects
- (D) Control Systems for Turbines and Farms - 5 projects
- (E) Energy Storage and Grid Intergration - 1 Project
- (F) Foundations and Towers - 2 Projects

2023-2024 PROJECTS

- Machine-Learning Based Curing Cycle Optimization in Wind Blade Manufacturing
  Project ID: A1-23
- Riblet Treatments on Energy Production and Loads of Turbines
  Project ID: A2-23
- Structural Wind Blade Repair Optimization
  Project ID: A3-23
- Mechanical Properties Enhancement Prediction for Matrix Materials
  Project ID: A4-23
- Machine Learning-enabled Condition Monitoring of Wind Turbines Using High-Resolution Voltage and Current Signals
  Project ID: B2-23
- Detecting the Onset of Icing in Wind Turbine Blades using SCADA Data and Strategies to Reduce Power Losses
  Project ID: B3-23
- Feature-based Identification of Data Collected Using Acoustic Blade Monitoring System
  Project ID: B4-23
- Farm-to-Farm Interactions: Field-data Analysis, Modeling, and Improved AEP Estimates
  Project ID: C1-23
- Wind Turbine Loads on the Main Shaft, Main Bearing and Tower Under Wake Steering
  Project ID: D1-23
- Short-term wind forecasting via surface pressure measurements
  Project ID: D2-23
- Foundation Stiffness Monitoring Using Optical Motion Magnification for Land-based and Offshore Wind Turbines
  Project ID: F1-23
- Wind Plant Design for Repowering
  Project ID: F2-23
- Wind Turbine Blade Sensor Energy Harvester
  Project ID: U1-24
- Blade Rotation Mechanism
  Project ID: U2-24
- Design of a Mounted Camera for Wind Turbine Monitoring
  Project ID: U3-24

For a cumulative list of all center projects 2014-2024 visit uml.edu/WindSTAR

Machine-Learning Based Curing Cycle Optimization in Wind Blade Manufacturing

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

Student Researchers:
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IAB Mentors:
Stephen Nolet, Shaghayegh Rezazadeh Kalehbasti, Joseph Wilson, Amir Salimi (TPI Composites)
Paul Ubrich, Nathan Bruno, Mirna Robles (Westlake Epoxy)
Xu Chen (GE Vernova)

The vacuum-assisted resin infusion mold (VARIM) process is widely used in wind blade manufacturing for its cost-effectiveness and reliability. This method involves laying the necessary reinforcements in a vacuum bag setup, infusing resin into the setup, and subsequently heating the entire assembly on a heated table at a constant temperature. Despite its widespread use, the current VARIM method encounters significant challenges, including prolonged curing times and defects arising from uniform heating across a blade structure composed of various materials with differing thicknesses. To address these issues, a multi-zone heated bed setup, tailored to the specific thicknesses of the blade, has been proposed. However, determining the optimal temperature for each zone presents a substantial computational challenge. This challenge can be effectively addressed through an innovative machine-learning approach.

Using a digital twin based on a high-fidelity multiphysics solver, a time-distributed LSTM model was trained to understand complex resin curing dynamics over every time step of the process. This eliminates the need for costly lab experiments, as the model learns heating patterns and curing behavior efficiently. Once trained, the machine-learning model functions as a digital twin, capable of predicting the degree of cure for a given temperature setpoint with an impressive accuracy of 96.73%. The trained ML model was subsequently utilized as a surrogate model in a Nelder-Mead optimization workflow, which is a black-box optimization method. This optimization approach aims to enhance the curing process by determining the optimal temperature distribution across the multi-zone heated bed. The results from the optimization indicate a potential improvement in curing time by approximately 12.5%, alongside a more uniform curing rate throughout the wind blade. The integration of a machine-learning model within the VARIM process represents a significant step forward in addressing the current limitations of uniform heating and long curing times. By utilizing a digital twin and an optimization workflow, the proposed method offers a practical solution for achieving optimal temperature distribution tailored to blade thickness, thereby enhancing the efficiency and quality of wind blade manufacturing.

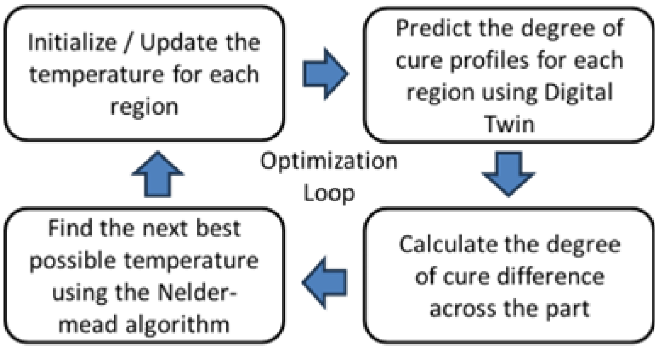

Figure 1. Optimization loop to calculate optimum temperature setpoints.

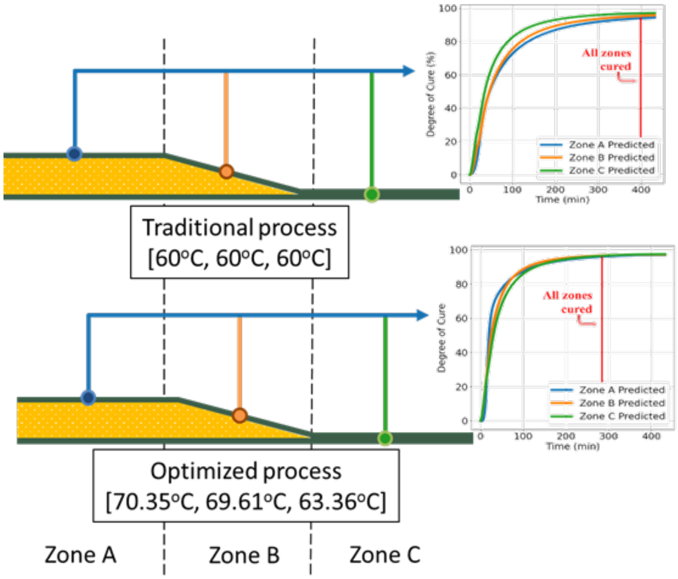

Figure 2. The resulting improvement of curing profiles when compared to the traditional uniform heating process. The graphs show an improvement in curing time and a smaller difference in the degree of cure between the three zones.

PROJECT ID: A1-23

Riblet Treatments on Energy Production and Loads of Turbines

Principal Investigator:
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IAB Mentors:
Takashi Yuito, Shintaro Tsuchihashi, Takaya Higashino (Nikon)
Neal Fine (Arctura)
Teja Dasari (Xcel Energy)
Traci Pashley (Pattern Energy)

Enhancing energy production and reducing turbine loads are crucial for lowering the Levelized Cost of Energy (LCOE) in wind turbines. In the previous project, we demonstrated that applying riblet treatments on blade surfaces effectively improves aerodynamic performance. Numerical simulations revealed that riblets could positively influence a turbine's annual energy production. However, long-term exposure to real environmental conditions may cause surface degradation, and its effects on turbine efficiency and loads under varying operating conditions are not yet fully understood. In this project, we quantified the aerodynamic performance of riblet-treated surfaces exposed to outdoor conditions through wind tunnel testing. The lift and drag coefficients obtained were then used as inputs for numerical simulations assessing the performance of a utility-scale wind turbine subjected to turbulent incoming flows using an actuator disk model. Additionally, a new experimental platform—the G06 model turbine—was used to evaluate the impact of riblet films on energy production. The results highlighted that despite the exposure to outdoor environments for three months, the riblet film retains the capability of enhancing blade lift/drag ratio by approximately 2%. Furthermore, numerical simulations showed that the turbine's power output could increase by 1.8% with riblet films after three months of exposure. Wind tunnel experiments using G06 model turbines revealed that when 50% of the blade span near the tip was covered in riblet films, power output increased by approximately 2.4% across a wide range of wind speeds and tip speed ratios. In conclusion, both experimental and numerical analyses demonstrated that riblet films remain effective in enhancing wind turbine performance, even after exposure to outdoor conditions.

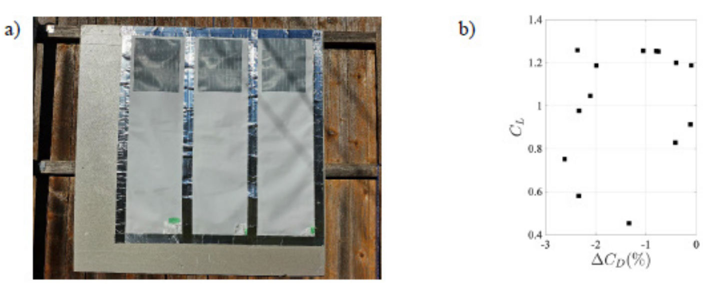

Figure 1. a) Photograph of riblet films exposed in outdoor environment in DFW area; b) Drag reduction percentage of riblet film after 3-month exposure to outdoor environments.

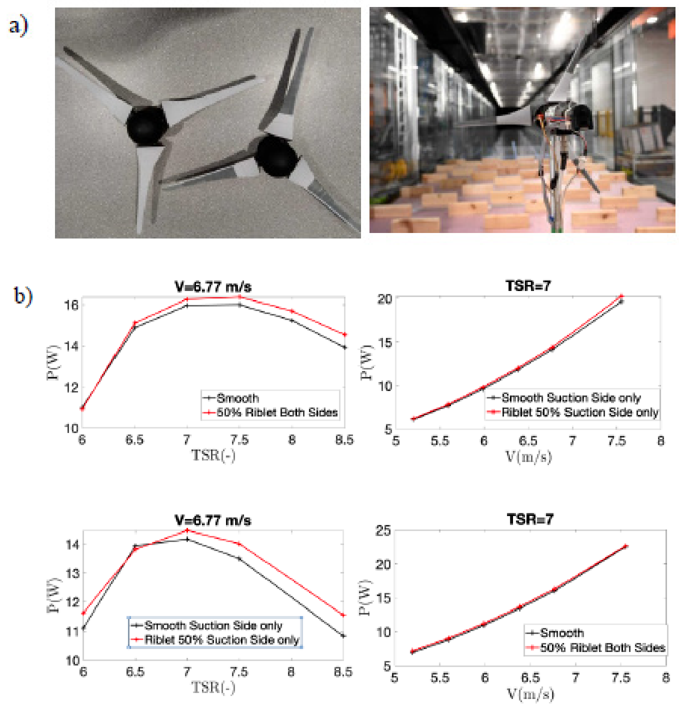

Figure 2. a) Photograph of G06 turbine blades covered with riblet films; b) Power output of G06 turbines with smooth and riblet film coverage.

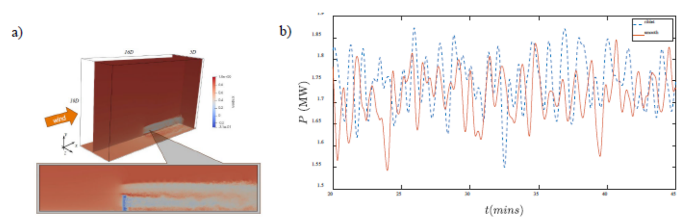

Figure 3. a) Numerical simulations with actuator disk model for flow over wind turbines; b) time series of turbine power output with smooth and riblet film coverage.

PROJECT ID: A2-23

Structural Wind Blade Repair Optimization

Principal Investigator:
Marianna Maiaru (Columbia University)

Co-Principal Investigators:
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Student Researchers:
Sagar P. Shah (Columbia University)
Michael N. Olaya, Evgenia Plaka
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IAB Mentors:
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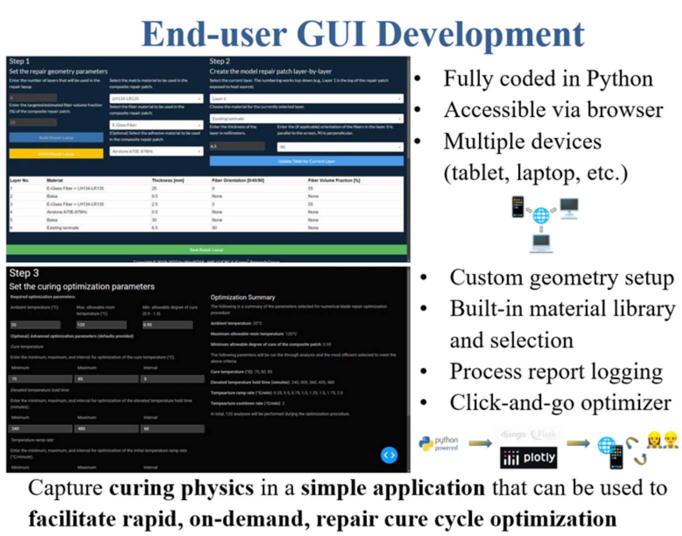
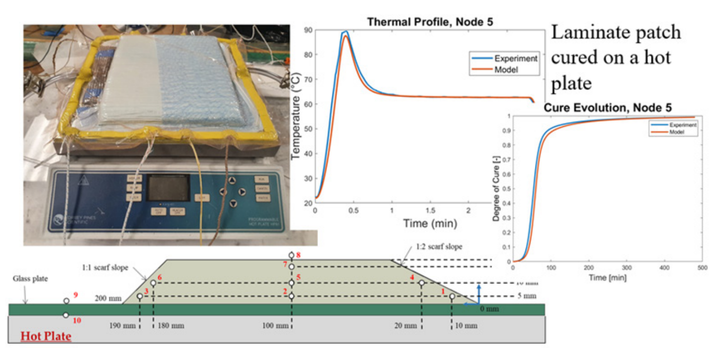
Paul Ubrich, Nathan Bruno (Westlake Epoxy)
Jian Lahir (EDPR)
Ben Rice (Pattern Energy)
Ivan Liang (Olin Epoxy)

Efficient structural repair of wind turbine blades is essential to reducing the Levelized Cost of Energy (LCOE) for wind energy. Repairs carried out up-tower are sensitive to environmental conditions whose effects on the material properties during processing need to be accounted for to accurately predict the repair outcome. Furthermore, optimizing the repair cure cycle is needed to reduce the turbine downtime. Insights on the effect of curing parameters are required to schedule a repair in optimal conditions. This study addresses the structural repair of wind turbine blades by leveraging both modeling and testing efforts to deliver a reliable and fast tool for the prediction of curing for structural wind turbine repairs. Finite Element and Finite Difference analyses were used to analyze repair procedures and enhance the repair tool. Modeling efforts included simulating different repair sizes, including structural repairs in which the use of balsa was required; the analysis of multiple repair parameters; and the scalability of simulations for larger repairs in the field. An extensive database of complex repair scenarios provided insight into the appropriate boundary conditions to increase the reliability of the 1D predictions. The material characterization results were organized in a material database integrated in the Python GUI for the repair tool to access on demand. Preliminary analyses were carried out to quantify the impact of optimized repair on the LCOE through techno-economic evaluation. This project provided the knowledge needed to enable repair optimization, benefitting wind farm owner-operators, and material suppliers. The work: 1) enabled the determination of the most and least favorable repair conditions; 2) provided recommendations on repair cure cycle optimization to reduce the time needed to cure evenly the blade reducing the down time of the turbine; 3) facilitated the development of a material database for a repair tool (Python GUI); 4) led to the development of a repair tool prototype for IAB use implemented in Python; 5) laid the groundwork for techno-economic evaluation to quantify the impact of optimized repair on the LCOE.





Mechanical Properties Enhancement Prediction for Matrix Materials

Principal Investigator:
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Co-Principal Investigators:
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Student Researchers:
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Ivan Liang (Olin Epoxy)
Mitch Rencheck (EPRI)
Joyee Zhu (GE Vernova)
Paul Ubrich, Nathan Bruno (Westlake Epoxy)

It is estimated that the U.S. will have more than 720,000 tons of blade material to dispose of over the next 20 years, not accounting for newer, longer, higher-capacity turbines required to meet the 38,000 terawatt-hours global electricity demand expected by 2050. Designing thermoplastic recyclable wind blades is of paramount importance to address this challenge of waste accumulation and effectively lower the LCOE. The design process of thermoplastic blades should consider the materials, manufacturing processes, and end-of-life disposal options to minimize waste and maximize the recovery of valuable materials.

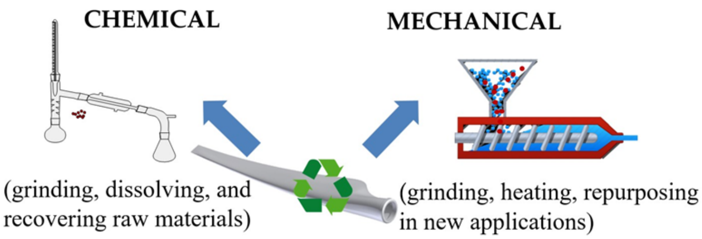

Figure 1. Problem Statement

The objectives of this work are (1) to test and compare two methods for recycling the Elium-glass composites to determine the optimal route for recovery of value from thermoplastic composite blades; and (2) determine Elium's creep behavior for design. The in-situ polymerized Elium resin is unique in that its linear chains can both melt and flow, and dissolve in common organic solvents. While melt processing is a well-established and high efficiency route for recycling thermoplastics, the high viscosity of the cured resin and its interfacial interactions with the glass fibers means it is not feasible to remove and recover the Elium using thermal energy alone. Based on preliminary studies of Elium recyclability, we evaluated two methods: solvent-based dissolution and separation of the acrylate resin from the fibers and grinding and compounding with thermoplastic matrices. We obtained samples of laminates and conducted dissolution experiments using two solvents. We mapped solvents using the Hansen solubility parameter framework to predict the least hazardous and most economical choices for the recycling study. Spectroscopic and microscopy studies determined the extent of separation and the retention of high-quality resin and fiber. For the second recycling method, we evaluated grinding and compression molding neat cured Elium into reformed parts. We used mechanical shredding equipment to downsize the Elium plaques, then blended the particles into virgin polymethylmethacrylate using b. The blends were batch melt mixing, injection molded into tensile and impact specimens, and their mechanical properties tested.

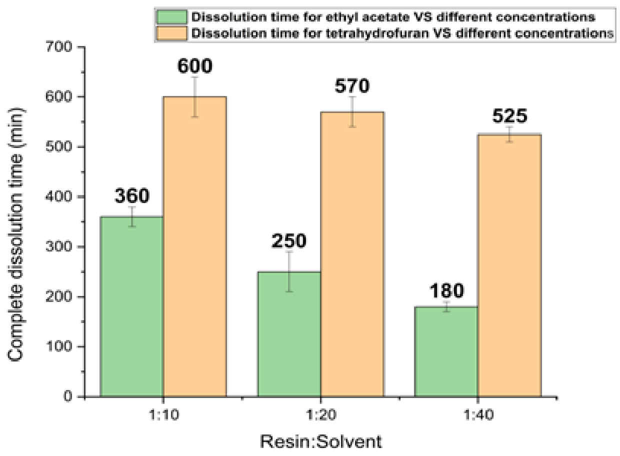

Figure 2. Results of dissolution studies

Reducing, reusing resources and recycling raw materials will contribute to produce cleaner energy and reduce the LCOE. The knowledge generated by this research will enable the industry to identify optimal procedures for composite recyclability and identify performance of recycled parts.

PROJECT ID: A4-23

Machine Learning-enabled Condition Monitoring of Wind Turbines Using High-Resolution Voltage and Current Signals

Principal Investigator:
Jie Zhang (University of Texas at Dallas)

Student Researchers:
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IAB Mentors:
Vahid Jahangiri Leeward Renewable Energy)
Phil Gauthier (EDF Renewables)
Isidro Mendoza, Pankaj Salunke, Aditya Krishna (EDP Renewables)
Lothar Breuss (Bachmann Electronic Corp)
Curtis Fox (EPRI)
Jason Yosinski (Windscape AI)
Teja Dasari (Xcel Energy)
Bin Jou (FM Global)

The flourishing wind energy market is pushing modern wind turbines (WTs) into increasingly remote and harsh inland and offshore environments. With rising operation and maintenance costs, there is a growing demand for more reliable and cost-effective condition monitoring systems. In this project, we propose a bi-level condition monitoring framework for detecting inter-turn short circuit faults (ITSCFs) in WT generators. A benchmark dataset consisting of 75 ITSCF scenarios, along with generator current signals from a specific WT, has been created and made publicly available on Zenodo.

Rather than classifying all 76 possible conditions (75 ITSCFs + 1 normal operation) of the generator stator, we categorized ITSCF severity into three levels. The phase identification module is activated only when severe or medium fault categories are detected, enabling the localization of the faulty phase. Based on time and frequency features extracted through data processing, machine learning-based severity estimation and faulty phase identification modules provide valuable diagnostic information for wind farm operators and technicians.

We specifically analyzed and compared the performance of long short-term memory (LSTM) networks, gated recurrent unit (GRU) networks, and two-dimensional convolutional neural networks (CNNs) for both severity estimation and faulty phase identification. For experimental reference, we assessed the impact of different numbers of training scenarios on model performance. Numerical experiments demonstrated the CNN's computational efficiency and strong noise resistance, while the GRU network achieved the highest accuracy. The system's overall performance improved significantly, from 87.76% with 16 training scenarios to 99.95% with 52 training scenarios when tested on an unseen dataset of all 76 scenarios.

In addition to high-frequency data, we analyzed a SCADA dataset shared by one IAB member. This dataset spans one month with a 10-minute sampling frequency, and abnormalities are categorized into five levels. Preliminary results showed a 76.75% prognostic accuracy for predicting these severity categories using the proposed condition monitoring model.

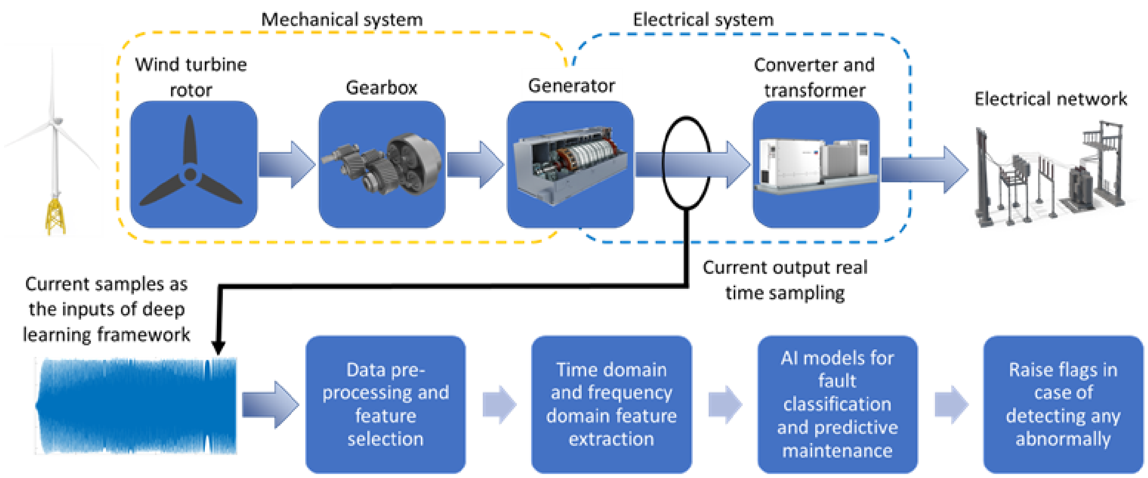

Figure 1. Overall framework of the proposed machine learning enabled condition monitoring

PROJECT ID: B2-23

Detecting the Onset of Icing in Wind Turbine Blades using SCADA Data and Strategies to Reduce Power Losses

Principal Investigator:
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Co-Principal Investigator:
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Student Researcher:
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Lothar Breuss (Bachmann Electronic Corp)
Teja Dasari (Xcel Energy)
Vahid Jahangiri (Leeward Renewable Energy)
Daniel Martinez (EDP Renewables)
Praanjal Nasery (EPRI)
Antonio Ruiz (EDPR Renewables)
Jason Yosinski (Windscape AI)

Icing on the blades of wind turbines during winter seasons causes a reduction in power and revenue losses. The prediction of icing before it occurs has the potential to enable mitigating actions to reduce ice accumulation. This project involved the development of a framework for the prediction of icing on wind turbines based on Supervisory Control and Data Acquisition (SCADA) data without requiring the installation of any additional icing sensors on the turbines. A Temporal Convolutional Network was considered as the model to predict icing from the SCADA data time series. The developed icing prediction framework includes the following components: data preprocessing, labeling of SCADA data for icing conditions, selection of informative icing features or variables in SCADA data, and design of a Temporal Convolutional Network as the prediction model. Two performance metrics to evaluate the prediction outcome were examined. Using SCADA data from an actual wind turbine, the model achieved an average prediction accuracy of 77.6% for future times of up to 48 hours. Furthermore, this icing prediction framework was extended to an entire wind farm. A cross-validation study was carried out to evaluate the extent predictors trained on a single turbine of a wind farm could be used to predict icing on the other turbines of a wind farm. Two fusion approaches of decision fusion and feature fusion were developed to generate farm-level icing predictions, in which multiple turbines were combined, thereby providing predictions at the wind farm level. It was shown that the developed fusion approaches improved prediction accuracy and decreased fluctuations across different prediction horizons when compared with single-turbine prediction. In decision fusion, icing prediction decisions from individual turbines were combined in a majority voting manner. In feature fusion, features of individual turbines were averaged first before conducting prediction. The results obtained indicate that both the decision fusion and feature fusion approaches generate farm-level icing prediction accuracies that are 7% higher with lower standard deviations or fluctuations across different prediction horizons when compared with predictions for a single turbine. The combination of this predictor with control of blade pitch, rotor speed and yaw to reduce power losses due to icing is left for future research.

Figure 1. Example of icing on wind turbine blades.

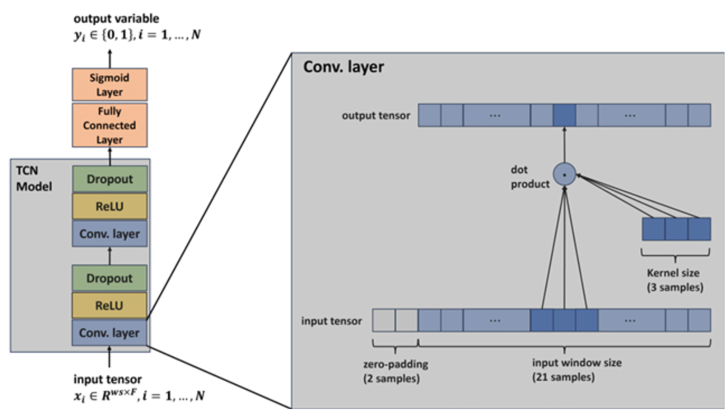

Figure 2. Developed Temporal Convolutional Network (TCN) model for ice prediction on wind turbines.

PROJECT ID: B3-23

Feature-based Identification of Data Collected Using Acoustic Blade Monitoring System

Principal Investigator:
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Co-Principal Investigators:
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Student Researcher:
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Lothar Breuss (Bachmann Electronic Corp)
Stephen Nolet (TPI Composites)
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Phil Gauthier (EDF Renewables)
Neal Fine (Arctura)
Noah Myrent (EPRI)

High operational loads cause significant bending and shear and thus are detrimental to wind turbine blades. Currently available condition monitoring systems are not capable of detecting different types and severity levels of damage and defects such as leading and trailing edge splits, holes and cracks. A comprehensive damage detection system that can monitor the blades for leading and trailing edge splits, delaminations, cracks and holes is currently not available. Consequently, it is vital to provide a low cost yet highly capable condition monitoring solution that will reduce the need for unscheduled maintenance.

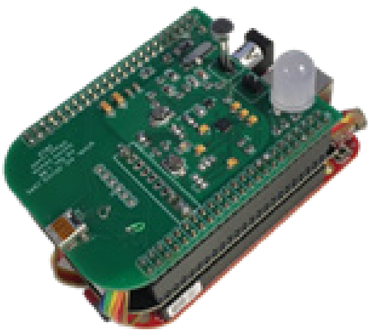

Figure 1. Acoustic sensing node circuitry.

Deployment of a previously developed wind turbine blade acoustic monitoring system has required complete understanding and mitigation of the mechanical, electrical and structural problems associated with the installation and operation of the system. Lessons learned has been leveraged in order to improve the current system design and its integration. The team has focused on the field tests on a full-scale turbine as well as improving and implementing the developed signal processing and machine learning algorithms to enable this technology in the near future.

This project is on further development of a blade damage detection and monitoring system. The project team will continue the efforts from our previous projects, which has successfully shown the feasibility of the proposed technique in the laboratory environment as well as in the field. In our cuurent project, we focus on post-processing, statistical analysis, and interpretation of data collected from past and current acoustic monitoring of wind turbines. The team has successfully implemented 4 acoustic monitoring systems on operational wind turbines so far. We have also implemented a blade external sensor at the Xcel Energy Wind Farm.

The acoustic sensors collect data at high sampling rates generating an abundance of useful blade structural integrity and other relevant data sets. However, processing and decision-making using these datasets have been cumbersome and time taking without a user-friendly and self-explanatory data visualization, interpretation, and management interface. In this project, the team has been developing a Matlab/Python based Graphical User Interface (GUI) that will run several different established and custom signal-processing algorithms. The outcomes will be presented in terms of acoustic pressure and temperature plots.

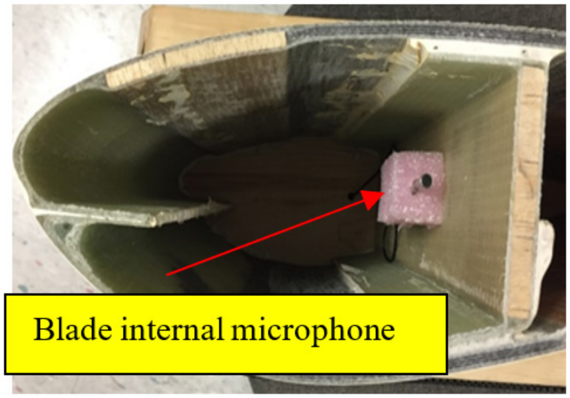

Figure 2. A close-up view of the blade-internal acoustic sensor (microphone) from a lab test.

PROJECT ID: B4-23

Farm-to-Farm Interactions: Field-data Analysis, Modeling, and Improved AEP Estimates

Principal Investigator:
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Student Researcher:
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IAB Mentors:
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Lou Bowers (Avangrid Renewables)
Teja Dasari (Xcel Energy)
Jason Yosinski (Windscape AI)
Antonio Ruiz, Daniel Cabezon (EDP Renewables)
Raja Pulikollu, Praanjal Nasery, Clement Jacquet (EPRI)

As wind farms increase in size and are installed in increasing proximity to other wind farms, the chance for and impact of farm-to-farm interactions increases. Farm-to-farm interactions occur when individual turbine wakes merge into large-scale long-range structures that can reduce the power of downstream farms. Utilizing data from several large wind farms, we study farm-to-farm interactions in the context of inflow variability and total power loss. First, we develop data-driven methods for detecting whether a given turbine is waked or unwaked. This can help determine whether a farm is under a large-scale farm-wake interaction or is merely impacted by individual, unique turbine wakes. Next, we cover mesoscale modeling needed to characterize the flow over large domains comprised of many farms. For instance, mesoscale variability is shown to produce 20-30% variability in power across two wind farms. To study mesoscale variability, we determine the optimal averaging period for SCADA data using several different analyses and conclude that 90-minute periods are a good trade-off to characterize spatial heterogeneity of the wind field yet not affected by wind turbulence. These are used to study the background mesoscale variability for an individual farm, but limited data could prevent the extension of this method to many farms. Furthermore, wind farm models are developed using geometric methods and machine learning to predict normalized farm power for arbitrary wind farm layouts even under variable inflow conditions, such as those induced by partial farm-wake interactions. These geometric models can accurately predict wind farm power and provide the needed estimates of unimpeded wind farm power that, when coupled with mesoscale methods that provide inflow conditions to waked wind farms if the waking wind farm is absent, can help estimate total farm power lost due farm-to-farm interactions.

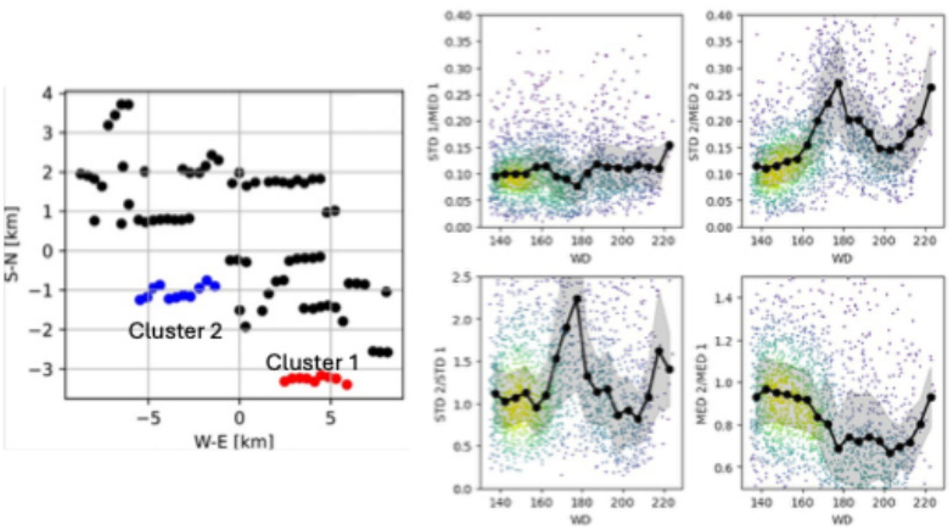

Figure 1. The selection of two clusters in a wind farm impacted by farm-to-farm interactions (left panel) and the difference in standard deviation and median of power indicating the occurrence of farm-to-farm interactions impeding the easterly cluster but not the westerly cluster for wind directions between 180^ and 200^ (middle and right panels).

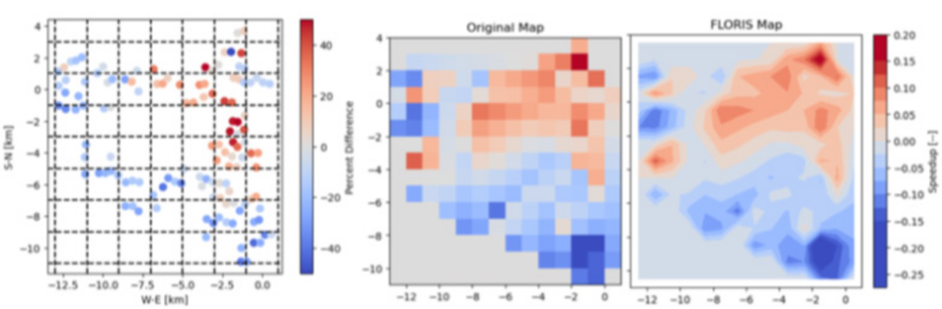

Figure 2. Spatial variability of the difference between FLORIS-predicted and SCADA wind speed measurements (left panel) that is then converted into a Cartesian grid (middle panel) and then to a background map that can be inputted to FLORIS to improve predictive accuracy (right panel) as well as describe the typical mesoscale variability at the site.

PROJECT ID: C1-23

Wind Turbine Loads on the Main Shaft, Main Bearing and Tower Under Wake Steering

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

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

Student Researchers:
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(University of Texas at Dallas)

IAB Mentors:
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Lothar Breuss (Bachmann Electronic Corp)
Phillip Gauthier (EDF Renewables)
Teja Dasari (Xcel Energy)
Curtis Fox (EPRI)
Antonio Ruiz, Daniel Cabezon Martinez (EDPR)
Bin Jou (FM Global)

Wake steering via yaw control of wind turbines can increase AEP. This wind farm flow control technique involves intentional misalignment of selected turbines to divert their wakes away from downstream turbines to boost overall wind plant power output. Prior WindSTAR projects have demonstrated that cluster-based extremum seeking yaw control is a viable algorithm for wake steering. Past projects have used small-scale wind turbines (rotor diameter D = 0.2 m) with no hub load measurements and no rotor speed control.

This project examines loads under wake steering for larger turbines designed and fabricated by the Technical University of Munich: the G06 wind turbine. The G06 has rotor diameter D = 0.6 m, variable speed and pitch controls as well as active yaw control provided by a servomotor at the tower-base. This turbine can achieve good wake similarity to a full-scale 10 MW machine, which facilitates the extrapolation of wake steering results from wind tunnel experiments to utility-scale machines.

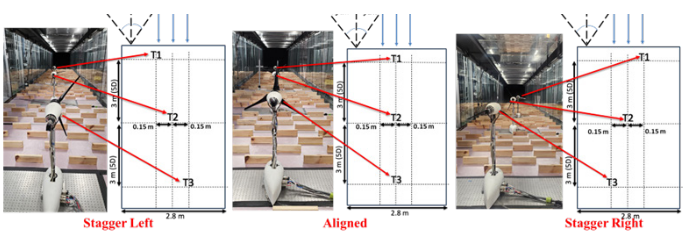

Figure 1. Photographs of G06 turbines in wind tunnel experiments, captured from a downstream-to-upstream perspective with various layouts.

Three G06 turbines were arranged in three different configurations (Fig. 1). The upstream turbine is T1 and the downstream turbines are T2 followed by T3 along the streamwise direction. The configurations differ in the placement of T1 and T3 relative to T2 along the spanwise direction. This approach allows testing cases where the flow impinging on the downstream turbines has full wake (aligned configuration) or partial wake conditions (staggered configurations). The log-of-power PI ESC algorithm (LP-PIESC) from our prior work has been implemented on both T1 and T2 to simultaneously determine yaw angles γ_1 and γ_2 that maximize the total farm power. Six independent runs of 20 min duration were done for each configuration, with the same incoming flow conditions. For the first 10 minutes, the turbines operated with no yaw misalignment (yaw control off). Then the LP-PIESC algorithms for T1 and T2 were turned on, and the experiments continued for another 10 minutes. In all cases, nearly optimal yaw angles were obtained in about one second.

Figure 2 shows the average power of all six runs with and without yaw control on T1 and T2 via LP-PIESC. In all configurations, the power of T1 is reduced while the power of T2 and T3 is increased, leading to an overall power gain in all cases. The case with the largest power gain (10%) is the staggered right case. For this case, the yaw angles attained by the controllers were $\gamma_1=-20$ deg and $\gamma_2=-10$ deg. The staggered left configuration also shows a similar power gain (9%) but now the yaw angles converge to $\gamma_1=+20$ deg and $\gamma_2=+10$ deg.

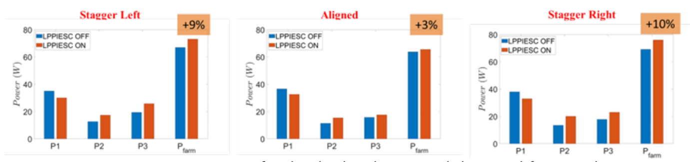

Figure 2. Mean power output of individual turbines and the wind farm with various layouts. The numbers in the orange boxes are the total power gains.

Wind turbine loads were analyzed for all cases. The most important cases are the staggered configurations because they produce the largest power gains. Thus, one would expect increases in some fatigue loads. Figure 3 shows damage equivalent loads (DELs) for the staggered configurations and two main components – the hub (e.g., a proxy for the main bearing) and the tower. The DELs with no wake steering are all normalized to one (blue bars). The increased magnitude (20 deg) of the yaw angle for T1 yields a decrease in the DELs of fore-aft tower moment for both layouts. However, no dominant trend for the variation of DELs at the hub for T1 is observed in the wind tunnel measurements. T1 hub DELs show increase for one configuration (left) and decrease for the other (right). There is a consistent increase in the DELs of the downstream turbine T2 for both the yaw hub moment and fore-aft tower moment; the T2 hub tilt moment DEL reduces in both configurations. While hub loads under wake steering can be sensitive to the specific configuration, the DEL increases in the downstream turbine T2 are consistent. Fatigue loads for critical turbine components as functions of effective wind velocities, turbine yaw angles and turbine rotation orientations under wake steering should be evaluated prior to implementation of wake steering.

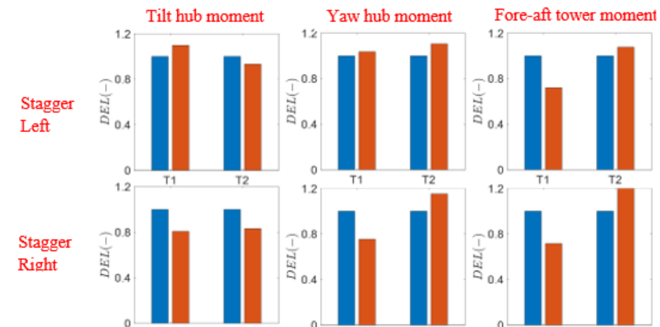

Figure 3. DELs for the bending moments of the turbine hub (tilt and yaw) and the tower (fore-aft) with stagger left and stagger right layouts.

PROJECT ID: D1-23

Short-term wind forecasting via surface pressure measurements

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

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

Student Researchers:
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IAB Mentors:
Joshua Morris (GE Vernova)
Jason Yosinski (Windscape AI)
Phillip Gauthier (EDF Renewables)
Teja Dasari (Xcel Energy)
Daniel Cabezon, Antonio Ruiz (EDP Renewables)

As wind farms increase in size and are installed in increasing proximity to other wind farms, the chance for and impact of farm-to-farm interactions increases. Farm-to-farm interactions occur when individual turbine wakes merge into large-scale long-range structures that can reduce the power of downstream farms. Utilizing data from several large wind farms, we study farm-to-farm interactions in the context of inflow variability and total power loss. First, we develop data-driven methods for detecting whether a given turbine is waked or unwaked. This can help determine whether a farm is under a large-scale farm-wake interaction or is merely impacted by individual, unique turbine wakes. Next, we cover mesoscale modeling needed to characterize the flow over large domains comprised of many farms. For instance, mesoscale variability is shown to produce 20-30% variability in power across two wind farms. To study mesoscale variability, we determine the optimal averaging period for SCADA data using several different analyses and conclude that 90-minute periods are a good trade-off to characterize spatial heterogeneity of the wind field yet not affected by wind turbulence. These are used to study the background mesoscale variability for an individual farm, but limited data could prevent the extension of this method to many farms. Furthermore, wind farm models are developed using geometric methods and machine learning to predict normalized farm power for arbitrary wind farm layouts even under variable inflow conditions, such as those induced by partial farm-wake interactions. These geometric models can accurately predict wind farm power and provide the needed estimates of unimpeded wind farm power that, when coupled with mesoscale methods that provide inflow conditions to waked wind farms if the waking wind farm is absent, can help estimate total farm power lost due farm-to-farm interactions.

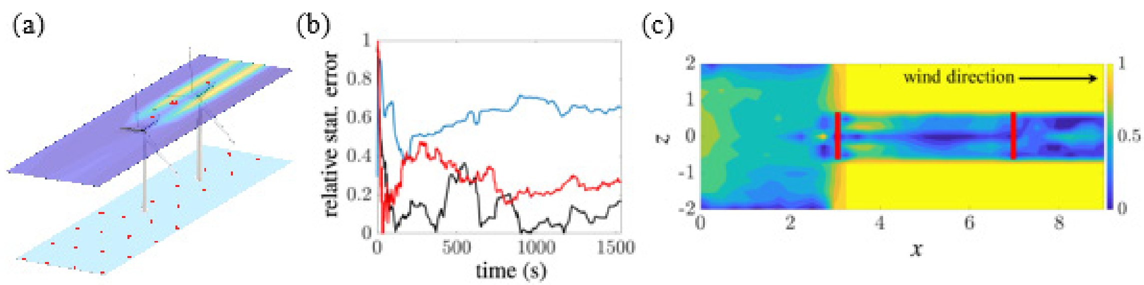


Figure 1. (a) Computational (top) and sensing planes (bottom). Red dots are sensors, and the star is an estimation point. (b) Relative error in estimating the velocity variance at the estimation point using the linearized (blue), extended (red), and unscented (black) Kalman filters. (c) Spatial variation of this relative error over a 2D domain at hub height from the extended Kalman filter.

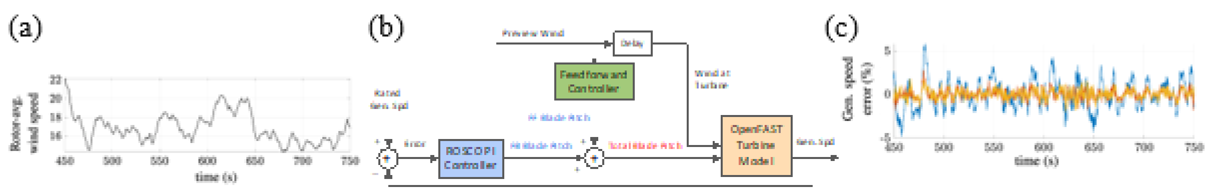


Figure 2. (a) Gust-infused wind speed impacting turbine rotor. (b) Block-diagram of feedforward-feedback control configuration. (c) Performance of feedforward-feedback control for generator speed regulation with the result of the baseline ROSCO feedback controller in blue and results of feedforward-feedback control in orange and red.

PROJECT ID: D2-23

Foundation Stiffness Monitoring Using Optical Motion Magnification for Land-based and Offshore Wind Turbines

Principal Investigator:
Alessandro Sabato (University of Massachusetts Lowell)

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

Student Researcher:
Fabio Bottalico (University of Massachusetts Lowell)

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

This report investigates the use of Optical Motion Magnification (OMM) to measure imperceptible motions of wind turbine (WT) foundations, aiming to identify displacements indicative of foundation failures. OMM has already shown the capability to measure displacements as low as 2µm with an accuracy of ~95% at close range. This project aimed to combine wind speed measurements at hub height via a UAV-mounted anemometer with foundation displacement data to estimate foundation stiffness. Traditional, destructive methods for assessing foundation integrity are costly and often inconclusive. Contact-based technologies, while accurate and nondestructive, have limitations such as high costs and extensive setup times. OMM offers a non-invasive alternative, capable of amplifying subtle motions in videos to provide full-line-of-sight measurements. This project involved field experiments on operational WT foundations at a wind farm in Texas. Tests were conducted on six healthy WTs under mid-to-high wind conditions. Displacement signals obtained using OMM were compared against reference data from high-sensitivity geophones. The study also compared a commercial OMM system with a custom-made system using an open-source OMM software and a high-resolution camera. Additionally, camera-mounted accelerometers and a stationary subtarget placed in the cameras' field of view were used to compensate for camera motion caused by wind gusts. The UAV-mounted anemometer successfully measured wind speeds at hub height, unaffected by the UAV's propellers. Tests on WT foundations showed that healthy foundations move by extremely small amounts, perceivable only with seismic-level accelerometers, below the noise floor of the OMM algorithm at the distance used during the tests. Both the commercial OMM system and the custom-made system provided similar results despite the custom-made system showing smaller camera motions, but the camera-based measurements were off by two orders of magnitude compared to accelerometer-based measurements and showed no correlation with wind speed. This suggests that OMM may be amplifying the sensor's noise when measuring healthy foundations. The study concluded that while OMM is effective in distinguishing healthy from questionable foundations, it is not sensitive enough to capture the minute motions of healthy WT foundations. Current camera technology and OMM algorithms are insufficient for estimating the structural stiffness of healthy WT foundations. Further advancements in technology are needed for OMM to be a viable condition monitoring tool for WT foundations.

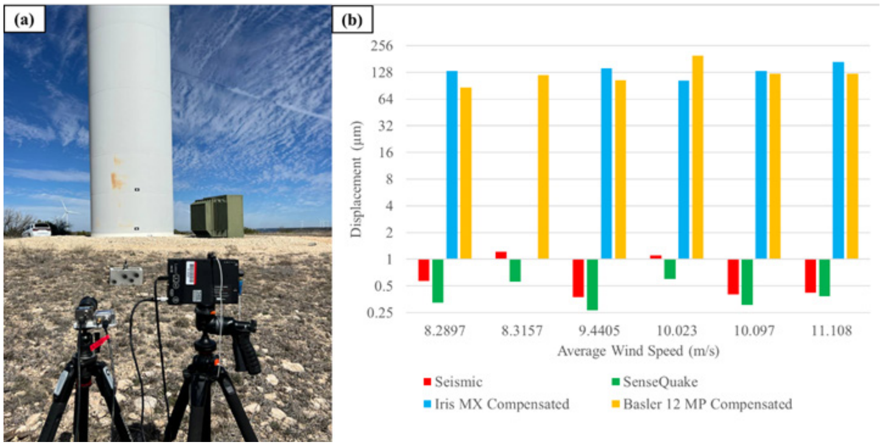


Figure 1. Outcomes of project F1-23: (a) The two cameras used to compare different OMM algorithms during a WT foundation test. and (b) vertical displacements of the six WT foundations measured with each sensor in different wind speed conditions.

PROJECT ID: F1-23

Wind Plant Design for Repowering

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

Student Researchers:
Dan Bouzolin, Kyle Settelmaier
University of Texas at Dallas)

IAB Mentors:
Lothar Breuss (Bachmann Electronic Corp)
Phillip Gauthier (EDF Renewables)
Sarah Oblon, Alberto Llana Hernanz, Isidro Mendoza, Adam Johs (EDP Renewables)
Brandon Fitchett, Noah Myrent, Lili Haus, Curtis Fox (EPRI)

Currently, wind plants are designed for 20-30 years of operation, with decommissioning typically planned at end-of-service. However, there is great interest and need to begin repowering the numerous turbine assets that are reaching or nearing their original design lifetime because repowering provides many benefits in leveraging the upfront capital investments, permitting, footprint, electrical infrastructure, grid connection, etc. of the original plant. While repowering offers a number of potential attractive benefits, open questions remain regarding: (1) the financial implications of repowering, (2) risk and uncertainty in the reliability of the aged to-be-reused components (such as towers and foundations) for partial repowering (figure, Left), and (3) the optimal timing of a repowering in a plant's lifetime and the best repowering strategy.

The research of the F2-23 (Wind Plant Design for Repowering) project addressed these questions as well as other open questions faced by the WindSTAR IAB members with respect to making repowering decisions. One of the primary products of the F2-23 project is a first-ever Design for Repowering (DFR) framework – a comprehensive, multi-criteria decision-making method used to design a wind farm with considerations for future repowering activity (i.e., planned repowering). The figure (Upper Right) shows the various elements of the DFR framework introduced in this work.

In the second major product of F2-23, we focus on applying a major aspect of the DFR framework (e.g., Novel Component Designs) to one of the most crucial components of a turbine, the tower, by examining a new concept that we term as Future-Proof Structural Engineering (FPSE) whereby a component (e.g., a tower) is over-built from the outset to achieve a longer design lifetime (figure, Lower Right). FPSE is devised to ensure the longevity of reusable components (such as the tower and foundation) in a planned partial repowering scenario. Further, an economic analysis framework for repowering was developed and applied to case studies comparing various economic metrics for repowering scenarios including a baseline decommissioning case against Design for Repowering and Future-Proof Structural Engineering cases. The results of these studies can be leveraged to guide future repowering decisions and to design for repowering from the project initial design phase.

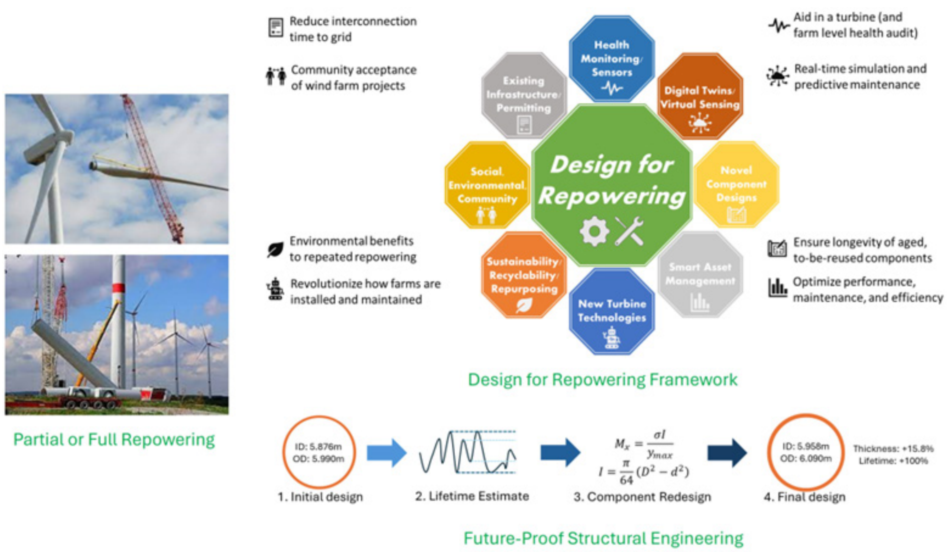


Figure 1. Wind Plant Design for Repowering: (1) Left: Options for repowering include partial repowering (replacement of only certain components and continued use of other components) or full repowering (replacement of the entire wind turbine, typically with new and larger machines), (2) Upper Right: a Design for Repowering (DFR) framework – a comprehensive, multi-criteria decision-making method used to design a wind farm with considerations for future repowering activity (i.e., planned repowering), and (3) Lower Right: Future-Proof Structural Engineering (FPSE) is introduced whereby a component (e.g., a tower) is over-built from the outset to achieve a longer design lifetime.

PROJECT ID: F2-23

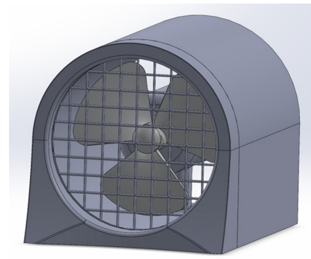
2023-2024 PROJECT HIGHLIGHTS

Wind Turbine Blade Sensor Energy Harvester

Project Instructor:
Christopher Niezrecki (University of Massachusetts Lowell)

Sudent Researchers:
Caleb Barannikov, Luke Mulcahy (University of Massachusetts Lowell)

Distributed sensors within wind turbine blades require electrical power, but running wires along the length of the blade is problematic for installation and because of lightning issues. This project designed a new approach to power wind turbine sensors on blades by using local energy harvesting. The energy harvester is able to power a small sensor package in a remote location by using the mechanical power available as the blade rotates.



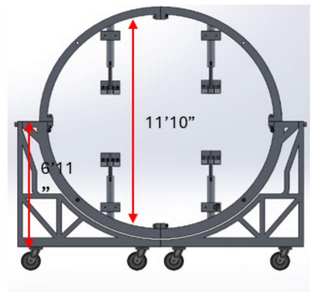
PROJECT ID: U1-24

Blade Rotation Mechanism

Project Instructor:
Christopher Niezrecki (University of Massachusetts Lowell)

Sudent Researchers:
Dylan Tang, Madelyn Sampson, Samuel Harris, Nolan Preble, Paul Laplante (University of Massachusetts Lowell)

Currently, wind turbine blades are rotated by supporting the blade root and an outboard location. Two cranes at the blade root control the rotation and the outboard saddle is free to rotate as the blade does. Due to saddle constraints, the load resultant goes through the weakest point on the blade profile and can cause damage to the blade. Rotation carts are used in manufacturing to rotate the blade during the painting process and connect to the blade at the strongest point. The goal of this project was to design a rotation mechanism that could attach to the lifting saddles, rather than the blade profile, as the current ones do.



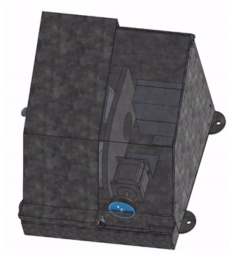
PROJECT ID: U2-24

Design of a Mounted Camera for Wind Turbine Monitoring

Project Instructor:
Christopher Niezrecki (University of Massachusetts Lowell)

Sudent Researchers:
Jagger Roffee, Collin Adams, Timothy Chea, Dat Vo, Mark Price (University of Massachusetts Lowell)

This project designed a robust camera mounting system that can withstand harsh environmental conditions (e.g., wind, rain, temperature) to monitor the blades of a turbine. The design includes the camera position selection to maximize visibility of the blade surface in identifying cracks before failure occurs. The outcome of the project included mounting system design, cost evaluation and installation process.



PROJECT ID: U3-24

ACTIVE PROJECTS: 2024-2025

- **Investigation of Riblet Surface Durability and its Impact on Wind Farm Performance**
  Project ID: A1-24
  PIs: Yaqing Jin, Stefano Leonardi (University of Texas at Dallas)
  Mentors: Nikon Corporation

- **Integration of Machine-Learning Based Approach for Curing Cycle Process Optimization of Vacuum Assisted Resin Infusion Process (VARIM)**
  Project ID: A2-24
  PI: Dong Qian, Hongbing Lu (University of Texas at Dallas)
  Mentors: GE, Westlake Epoxy

- **Recycling Epoxy Composites through Vitrimerization**
  Project ID: A5-24
  PI: Amir Ameli, James Reuther (University of Massachusetts Lowell)
  Mentors: Avangrid, Westlake Epoxy

- **Internal and External Inspection of Wind Turbine Blades Using Computer Vision and Artificial Intelligence**
  Project ID: B1-24
  PI: Alessandro Sabato, Christopher Niezrecki (University of Massachusetts Lowell)
  Mentors: FM Global, GE, Leeward Renewable Energy, MassCEC, Pattern

- **Advancing Condition Monitoring and Predictive Maintenance for Turbine Electrical Components: A Digital Twin Framework Approach**
  Project ID: B2-24
  PI: Jie Zhang (University of Texas at Dallas)
  Mentors: Avangrid, EDF Renewables, FM Global

- **Benchmarking of Commercially Available Acoustic Blade Monitoring Systems through Field Testing**
  Project ID: B3-24
  PI: Murat Inapolat, Christopher Niezrecki (University of Massachusetts Lowell)
  Mentors: EDF Renewables, FM Global, GE, Hutchinson, Pattern, Xcel Energy

- **Condition Monitoring of Wind Turbine Foundations using accelerometers and Generative AI**
  Project ID: B4-24
  PI: Nasser Kehtarnavaz, Mario Rotea (University of Texas at Dallas)
  Mentors: Avangrid, Hutchinson, EDF Renewables, Leeward Renewable Energy

- **Local Sensor Energy Harvesting to Monitor Blade Structural Health**
  Project ID: B5-24
  PI: Murat Inapolat, Christopher Niezrecki (University of Massachusetts Lowell)
  Mentors: Hutchinson

- **Multi-scale Data-driven Modeling of Neighboring Wind Farms**
  Project ID: C1-24
  PIs: Giacomo Valerio Iungo (University of Texas at Dallas)
  Mentors: Avangrid, GE, Nikon Corporation, Xcel Energy

- **Repowering of Wind Farms with Digital Health Audits of Turbine Components**
  Project ID: F1-24
  PIs: D. Todd Griffith (University of Texas at Dallas)
  Mentors: Avangrid, EDF Renewables, FM Global

2021-2024 OUTCOMES

Through August 31, 2024

For a cumulative list of all center outcomes visit uml.edu/WindSTAR

Products:

1. Software - Machine learning model for icing prediction in wind turbines from SCADA data
2. Software - Machine learning model for predicting temperature and curing degree in vacuum assisted resin infusion process
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. 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 176,2024,107835,ISSN 1359-835X.
2. Zani, Md. R., Maor, N. S., Bhamitipadi Suresh, D., & Jin, Y. (2024). Turbulent boundary layer control with multi-scale Riblet design. Energies, 17(15), 3827.
3. Cao, D., Xu, T., Zhang, M., Wang, Z., Griffith, D. T., Roy, S., Baughman, R. H., &Lu, H. (2024). Strengthening sandwich composites by laminating ultra-thin oriented carbon nanotube sheets at the skin/core interface. Composites Part B: Engineering,111496.
4. Zhang, Y., Kehtarnavaz, N., Rotea, M., & Dasari, T. (2024). Prediction of icing on wind turbines based on SCADA data via temporal convolutional network. Energies,17(9), 2175.
5. Zhang, Y., Rotea, M., Kehtarnavaz, N. (2024), Wind Farm Prediction of Icing Based on SCADA Data. Energies, 17, 4629.
6. Bian, N., Ren, Y., Shrivastava, A., Wang, Z., Yang, D. J., Roy, S., Baughman, R., &Lu, H. (2024). Enhancing the interlaminar adhesion of carbon fiber composites via carbon nanotube sheets. Academia Materials Science.
7. Cao, D., Lu, H., & Griffith, D. T. (2024). Cohesive zone modeling of the buckling behavior of a fusion-joined, additive-manufactured wind blade. Academia Materials Science.
8. Aju, E. J., Gong, P., Kumar, D., Rotea, M. A., & Jin, Y. (2024). Power output fluctuations and unsteady aerodynamic loads of a scaled wind turbine subjected to periodically oscillating wind environments. Journal of Renewable and Sustainable Energy, 16(5).
9. Moss, C., Maulik, R., Moriarty, P., & Iungo, G. V. (2023). Predicting Wind Farm operations with Machine Learning and the p2drans model: A case study for an awaken site. Wind Energy.
10. Li, H., and Zhang, J. (2023). "Towards Sustainable Integration: Techno-Economic Analysis and Future Perspectives of Co-Located Wind and Hydrogen Energy Systems." ASME. J. Mech. Des. February 2024; 146(2): 020903.
11. Bernardoni, F., Rotea, M. A., & Leonardi, S. (2024). Impact of yaw misalignment on turbine loads in the presence of wind farm blockage. Wind Energy, 27(6), 535–548.
12. Lingad, M V and Rodrigues, M and Zare, A and Leonardi, S. (2024). Three-dimensional stochastic dynamical modeling forwind farm flow estimation. Journal of Physics: Conference Series. 2767 (5) 052065.
13. Zhang, R., Liu, Y., Zheng, T. et al. A fast spatio-temporal temperature predictor for vacuum assisted resin infusion molding process based on deep machine learning modeling. J Intell Manuf 35, 1737-1764 (2024).
14. Bouzolin, D., Settelmaier, K., and Griffith, D.T., â€œDesign for Repowering of Wind Farms: An Initial Framework, Journal of Physics: Conference Series, Volume 2767.
15. 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.
16. Shah, Sagar P., Sagar U. Patil, Christopher J. Hansen, Gregory M. Odegard, and Marianna Maiarù. "Process Modeling and Characterization of Thermoset Composites for Residual Stress Prediction." Mechanics of Advanced Materials and Structures, December 20, 2021, 1–12.
17. Cao, D., Malakooti, S., Kulkarni, V. N., Ren, Y., Liu, Y., Nie, X., Qian, D., Griffith, D. T., & Lu, H. (2021). The effect of resin uptake on the flexural properties of compression molded sandwich composites. Wind Energy.
18. Letizia, S., Zhan, L., & Iungo, G. V. (2021). LiSBOA (LiDAR statistical Barnes objective analysis) for optimal design of lidar scans and retrieval of wind statistics-part 1: Theoretical framework. Atmospheric Measurement Techniques, 14(3), 2065-2093.
19. Letizia, S., Zhan, L., & Iungo, G. V. (2021). LiSBOA (LiDAR statistical Barnes objective analysis) for optimal design of lidar scans and retrieval of wind statistics-part 2: Applications to lidar measurements of wind turbine wakes. Atmospheric Measurement Techniques, 14(3), 2095-2113.
20. S. P. Shah and M. Maiarù, "Effect of Manufacturing on the Transverse Response of Polymer Matrix Composites," Polymers, vol. 13, no. 15, Art. no. 15, Jan. 2021.

Conference Papers:

1. Tubije, J. M., Jin, Y., & Leonardi, S. (2024). Numerical investigation of effects of Riblets on wind turbine performance. Journal of Physics: Conference Series,2767(2), 022023.
2. Griffith, D. T., Cao, D., Lu, H., & Qian, D. (2023). Composite materials in wind energy: Design, manufacturing, operation, and end-of-life. IOP Conference Series: Materials Science and Engineering, 1293(1), 012002.
3. Yan, J., Senemmar, S., and Zhang, J., (2024), Inter-turn short circuit fault diagnosis and severity estimation for wind turbine generators, In Journal of Physics: Conference Series, Vol. 2767, IOP Publishing, p. 032021.

4. S. Abootorabi, S. Leonardi, M. Rotea, and A. Zare (2024), Short-term wind forecasting using surface pressure measurements, In Proceedings of the 2024American Control Conference, Toronto, Canada, pp. 1022-1027.
5. M. V. Lingad, M. Rodrigues, S. Leonardi, and A. Zare (2024), Three-dimensional stochastic dynamical modeling for wind farm flow estimation, J. Phys. Conf. Ser., vol. 2767, no. 5, p. 052065.
6. Ahmed, W. U., Moss, C., Roy, S., Shams Solari, M., Puccioni, M., Panthi, K., Moriarty, P., & Iungo, G. V. (2024). Wind Farm wakes and farm-to-farm interactions: Lidar and wind tunnel tests. Journal of Physics: Conference Series, 2767(9),092105.
7. Rotea, M. A., Kumar, D., Aju, E. J., & Jin, Y. (2024). Multi-row extremum seeking for Wind Farm Power Maximization. Journal of Physics: Conference Series, 2767(3),032043.
8. F. Bottalico, and A. Sabato, Natural pattern tracking for 3D digital image correlation, in proceedings SPIE Smart Structures/NDE 2024, Long Beach, CA, March 25-28, 2024.
9. F. Bottalico and A. Sabato, Pattern-less stereophotogrammetry for structural dynamic measurements, in proceedings IMAC XLII, Orlando, FL, January 29 – February 2, 2024.
10. Ng, C., A., Pozzi, C., Lyon, S., Inalpolat, M., Niezrecki, N., and Luo. Y., "IoT acoustic sensor design and antenna selection for a wind turbine structural health monitoring system", Proceedings of SPIE Smart Structures+Nondestructive Evaluation, Long Beach, CA, March 25–28, 2024.
11. F. Bottalico and A. Sabato, Assessment of three-dimensional displacements via a novel natural-pattern tracking algorithm, in proceedings ISMA-USD Conference, Leuven, Belgium, September 9 - 11, 2024, in press.
12. M. V. Lingad, M. Rodrigues, S. Leonardi, and A. Zare, Three-dimensional stochastic dynamical modeling for wind farm flow estimation, J. Phys. Conf. Ser., vol. 2767, no. 5, p. 052065, 2024.
13. 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.
14. 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.
15. Yang, F., Pu, S., Akin, B., Butler, S. W., & Wang, G. (2021). Package degradation's impact on SIC mosfets loss: A comparison of Kelvin and Non-Kelvin Designs. 2021 IEEE Applied Power Electronics Conference and Exposition (APEC).
16. Zhang, N., Pu, S., & Akin, B. (2021). An automated multi-device characterization system for Reliability Assessment of Power Semiconductors. 2021 IEEE 13th International Symposium
17. Gondle, Raj K., Pradeep U. Kurup, and Christopher Niezrecki. "Evaluation of Wind Turbine-Foundation Degradation." In International Conference of the International Association for Computer Methods and Advances in Geomechanics, pp. 21-28. Springer, Cham, 2021.
18. Shah, Sagar, Evgenia Plaka, Mathew Schey, Jie Hu, Fuqiang Liu, Tibor Beke, Scott E. Stapleton, and Marianna Maiaru. "Quantification of Thermoset Composite Microstructures for Process Modeling." In AIAA Scitech 2021 Forum, p. 1774. 2021.
19. Sagar Shah, Marianna Maiaru – Effect of Manufacturing on the Transverse Response of Polymer Matrix Composites, ASC 2021, Proceedings of American Society for Composites
20. Gondle, R.K., Kurup, P.U., and Niezrecki, C. "Evaluation of Wind Turbine-Foundation Degradation," Paper accepted to the 16th International Conference of the International Association for Computer Methods and Advances in Geomechanics (IACMAG), Torino, Italy, May 5-8, 2021.

Selected Presentations:

1. Bottalico, F. and Sabato, A. Pattern-less stereophotogrammetry for structural dynamic measurements IMAC XLII, Orlando, FL, January 29 – February 2, 2024.
2. A. Sabato: Revolutionizing structural monitoring: advancing aerial-borne 3D computer vision for assessment of large-scale engineering systems, invited seminar at University of Central Florida, Orlando, FL, February 1, 2024.
3. A. Sabato: Revolutionizing structural monitoring: advancing aerial-borne 3D computer vision for assessment of large-scale engineering systems, invited seminar at Rensselaer Polytechnic Institute, Troy, NY, February 7, 2024
4. A. Sabato: Advancement of drone-borne 3D computer vision measurements for assessment of large-scale engineering systems, invited seminar at University of New Mexico, Albuquerque, NM, March 4, 2024.
5. Ng, C., A., Pozzi, C., Lyon, S., Inalpolat, M., Niezrecki, N., and Luo. Y., "IoT acoustic sensor design and antenna selection for a wind turbine structural health monitoring system", SPIE Smart Structures+Nondestructive Evaluation, Long Beach, CA, March 25–28, 2024.
6. Bottalico, F. and Sabato, A. Natural pattern tracking for 3D digital image correlation, SPIE Smart Structures/NDE 2024, Long Beach, CA, March 25-28, 2024.
7. Cimorelli, J., Eniola, V., Niezrecki, C., Jin, X., and Willis, D., "Wind Energy and Hydrogen Energy Storage System Modeling for Navy Microgrids," Student Research and Community Engagement Symposium, Lowell, MA, April 2, 2024.
8. Zare, "A stochastic framework for quantifying and data‐enhanced dynamical modeling of uncertainty," (a) University of Michigan–Ann Arbor, MI, February 2024;(b) The University of Toledo, OH, March 2024; (c) Sapienza University of Rome, Rome, Italy, June 2024.
9. Cimorelli, J., Eniola, V., Niezrecki, C., Jin, X., and Willis, D., "A Design and Optimization Tool for Integrated Renewable-Hydrogen Microgrid Systems," Offshore Energy and Storage Symposium 2024, New Beford, MA, July 10-12, 2024.
10. Eniola, V., Cimorelli, J., Niezrecki, C., Jin, X., and Willis, D., "Investigating Wind Speed Fluctuation Effects on Optimal Sizing of Hybrid Wind-Hydrogen Energy Subsystems," Offshore Energy and Storage Symposium 2024, New Beford, MA, July 10-12, 2024.
11. C. Niezrecki - Keynote Speaker: Offshore Energy and Storage Society (OSES), "Offshore Wind: Challenges and Opportunities," New Bedford, MA, July 11, 2024.
12. Speaker: 5th International Congress on Advanced Materials Sciences and Engineering (AMSE-2024), "Wind Turbine Blade Recycling and Repurposing: Challenges and Opportunities," Opatija, Croatia, July 24-26, 2024 (invited)
13. Bottalico, F. and Sabato, A. Assessment of three-dimensional displacements via a novel natural-pattern tracking algorithm, in proceedings ISMA-USD Conference, Leuven, Belgium, September 9 - 11, 2024
14. Mario A. Rotea, "Wake Steering via Log-of Power Extremum Seeking Yaw Control,"2024 Sandia Blade Workshop, Sep 16-20, 2024, Albuquerque
15. Hamid, S., and Niezrecki, C., "End-of-Life Management of Wind Turbine Blades: Challenges, Innovations, and Comparative Perspectives on Composite Material Recycling," NAWEA/WindTech 2024 Conference, New Brunswick, NJ, October 30 - November 1, 2024 (poster).
16. Cimorelli, J., Eniola, V., Niezrecki, C., Jin, X., and Willis, D., "Modeling of Wind-Hydrogen Integrated Systems for Resilient Microgrid Operation," NAWEA/WindTech 2024 Conference, New Brunswick, NJ, October 30-November 1, 2024.

2021-2024 OUTCOMES

Through August 31, 2024

For a cumulative list of all center outcomes visit uml.edu/WindSTAR

17. Invited speaker – M. Inalpolat, Wind Turbine Blades conference hosted by AMI, "Structural health monitoring of operational wind turbine blades using an acoustics-based approach", Boston, MA (10/2/2024).
18. Bouzolin, D. Todd Griffith, D. "Design for Repowering of Wind Turbines Through Future-Proof Structural Engineering: Case Study of Tower Repowering, "NAWEA/WindTech 2024, Rutgers University, New Brunswick, NJ, USA, Oct. 30-Nov. 1, 2024.
19. Mario. A. Rotea, "Wind farm control," NAWEA/WindTech 2024, Oct 30 – Nov 1,2024, Rutgers-New Brunswick
20. Eniola, V., Cimorelli, J., Niezrecki, C., Willis, D., and Jin, X., "Optimizing Wind-Hydrogen Integrated Microgrid Design: Accounting for Wind Speed Fluctuations," NAWEA/WindTech 2024 Conference, New Brunswick, NJ, October 30-November 1, 2024.
21. Inalpolat, M., and Niezrecki, C., "Operational Blade Monitoring using a Sparse Acoustic Sensor Array" NAWEA/WindTech 2024, New Brunswick, NJ, October 30-November 1 2024.
22. C. Moss, & G. Valerio Iungo; Data-driven Modeling of Complex Wind-farm Flows,The Bluebonnet Symposium on Thermal-Fluid Sciences, March 24, 2023, Dallas,TX.
23. Maor, N., Zani, M. R., Aju, E. J., Gong, P., & Jin, Y. (2023). Investigation of Riblets on the Aerodynamic Performance of Wind Turbine Blades. Bulletin of the American Physical Society.
24. D. Qian, R. Zhang, Y. Liu and H. Lu, A Digital Twin for Vacuum Assisted Resin Infusion Molding Process Based on Deep Machine Learning Modeling (Keynote),2023 ASME IMECE Conference, New Orleans, LA, November 1, 2023
25. M. Inalpolat, FM Global, "An Integral Acoustics-based Wind Turbine Blade Structural Health Monitoring System ", (11/17/2023).
26. M. Inalpolat, National Offshore Wind Energy R&D Consortium, "Development of a Novel Structural Health Monitoring System for Offshore Wind Turbine Blades", Brooklyn, NY, 12/04/2023.
27. A. Sabato: Revolutionizing structural monitoring: advancing aerial-borne 3D computer vision for assessment of large-scale engineering systems, invited seminar at Stevens Institute of Technology, Newark, NJ, December 6, 2023.
28. 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.
29. 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.
30. 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.
31. 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
32. Mishra, I., Griffith, D.T., Sensitivity Analysis Of Wind Turbine Digital Twin Model To Uncertain Model Input Parameters, NAWEA/WindTech 2022 Conference, Newark, Delaware, September 20-22, 2022.
33. 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.
34. Bernardoni, F., Ciri, U., Rotea, M.A., Leonardi, S., Identification of interacting turbines with time variant wind direction In: EAWE PhD Seminar 2021, November 3rd-25th, Porto, PT, 2021
35. Aju, E., Kumar, D., Rotea, M., & Jin, Y. (2021). On the wake dynamics, flow loading and power output of wind farms under wake steering control: a wind tunnel experiment. In APS Division of Fluid Dynamics Meeting Abstracts (pp. T27-009).

Master of Science Thesis:

1. Nir Saar Maor, "Experimental study of riblet treatments on aerodynamic performance and energy production of wind turbines." Mechanical Engineering, University of Texas at Dallas, Fall 2024.
2. Joseph McDonald – "Composites for Wind Turbine Blade Repair," M.S. in Mechanical Engineering, December 2021.
3. Diltz, Natalie Lynne. "Monitoring and Assessment of Wind Turbine Foundation Degradation." M.S. Thesis., University of Massachusetts Lowell, 2021.

PhD Dissertations:

1. Wasi Uddin Ahmed, "Wind-Tunnel investigations of wind-turbine blade aerodynamics with plasma actuators and rotor interactions with the incoming boundary layer." Mechanical Engineering, University of Texas at Dallas, Spring 2024.
2. Nahal Aliheidari, "Long-Term Environmental Durability Assessment of Fiber-Reinforced Composite/Adhesive Joints," Plastics Engineering, University of Massachusetts Lowell, Spring 2024.
3. Emmanuvel Joseph Aju, "Wind-Tunnel investigations of wind-turbine performance: winglet pitching, yaw misalignment, and periodically oscillating wind environments." Mechanical Engineering, University of Texas at Dallas, Spring 2024.
4. Fabio Bottalico, "Development of a UAV-Borne Stereophotogrammetry System for Dynamic Measurements on Large-Scale Str." Fabio_Bottalico@student.uml.edu, Ph.D. Mechanical Engineering
5. Yujie Zhang, "Machine Learning Solutions for Wind Turbine and Wind Farm Applications." Electrical and Computer Engineering, University of Texas at Dallas, Fall 2024.
6. Devesh Kumar, "Advanced log-of-power extremum seeking control for wind power maximization," Mechanical Engineering, University of Texas at Dallas, Spring 2023. Controls Engineer at Drive System Design.
7. Chang Liu, "Active Load Control of Wind Turbines Using Plasma Actuation," Ph.D. in Mechanical Engineering, University of Texas at Dallas, Fall 2022.
8. Caleb Traylor, "Computational Investigation into the Aeroacoustics of Wind Turbine Blades for Structural Health Monitoring," Ph.D. in Energy Engineering, UMass Lowell, August 2022.
9. Joshua Morris, "Design, Characterization, and Analysis Methods for Low Frequency Mechanical Metamaterials" Ph.D. in Mechanical Engineering, UMass Lowell, August 2022.
10. Sagar Shah, "Transverse Property Prediction of Thermosetpolymer Matrix Composites," Ph.D. in Mechanical Engineering, UMass Lowell, November 2022.
11. 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.
12. 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.
13. Jaclyn V. Solimine, "Development of Robust, Data-Driven Damage Identification Techniques for the Passive Acoustics Based Structural Health Monitoring of Wind Turbine Blades", Ph.D. in Mechanical Engineering, UMass Lowell, December 2021.

14. Stefano Letizia, "Wind farm flow and power capture: optimal design of LiDAR experiments, flow physics, and mid-fidelity modeling," Ph.D. in Mechanical Engineering, University of Texas at Dallas, Fall 2021.

Interns at Member Companies:

1. Thor Westergaard, Intern at Leeward Renewable Energy, Summer 2020.
2. Stefano Letizia, recipient of WindSTAR NSF INTERN at UT Dallas, Intern at EDP Renewables.
3. Alessandro Cassano, recipient of WindSTAR NSF INTERN at UMass Lowell, Intern at TPI Composites, Spring 2020.

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

RECENT CENTER EVENTS

IAB Meetings:

- University of Massachusetts Lowell, June 12-13, 2024
- University of Texas at Dallas, January 23-24, 2024

Invited Keynote Speakers for Center Banquets:

- Coordination, Innovation, & Flexibility to Maintain Grid Reliability During the Clean Energy Transition , Marianne Perben, Director, Planning Services, ISO New England Inc., June 12, 2024
- How wind can help transition the U.S. and world to 100% clean, renewable energy and storage for everything, Dr. Mark Z. Jacobson, Stanford University, January 23, 2024

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